Satellite Observation of Urban Heat Island Effect

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Abstract. Remote sensing is a key application in global-change science and urban climatology. Urbanization, the conversion of other types of land to uses associated with growth of populations and economy has a great impact on both micro-climate as well as macro-climate. By integrating high-resolution and medium-resolution satellite imagery with other geospatial information, several land surface parameters have been investigated including impervious surfaces and land surface temperatures for Bucharest metropolitan area in Romania. The aim of this study is to examine the changes in land use/cover pattern in a rapidly changing area of Bucharest metropolitan area in relation to urbanization since the 1990s till 2011 and then to investigate the impact of such changes on the intensity and spatial pattern of the UHI effect in the region. Investigation of radiative properties, energy balance and heat fluxes is based on satellite data provided by various sensors Landsat TM, ETM+, MODIS and IKONOS. This paper demonstrates the potential of moderate-and high resolution, multispectral imagery to map and monitor the evolution of the physical urban environment in relation with micro and macroclimate conditions. The continuous increase of power consumption and area of paved roads and decrease of urban vegetation land cover caused the growth of UHI intensity. Urban green land had a positive effect on mitigation of heat island in Bucharest area. The so called effect of “urban heat island” must be considered mostly for summer periods conditions and large European scale heat waves, when its health effects on people of the city with chronic respiratory or circulatory system can be important. In Bucharest urban and periurban areas, the range of average net radiation extracted from MODIS time series data during 2002-2011 summer period was in the order of 690-810 Wm⁻², function of the subregion tested areas as the net radiation is partitioned to sensible heat and storage heat. During summer heat wave events of 2003, 2007 and 2010 years, the average extracted net radiation was in the range of 800-950 Wm⁻².

Keywords. Satellite remote sensing, Urban Heat Island, heat wave, multisensor satellite remote sensing, land surface temperature, Bucharest.

1. Introduction

Climate change and extreme climate events are the great environmental concerns facing mankind in the twenty first century. Surface temperatures are expected to continue to increase globally and major changes are likely to occur in the global hydrological and energy cycles.

In the past century, that average global surface temperature had increased about 0.74°C [1]. One of the major phenomenons associated with climate change and global warming is the Urban Heat Island (UHI), in which surface air temperature in the urban area is higher than in the surrounding periurban areas. As a result of urbanization and industrialization UHI is considered one of the major problems for human populations and urban ecosystems in the twenty-first century. Urban Heat Island effect will surely influence the regional climate, environment, and socio-economic development. Much more, extreme climatic events as heat waves will amplify the UHI effect with severe urban ecosystem health consequences.

The generation and characteristics of UHI and use of satellite remote sensing data have been extensively studied during the past several decades [2], [3], and [4].
Satellite remote sensing imagery and geospatial products of moisture, reflectance, and surface temperatures is a key tool for UHI intensity assessment and mesoscale modelling through specification of urban land cover distributions, land surface temperatures and urban energy budget characteristics. The knowledge of urban surface energy budgets and urban heat islands is significant to assess urban climatology, global environmental change, and human–environment interactions important for planning and management practices.

As urban systems play a vital role in social and economic development in all countries, its environmental changes must be investigated on different spatial and temporal scales in direct relationship with urban climate warming and urban sprawl growth and population concentration. Due to the non-vegetated impervious surfaces of extensive constructions, huge quantities of solar radiation are stored and re-radiated in urban areas. These tend to be accelerated by anthropogenic heat released from vehicles, power plants, air conditioners and other heat sources. On the other hand, in developed countries, in response to expanding networks of roads to rural areas and an increasing reliance on the automobile, populations began scattering from cities to suburbs. As a consequence, at the fringe of cities, the rate of land conversion from vegetated to non-vegetated area exceeds the comparative rate of population growth and these low populated urbanized areas often expand disorderly on a metropolitan scale.

Urban land covers as the biophysical states of the earth’s surface and immediate subsurface are sources and sinks for most of the material and energy movements and interactions between the geosphere and biosphere. Changes in land cover include changes in biotic diversity, actual and potential primary productivity, soil quality, runoff, and sedimentation rates, and cannot be well understood without the knowledge of land use change that drives them. So, urban development can profoundly alter the urban landscape structures, ecosystem processes, and local climates. Timely and accurate information on the status and trends of urban ecosystems is critical to develop strategies for sustainable development and to improve urban residential environment and living quality. Urbanization changes land use, often in negative ways and increases environmental degradation by diminishing biodiversity, lowering ecosystem productivity, deteriorating watershed discharge characteristics, and interrupting biogeochemical cycles [5]. The rates of urbanization are characterized by creating a typology of urbanization trends based on quantities that are indicative to the potential environmental impacts. As future climate trends have been predicted to increase the magnitude and negative impacts of urban heat waves in metropolitan areas, there is an urgent need to be developed adequate strategies for societal vulnerability reducing [6].

In order to examine the temporal and spatial characteristics of the UHI during the period of 1990 to 2011 in Bucharest metropolitan areas in Romania, this paper used in situ biogeophysical and time series satellite data to characterize the annual, seasonal variations of the UHI in urban and periurban areas and to study the relationship between the UHI intensity and urban rapid growth. Investigation of radiative properties, energy balance and heat fluxes is based on satellite data provided by various sensors Landsat TM, ETM+, MODIS, NOAA, urban growth by IKONOS.

2. Urban Heat Island (UHI)

During the past century, the increase in global surface temperature of about 0.74°C [1] was recorded. One of the major phenomenons associated with climate change is the Urban Heat Island (UHI) effect, in which surface air temperature in the urban area is higher than in the surrounding periurban and rural areas. The term ‘Urban Heat Island’ was introduced by Manley in 1958 year [4] and has been extensively used in urban climate research. The UHI effect is the temperature increase in the urban areas compared to that in surrounding rural areas and is caused by the increased use of impervious land surfaces covered by anthropogenic material, the complexity of the three dimensional structures of the surface, and the coincident decrease of vegetation coverage, as well as
anthropogenic heat discharge due to human activities. Rapid urbanization transforms the natural landscape to anthropogenic urban land and changes surface physical characteristics. By covering the urban areas with specific infrastructure (buildings, roads, parking lots, and other paved surfaces), urban zones usually experience higher solar radiation absorption and a greater thermal conductivity and capacity for releasing heat stored during the day at night. As urban landscape contains a variety of surfaces with contrasting radiative, thermal, aerodynamic and moisture properties, the different surfaces which possess diverse thermal differences alter surface energy budgets and directly affects urban climate. The conversion of land use and land cover from rural to urban can impact the trends in temperature similar to that expected under an enhanced greenhouse warming scenario. Also, the presence of buildings alters surface roughness around urban with influences associated with changes in surface properties like urban air quality, surface-forced mesoscale circulation associated with variations in spatial patterns of the surface sensible and latent heat flux, and precipitation over urban areas.

Heat islands can be defined for different layers of the urban atmosphere, and for various surfaces and even the subsurface. It is very important to distinguish between these different heat islands as their underlying mechanisms are acting different regarding urban microclimate. Anyway, an urban heat island refers to the excess warmth of the urban atmosphere compared to the non-urbanized surroundings. Atmospheric heat islands are best expressed under calm and clear conditions at night when radiative cooling differences are maximized between urban and surrounding rural locations. The atmospheric heat island phenomenon can be classified into two types, the canopy urban heat island effect and the boundary-layer urban heat island effect. These definitions are based on the scale and height of their appearance. The former occurs on the microscale, and the latter occurs on the local or mesoscale. The canopy urban heat island is affected by local building geometry and materials. On the other hand, the boundary-layer urban heat island is governed by heated air from upwind urban areas and the underlying canopy layer in which the canopy urban heat island occurs. Another important parameter is the heat island intensity, which is defined as the temperature difference between urban and rural zones and is used to delineate heat island areas. As global warming patterns continue, researchers anticipate increases in the severity, frequency and duration of extreme heat events. UHI is considered one of the major problems for human populations in the twenty-first century as a result of urbanization and industrialization [7].

3. Land surface temperature

Satellite remote sensing derived biophysical parameters of Earth’s cover provide great potential for urban land cover construction materials and the composition and structure of urban canopies, for improving the understanding of the urban surface energy budgets, and observing the urban heat island (UHI) effect. Especially high-resolution Thermal Infrared (TIR) imagery has the advantage of providing a time-synchronized dense grid of temperature data over a whole city and distinctive temperatures for individual buildings. Knowledge of urban surface energy budgets and urban heat islands effects is very important for research themes like as urban climatology, global environmental change, and human–environment interactions as well as for planning and best urban management practices.

The digital remote sensing method provides not only a measure of the magnitude of surface temperatures of the entire metropolitan area, but also the spatial extent of the surface heat island effects. Geospatial Earth Observation data provided by multispectral, multispatial, multitemporal satellite sensors are useful tools for urban surface analysis of thermal patterns and their relation to urban land cover and biogeophysical characteristics and investigation of the relation between the atmospheric heat island, which consists mainly of the canopy urban heat island, and the surface heat island.
In urban heat island studies, land surface temperature $T_s$ is one of the most important biophysical parameter which modulates the air temperature of the lowest layers of the atmosphere, being of prime importance to the urban environment because of its key role in the energy balance of the surface. Also, $T_s$ helps to determine the internal climate among buildings, but also influences energy exchanges that affect the comfort of city dwellers [8]. In order to retrieve $T_s$ from at-sensor satellite and auxiliary data have been developed three methods: single-channel method, split-window technique, and multi-angle method. Because the last two methods require at least two channels, single-channel method is the only method that can be applied to the Landsat TM and ETM platforms, with one thermal channel [9]. In this study, $T_s$ was derived from the corrected Landsat TM and ETM TIR band by using the method described in [10], which does not require atmospheric parameters being widely used. The UHI effect can be measured for the individual thermal images and then compared between different time periods. The retrieval methods of brightness temperature from the TM and ETM+ images are different for Band 6.

In order to retrieve $T_s$ from at-sensor satellite and auxiliary data have been developed three methods: single-channel method, split-window technique, and multi-angle method. Because the last two methods require at least two channels, single-channel method is the only method that can be applied to the Landsat TM and ETM platforms, with one thermal channel, while for MODIS satellite data is used split-window technique.

3.1. Brightness temperature from the Landsat TM images

First, the digital numbers DN of thermal band 6 of Landsat TM have been transformed into absolute radiance by formula:

$$ L_\lambda = \frac{DN}{255} (L_{\text{max}} - L_{\text{min}}) + L_{\text{min}} \quad (1) $$

where $L_\lambda$ are the spectral radiance, $L_{\text{max}}$ and $L_{\text{min}}$ (mW/ (cm$^2$.sr)) are spectral radiances for each band having values of $L_{\text{max}}=1.896$ mW/ (cm$^2$.sr) and $L_{\text{min}}=0.1534$ mW/ (cm$^2$.sr). Then, spectral radiance is converted to at-satellite brightness temperature in Kelvin, $T$ (K), by the following equation:

$$ T_s = \frac{K_1}{\ln\left(\frac{K_2}{L_\lambda + b} + 1\right)} \quad (2) $$

where, $K_1=1260.56$K and $K_2=60.766$ mW/ (cm$^2$.sr. $\mu$m ), which are pre-launch calibration constants; $b$ represents effective spectral range, when the sensor's response is much more than 50%, $b=1.239(\mu$m) [11].

3.2. Brightness temperature from the Landsat ETM images

Radiance values from the Landsat ETM+ thermal band have been transformed to radiant surface temperature values using thermal calibration constants supplied by the following relation:
\[ T_s = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} \]  

(3)

where \( T_s \) is radiant surface temperature (K), \( K_1 = 666.09 \) is calibration constant 1, \( K_2 = 1282.71 \) is calibration constant 2 and \( L_\lambda \) is spectral radiance of thermal band pixels, expressed by the following equation:

\[ L_\lambda = \text{gain} \times \text{DN} + \text{offset} \]  

(4)

where Digital Numbers (DNs) in each band of the Landsat TM and Level 1G ETM+ imagery used were converted to physical measurements of at sensor radiance (LE) using a formula that accounts for the transformation function used to convert the analog signal received at the sensor to DNs stored in the resulting image pixels, gain = slope of the radiance/DN conversion function, DN= digital number of a given pixel, and offset = intercept of the radiance/DN conversion function. Gain and offset values are supplied in metadata accompanying each ETM+ image, and the DN to radiance formula [12].

3.3. Land Surface Temperature derived from MODIS satellite data

MODIS is an EOS instrument that will serve as the keystone for global studies of atmosphere, land and ocean processes. It scans ±55° from nadir in 36 bands, with bands 1-19 and band 26 in the visible and near infrared range, and the remaining bands in the thermal infrared from 3-15 \( \mu \)m. The 36-band MODIS satellite scanner has 1 km\(^2\) pixels at nadir for the thermal infrared bands that will be used for LST. For a given MODIS pixel, the split-window Land Surface Temperature algorithm requires emissivities in bands 31 and 32. With 15 emissive bands, the Moderate Resolution Imaging Spectroradiometer (MODIS) on-board the EOS-TERRA platform offers new perspective in earth observation in the infrared spectrum (3-15 \( \mu \)m). Because chemical components of the atmosphere have various absorption bans, only seven MODIS emissive bands are useful for land surface remote sensing. MODIS has four bands (20, 21, 22, 23) in the 3-5 \( \mu \)m atmospheric window. Surface properties in the infrared are specified either in terms of emissivity or reflectance, the emissivity being related to the directional hemispheric reflectance by Kirchhoff's law.

The emissivity estimation is accomplished by the use of linear bidirectional reflectance distribution function (BRDF) models, which have spectral coefficients derived from laboratory measurements of material samples and have structural parameters derived from approximate descriptions of the cover type. The emissivity of a surface is a function of many factors, including water content, chemical composition, structure and roughness. The identification of surface moisture for improved emissivity estimates is under investigation. We will need to apply more information in the classification look-up scheme to refine the estimates.

4. Methods

The surface urban heat island effect is quantified from remote sensing satellite data for thermal emissivity of land surfaces and the derived land surface temperatures (Ts) from MODIS Terra/Aqua sensor which are particularly suitable due to its global coverage, radiometric resolution and dynamic ranges of land cover types and high calibration accuracy in multiple thermal bands. The underlying algorithms use other MODIS data as input, including geolocation, radiance fields, cloud
masking, atmospheric temperature, water vapour, snow, and land cover. Temperatures are extracted in Kelvin; accuracy of 1 K is yielded for materials with known emissivities [10]. Remotely sensed data and above ground air temperatures are not identical, but related [8].

Ts have the advantage of spatially explicit datasets, compared to single measurement points. The UHI of the canopy layer is determined by measuring air temperatures (usually 2 m above ground) by comparing temperatures from point measurements between the city centre versus surrounding rural areas followed by a classical approach to analyze the difference of urban and rural temperatures. A variety of remote sensing products are also available in time series. Thus, remote sensing satellite data are frequently used for assessing surface UHIs [10] with a variety of indicators. This work analyses time-series Land Surface Temperature (LST) generated by Moderate Resolution Imaging Spectroradiometer (MODIS) data on-board NASA Terra and Aqua satellites, namely Terra MOD11A2 and Aqua MYD11A2 with a resolution of approximately 1km and aggregated for eight consecutive days. The monthly mean LST per pixel and time of day by aggregating the available 8-days-mean were computed. An accuracy of the MODIS products better than 1 °K for most cases of validation was reported whereas other studies found larger biases for vegetation at some sites [11]. Based on the comparison of different satellites with respect to in-situ measurements of LST in urban areas found less than 5% differences for MODIS LSTs [12].

5. Study area and data

Urban metropolitan area Bucharest described by a star-shaped pattern (Figure1), placed in the South – Eastern part of Romania, is bounded by latitudes 44.33 °N and 44.66 °N and longitudes 25.90 °E and 26.20 °E. Its central region has the main coordinates: latitude 44°25′N, longitude 26°06′E. The city is crossed by the Dâmbovita and Colentina rivers and is surrounded by forests, which makes Bucharest a city with large green areas, which have come parks and, at the same time, places for rest and entertainment, such as: Baneasa, Herastrau, Floreasca, Tei, Lebada Fun area. Herastrau Park is the largest in the city, being situated on the Colentina River, including the Herastrau and Floreasca lakes, providing special opportunities of entertainment.

Bucharest is one of the most crowded capital in Eastern Europe and maybe the most polluted. Economical development results in traffic increase (presently six times increase in comparison to 1990 year) as well as some industries placed in the surroundings of the city whose activities causes high concentration of heavy metals (sometimes above the acceptable limits). Multi-spectral and multi-temporal satellite imagery provide the most reliable technique of monitoring of different urban structures regarding the net radiation and heat fluxes associated with urbanization at a regional scale. Investigation of radiation properties, energy balance and heat fluxes for Bucharest urban area, Romania was based on multispectral and multitemporal cloud free satellite data: Landsat TM 27/08/1989, 21/08/1990; Landsat ETM:23/07/2002, 12/09/2004, 20/08/2007, 16/08/2011, radiometric and geometrically corrected, pan-sharpened, multi-spectral IKONOS sub-scene of 1 m pixel resolution acquired 27/07/2005, 12/09/2007 and 12/07/2009; time series MODIS Terra/Aqua data for period 2002-2011 have been used to characterize surface spectral temperature and emissivity. This imagery is produced by merging 11-bit of 1m resolution panchromatic 450-900 nm and 4 m resolution multi-spectral - blue 450-530 nm, green 520-60 nm, red 630-720 nm and near infrared 770-880 nm channels via principal component analysis. The images have been divided in several sub scenes, chosen as study areas, covering a part of Bucharest town. In situ-monitoring meteorological as well as the ENVI 4.7, IDL 6.3 and ILWIS 3.1 software have also been used.
6. Results

Bucharest metropolitan region is under continuous influence of characteristic meteorological-climatic fluctuations of continental climate, periodically during summer, with registered heat waves for periods of time longer than five consecutive days with serious impact on urban heat island and inhabitants’ health using the land surface thermal. Based on data provided by the MODIS Terra/Aqua LST Day/Night data, MODIS MOD11A1 (Terra) and MYD11A1 (Aqua) products (provided by Oak Ridge National Laboratory Distributed Active Archive Center ORNL DAAC, MODIS subsetted land products, [http://daac.ornl.gov/MODIS/modis.html], we were able to assess the LST evolution in the greater area of Bucharest for summer heat waves periods as well as to evaluate and delineate the Urban Heat Island (UHI) pattern and magnitude. Present research focuses on the periods of months May-August from 2002 to 2011. As the land cover has a significant influence on the extension and the geometry of the Bucharest UHI, a strong correlation was performed. The Land Surface Temperature (LST) derived from MODIS data in the Bucharest urban area was compared with the rural surrounding area for night and for daytime.

Changes in the urban and periurban land cover and land surface properties as well as in the atmospheric abundance of greenhouse gases and aerosols, in solar radiation alter the energy balance of the climate system. These changes are expressed in terms of radiative forcing, which is used to compare how a range of human and natural factors drive warming or cooling influences on regional and global climate. Given the ability to define land cover characteristics at the site level based on attributes such as physiognomy, horizontal and vertical structure of built environment, vegetation phenology and leaf morphology, direct parameterisation and mapping using remotely sensed data can enhance the ability to characterize and monitor these important biogeophysical parameters.

In this study, higher LST values are reported in the Aqua LST data in comparison to the Terra LST data as MODIS Terra overpass time is considered between 08:30 and 10:30 UTC, while Aqua overpass time is considered between 11:30 and 13:30 UTC for metropolitan study area. Thus, Aqua data acquisition is closest to the time when maximum of temperature is recorded. In general the increase of LST ranges from 3 to 12° K, depending mainly on the relative land cover type. The highest LST increase, of the order of 6–14° K, is observed in the built urban and industrial areas at the periphery of the city. Smaller increase is observed in agricultural and forested areas (5–14° K), and near surface water lake Ciurel and Dambovita river. The different values of LST increase are
attributed to the difference in the emitted radiance from each land type and/or the urban heat island effect.

Bucharest expanded in all directions during the 21 years period covered by the available satellite images. Change analysis during period of (1990 -2011) from Landsat TM and ETM+ and IKONOS satellite data showed a strong urban growth inside of the town but also in periurban areas as an increase of overcrowded urban area for all 6 sectors belonging to Bucharest metropolitan area.

Urban temperature trend analysis by using the annual mean of daily minimum temperatures reflects the degree and continuity of the minimum temperature trend in a year. To estimate the influence of urbanization on the thermal environment, trends of the temperature differences between the targeted station and a rural station have been commonly used. By subtracting the rural station data, the influence of background climate can be minimized and the influence of the land cover on the temperature can be clearly extracted. Since the long-term temperature change is often non-stationary, we need to investigate the times series dataset. In order to investigate the existence of turning points and the trend of time series temperature data, a statistical approach was applied to detect variation (structural changes). Figure 2 illustrates a classification of urban land cover based on IKONOS 12/07/2009 image.

Supervised classifications of individual land covers have been performed using the reflective bands of the Landsat TM and ETM + as well as IKONOS data. The overall classification accuracy in Figure 3 was approximately 91%.The classes selected for these supervised land cover classifications were based on the V-I-S model which divides urban and periurban land cover composition into three major categories-vegetation-V, impervious surface-I, and soil-S. These three general categories have highly contrasting responses in terms of energy flux (absorption, retention, emission) and moisture dynamics (uptake, evapotranspiration, runoff), which in turn affect energy flows. The V-I-S model was developed explicitly for ecological purposes, as distinct from the more common urban land use classifications. The thermal response per land cover type is assessed according to the thermal band 6 (TIR) within Landsat TM and ETM+ imagery. UHI intensity is related to patterns of land use/cover changes (LUCC), e.g. the composition of vegetation, water and built-up and their changes.

The aim of this study was to examine the changes in land use/cover pattern in a rapidly changing area of Bucharest metropolitan area in relation to urbanization from 1990 till 2011 and then to investigate the impact of such changes on the intensity and spatial pattern of the UHI effect in the region.

Our analysis showed that higher temperature in the UHI was located with a scattered pattern, which was related to certain land cover types. In order to analyze the relationship between UHI and land cover changes, this study attempted to employ a quantitative approach in exploring the relationship between temperature and several indices, including the Normalized Difference Vegetation Index (NDVI). Such analysis is very helpful in urban mesoscale models and urban climate studies. Preliminary results of our TIR bands analysis from Landsat TM and ETM + and MODIS show maximum and minimum energy readings of individual land covers, according to training sites selected in the supervised classification. Not surprisingly, water shows the lowest maximum energy reading and lowest minimum reading of each of the land cover types.
The impervious surfaces such as light and dark impervious and bright roofs show among the highest minimum and also the highest maximum readings. This suggests that impervious surfaces tend to absorb incoming light energy and retain heat energy more readily than do natural surfaces. Bright roofs show the largest within-class variation among training sites. This is undoubtedly due to the difference in pitch and aspect of the roofs within the training site. The anomaly, however, is the dry soil category, with the largest within-class variation by training site. Dry soil also contains both the highest minimum and the highest maximum readings. This is a direct reflection of the hot dry climate in this urban environment during summer periods. These areas are affected by increased air pollution, having a high density population and big automobile traffic that exists in the urban area and especially in the central part of Bucharest town. Vegetation was classified by using the spectral pattern of VNIR band reflectance with the minimum distance method. Since the boundary zones of urban and periurban vegetation coverage were often misclassified, NDVI parameter was used to distinguish vegetation from soil and builted areas. The thresholds of NDVI for division of vegetation were decided manually for each date. Based on this procedure, rural areas were classified into five land cover types: field, paddy field or orchard, lawn, forest, and bare soil. The land cover map for urban and periurban Bucharest area was established based on the remote sensing-based elements like: flat pavement, road, industrial area, low-rise dwelling, mid-/highrise dwelling, commercial/business area and low-rise building, vegetation, forest.
In Bucharest urban and periurban areas, the range of net radiation extracted from MODIS Terra time series data during 2002-2011 summer period was in the order of 690-810 Wm\(^{-2}\), function of the subregion tested areas as the net radiation is partitioned to sensible heat and storage heat. During the summer heat wave events of 2003, 2007 and 2010, the average extracted net radiation was in the range of 800-950 Wm\(^{-2}\). During the summer heat wave events of 2003, 2007 and 2010, the average extracted net radiation was in the range of 800-950 Wm\(^{-2}\). At the microscale, surface albedo and temperature should have large variety in urban sectors because of the large material and structural versatilities.

![Figure 4: Land surface temperatures map based on LANDSAT ETM 16/08/2011 data.](image)

The storage heat flux exceeds the sensible heat flux in urban areas, whereas the sensible heat flux is higher than storage heat flux in industrial areas. In particular, negative storage heat flux appears at a number of industrial points. This tendency shows that high surface temperature in the industrial areas in Bucharest is induced by mass energy consumption, because most of the anthropogenic heat discharge is transferred to the atmosphere as sensible heat. Figure 4 shows a land surface temperature map based on LANDSAT data. The city center, Otopeni and Baneasa airports and major roads with high traffic values were found to have the highest land surface temperature values, while parks with vegetation, neighbouring forests, farmlands, and gardens had the lowest land surface temperature values.

Analyzing the 3-year 2007-2009 time series of MODIS Terra satellite-based observations, our results suggest that the annual variation of monthly mean UHI intensity is larger in daytime than in night-time for Bucharest metropolitan area. Figure 5 illustrates this in case of summer day-time and night-time and Figure 6 presents the case of winter day-time and night-time UHI intensity patterns respectively.
Satellite data analysis stressed a clear temperature contrast between the central, median and peripheral zones of Bucharest city. Monthly average values of the temperature differences between urban and rural areas range between 1°C and 6°C. The population of the city (which is highly correlated with the industry) is the main factor of increasing UHI intensity that is modified by orography. Also monthly mean spatial structures of UHI show that the most intense UHI occurs in day-time in the summer period (May–June–July–August), being greater during heat wave events. Information on the spatial pattern and temporal dynamics of land cover and land use of urban areas is critical to address a wide range of practical problems relating to urban regeneration, urban sustainability and rational planning policy as well as for more sustainable urban transport policies.

In recent years, the impact of weather on human health has become an issue of increased significance, especially considering the potential impacts of global warming and an increased urban
heat island effect due to urbanization. Exposure to ambient temperature is often defined as some combined metric of temperature and relative humidity or dew point temperature, such as heat index, humidex, or apparent temperature and of other variables, such as day of the week, time trend and barometric pressure and atmospheric pollution.

Elevated temperature values during UHI phenomenons in Bucharest are associated with increased risk of those people dying from cardiovascular, respiratory, cerebrovascular, and some specific cardiovascular diseases, such as ischemic heart disease, congestive heart failure and myocardial infarction. Vulnerable subgroups also included: women, those with lower socioeconomic status, and several age groups, particularly the elderly over 65 years as well as infants and young children. UHI is directly responsible, acting to worsen the adverse health effects from exposure to extreme thermal conditions.

7. Conclusion

Satellite data analysis stressed a clear temperature contrast between the central, median and peripheral zones of Bucharest city. The monthly average values of the temperature differences between urban and rural areas range between 1°C and 6°C. The population of the city (which is highly correlated with the industry) is the main factor of increasing UHI intensity that is modified by orography. Also, monthly mean spatial structures of UHI show that the most intense UHI occurs in day-time in the summer period (May–June–July–August), being greater during heat wave events.

The urban subscene areas of high temperature have been consistent with built-up areas, which can be seen by comparing land use/cover with temperature maps. Urban local land cover, grass, concrete, soil, water, etc., largely dictates the energy exchanges between the earth and atmosphere. The urban heat island has been described as “one of the most clearly established examples of inadvertent modification of climate”.

There is no doubt that the Urban Heat Island (UHI) has a strong impact on human health. UHI serves to enhance the intensity of heat waves, which in turn have adverse effects on human health due to an increased exposure to extreme thermal conditions. As a result, heat related mortality is depending on UHI instensity.

One of the great challenges facing our current generation of scientists and engineers is how to mitigate the harmful effects of Urban Heat Island and make the sustainable cities.

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