ASSESSMENT OF BUCHAREST URBAN GREEN LAND-COVER CHANGES THROUGH TIME-SERIES SATELLITE DATA

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ABSTRACT

In this paper, we describe recent results using time-series satellite remote sensing data from NASA's MODIS Terra/Aqua and NOAA/AVHRR satellite to study urban/periurban vegetation land-cover changes in Bucharest metropolitan area in Romania. In order to provide vegetation land cover change detection information have been investigated Normalized Difference Vegetation Index (NDVI) and Leaf Area Index (LAI) biophysical variables. NDVI and LAI are key parameters involved in a variety of ecosystem processes, such as light and rain interception, transpiration, photosynthesis, plant respiration and soil respiration. For instance, LAI has a large impact on reflectance spectra especially in the near-infrared (NIR), the visible part of the spectrum is strongly affected by leaf chlorophyll, and leaf water is the prevalent factor influencing the reflectance in the mid-infrared wavelengths. Their precise temporal and spatial assessment is crucial for the understanding of vegetation processes and for the parameterization of ecosystem models that quantify carbon, water, and energy fluxes. Training and validation are based on a reference dataset collected from IKONOS high resolution remote sensing data. The mean detection accuracy for period 2000- 2013 was assessed to be of 88%, with a reasonable balance between change commission errors (21.9%), change omission errors (28.6%), and Kappa coefficient of 0.71. Annual change detection rates across the urban/periurban areas over the study period were estimated at 0.75% per annum in the range of 0.45% (2000) to 0.77% (2014).Vegetation dynamics in urban areas at seasonal and longer timescales reflect large-scale interactions between the terrestrial biosphere and the climate system.

INTRODUCTION

Urban vegetation, known as green space that includes vegetated areas such as parks or forest stands, and isolated trees growing along streets, in street medians, or private property, is a critical issue for both a healthy population as well as for city economy. Urban vegetation cover in cities is constantly changing due to various natural and anthropogenic pressures. Natural forces for change include natural regeneration, vegetation growth and vegetation mortality from insects and diseases or old age.

Anthropogenic factors that influence urban vegetation cover include tree planting and tree mortality or removal from either direct or indirect human actions such as development and air pollution. The combination of these factors through time determines existing and future vegetation cover levels. Accurate information is essential for estimation of changes in surface energy balance and atmospheric greenhouse gas emissions, and Urban Heat Island function at local and regional scale as well as urban land cover/use dynamics in frame of global warming. Through reducing air pollution, and providing recreational places, green spaces play important functions in urban environments.

Through their environmental, aesthetic, social and economic contributions to residents' health and wellbeing, urban vegetation spaces play a major role in urban ecosystems. From an environmental standpoint, green spaces have an important role to carbon sequestration, mitigation of the effects of storm-runoff and air pollution, production of oxygen, microclimate regulation and conservation of urban biodiversity and soil–water protection. Urban vegetation land cover change is a direct measure of quantitative increase or decrease in sources of urban pollution and the dimension of extreme climate events and changes that determine environment quality. The shape and form of urban vegetation reflectance spectra depends on many factors such as vegetation structure, leaf biochemical composition, soil background, and the view and illumination geometry.

With the rapid change of Bucharest metropolitan area in Romania, during the past decades, urban green was fragmented and dispersed causing impairment and dysfunction of these important urban elements. 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 (1), (2), (3).

The aim of this paper was to achieve the regional-scale assessment of urban vegetation land cover changes by means of an NDVI-based (functional) indicator and Leaf Area Index (LAI) using freely available time series NASA's MODIS Terra/Aqua (Moderate Resolution Imaging Spectroradiometer) and NOAA/AVHRR satellite data.

SATELLITE REMOTE SENSING METHODS

Time series satellite remote sensing represent an important investigation tool of urban vegetation land cover monitoring at local, and regional scales, being an integrated part of the advanced Information Technology and Telecommunication Infrastructure. It is based on building spectral databases, global large datasets, refining validation, calibration procedures in multi-source, multi-temporal environment available for biophysical and spectral modeling.

Satellite remote sensing can help to rapidly assess the dimension of vegetation land cover damage due to climate and anthropogenic impacts and therefore better manage of urban ecosystems. The practical value of remotely-sensed data has increased significantly in this context with the advent of new, very high spatial resolution optical sensors (US Space Imaging IKONOS, QuickBird and OrbView systems). However, these new sensors demand new information-extraction methods. Digital map data products can provide information on various aspects of the forested areas. Accurate quantification of the extent of vegetation land cover changes in metropolitan area of Bucharest, Romania is important for assessing how this LCLUC (Land Cover Land Use Changes) affects ecosystem services such as aesthetics, biodiversity, urban climate and mitigation of extreme climate events. MODIS (MODerate Resolution Imaging Spectroradiometer) sensors aboard on NASA's TERRA/AQUA satellites, with significantly improved spatial and spectral resolutions, offer exceptional opportunities for quantifying urban vegetation and ecosystems processes. The Moderate Resolution Imaging Spectroradiometer (MODIS) acquires data over the entire Earth's surface in nearly daily intervals, and its products are generated in multiple spatial resolutions. Because of the frequent repeat cycle, MODIS can fill in scattered cloudy days, capture phenological changes (4), and identify land surface changes more frequently than Landsat TM/ETM. MODIS's spatial resolution of 250–1000 m allows more detailed observations than its predecessor, the Advanced Very High Resolution Radiometer (AVHRR). The MODIS vegetation index products include NDVI and the enhanced vegetation index (EVI). The NDVI is one of most common spectral vegetation indices and widely applied for tracking vegetation dynamics, especially suitable for
areas with a relative low density of biomass, like urban regions, where NDVI values are usually less than 0.7 as indicated by our data sets. On the other hand, EVI retains sensitivity to vegetation dynamics at a high biomass level whose NDVI saturation likely occurs (4), (5). Moreover, no EVI products are available at the 250 m resolution. Therefore, the 250 m MODIS NDVI was used in this study to evaluate greenness responses to vegetation land cover in the metropolitan area of Bucharest in Romania.

Imaging spectroscopy (5), also known as hyperspectral imaging, is concerned with the measurement, analysis, and interpretation of spectra acquired from a given scene (or specific object) at a short, medium or long distance by an airborne or satellite sensor. The special characteristics of hyperspectral datasets pose different processing problems, which must be necessarily tackled under specific mathematical formalisms, such as classification and segmentation or spectral mixture analysis. Airborne Visible Infra-Red Imaging Spectrometer (AVIRIS) scanner data cover now the wavelength region from 0, 4 - 2, 5 µm using more than two hundred spectral channels, at nominal spectral resolution of 10 nm. Spectral reflectance measurements from the field environment and laboratory samples are needed for many purposes including vegetation, soil and water composition as well as for test surface reflectance models. Field spectroradiometers are generally used to collect such data and the technique of field spectroscopy is well established for this purpose (6). Typically, target measurements are sandwiched between the target and calibrated reference panel measurements in quick succession, typically within 1 min and assume that the irradiance is virtually unchanged.

The Sentinel 2 sensors system proposed by the European Space Agency will provide a significant improvement in spectral coverage, spatial resolution and temporal frequency over the existing sensors. The two multi-spectral sensors potentially provides a huge advance in qualitative and quantitative retrievals of NDVI and mapping of urban green, particularly when combined with Landsat 8 and MODIS data.

URBAN VEGETATION BIOGEOPHYSICAL PARAMETERS

Remotely sensed imagery reflects the biophysical features of the earth surface through recording their electromagnetic characteristics. The biogeophysical features can be readily altered by the changes in land use/land cover and the changes can be relatively easily detected using remotely sensed data. The general practice is that urban land cover can be inferred not only based on the biophysical composition but also on the arrangement pattern of land covers of the areas considered. Remote sensing is a key application in global-change science for urban environment and land use/cover dynamics analysis. Quantitative remote sensing involves the prediction of in situ quantities based on remote measurements of radiation (7). This prediction problem relies on statistical or physically based models relating remote and in situ measurements. Data from new high spatial, temporal, and spectral resolution satellite-based sensors promise to increase our understanding of global urban ecological and climatic processes and improve city and land planning capabilities. A difficulty in using remote sensing technology for urban studies is the diversity of features found in the urban environment, including different targets like concrete, asphalt streets and avenues, roofs of different materials, exposed soil, grass, trees, and water. Some of these targets are smaller than the pixel resolution. A landscape is composed of ever-changing elements. Their spatial and temporal patterns distinguish a landscape to an observer; at the same time they inform us of the complexity of dynamic processes at various scales. The changing pattern of the urban landscape, including the changing biophysical properties of that landscape, is a central theme in the fields of urban landscape ecology and environmental quality management and planning. The research and management issues are focused upon the relationship between the changes that occur in the composition of the landscape and the spatial configuration of landscape elements. The essential goal of modeling and monitoring urban environmental quality and change from remotely sensed data is to compare images at a spatial and temporal resolution appropriate to the ecological scale of the processes of interest. Satellite remote sensing instruments provide measurements at a variety of pixel resolutions, spatial extents and temporal scales. Two of the most common uses of multispectral and multitemporal satellite images are mapping land cover via image classification and land cover change via change detection in urban environments.

In order to understand better the urban vegetation land cover dynamics at local and regional scales, in satellite remote sensing data analysis, the estimation of biophysical parameters is of very high relevance .For instance, remotely sensed images can be used to estimate urban green vegetation, water content, urban soil, lakes and rivers pollution and spatio-temporal changes. To relate the image acquired by the satellite sensor to biophysical parameters, model-based estimation algorithms are commonly used. Two different approaches can be considered. In physical modeling, predefined direct models of the estimated biophysical parameters are adopted. These models are designed to account for all parameters affecting the radiometric characteristics of the remote sensing data, such as atmospheric conditions, sun angle, sensor gain and offset, and viewing geometry. In empirical modeling, regression techniques are commonly developed. These techniques relate the remotely sensed data with the investigated biophysical parameters according to interpolation methods applied over a training set constituted by pairs of in situ measurements and collected radiances.

The environment influences or modulates the information that can be extracted from remotely sensed data. This concept introduced the environmental modulation transfer function, as type of information that can be extracted is a function of the types of land use and land cover, the number of categories, the size, pattern and shape of the parcel units, the changing nature of the environment, history of settlement, economic factors, climate, and other aspects of the environment as a function of sensor and interpretation objectives. The urban environment is quite variable, being one of the most complex and capricious in form and function of all land cover categories. Knowledge on biophysical properties of urban ecosystems retrieved from satellite images enables to improve monitoring of these unique areas. From a methodological viewpoint, for some kinds of biophysical parameters, it is common to define parametric model-based estimation algorithms. These algorithms rely on a specific model that relates the studied biophysical parameter to measures acquired by the selected satellite sensor.

Spectral Vegetation Index

Urban– periurban 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 . This study used Normalized Difference Vegetation Index NDVI expressed as:

$$NDVI = (\rho_{NIR} - \rho_R)/(\rho_{NIR} + \rho_R) \tag{1}$$

For Green Vegetative Cover of urban-periurban 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:

$$f_c = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}} \tag{2}$$

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 (2) 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 by (8). 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).

The LAI (Leaf Area Index) estimation using VIs (Vegetation Indices) is based on the combination of a chlorophyll sensitive band (typically the red band) and a band located in the high reflectance plateau of vegetation canopies (NIR band). The high canopy penetration ability of the NIR band makes it highly useful for tracking variations in biomass and LAI. NDVI has been extensively used for the retrieval of LAI as it combines the NIR band (ρ_{NIR}) and red band (ρ_R) reflectances (9).

Leaf Area Index (LAI)

Leaf Area Index (LAI) is the leaf area per unit ground area. LAI is a factor that indicates how many leaf (or photosynthetically active) surfaces are in a column extended from, the ground area under the canopy diameter, up through the canopy. LAI can be estimated from the normalized difference of the vegetation index (NDVI), because NDVI represent the relative seasonal changes in vegetation rather than vegetation amount. There is a significant relationship between NDVI and LAI. Assuming that NDVI/LAI relationship is linear and the maximum NDVI value in a season correspond to the maximum LAI of vegetation cover, LAI can be inferred from NDVI as:

$$LAI_i=LAI_{max}*(NDVI_i–NDVI_{min})/(NDVI_{max}–NDVI_{min}) \quad (3)$$

Where max, min and 'i' are the maximum, minimum and period values observed, respectively (10). Maximum and Minimum NDVI values can be determined by multi-temporal NDVI observations from the satellite sensor. The formulation of LAI as a fraction of the maximum NDVI observed in a season facilitates the integration of data from different sensors. High and coarse resolution satellite observations can be combined to get more reliable estimates of LAI patterns in a landscape. LAImax can be determined empirically by assigning different values to a land cover categories, and LAIi can be then obtained by combining NDVI information from different dates.

Even when a linear relationship between NDVI/LAI is often assumed, the relationship is not always linear since the vegetation indices approach a saturation level asymptotically for LAI ranging from 2 to 6, depending on the type of vegetation cover, and environmental conditions. However, by assuming a non-linear relationship, the LAI estimates from NDVI are then highly dependent upon certain factors such as canopy geometry, leaf and soil optical properties, sun position and cloud coverage. The variation of NDVI as a function of LAI can be expressed by a modified Beer's law:

$$NDVI=NDVI_a+(NDVI_{bs}–NDVI_a)*exp(-K_{ndvi}*LAI) \quad (4)$$

where $NDVI_{bs}$ = vegetation index corresponding to that of the bare soil; $NDVI_a$ is the asymptotic value of NDVI when LAI tends towards infinity; and K_{ndvi} is the coefficient that controls the slope of the relationship (extinction coefficient. The joint analysis of in-situ and satellite remote sensing monitoring of urban vegetation biogeophysical parameters and the spatial patterns of NDVI (Normalized Difference Vegetation Index) 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 vegetation to anthropogenic and climate stresses and for quantifying vegetation cover dynamics in urban areas (11).

STUDY AREA AND DATA USED

Urban metropolitan area Bucharest described by a star-shaped pattern (Fig1), 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).

The investigations have been focused on estimating of urban/periurban vegetation land cover dynamics using time series MODIS Terra/Aqua data. We used 16-day MODIS NDVI composites with a 250 m spatial resolution (MOD13Q1 collection 5) and MODIS LAI (MOD15A2) 8- day composite mainly for their capacity to detect anthropogenic and climate urban vegetation land cover changes. The MODIS Terra/Aqua images were acquired between 2002 and 2013 period and were used to derive eleven years of NDVI and LAI temporal profiles. Missing values were replaced by linear interpolation considering neighbouring values within the NDVI time series and LAI time series. Have been selected 5 periurban test areas and 5 urban test areas. In situ-monitoring spectroradiometrical additional data were used . ENVI 4.7, IDL 6.3 and ILWIS 3.1 softwares have been used.

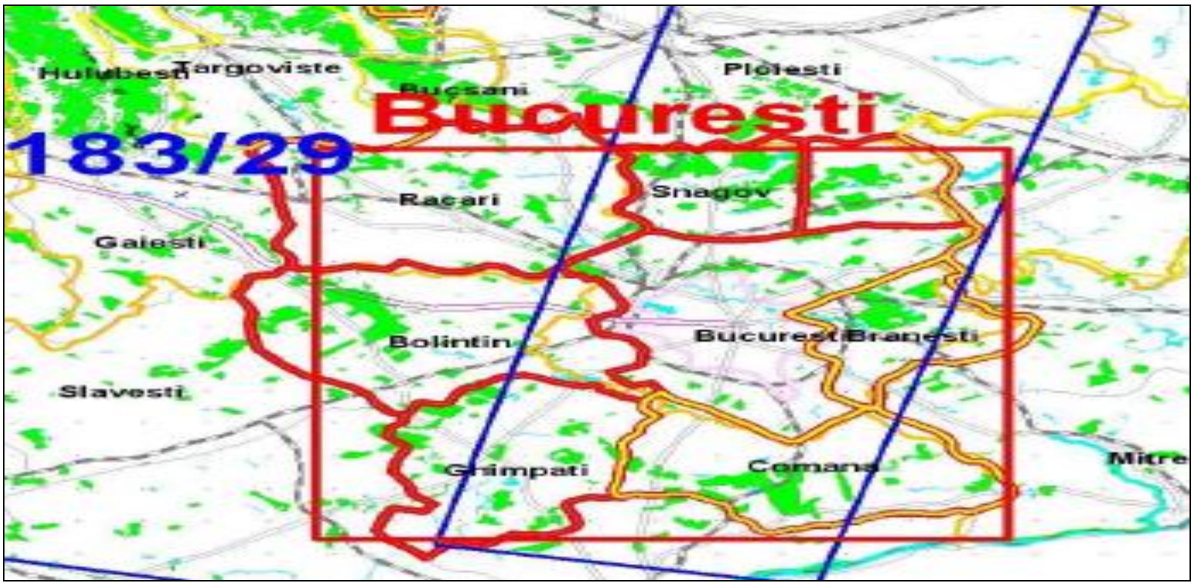

Figure 1.Test site urban Bucharest area

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. Have been identified vegetation land cover changes during 2002- 2013 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 (a) being repeatable; (b) 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 3 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.

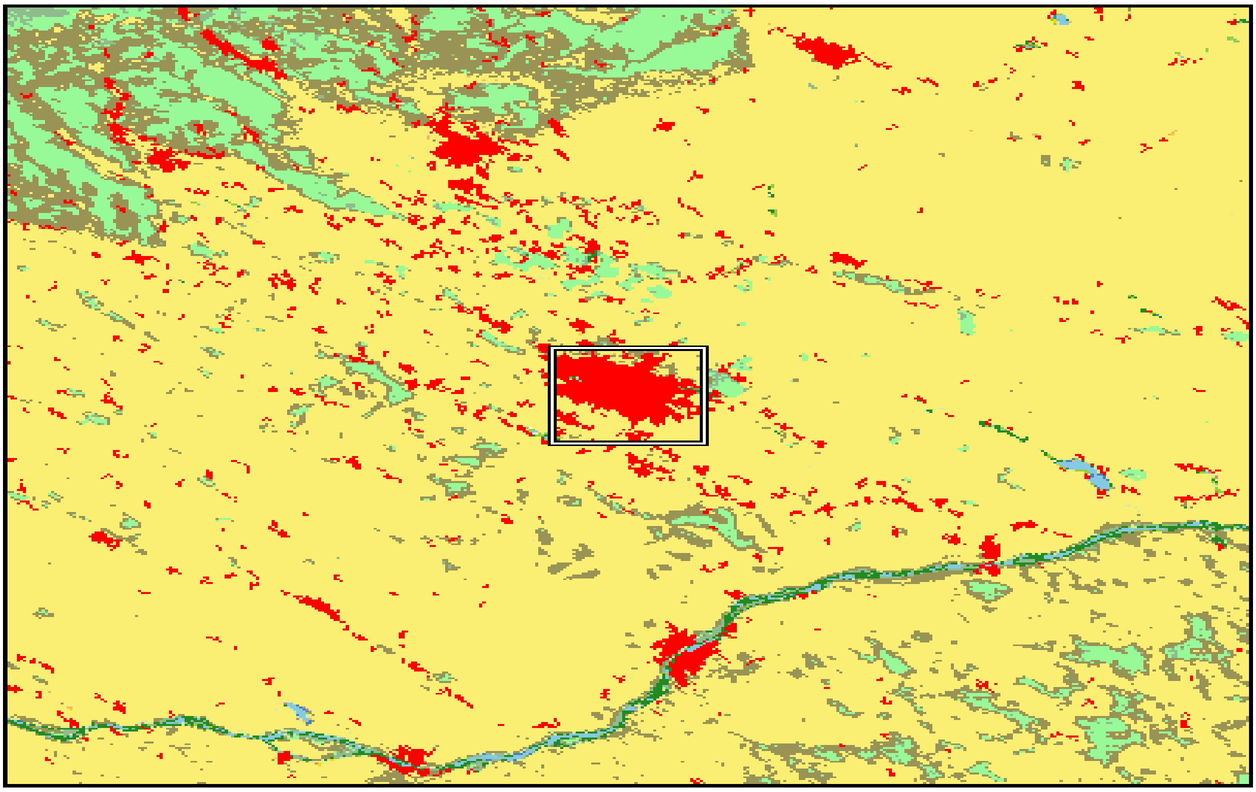

Figure 2. Land cover classification for metropolitan area Bucharest, based on MODIS/Terra time series data for 2002-2013 period.

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 2003, 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 as can be seen in Figure 3. So, climate impacts on urban/periurban vegetation land cover are significantly visible.

As urban vegetation cover quality indicator, the NDVI-based vegetation cover classification was produced by means of unsupervised multivariate statistical techniques and compared with spatio-temporal changes during 2002-2013 period, statistical indicators, and field data related to land cover management observed in the study area. We examined spring-to-summer seasonality of

NDVI/EVI biophysical parameters of land cover vegetation for Bucharest metropolitan area and its relation to canopy LAI of periurban forested areas Baneasa and Cernica. Time series MODIS satellite data analyses and radiative transfer simulation suggest that reflectance in the selected forested areas is affected by various changes in surface conditions, such as snow melt, canopy LAI, tree density, and forest floor conditions as well as precipitations, land and air surface temperature.

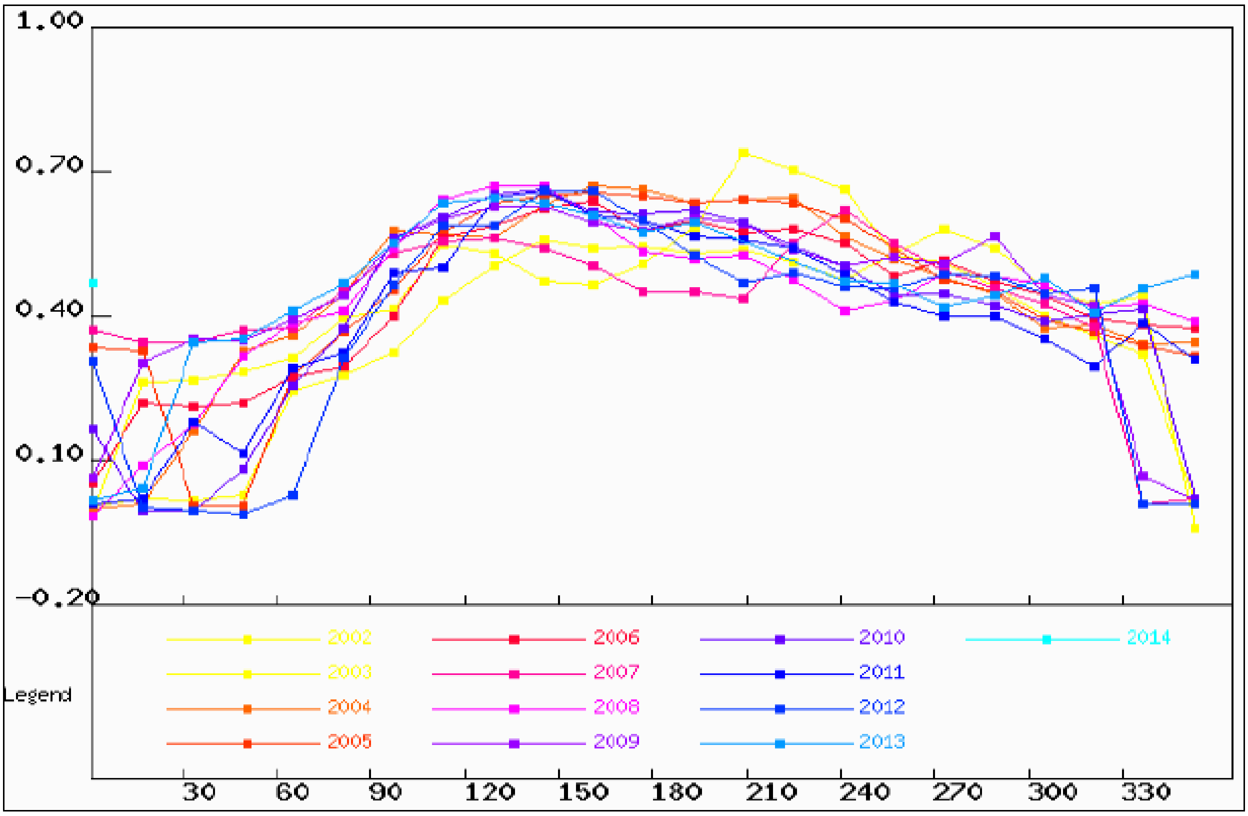

Figure 3. Temporal variation of MODIS/Terra NDVI parameter during 2002-2013 period for Bucharest metropolitan area.

The reflectance signature from complicated land surfaces generally precludes accurate estimates of forest canopy LAI. Figure 4 presents the temporal variation of MODIS/Terra LAI parameter during 2002-2013 period for Bucharest metropolitan area.

Training and validation are based on a reference dataset collected from IKONOS high resolution remote sensing data. The mean detection accuracy for period 2002- 2013 was assessed to be of 88%, with a reasonable balance between change commission errors (20.3%), change omission errors (25.7%), and Kappa coefficient of 0.71. Annual change detection rates across the urban/periurban areas over the study period (2002–2013) were estimated at 0.75% per annum in the range of 0.46% (2002) to 0.76% (2012) and 0.77% (2014) .MODIS NDVI time series data have great potential for urban/periurban vegetation land cover studies. A major source of error is the spatial resolution of the sensor which makes it highly susceptible to the problem of mixed pixels common in studies of urban environments.

Another challenge is the sparse vegetation responsible for increased soil reflectance and high variability of soil background in some areas. Our study utilized also detailed land cover information derived from Landsat and IKONOS imagery and then translated it to the scale of MODIS data. This allowed us to minimize spatial uncertainties. As vegetation dynamics below the time span of 14–16 days were undetectable, however, uncertainties due to high temporal variability of vegetation and limitations of the standard NDVI product still exist.

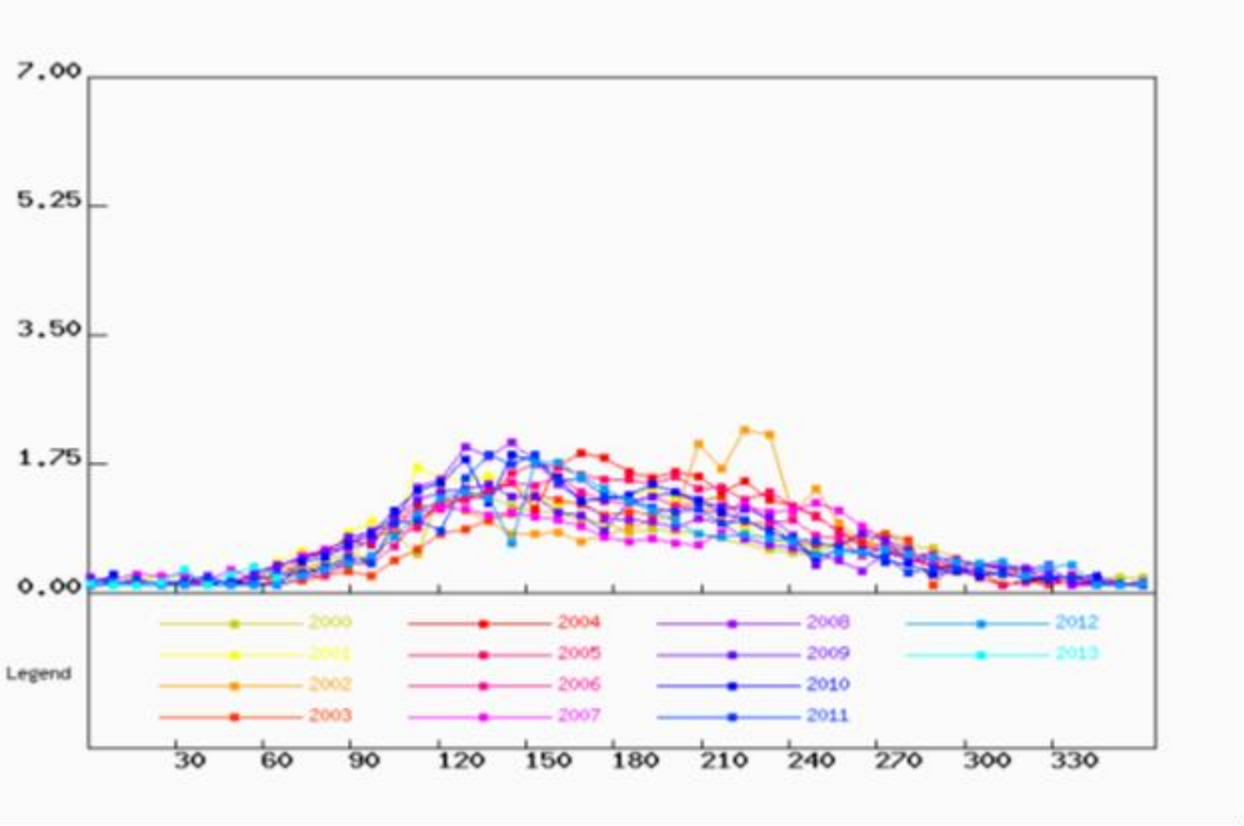

Figure 4. Temporal variation of MODIS/Terra LAI parameter during 2002-2013 period for Bucharest metropolitan area.

This problem can be partially alleviated by obtaining raw surface reflectance data and computing NDVI at a time step of 1–2 days. Cloud-free conditions frequent in the Bucharest metropolitan area should make this option feasible. This study is an important step toward these future goals. As a result, phenology has recently emerged as an important topic with relevance to a wide array of climate and ecological research including regional and global carbon modeling, ecological assessment, and agroforest monitoring. Accurate information is essential for estimation of changes in surface energy balance and atmospheric greenhouse gas emissions, and Urban Heat Island function at local and regional scale as well as urban land cover/use dynamics in frame of global warming.

CONCLUSIONS

Environmental impacts in the face of accelerating urbanization and future climate changes. As most climate models predict for next years a warmer and drier climate for this area, the difference between the metropolitan region and the surrounding agroforested areas may become larger. The effects of rapid and extensive urbanization in bucharest metropolitan region seem to have a potential to significantly alter the carbon source–sink relationship. Urban vegetation land cover quality defined by MODIS NDVI time series indices refers to the state or vegetation condition, including its soil, water and biological properties, and it relates to the capacity of a vegetation land cover to provide economically viable productions and urban ecosystem services at all observation scales. To promote sustainable urban management and inform effective conservation policies, vegetation land cover quality needs to be assessed with respect to the specific functions and types of the actual land cover. Ideally, an indicator of urban vegetation land cover quality represents a proxy for the functional role of a land, integrating factors and processes that determine its efficiency.

ACKNOWLEDGEMENTS

This work was supported by Romanian National Authority for scientific research, Program STAR, contract 46/2012 BUGREEN, 73/2013 VRAFORECAST and PNII Contract 86/2014.

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