Pol. J. Environ. Stud. Vol. 24, No. 2 (2015), 529-535

Original Research

Normalized Difference Vegetation Index (NDVI) as the Basis for Local Forest Management. Example of the Municipality of Topola, Serbia

Miomir M. Jovanović*, Miško M. Milanović

University of Belgrade, Faculty of Geography, Belgrade, Serbia

Received: 1 October 2013
Accepted: 14 August 2014

Abstract

In this article we clearly showed that determination of spectral index of vegetation can be of great help in forest management, particularly on the regional and local levels. Forest detection technology based on remote sensing has advanced to a point where it surpasses all other types of wood detection techniques. The main goal of this paper is to present the results of the implementation of remote sensing in the analysis of forests in the municipality of Topola through the use of normalized difference vegetation index (NDVI). With regard to the fact that vegetation in Serbia is increasingly destroyed, the authors of this paper would like to suggest application of a method that is based on interconnectivity of surface evaluation and analytical deciphering of remotely sensed images. Forests are clearly distinguished on images in terms of their borders, forms, and tonalities, which makes them easily noticeable even on the small images. The application of this method is not limited only to analysis of the current state of forests. It may also cover degraded forest areas and help in the detection of illegal timber harvesting. Hence it can serve as the basis for the much better future local forest management of Serbian municipalities, and can easily be applied to other Balkan countries that have similar situations in the sphere of local forest management.

Keywords: difference vegetation index, forest management, municipality of topola, Serbia

Introduction

Remote sensing has been defined as the detection, recognition, or evaluation of objects by means of distant sensing or recording devices. In forestry, information extracted visually from aerial photography is well-understood, well-used, and integrated with field surveys.

However, although remote sensing technology has recently emerged to support data collection and analysis methods in forest management [1-3], it is still rarely used, since remote sensing data and methods are complex, not well understood, and probably not well suited by those who might best use it [4].

Actually, the main problem concerning forest policies and management stems from the fact that ignoring common goods – like forests – which are difficult to produce and easy to deplete [5-7], leads to tragic results, since it is very difficult to restrict the rate at which they are consumed [8-10]. The size of many forests and the inevitable complications involved in monitoring the use of the forest and balancing one use against another, make exclusion or restrictions on access intrinsically problematic [11-12].

*e-mail: miomir.m.jovanovic@gmail.com
miomir@gef.bg.ac.rs

There is enough available evidence that convincingly shows that illegal and corrupt activities constitute a major underlying cause of forest decline worldwide [13-16]. The main reason for this is that governments and private landowners cannot control these illegal operations.

It is usually pointed out that core characteristics of successful remote sensing applications in forestry include a need for up-to-date information on the forests: a) over an area too large or b) otherwise difficult to survey on the ground [4].

But, at the same time, forest policies are not likely to work when imposed on a country as a whole [9], and there is a pronounced shift around the globe of forest management authority from central government to municipalities (in Bolivia, Zimbabwe, Tanzania, Indonesia, Philippines, India, USA, Canada, China, etc.) [17].

Actually, the aim of good local forest management is to: 1) strengthen the local rule of law, 2) improve local accountability and transparency (especially, through establishing clear mechanisms for the provision of and access to information and mechanisms and procedures for reporting grievances and misbehaviour), 3) strengthen local participatory planning and decision-making, and 4) improve local governance effectiveness and efficiency through development of effective monitoring and evaluation systems at local and central levels [18].

Two of these four key dimensions of “good forest management and governance” have been taken up and pursued by many countries on national and international levels. Unfortunately, accountability and transparency, as well as governance effectiveness and efficiency have not received equally broad recognition. Especially at the local level, which plays a crucial role in good governance, has received comparatively little or no attention [18].

Given the importance and complexity of the problem [19-21], we are going to show that normalized difference vegetation index (NDVI) can establish clear mechanisms for the provision of and access to essential information about forests and should be implemented in local forest management in Serbia.

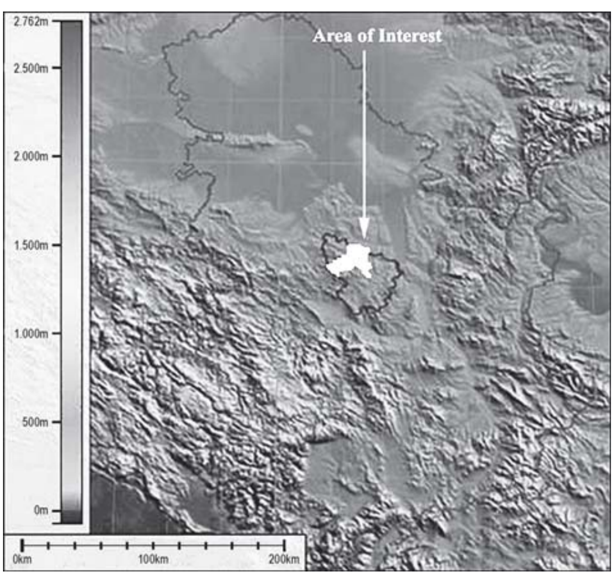

Fig. 1. Position of Topola municipality in the Republic of Serbia.

In Serbia 30% of land is under forest – 50% of forests are state-owned, 50% privately owned. Forest management is in a very poor condition: enterprises for state forest management are in an unsatisfactory condition and their restructuring process has only started, while privately owned forests characterize a great number of small forest holdings with small economic capacity (average private holding is 0.5 ha) [22], whose owners have been over-felling their forests for decades to meet the most urgent needs of their livelihood, characterized by a poor state, and fragmented holdings, and unsolved property relations, which makes forest management even more difficult [23].

The basic idea of this study is to improve the local forest management system in Serbia through the use of a more precise methods for the assessment of land use changes and forest areas.

The main purpose of this research is to analyse NDVI, which is praised as an efficient tool for classification and estimation of vegetation cover [24-28], and to evaluate its suitability for local forest management in Serbia.

Also, the results of this study can be easily applied to the other Balkan countries that have a similar situation in the sphere of local forest management.

Study Area

The research object of this paper is forests of Topola municipality detected on satellite images obtained from a LANDSAT satellite.

The territory of Topola municipality is located in central Serbia (Fig. 1) and extends over 357 km^2, with 51 km^2 (approximately 14%) of its total area under forest. It consists of the river basin and the potamon zone of the rivers Jasenica and Kubršnica as its largest tributary [29]. Along the western and southwestern parts of the municipality-stands Rudnik Mountain. Topola’s geographical position is 44º08´ latitude North, which is the most southern point at the triangle of the municipalities of Gornji Milanovac, Kragujevac, and Topola, and 44º21´ latitude north, which is the most northern point of the municipality’s territory.

Materials and Methods

In our study we could not make any reliable long-time comparative analysis between NDVI and official forest inventories, since national forest inventory in Serbia has been performed only rarely: the last three national forest inventories in a 20-year range were in 1961, 1979, and 2003-2006 (alhough since 2007 official estimates of the forest areas have been made every year).

Hence, we compared results for Topola municipality obtained by NDVI for 2011, with official forest area estimates for 2011 (performed at the end of the year) [30].

NDVI relates the spectral absorption of the chlorophyll

Table 1. Different spectral channels of images (produced by LANDSAT satellite) used in this paper.

LANDSAT 5 (TM sensor)	Wavelength (μm)	Resolution (m)
Band 1	0.45 – 0.52	30
Band 2	0.52 – 0.60	30
Band 3	0.63 – 0.69	30
Band 4	0.76 – 0.90	30
Band 5	1.55 – 1.75	30

in the red with a reflection phenomenon in the near infrared, influenced by the leaf structure type [31-34].

In order to obtain forest-area data with 30 m^2 precision, we used NDVI and applied necessary corrections of visible red in a constellation with infrared spectrum of satellite images, following Idrisi software procedure – GIS analysis/mathematical operation/image calculator, and then equation:

$$NDVI = (NIR-RED)/(NIR+RED) \quad (1)$$

...in which NIR is near infrared channel, and RED is red channel from the visible part of the spectrum [35]. (In order to include JPG and TIF format images in our study, we exported Idrisi images into Global Mapper).

This procedure enables avoidance of mistakes and deviations in the process of combining vector and raster contents, thus allowing subsequent image photo interpretation of an area to be examined [36]. It is achieved by determining beforehand the same georeferenced values: coordinate system, projection, and date for both raster and vector elements; then the raster image is imported onto vector content, and contents are overlapped using the principle of layers [37-43].

To obtain Figs. 2, 3, 4, and 5 we used five different spectral channels of LANDSAT satellite, with 30 m spatial resolution (Table 1). Images were made during August 2011, with minimum existence of clouds [44, 45].

In order to more precisely distinguish sick and damaged tree areas (and their volume of timber) [24], on NDVI images we imposed pseudo colour composite 4, 5, 1, using Idrisi software (image calculator). Pseudo colour composite 4, 5, 1 appears in shades of reds, browns (healthy, and oranges and yellows (sick trees). This composite increases sensitivity of detection of various stages of plant growth or stress and shows high reflectance in healthy vegetated areas.

Since official forest area estimates of Topola for 2011 don't include data about sick and damaged tree areas [46], we had to perform visual inspection (using GPS) in order to verify Idrisi results.

Results and Discussion

In Fig. 2 we presented the city of Topola together with surrounding settlements and municipality borders.

The next image (Fig. 3) and Table 2, which are the results of the NDVI applied through the Idrisi software, clearly indicate all the vegetation and its typical values for Topola municipality.

Results obtained through the application of NDVI reveal that agricultural land dominate (70%), and forests occupy 14.2 % (5,100 ha), while the rest of the municipality area includes grass areas, meadows, pastures, shrub vegetation, vineyards, urban areas, and more. Forests are clearly distinguished on images in terms of their borders, forms, and tonalities, which makes them easily noticeable even on small images.

Negative values of NDVI ranging from 0 to -0.3 are displayed in shades from light green to dark purple. These low negative values are detected in arable agricultural land (without vegetation) and are shown in shades of light green.

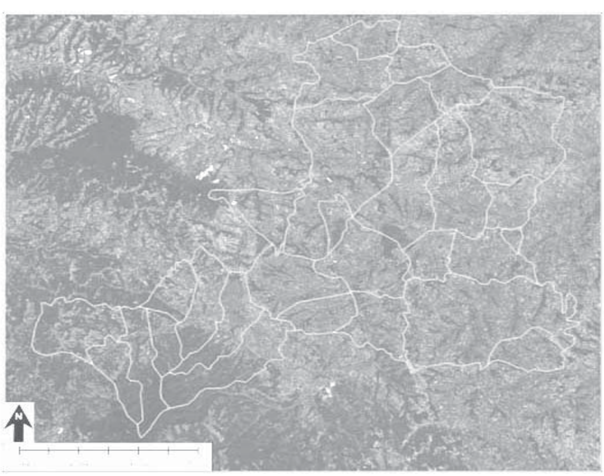

Fig. 2. Enlarged natural composite image (Band 1, Band 2, and Band 3) that displays borders of Topola municipality and settlements on its territory.

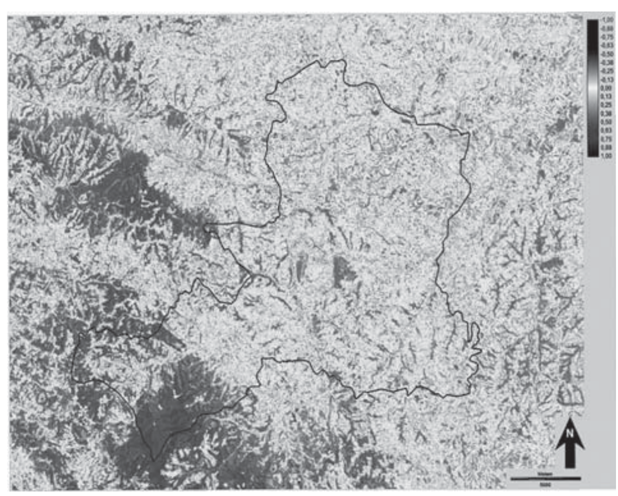

Fig. 3. A map of NDVI of Topola municipality.

Table 2. Topola's municipality NDVI values.

Types of land use and vegetation	Typical NDVI values for Topola municipality
Arable agricultural land (without vegetation)	-0.3 – 0
Grass areas, meadows, and pastures	0 – 0.13
Shrub vegetation	0.25
Forests	0.4 – 0.85

On the other hand, vegetation areas in the municipality of Topola are presented with values between 0 and 1.

Grass areas, meadows, and pastures have values that range from zero (in yellow colour – due to more intense reflectance of infrared radiation) up to 0.13 (light orange tones) [47].

Shrub vegetation has NDVI value of 0.25, since reflectance of infrared rays is decreasing (darker red tones).

Forest vegetation, with maximal positive NDVI values of 0.85 (due to minimal reflectance of infrared rays), is easily observed. Forests, as easily recognizable dense schematic groups, appear at higher altitudes, especially in the southwest (as well as in the west and in the central part of the municipality).

Approximately 95% of the forest areas are under broad-leaved forests (mostly beech forests). Zones of these broad-leaved forests are mostly situated at higher altitudes, all the way to the highest points at the territory of the municipality. At lower terrains, there are mixed forests composed of various types of trees.

Agricultural and forest areas are presented in the following map (Fig. 4).

In this part of the article we are going to further discuss results obtained for: total forest area, healthy and sick forest areas share, and volume of its timber.

Through our comparative analysis of NDVI and official forest estimates, it has become evident that we obtained very precise results with NDVI.

Map of Agricultural and Forest Areas

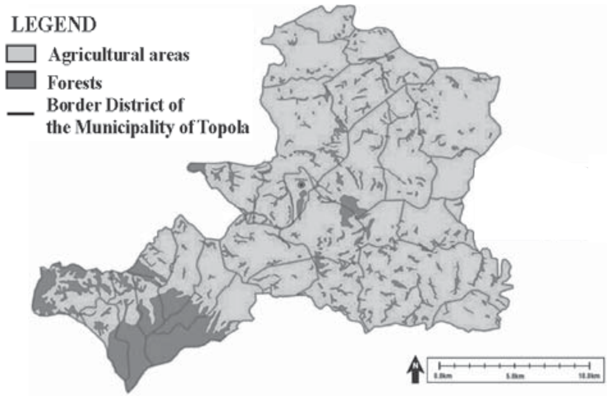

Fig. 4. A map of agricultural and forest areas obtained on the basis of remote sensing research.

Topola municipality total area obtained by NDVI was the same as official statistics (357 km^2), while forest area obtained by NDVI (50.73 km^2) is approximately similar to official forest area estimates (52 km^2). Hence NDVI results, when compared with official forest estimates, show a mere 1.3 km^2 (2.6 %) difference for Topola's forest area. Not only do these results completely comprise ±5% errors allowed for this method, but it also gives us space for further analysis and investigation.

Results obtained by a combination of NDVI images and pseudo colour a composite 4, 5, 1 (Fig. 5 and Table 3) reveal that percentage share of sick trees area (3.80 km^2) and volume of sick timber (38,608 m^3) is approximately the same at 7.5% of total forest area (50.73 km^2) and 7.5% of the total volume of timber (515,417 m^3).

Visual inspection shows that our NDVI results for sick trees area (4.2% error) are within ±5% errors allowed for NDVI method. Evidently, NDVI can provide local forest managers in Serbia with essential information on areas where vegetation thrives or those where it is "under stress", as well as on vegetation alterations induced by human activities such as deforestation, or natural alterations (caused by forest fires and changes evident in phenological phases) that are not properly (or not at all) covered with official forest inventory.

Clearly, NDVI can be of great help in acquiring new and improving existing knowledge about the state of forests, especially at the regional and local levels. This is extremely important, since forest policies are not likely to work when imposed on a country as a whole [9], and in this article we moved away from national-level studies of forests toward more comprehensive accounts of forests at the local level.

To summarize, NDVI is relatively cheap and quick, provide local forest managers with a lot of essential information, it is easy to be implemented and has scientific objectivity that to a large extent can help in avoiding possible corruption in the sphere of forest management. Especially

Health state of Topola's Forests

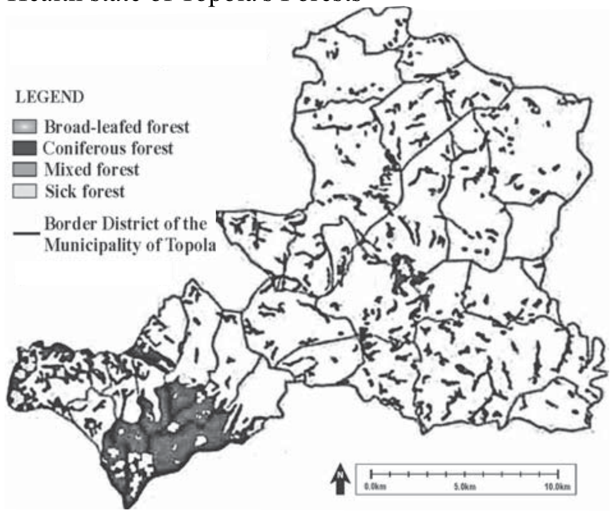

Fig. 5. Health condition of Topola's forests.

Table 3. Health state of Topola's forests.

Type of forest	Forest area [km^2]			Volume of timber [m^3]		
	Total area [km^2]	Healthy trees area [km^2]	Sick trees area [km^2]	Total volume of timber [m^3]	Volume of healthy timber [m^3]	Volume of sick timber [m^3]
Broad-leaved forest	48.63	45.11	3.52	494,080.8	458,317.6	35,763.2
Coniferous forest	0.17	0.15	0.02	1,727.2	1,524	203.2
Mixed forest	1.93	1.67	0.26	19,608.8	16,967.2	2,641.6
TOTAL	50.73	46.93	3.80	515,416.8	476,808.8	38,608

Results obtained by combination of NDVI image and pseudo colour composite 4, 5, 1

in municipalities with pronounced illegal logging [13, 15, 16, 48], like southern Serbian municipalities that – due to illegal logging – witnessed 10% of forest area loss in just a few years [23, 49, 50], NDVI can provide local forest managers with several essential updates per year about forest areas [51-55].

Conclusion

Through our analysis of NDVI results for Topola municipality, it became evident that NDVI is a suitable tool for local forest management in Serbia.

Topola municipality total area obtained by NDVI was the same as official statistics (357 km^2), while forest areas obtained by NDVI (50.73 km^2) are approximately similar to official forest area estimates (52 km^2). Hence NDVI results, when compared with official forest area estimates, show a mere 1.3 km^2 (2.6 %) difference for Topola's forest area. Not only that these results completely comprise ±5% errors allowed for this method, but it also gives us space for some further analysis and investigation. Results obtained by a combination of NDVI and pseudo color composite 4, 5, 1 (also within ±5% error range) reveal that percentage share of sick trees area (3.80 km^2) and volume of sick timber (38,608 m^3) is approximately the same at 7.5% of total forest area (50.73 km^2) and 7.5% of the total volume of timber (515,417 m^3).

Evidently, NDVI is very promising in countries like Serbia that very seldom (every 20 years) perform national forest inventories, since it is: relatively cheap and quick, provide forest managers with a lot of essential information and it is easy to be implemented and has scientific objectivity that to a large extent can help in avoiding possible corruption in the sphere of forest management.

In municipalities with pronounced illegal logging, NDVI can provide local forest managers with several essential updates per year about forest areas. This is of crucial importance for preventing illegal logging, which is especially pronounced in southern Serbian municipalities.

Also, by performing analysis over time, NDVI can provide information on areas where vegetation thrives or those where it is "under stress", as well as on vegetation alterations induced by human activities such as deforestation or natural alterations caused by forest fires and changes evident in phenological phases. NDVI is adequate for monitoring data of long-term processes such as vegetation growth through a season, or annual rate of deforestation, etc.

In short, in order to properly manage forests in Serbia – common resources difficult to be produced and easy to be depleted – more comprehensive account of forest areas through the use of NDVI clearly offers policymakers more sophisticated possibilities of forest management from which to derive policy options.

Acknowledgements

This paper contains the research results of project No. 37010 supported by the Ministry of Education Science and Technological Development of the Republic of Serbia.

References

1. COSTANTINI M. L., ZACCARELLI N., MANDRONE S., ROSSI D., CALIZZA E., ROSSI L., NDVI spatial pattern and the potential fragility of mixed forested areas in volcanic lake watersheds. For. Ecol. Manage. **285**, 134, **2012**.
2. KUVAN Y., EROL Y.S., YILDIRIM H.T., Forest Managers' Perceptions of the Foremost Forestry Issues and Functions in Turkey. Pol. J. Environ. Stud. **20** (2), 394, **2011**.
3. PAIVINEN R., BRUSSELAN J. V., SCHUCK A., The growing stock of European forests using remote sensing and forest inventory data. Forestry. **82** (5), 479, **2009**.
4. FRANKLIN S., Remote sensing for sustainable forest management. Lewis Publishers: New York, I, 81, **2001**.
5. HANLEY N., SHOGREN J., WHITE B., Introduction to Environmental Economics. Oxford University Press, 20-24, **2001**.
6. JOVANOVIC M., Kuznets curve and urban transport - The scope of I+M programs. Glasnik Srpskog geografskog društva. **92** (4), 137, **2012**.
7. TIETENBERG T., LEWIS L., Environmental and natural resource economics. Pearson, 306, **2012**.
8. CHAKRAVARTY S., GHOSH, S.K., SURESH C.P., DEY A.N., SHUKLA G., Deforestation: Causes, Effects and Control Strategies. In: Okia C. A. (Ed.) Global Perspectives on Sustainable Forest Management; InTech: Rijeka, 4-8, **2012**.
9. GIBSON C., McKEAN M., OSTROM E., Explaining De-

forestation: The Role of Local Institutions. In: GIBSON C., McKEAN M., OSTROM E. (Eds) People and Forests. Cambridge, Massachusetts: The MIT Press, 3-8, **2000**.
10. McKEAN M., OSTROM E., Common Property: What Is It, What Is It Good for, and What Makes It Work? In: Gibson C. McKean M., Ostrom E. (Eds) People and Forests. The MIT Press: Cambridge, Massachusetts, 28, **2000**.
11. DALE V. H., Management of forests as ecosystems: a success story or a challenge ahead? In: Pace M. L., Graffman P. M. (Eds) Success, Limitations, and Frontiers in Ecosystem Science; Springer-Verlag: New York, 50, **2008**.
12. MONTEIRO A., SOUZA C., Remote Monitoring for Forest Management in the Brazilian Amazon. In: GARSIA J., DIEZ-CASERO J. (Eds) Sustainable Forest Management – Current Research. InTech: Rijeka, 68, **2012.**
13. BRACK D., Illegal logging and the illegal trade in forest and timber products. Int. Forestry Rev. **5** (3), 196, **2003**.
14. BLASER J., CONTRERAS A., OKSANEN T., PUUSTJÄRVI E., SCHMITHÜSEN F., Forest Law Enforcement and Governance Process for Europe and Northern Asia. World bank: Washington DC, 6, **2005**.
15. CONTRERAS-HERMOSILLA A., The Underlying Causes of Forest Decline. CIFOR Occasional paper no. **30**, 17, **2000**.
16. MARKUS-JOHANSSON M., MESQUITA B., NEMETH A., DIMOVSKI M., MONNIER C., KISS-PARCIU P., Illegal Logging in South Eastern Europe. World bank: Washington DC, 82, **2010**.
17. EDMUNDS D., WOLLENBERG E., (Eds) Local Forest Management – The Impacts of Devolution Policies. Earthscan: London, 2, **2004.**
18. RAMETSTEINER E., Improving Governance for Sustainable Forest Management at local and regional levels in: UN. Enabling Sustainable Forest Management. UN: New York, 10, **2007**.
19. LEE B., KIM S.Y., CHUNG J., PARK P.S., Estimation of fire severity by use of Landsat TM images and its relevance to vegetation and topography in the 2000 Samcheok forest fire. J. For. Res. **13**, 197, **2008**.
20. OJEA E., RUIZ-BENITO P., MARKANDYA A., ZAVALA M. A., Wood provisioning in Mediterranean forests: A bottom-up spatial valuation approach. For. Policy Econ. **20**, 78, **2012**.
21. BISHOP J., LANDELL-MILLS N., Forest Environmental Services. In: PAGIOLA S., LANDELL-MILLS N., BISHOP J. (Eds) Selling Forest Environmental Services. Earthscan: London, 15, **2002**.
22. GLAVONJIC B., JOVIC D., VASILJEVIC A., KANKARAS R., Forest and Forest Products Country Profile: Serbia and Montenegro. United Nations: Geneva, 64, **2005**
23. THE REPUBLIC OF SERBIA - MINISTRY OF AGRICULTURE, FORESTRY AND WATER MANAGEMENT - DIRECTORATE OF FORESTS. Forestry Development Strategy for Serbia. Belgrade, 5-6, **2006**.
24. CAMPBELL J., WYNNE R., Introduction to Remote Sensing. Guilford Press: New York, 485, **2011**.
25. COUTURIER S., GASTELLU-ETCHEGORRY J. P., PATIN P., MARTIN E. A model-based performance test for forest classifiers on remote-sensing imagery. For. Ecol. Manage. **257**, 24, **2009**.
26. MENG Q., CIESZEWSKI C., MADDEN M., Large area forest inventory using Landsat ETM+: A geostatistical approach. ISPRS. J. Photogramm. **64**, 27, **2009**.
27. MILANOVIĆ M., LJEŠEVIĆ M., BAKRAČ S., NOVKOVIĆ I., Possibility Analysis of Vegetation Processing Satellite Images of Infrared Spectrum*.* Proceedings of the 9th International Conference on Fundamental and Applied Aspects of Physical Chemistry, Volume II, Physical Chemistry, Belgrade, **2008**.
28. NE WIN R., SUZUKI R., TAKEDA S., Remote sensing analysis of forest damage by selection logging in the Kabaung Reserved Forest, Bago Mountains, Myanmar. J. For. Res. **17**, 121, **2012**.
29. REGIONAL ECONOMIC DEVELOPMENT AGENCY OF ŠUMADIJA AND POMORAVLJE – KRAGUJEVAC. Socioeconomic analysis of Topola municipality; Office for local economic development: Topola, **2009** [In Serbian].
30. STATISTICAL OFFICE OF THE REPUBLIC OF SERBIA. Municipalities and regions of the Republic of Serbia, 2012. Statistical Office of the Republic of Serbia: Belgrade, **2013**.
31. CINGOLANI A. M., RENISON D., ZAK M. R., CABIDO M.R., Mapping vegetation in a heterogeneous mountain rangeland using landsat data: an alternative method to define and classify land-cover units. Remote Sens. Environ. **92**, 85, **2004**.
32. KALACSKA M., SANCHEZ-AZOIFEFA G., RIVARD B., CAELLI T., WHITE H., Ecological fingerprinting of ecosystem succession: Estimating secondary tropical dry forest structure and diversity using imaging spectroscopy. Remote Sens. Environ. **108** (1), 85, **2007**.
33. REMMEL T. K., PERERA A. H., Fire mapping in a northern boreal forest: assessing AVHRR/NDVI methods of change detection. For. Ecol. Manage. **152**, 121, **2001**.
34. WANG Q., TENHUNEN J., Vegetation mapping with multitemporal NDVI in North Eastern China Transect (NECT). Int. J. Appl. Earth Obs. **6**, 20, **2004**.
35. LUNETTA R., KNIGHT J., EDIRIWICKREMA J., LYON J., WORTHY D., Land-cover change detection using multi-temporal MODIS NDVI data. Remote Sens. Environ. **105** (2), 146, **2006**.
36. BHANDARI A.K., KUMAR A., SINGH G.K., Feature Extraction using Normalized Difference Vegetation Index (NDVI): a Case Study of Jabalpur City. Procedia Technol. **6***,* 613, **2012**.
37. HÁJEK F., Process-based approach to automated classification of forest structures using medium format digital aerial photos and ancillary GIS information. Eur. J. For. Res. **127**, 117, **2008**.
38. HAY G. J., CASTILLA G., WULDER M. A., RUIZ J. R., An automated object-based approach for the multiscale image segmentation of forest scenes. Int. J. Appl. Earth Obs. Geoinf. **7**, 349, **2005**.
39. JOHNSON L.F., TROUT T.J., Satellite NDVI Assisted Monitoring of Vegetable Crop Evapotranspiration in California's San Joaquin Valley. Remote Sens. **4** (2), 444, **2012**.
40. MIAO X., GONG P., CARRUTHERS R., Estimation of yellow starthistle abundance through CASI-2 hyperspectral imagery using linear spectral mixture models. Remote Sens. Environ. **101** (3), 330, **2006**.
41. THOMPSON I. D., MAHER S. C., ROUILLARD D. P., FRYXELL J. M., BAKER J. A., Accuracy of forest inventory mapping: Some implications for boreal forest management. For. Ecol. Manage. **252**, 209, **2007**.
42. THOONEN G., HUFKENS K., BORRE J. V., SPANHOVE T., SCHEUNDERS P., Accuracy assessment of contextual classification results for vegetation mapping. Int. J. Appl. Earth Obs. Geoinf. **15**, 11, **2012**.
43. ZABALA A., PONS X., Effects of lossy compression on remote sensing image classification of forest areas, Int. J. Appl. Earth Obs. Geoinf. **13**, 45, **2011**.
44. LI A., DENG W., LIANG S., HUANG C., Investigation on

the Patterns of Global Vegetation Change Using a Satellite-Sensed Vegetation Index. Remote Sens. **2**, 1531, **2010**.
45. MURAKAMI T., Seasonal variation in classification accuracy of forest-cover types examined by a single band or band combinations. J. For. Res. **9**, 214, **2004**.
46. BANKOVIĆ S., MEDAREVIĆ M., PANTIĆ D., Reliability of information on the growing stock as the base of real forest management planning. Glasnik Šumarskog fakulteta. **86**, 69, **2002** [In Serbian].
47. VAN LEEUWEN W. J. D., ORR B. J., MARSH S. E., HERRMANN S. M., Multi-sensor NDVI data continuity: Uncertainties and implications for vegetation monitoring applications. Remote Sens. Environ. **100**, 71, **2006**.
48. AMACHER G., OLLIKAINEN M., KOSKELA E., Economics of Forest Resources. The MIT Press: Cambridge, Massachusetts, 145, **2009**.
49. ANFODILLO T., CARRER M., GIACOMA E., LAMEDICA S., PETTENELLA D., Challenges and priority for adapting the management of Carpathians forests to new environmental and socio-economic conditions. University of Padova: Padova, 152, **2008.**
50. REC. Illegal logging activities in the Republic of Serbia - A. FACT-FINDING STUDY. Regional Environmental Center: Belgrade, 47, **2009.**
51. BELLONE T., BOCCARDO P., PEREZ F., Investigation of vegetation dynamics using long-term normalized difference vegetation index time-series. Am. J. Environ. Sci. **5**, 461, **2009**.
52. CHEN J., JONSSON P., TAMURA M., GU Z., MATSUSHITA B., EKLUNDH L., A simple method for reconstructing a high-quality NDVI time-series data set based on the Savitzky–Golay filter. Remote Sens. Environ. **91**, 332, **2004**.
53. CORRAL-RIVAS J.J., WEHENKEL C., CASTELLANOS-BOCAZ H.A., VARGAS-LARRETA B., DIEGUEZ-ARANDA U., A permutation test of spatial randomness: application to nearest neighbour indices in forest stands. J. For. Res. **15**, 218, **2010**.
54. FENSHOLT R., RASMUSSEN K., NIELSEN T.T., MBOW C., Evaluation of earth observation based long term vegetation trends – Intercomparing NDVI time series trend analysis consistency of Sahel from AVHRR GIMMS, Terra MODIS and SPOT VGT data. Remote Sens. Environ. **113**, 1887, **2009**.
55. MARTINEZ B., GILABERT M.A., Vegetation dynamics from NDVI time series analysis using the wavelet transform. Remote Sens. Environ. **113**, 1825, **2009**.