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Quality of Life in Metropolitan Athens, Using Satellite and Census Data: Comparison between 1991 and 2001

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ABSTRACT

This study presents an aggregated quality-of-life (QOL) index representing the combined attributes of the physical, economic, and social environment of a city. Information about the physical environment was derived from Landsat TM/ETM+ image data, whereas information regarding the socio-economic environment of the city was obtained from national census data. In particular, the indicators used to describe the physical environment were land-surface temperature (LST), vegetation, and land cover and use. On the other hand, the indicators used to describe the socio-economic environment of the city were population density, education level, unemployment rate, percentage of employers, and household density. The QOL index was calculated at a municipality level by integrating all indicators mentioned above in a geographic information system (GIS) environment.

The QOL index was applied to measure the QOL in the city of Athens, Greece, and to assess changes over the decade 1991–2001. It is concluded that the QOL index can be a valuable tool for urban design because it can provide urban planners and local administrators with a broad overview of trends, identifying communities where further actions for sustainable development are needed.

Introduction

The term quality of life (QOL) is used to describe the well-being of the citizens of an urban area; that is to say, how people feel about the environment and the society in which they live. Most sociologists believe that QOL reflects both objective and subjective elements. For example, employment is an objective criterion; however, how satisfied people are about their work is clearly subjective. For defining QOL, a number of indicators are commonly used, representing the most important aspects in the life of a person (e.g., education, employment) or the state of the physical environment. Generally, commonly acceptable indicators for expressing the urban QOL are classified into two main categories: (1) the physical environment and (2) the socio-economic environment. In the past, most studies of QOL were conducted on the basis of only census data. With the systematic degradation of the physical environment, the incorporation of physical data into the QOL index is required to depict in a more adequate way the findings of a QOL study for a city. Moreover, the frequent evaluation of the life quality in a city is very important because it enables the monitoring of progress as well as provides information to local authorities about the policy they could deliver to resolve or even anticipate community problems arising from poor strategy for sustainable design in an urban area.

The scope of this study was to measure the QOL in the urban environment of the metropolitan Athens area, which consists of the prefecture of Athens (48 municipalities) and part of the prefecture of Piraeus (seven municipalities covering the southwest part of the Attica basin). To achieve this, we developed a QOL index, based on the Atlas of Canada QOL model (Quality of Life Indicators Project 2002; Morton 1999), which aggregates the physical, economic, and social characteristics of an urban area at a municipality level. The index was initially calculated for 1991 and 2001, and then changes in QOL over the 1991–2001 decade were detected for Athens. The physical environment indicators were derived from high-resolution Landsat TM/ETM+ image data, with land-cover information for Athens extracted from the Corine Land Cover (CLC) databases for Greece, which were provided in vector format for the reference years 1990 and 2000. The socio-economic indicators were obtained from the 1991 and 2001 Greek census data at the municipality level.

The metropolitan Athens area is the central part of the Attica region. It is delimited by the mountains of Parnitha, Ymittos, Penteli, Aigaleo, and the Saronikos Gulf, covering the Attica basin of 415 km^2 area and having a population of 3,130,841 inhabitants (2001 census), which is nearly one-third

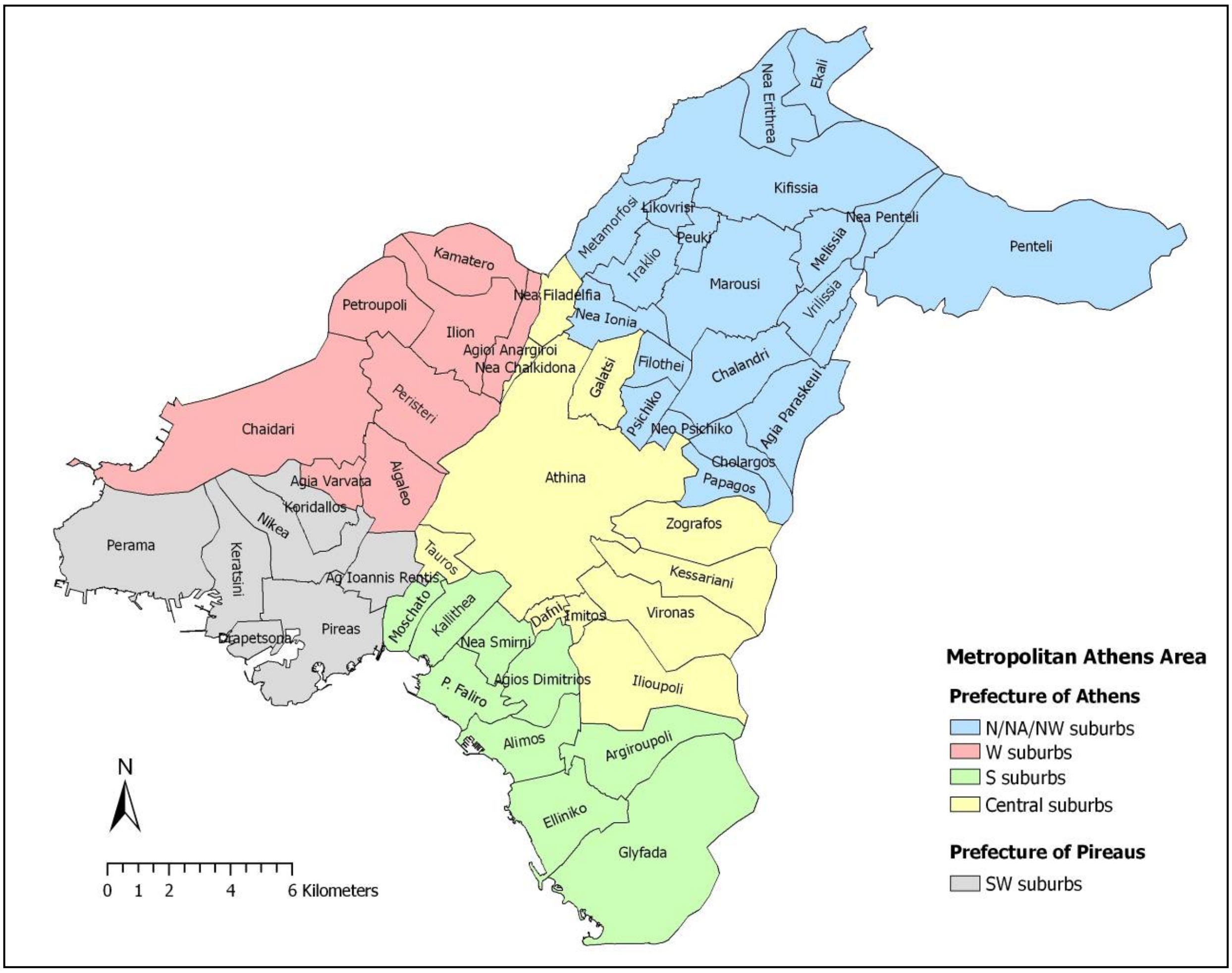

Figure 1. Vector map of municipalities in metropolitan Athens area

(28.5%) of the population of Greece. The population density reported for the prefecture of Athens is 7.4 thousand inhabitants/km^2, whereas for the seven mainland municipalities of the prefecture of Piraeus, the population density is even higher, reaching up to 9.2 thousand inhabitants/km^2. Figure 1 shows the 55 municipalities comprising the metropolitan Athens area.

Dataset

Two Landsat images were employed in this study: a Landsat 5 TM image dated June 21, 1991, and a Landsat 7 ETM+ image dated August 11, 2001. TM and ETM+ sensors can provide image data in the visible (VIS) and thermal infrared (TIR) spectral region. The TIR band (band 6) on both sensors operates in the spectral range of 10.4 to 12.5 μm and is designed to record image data with high spatial resolution (120 m for TM and 60 m for ETM+) suitable for detecting and mapping the land surface temperature (LST) variations at the city scale. Moreover, the high spatial resolution of both sensors (30 m) in the VIS (0.45–0.69 μm) and near-infrared (NIR) (0.76–0.90 μm) spectral regions, makes them suitable for measuring urban vegetation with the use of the Normalized Difference Vegetation Index (NDVI). The image data were acquired via the USGS EROS Data Center to a processing level of 1G with georeferencing to UTM/WGS84 map projection.

To better comprehend the urban characteristics of the area under study, the thematic land-cover and land-use (LULC) data from the CORINE Land Cover (CLC) database for Greece were used. In particular, two CLC databases were employed: the first referred to 1990, and its update referred to 2000 (hereafter denoted as CLC90 and CLC00, respectively). These databases are part of the CORINE program proposed by the European Commission in 1985 with the aim to COoRdinate INformation on the Environment (CORINE). At present, the CLC database covers more than 30 countries and maps the European environmental landscape with 44 thematic classes at the 1:100,000 scale. CLC90 and CLC00 for Greece were provided in a vector format.

Finally, the location and boundaries of the municipalities comprising metropolitan Athens were available from a vector (shapefile) map.

Methodology

Extraction of the Physical Environment Indicators

Land surface temperature (LST). Estimation of LST from satellite thermal data required conversion of the digital number (DN) of the image pixels into (a) at-sensor spectral radiance L_λ and (b) effective at-sensor temperature T_B, using the sensor calibration data. The equations applied to the thermal band (band 6) image's pixels for converting into at-sensor spectral radiance values were (Chander and Markham 2003):

For TM6 band: $$L_\lambda = 0.055158 \cdot DN + 1.2378 \quad \text{W/(m}^2\text{.sr.}\mu\text{m)} \qquad (1)$$

For ETM+6 band: $$L_\lambda = 0.066824 \cdot DN + 0.0 \quad \text{W/(m}^2\text{.sr.}\mu\text{m)} \qquad (2)$$

For Landsat TM/ETM+, conversion from at-sensor spectral radiance values into effective at-sensor temperature values was accomplished by:

$$T_B = \frac{K_2}{\ln(\frac{K_1}{L_\lambda} + 1)} \qquad (3)$$

where T_B is the effective at-sensor temperature in degrees Kelvin, K_1 is the first calibration constant in W/(m^2.sr.μm) equal to 607.76 for TM and 666.09 for ETM+, whereas K_2 is the second calibration constant in Kelvin equal to 1260.56 for TM and 1282.71 for ETM+. Finally, LST was estimated from the effective at-sensor temperature after correcting for surface emissivity (Artis and Carnahan 1982):

$$LST = \frac{T_B}{(1 + \frac{\lambda \cdot T_B}{\rho} \ln \varepsilon)} \qquad (4)$$

In equation (4), λ is the wavelength of emitted radiance (11.5 μm), $\rho = hc/K$ (1.438×10^{-2} m K), T_B is the effective at-sensor temperature in Kelvin, and ε is the spectral surface emissivity. In this study, a surface emissivity value of 0.93 was used, representing the mean surface emissivity of urbanized areas in Athens (Stathopoulou et al. 2007). LST was regarded as a negative indicator of the physical environment of Athens, as previous studies have shown that high LST values have a negative impact on urban climatology (Stathopoulou and Cartalis 2007), increase human thermal discomfort (Stathopoulou et al. 2005), and increase energy demand (Santamouris et al. 2001; Stathopoulou et al. 2006).

Vegetation. The NDVI was calculated from both 1991 and 2001 images to determine the amount of vegetation present in the study area for the two years. Generally, its calculation is accomplished by a simple equation using two satellite bands: one band in the VIS region (e.g., TM/ETM+ band 3) and one in the NIR region (e.g., TM/ETM+ band 4). Prior to the NDVI calculation, the DN values of the image pixels of TM/ETM+ bands 3 and 4 were converted to spectral radiance according to equations (1) or (2) and then to at-sensor spectral reflectance ρ_λ applying the following equation:

$$\rho_\lambda = \left(\frac{\pi \, . \, L_\lambda \, . \, d^2}{ESUN_\lambda \, . \, \cos \theta_s} \right) \qquad (5)$$

where L_λ is the at-sensor spectral radiance as computed from equation (1) or (2), d is the mean distance between the earth and the sun (in astronomical units), $ESUN_\lambda$ is the mean solar exoatmospheric irradiance in TM/ETM+ bands 3 and 4 (W/m^2 μm), and θ_s is the solar zenith angle (in radians). The reason is that when comparing images from different sensors, there are two advantages to using reflectance instead of radiances. First, the cosine effect of different solar zenith angles due to the time difference between data acquisitions can be removed, and second, it compensates for different values of the exoatmospheric solar irradiances arising from spectral band differences (Chander and Markham 2003). The $ESUN_\lambda$, d and θ_s values for the two TM/ETM+ images were given in the images header files. Therefore, the equation applied to calculate NDVI was:

$$NDVI = \frac{\rho_4 - \rho_3}{\rho_4 + \rho_3} \qquad (6)$$

Vegetation was regarded a positive indicator of the physical environment of metropolitan Athens because it can provide many aesthetic and environmental benefits to its citizens.

Land cover and land use (LCLU). In a geographic information system (GIS) environment, the geographic region covered by the study area was initially extracted from the CLC90 and CLC00 databases for Greece. Within the study area, the following categories of land cover and land use were identified: (a) continuous urban fabric, (b) discontinuous urban fabric, (c) industrial/commercial units, (d) road/rail networks and associated land, (e) port areas, (f) airports, (g) mineral extraction sites, (h) dump sites, (i) construction sites, (j) green urban areas, (k) sport and leisure facilities, (l) agricultural areas, and (m) forests and semi-natural areas. These categories were grouped into six new ones named as:

1. Urban fabric (including continuous and discontinuous urban fabric)
2. Artificial non-agricultural vegetated areas (including green urban areas, sport and leisure facilities)
3. Urban-use areas (including industrial/commercial units, road/rail networks and associated land, port areas, airports, mineral extraction sites, dump and construction sites)
4. Agricultural areas
5. Forests and semi-natural areas
6. Water surfaces

The category of urban-use areas was regarded as a negative indicator of the physical environment of Athens because most citizens believe the location of such infrastructures within their municipality leads to the deterioration of their QOL. Therefore, the percentage of urban-use areas corresponding to each municipality was estimated for 1991 and 2001 by dividing the land area (in m^2) covered by urban use to the total area of each municipality. The spatial distribution of the different land-cover types over the metropolitan Athens area for 1991 and 2001 is illustrated in Figure 2.

Extraction of the Socio-economic Indicators

The socio-economic indicators used for describing the living environment of metropolitan Athens for 1991 and 2001 were population density (citizens/km^2), education level (defined as the percentage of graduates from higher educational and technical institutions), unemployment rate, percentage of employers, and household density (households/km^2). All indicator data were obtained from the 1991 and 2001 census data supplied by the General Secretariat of National Statistical Service of Greece (www.statistics.gr) at a municipality level. Each indicator was characterized as positive or negative, based on its impact on QOL. From this point of view, the education level and the employers' rate were considered positive indicators, whereas the population density, unemployment rate, and household density were considered negative ones.

Extraction of the Quality of Life Index

Firstly, the municipality vector map was overlaid on the LST, NDVI, and LCLU maps for 1991 and 2001, and mean values for LST and NDVI as well as the urban-use percentage were calculated per municipality. These values were then integrated with the values of the socio-economic indicators as attributes of the municipality vector map in a GIS. For a fair comparison between QOL in 1991 and 2001, all indicator values were normalized into the range 0 to 1.

In the case of a positive indicator (e.g., vegetation), the value of 0 indicated the least positive influence on the QOL of citizens (practically implying a negative impact on QOL), whereas the value of 1 represented the most positive influence on the QOL. Likewise, in the case of a negative indicator (e.g., the unemployment rate), the value of 1 indicated the worst influence on QOL, in contrast with the value of 0, which implied the least negative impact on QOL. Following normalization and on the basis of the hypothesis that all indicators equally affect QOL, all indicator values were summed, resulting in a QOL score for each municipality, which was further classified into five levels of QOL: low, fair, moderate, good, and high.

Results and Conclusions

Figure 3 shows the QOL for the 55 municipalities/communities of the Athens metropolitan area for 1991 and 2001, respectively. By examining Figure 3, it can be observed that, in 1991, most municipalities were characterized by a fair and moderate life quality, with the good and high QOL levels recorded mainly at the municipalities of the N/NE/NW suburbs of the prefecture of Athens. In particular, 14 municipalities displayed a low QOL, 16 municipalities displayed a fair QOL, 16 municipalities displayed a moderate QOL, five municipalities displayed a good QOL, and four municipalities displayed a high QOL. The municipalities placed in the N/NA/NW suburbs of the prefecture of Athens presented moderate-to-high QOL levels, the municipalities at the central and southern suburbs of the prefecture of Athens presented low-to-moderate QOL levels, whereas the municipalities of the western suburbs of the prefecture of Athens as well as of the southwestern suburbs of the prefecture of Pireaus presented low-to-fair QOL. The lowest QOL score was measured for the municipality of Drapetsona, whereas the highest QOL score was measured for the municipality of Ekali.

In 2001, most municipalities were characterized by a fair QOL, followed by a moderate QOL, whereas the number of municipalities experiencing a good or high QOL was found to have decreased by one, compared with the number in 1991. In particular, in 2001, 14 municipalities presented a low QOL, 17 municipalities presented a fair QOL, 16 municipalities presented a moderate QOL, six municipalities were characterized by a good QOL, and only two presented a high QOL. Moderate-to-high QOL levels were associated with municipalities mainly of the northern and eastern parts of metropolitan Athens, whereas low and fair QOL levels were observed in the central and western suburbs of the prefecture of Athens as well as at the southwestern suburbs of the prefecture of Pireaus. The lowest QOL score was measured for the municipality of Agios Ioannis Rentis, whereas the highest QOL score was measured again for the municipality of Ekali.

From Figure 4, it can be said that most of the changes in life quality between 1991 and 2001 occurred at municipalities placed in the N/NA/NW suburbs of Athens, whereas limited or no QOL changes were observed for municipalities of the central, southern, and western suburbs of Athens as well as of the southwestern suburbs of Piraeus. It must be noted that municipalities with fair QOL did not present significant changes in QOL between 1991 and 2001. The only exception was the municipality of Galatsi, which improved its QOL from low in 1991 to fair in 2001. During the decade, Galatsi presented an increasing trend in its education level and a decreasing trend in its unemployment rate, percentage of urban use, and LST. These variations prevailed against the decreasing trends in population and household density, thus resulting in an improved QOL for Galatsi in 2001, compared with 1991. The data used for measuring the QOL in Penteli revealed a noticeable increase in the unemployment rate, a significant decrease in NDVI, and an increase in LST. These NDVI and LST changes were attributed to two forest fires that occurred in the summers of 1995 and 1999, respectively, which damaged a great amount of forest landscape in the area.

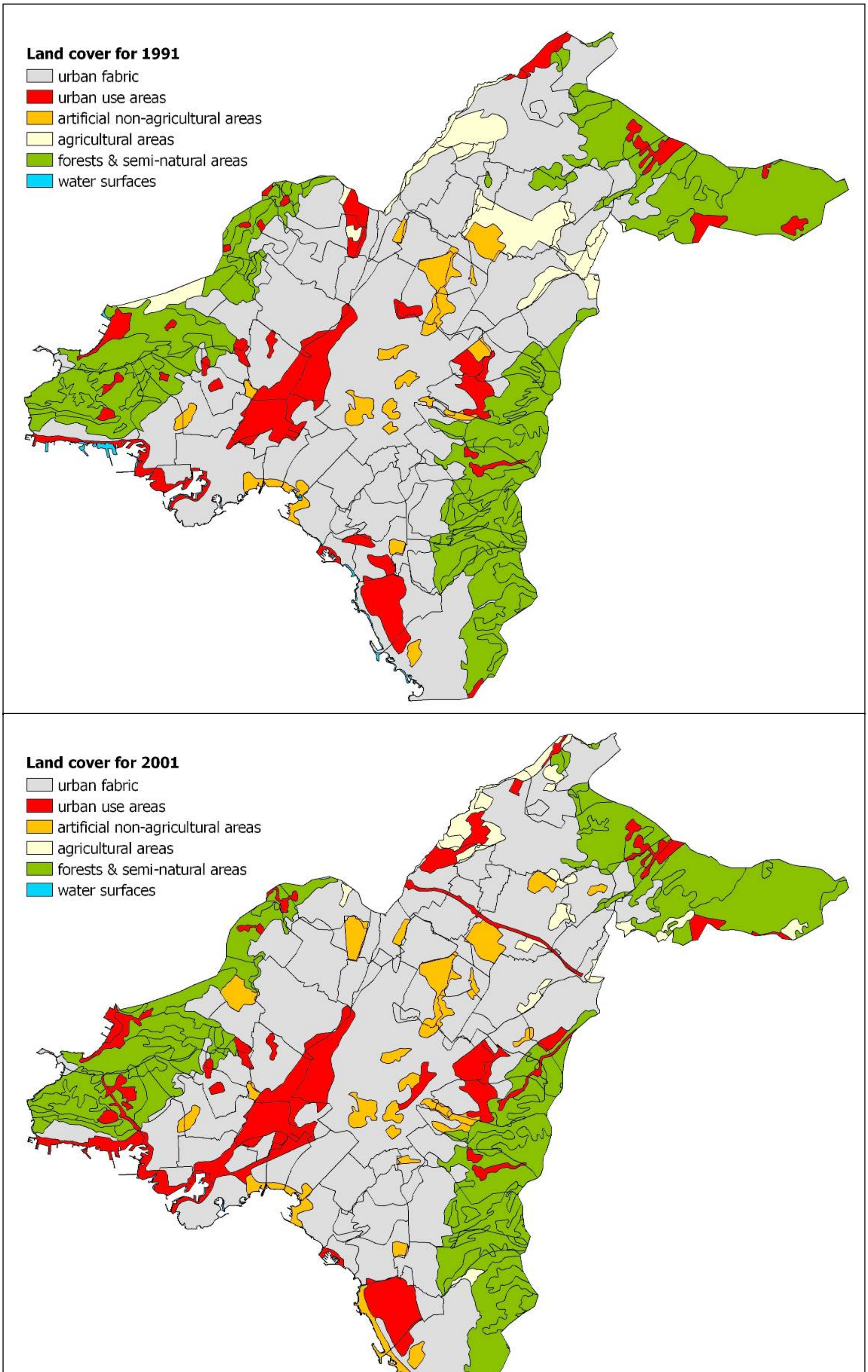

Figure 2. Land cover map of metropolitan Athens for 1991 and 2001

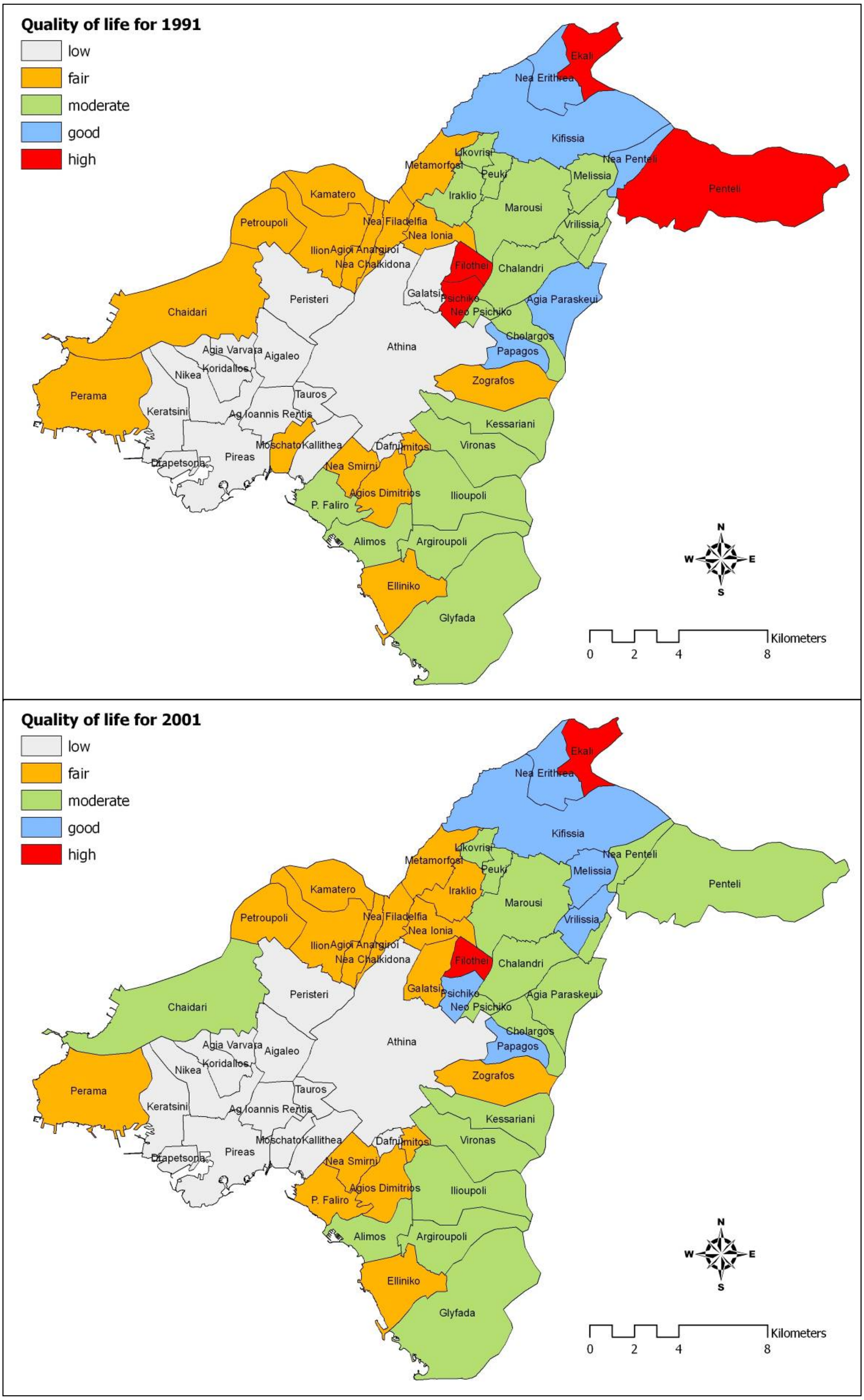

Figure 3. QOL maps for metropolitan Athens in 1991 and 2001

This damage led to a decrease in NDVI and at the same time to a significant increase in LST, thus degrading the life quality of the municipality from high to moderate. In regard to the municipality of Psichiko, it was found that life quality degradation was caused by a noticeable increase in the unemployment rate and decrease in the percentage of employers.

Taking into consideration all QOL changes that occurred during this period, it can be concluded that more municipalities appeared to have higher levels of QOL in 1991 than in 2001. In particular, in 1991, good and high levels of QOL were measured at nine municipalities, whereas low QOL was measured at 14. However, in 2001, good and high levels of QOL were observed at eight municipalities, while 14 presented low QOL levels. During the decade 1991–2001, four municipalities improved their QOL, 44 municipalities presented no change in their QOL, and only at seven municipalities' QOL deteriorated. Both in 1991 and 2001, the higher levels of QOL were mainly associated with municipalities of the N/NE/NW suburbs of Athens due to better physical environment, high education level, percentage of employers, and low unemployment rate. On the other hand, the lower levels of QOL were associated with municipalities of the central and western suburbs of Athens as well as of the southwestern suburbs of the Piraeus prefecture, resulting from poor physical environment, low education level, high population density, high unemployment, and low percentage of employers.

Results of this study were considered satisfactory, in the sense that the aggregated index could effectively provide an evaluation measurement and mapping of the urban life quality, which is helpful for identifying areas in which QOL needs to be improved through sustainable design. Moreover, the index could effectively highlight those indicators that can be held responsible for a measured QOL level. Certainly, the use of more data would favor a more accurate determination of QOL. The number of the physical and socio-economic indicators used in this study for QOL assessment (total of 8) cannot ensure an absolute determination of QOL, but only a good approximation of it, because QOL is assessed based on specific indicators that, although they play an important role in life quality, comprise only a small part of the physical and socio-economic profile of an urban area. Therefore, for a more reliable and accurate determination of QOL, the use of more indicators is suggested so more aspects of everyday living (e.g., household finances, personal security, accessability to services, median home value, air pollution, level of crime road traffic) can may be considered, leading to a more objective assessment of QOL levels.

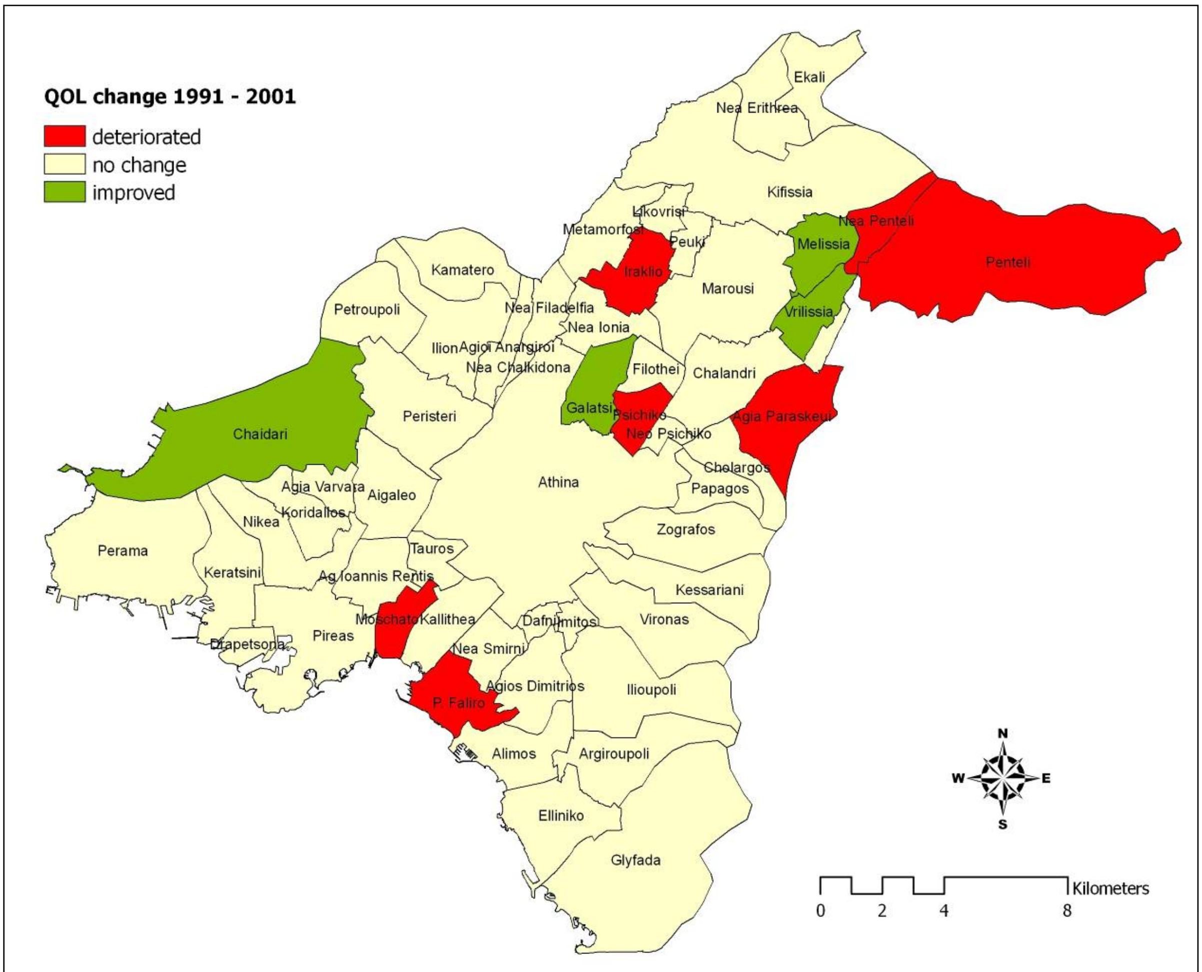

Figure 4. Changes in QOL for metropolitan Athens during the decade 1991–2001

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