Time series satellite data for spatio-temporal analysis of land cover biogeophysical parameters in Bucharest metropolitan area in Romania

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Abstract. The spatial variability and structures displayed by remote sensing imagery are essential information characterizing the nature and the scale of spatial variation of Earth surface processes. The rapid sensor technology development of remote sensing methods and the importance of analyzing of biogeophysical parameters for a better large-scale understanding and monitoring of the earth system has shown a growing interest in the last years. By integrating high-resolution and medium-resolution satellite imagery with other geospatial information, have been estimated several land surface biogeophysical parameters including 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 region in relation to urbanization since the 1990s till 2012 and then to investigate the impact of such changes on urban and periurban biogeophysical parameters including the land surface albedo and NDVI parameters in the region. Investigation of vegetation characteristics, radiative properties, energy balance and heat fluxes was 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

Keywords: time-series satellite data, land cover biogeophysical parameters, urbanization, Bucharest, Romania.

1. Introduction

During last years, the remote sensing community has shown a growing interest to the problem of estimating urban biogeophysical parameters from remote sensing data. This is motivated by the rapid sensor technology development and the importance of analyzing such parameters for a better large-scale understanding and monitoring of the earth system. Land use and land cover (LULC) influence a variety of processes important in characterizing urban ecosystems like as air quality, including deposition rates, biogenic emissions, albedo, surface temperatures and other parameters.

Several studies indicate that an increase of vegetation coverage (expressed by Normalized Difference Vegetation Index NDVI) across an urban region : a) increases the following biogeophysical variables: albedo for near-infrared wavelengths, absorption of solar radiation, roughness length, turbulence, evapotranspiration, relative and specific humidities, equivalent potential temperature, moisture retention, and minimum temperatures; b)decrease the following variables: albedo for visible wavelengths, infrared emission, surface winds, runoff and erosion, Bowen ratio, and maximum temperatures [1].

Another important biogeophysical parameter is Land surface temperature (LST) which is controlling the physical, chemical and biological processes in urban areas. It is very important factor for study of urban climate [2]. Surface and atmospheric modifications due to urbanization generally lead to a change of thermal physical properties over urban area that is warmer than the surrounding periurban areas, particularly at night. This phenomenon is called urban heat island (UHI). The occurrence of UHIs represents human-induced urban/rural contrast (in physical characteristics of the surface, such as albedo, thermal capacity and heat conductivity), which is mainly caused by replacement of vegetated areas by non-evaporating and impervious materials such as asphalt and concrete. UHI phenomenon leads to changes in radiative fluxes and in the near-surface flow. For example, in urban areas, the original higher level of latent heat flux over vegetated areas is changed into the higher level of sensible heat flux over the same areas due to land use and land cover changes; further, there obviously exist facts of reduced evapotranspiration and more rapid runoff of rain water.

Land surface albedo is important parameter for the remote sensing of atmospheric aerosol, cloud properties from space, climatic analysis, biogeophysically based land surface modeling of the exchange of energy, water, momentum, and carbon for various land use categories as urban, forestry and agriculture, as well as for surface energy balance studies. Many of the important environmental parameters in urban areas are best measured in-situ, but some parameters are better derived by remote sensing. Satellite remote sensing measures upwelling radiance, a parameter directly related to the albedo and surface reflectance of the urban mosaic. Albedo is a critical environmental parameter because it modulates energy fluxes and can be influenced by choices of building materials and land covers. Temporal variations in the albedo of the urban mosaic exert a strong influence on the energy flux through urban environments.

During last years urban/periurban vegetation land cover of Bucharest metropolitan area in Romania experienced serious degradation due to anthropogenic and climatic changes. Forests and urban green systems are all sensitive to environmental pollution and climatic factors having different vulnerability thresholds according to the vegetation species, the amplitude, and the rate of different stressors which can have both short-term and long-term implications for standing biomass, vegetation health and species composition. The aim of this study is to examine the changes in land use/cover pattern in a rapidly changing area of Bucharest metropolitan region in relation to urbanization since the 1990s till 2012 and then to investigate the impact of such changes on urban and periurban biogeophysical parameters including the land surface albedo, Normalized Difference Vegetation Index NDVI and land surface temperature LST parameters in the region.

2. Biogeophysical information derived from satellite data

Solar radiation incident on vertical and inclined surfaces consists of beam, sky-diffuse and ground-reflected components. The ground-reflected component may be significant, particularly in the northern latitudes due to low elevations of the sun and, at times, due to the presence of highly-reflecting snow cover. Accurate estimation of ground-reflected radiation would require knowledge of the foreground type and geometry, its reflectivity, degree of isotropy, the details of the surrounding skyline and the condition of the sky. Spectral fingerprints of Earth’s features (air, soil, vegetation, water) derived from satellite sensors in different spectral wavelengths provide information on biogeophysical parameters of the environment.

2.1. Land surface albedo

In general, part of the incident energy striking a surface may be absorbed, reflected, and transmitted. The corresponding surface properties associated with these three processes are absorptivity, reflectivity, and transmissivity. The fractions of the total incident energy associated with these properties are termed as absorptance, reflectance, and transmittance. When the sun is the source of the incident energy, the term albedo (α) is commonly used instead of reflectance.

Land surface albedo strongly depends on the Earth's surface properties of the land cover material that the sunlight strikes, as well as the incident direction and the hemispherical distribution of the incoming radiation. Studies of atmospheric heat balance have shown that 17.5% of the incident radiation is absorbed by the atmosphere, 47.5% is absorbed by the Earth's cover, and that the surface albedo of the Earth reflects 35% back into space [1].

Land surface albedo is an important parameter in describing the radiative properties of the Earth's surface. Urban applications need proper representation of the surface albedo's spatial and spectral variation, due in part to the distribution of vegetated surface types and growing conditions, and temporal variations, due largely to changes in the amount of vegetation over phenological growth cycles.

Land surface albedo (α) can be calculated from the following equations [5]:

$$H_m = H^{'}\{1-\alpha[0.25(S/S_o)+0.6(1-0.25(S/S_o))]\} \quad (1)$$

with H' monthly average of daily global irradiation that strikes the surface, defined by

$$H^{'} = H_o[A+(BS/S_o)] \quad (2)$$

H_m, S and S_o are monthly averages of measured daily global irradiation, S_o monthly averages of daily sunshine duration and monthly of the daily maximum possible duration of sunshine hours.

$$H_m = H_o[A+(BS/S_o)] \quad (3)$$

$$S_o^{'} = 2/15\cos^{-1}[(\cos 85^o - \sin L \sin\partial)/(\cos L\cos\partial)] \quad (4)$$

with L latitude of the sites in degrees, ∂ the declination angle of the sun in degrees and H_o the estimation of the monthly average of daily extraterrestrial irradiation. Then, can be defined A and B regression constants in the previous equations Eq.3-4 for each month of the year [6], [7].

In a shortened case surface albedo is defined as the ratio of reflected to incident solar radiation flux intensity (measured in W m^{-2}) on the earth's surface. The total energy reflected by the earth's surface in the short-wave domain is characterized by the short-wave (0.3±4.0 μ m) broadband albedo. The shortwave broadband albedo is one of the most important physical parameters for climate models, because it governs the exchange of solar radiation between the land surface and the atmosphere. Solar radiation energy is the fundamental source of power that drives the circulation of water and energy in the atmosphere, continents, and sea. Moreover, solar radiation at the ground level affects global climate and meteorology. Therefore, accuracy in the measurement of short-wave broadband albedo directly affects the results of a climate model. However, using satellite remote sensing techniques, albedo can be determined at the pixel level over an entire area. This allows more accurate estimation of climate models.

In the IPCC third assessment report, surface albedo is listed among those radiatively important components that are known at a very low confidence level. The uncertainty of radiative forcing due to insufficient knowledge of surface reflective properties is believed to be comparable or higher than radiative forcing produced by ozone, sulphate aerosols and aerosols from biomass and fossil fuel burning [2], [3], [4].

In the physical climate system, albedo determines the radiation balance of the surface and affects the surface temperature and boundary-layer structure of the atmosphere. In forest systems, albedo controls the microclimate conditions of tree and forest vegetation and their radiation absorption, which, in turn, affects ecosystem physical, physiological, and biogeochemical processes such as energy balance, evapotranspiration, photosynthesis, and respiration [5]. It has long been recognized that accurate surface albedo information is important for weather forecasting, climate projection and ecosystem modeling.

Land surface albedo is essential information used as an input parameter for numerical Regional Climate Models and Atmospheric General Circulation Models. Surface albedo dynamics are closely related to ecosystem dynamics. Therefore, impacts of climate change and variations on forest ecosystem processes could possibly affect surface albedo characteristics. Since the physical climate system is very sensitive to surface albedo, forest ecosystems could significantly feedback to the projected climate scenarios through albedo changes. As such, impacts of climate change on surface albedo and ecosystem feedbacks have been recommended for further investigation. This is of particular significance for those ecosystems whose structure is highly responsive to climate change and variations [6].

Earth's radiation budget changes, such as in albedo values, can be compared directly with the effects of greenhouse gases and aerosols through the concept of radiative forcing. Land cover change induced surface albedo change perturbs the radiation budget by modifying the absorption of shortwave radiation forcing which can then be compared with the radiative forcings by greenhouse gases, aerosols and solar output changes to assess the importance of surface albedo change in relation to these other climatic influences.

2.2. Vegetation Index

Forest cover dynamics was studied by means of vegetation indices (VIs) developed based on combinations of two or more spectral bands, using radiance, surface reflectance (r), or apparent reflectance (measured at the top of the atmosphere) values in the red (R), and the near infrared (NIR) spectral bands [7]. This study used Normalized Difference Vegetation Index NDVI expressed as:

$$NDVI = (\rho_{NIR} - \rho_R)/(\rho_{NIR} + \rho_R) \tag{5}$$

For *Green Vegetative Cover* of forested areas, the most commonly used index is the NDVI and it has been used in mixture modeling to compute green fractional vegetation cover (*fc*) the following relationship:

$$f_c = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}} \tag{6}$$

where NDVIsoil is the NDVI value of bare soils and $NDVI_{veg}$ is the NDVI value of a pure vegetation pixel. In order to use Eq.6 to compute fractional green cover, we used two parameters, $NDVI_{soil}$ and $NDVI_{veg}$, which can be empirically determined (0.1 and 0.8) as suggested in literature.

The fractional cover computed using Eq.6 is only an estimate of the green component. Vegetation can be distinguished using remote sensing data from most other (mainly inorganic) materials by virtue of its notable absorption in the red and blue segments of the visible spectrum, its higher green reflectance and, especially, its very strong reflectance in the near-IR. Different types of vegetation show often distinctive variability from one another owing to such parameters as leaf shape and size, overall plant shape, water content, and associated background (e.g., soil types and spacing of the plants (density of vegetative cover within the scene).

2.3.Land surface temperature

2.3.1.Land Surface Temperature (LST) extracted from Landsat TM/ETM data

In urban environment and urban heat island studies, land surface temperature Ts 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, LST 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 LST from at-sensor satellite and auxiliary data have been developed three methods: single-channel method, split-window technique, and multi-angle method [9]. 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. In this study, Ts were derived from the corrected Landsat TM and ETM TIR band (1 1.45 -12.50 m) 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.

2.3.2.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 ± 55o 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 μm. The 36-band MODIS satellite scanner has 1 km2 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 mμ). 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 mμ 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 [11]. 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 [12]. 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.

3. Study area and data used

Urban metropolitan area Bucharest described by a star-shaped pattern (Figure 1), 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 produces 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 the regional scale.

Investigation of biogeophysical properties, energy balance and heat fluxes for Bucharest urban area, Romania was based on multispectral and multitemporal cloud free time series satellite data: Landsat TM 27/08/1990, 21/08/1994; Landsat ETM: 23/07/2003, 12/09/2007, 16/08/2012, ASTER 16/07/2009, MODIS Terra/Aqua from 2000 to 2012. 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. This imagery is produced by merging 11-bit of 1 m 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.

Some MODIS subsetted land products, Collection 5. have been provided online [http://daac.ornl.gov/MODIS/modis.html] from ORNL DAAC, Oak Ridge, Tennessee, U.S.A.

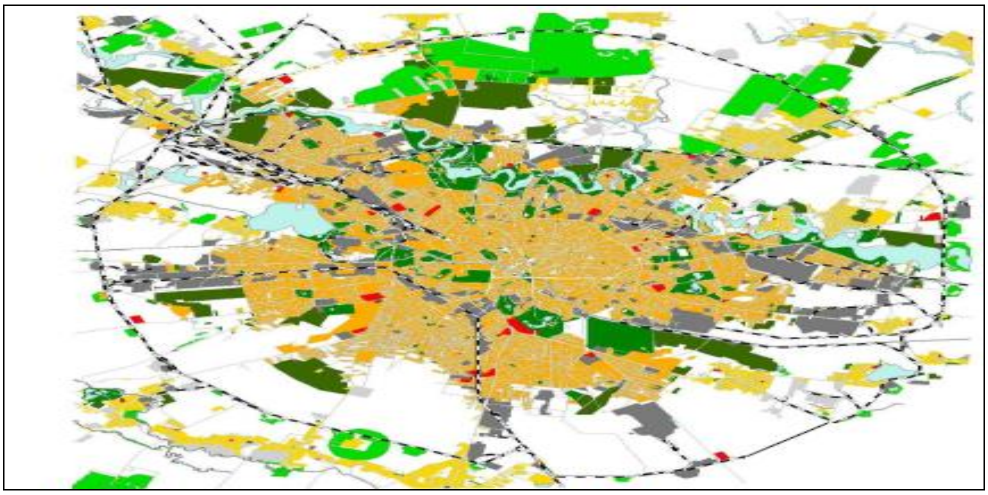

Figure 1. Test site urban Bucharest area

The images have been divided in several sub scenes, chosen as study areas, covering different sectors and periurban areas of Bucharest town. In situ-monitoring meteorological as well as ENVI 4.7, IDL 6.3 and ILWIS 3.1 softwares have been also used.

4. Results

The phenological patterns, biomass production, and species composition of urban/periurban vegetation land cover, are strongly affected by the climatic conditions of the Bucharest region, especially precipitation and heat wave events which are highly variable both inter-annually and intra-annually. From time series MODIS Terra/Aqua have been identified vegetation land cover changes during 2002- 2012 period and have been estimated the impacts of climate and anthropogenic factors.

Accuracy of image processing results (land cover classifications) was confirmed through ground sampling and analysis with portable GER 2600 spectroradiometer. These have been analyzed on the basis of absorption band position and shape, and classified on the basis of recurrent associations of absorption bands. Spectroscopic criteria are widely applied in hyperspectral image analysis for forest systems mapping. By analysis of the reflectance spectra of several vegetation, soil and water samples in the visible (VIS-SWIR) short-wave infrared interval 0,35 μm - 2,5 μm, was examined the feasibility of using detailed spectral information for recognizing the changes of vegetation land cover. The analysis of different classifications over selected test areas have shown urban forest changes due to high levels of atmospheric pollution mainly close of main road traffic and some local industries, air masses dynamics at local and regional level as well as due to deforestation for land-use conversion, insect and disease epidemics. This type of digital change detection has the advantage of (1) being repeatable; (2) facilitating the incorporation of biophysically relevant features from the visible, infrared and microwave parts of the electromagnetic spectrum ; and (3) requiring relatively low operational costs.

Figure 2 presents a land cover classification of the selected metropolitan area Bucharest, based on MODIS/Terra time series data for 2005-2011 years.

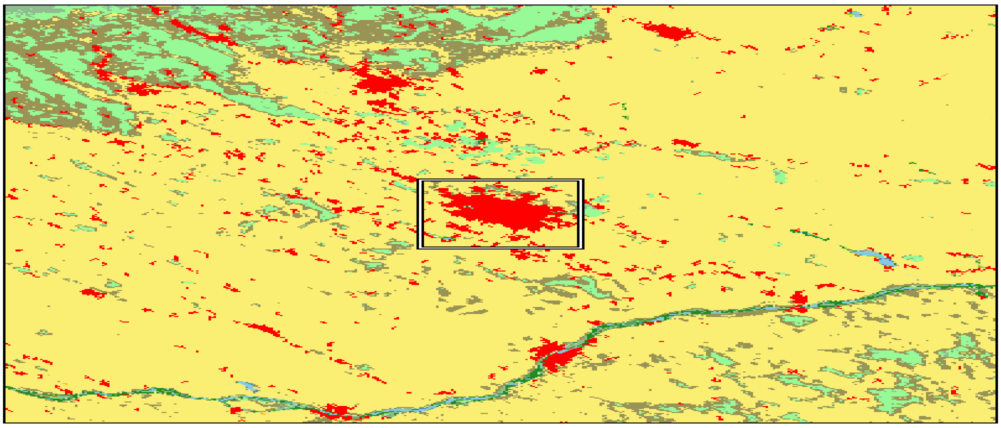

Figure 2. Land cover classification for metropolitan area Bucharest, based on MODIS/Terra time series data.

Figure 3 shows temporal variation of MODIS/Terra+Aqua BRDF and Calculated Albedo BRDF/MCD43A, 16-Day L3 Global 500m SIN Grid Approximately, for 10.5 km Wide x 10.5 km high of Bucharest metropolitan area. From this figure can be seen that during summer time albedo values are very low in the range of 0.05 to 0.12, while during winter time with snow cover of the land are higher in the range of 0.05 to 0.71.

Figure 4 illustrates temporal variation of MODIS/Terra NDVI parameter from MOD13Q1/250m_16_days_NDVI pixels where 38.89% pixels belong to the same class as the center pixel - Urban and Built-Up for Bucharest metropolitan area centered Latitude: 44.45 and Longitude: 26.1 for an areal extent of approximately 30.25 km Wide x 30.25 km High.

Summer period NDVI values, corresponding to vegetation period are placed in the range of 0.3 to 0.67. Was recorded a clear temporal variation of urban vegetation NDVI parameters with a decreasing trend during summer-autumn seasons due to low level of precipitations and increasing levels of land surface temperature. This fact has a negative impact on vegetation land cover in the South-Eastern part of Romania and through this on biomass resources. It is very clear that during summer of 2007 and 2012 years, characterized by recorded strong heat waves and land surface temperature anomalies, the periurban forest cover vegetation health recorded very low level values reaching 0,25. So, climate impacts on urban/periurban vegetation land cover are significant visible.

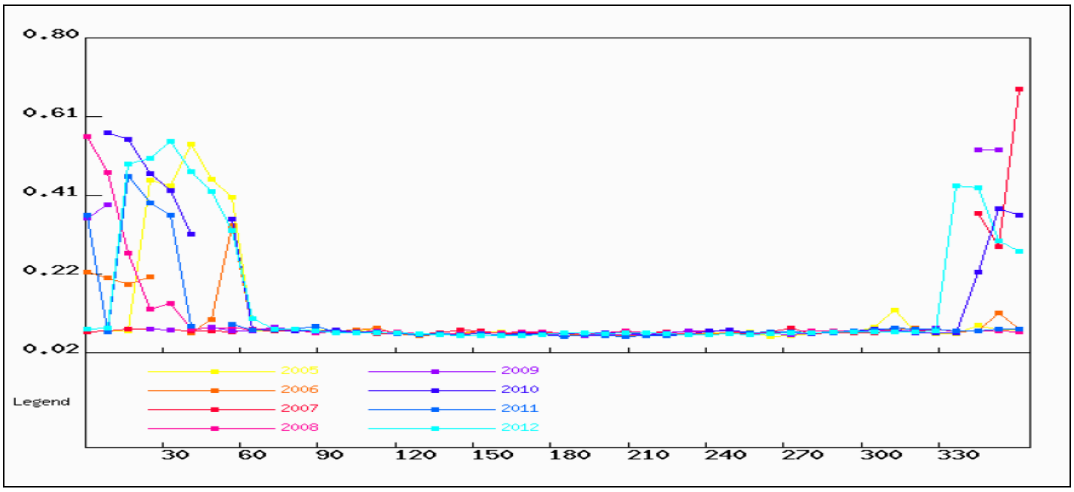

Figure 3. Temporal variation of MODIS/Terra Albedo parameter during 2005-2012 for Bucharest metropolitan area.

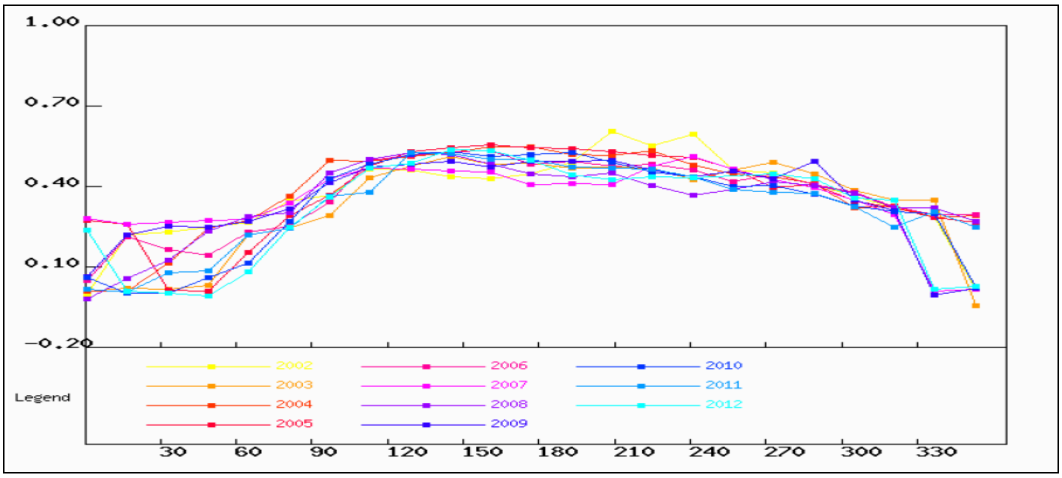

Figure 4. Temporal variation of MODIS/Terra NDVI parameter during 2002-2012 for Bucharest metropolitan area.

Large scale vegetation distribution is largely controlled by climate. Many studies indicate global climate change occurs as a result of anthropogenic greenhouse gases (GHG). The global average temperature increased by 0.5oC over the past century, and it is expected to continue increasing by an additional 1.4oC to 5.8oC by the end of 21st century. Romania also experienced a trend of climate variability with warming and flooding events. Climate change will result in changes in vegetation distributions, and then affect the environment of humans. It is important to assess possible responses of vegetation distribution to climate change. Temporal variation of MODIS/Terra NDVI/EVI parameter during 2005-2012 periods for Bucharest metropolitan area was correlated with temporal variation of MODIS/Terra (MOD11A2 product) land surface temperature LST parameter recorded during 2005-2012 period (Figure 5).

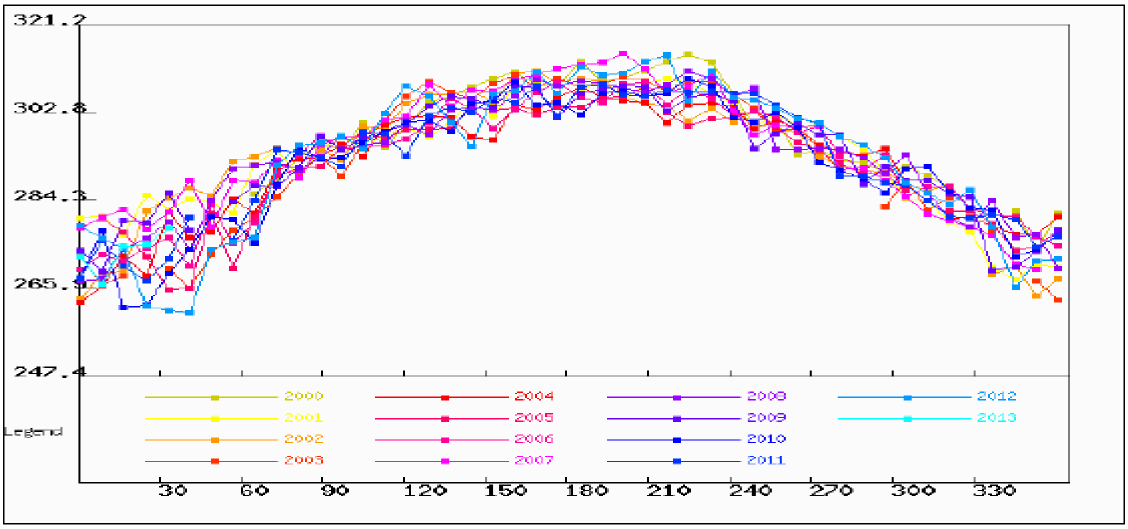

Figure 5. Temporal variation of MODIS/Terra LST parameter during 2000-2012 for Bucharest metropolitan area.

The highest land surface temperatures in metropolitan area of Bucharest have been recorded during July –August periods of years 2000, 2007 and 2012. The phenological patterns, biomass production, and species composition of urban green system, are strongly affected by the climatic conditions of the periurban Bucharest region, especially precipitation and heat wave events which are highly variable both inter-annually and intra-annually.

5. Conclusions

The joint analysis of in-situ and satellite remote sensing monitoring of urban biogeophysical parameters and the spatial patterns of land cover albedo, NDVI (Normalized Difference Vegetation Index) and oland surface temperature data derived from high temporal resolution satellite images like MODIS (Moderate Resolution Imaging Spectroradiometer) represents a successful tool for assessment of the functional response of Bucharest urban ecosystem to anthropogenic and climate stresses and for quantifying land cover cover dynamics in the metropolitan area.

The analysis of urban landscape patterns in Romania is important for projecting future urban landscape development, particularly in the context of global climate change and urbanization. Disturbances in urban ecosystems induced by both natural and human impacts lead to changes in urban structure or function. Since the dynamics of urban land covers is a very important topic in Romania, the assessment of urban biogeophysical parameters and land cover changes is very important to assess, forecast, and mitigate the risks and impacts of climatic and anthropogenic changes on urban environment and to provide early warning strategies on the basis of spectral information derived from satellite data.

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