Central European Geology, Vol. 62/1, 15–26 (2019)
DOI: 10.1556/24.61.2018.10
First published online July 19, 2018

Monitoring urban greenness evolution using multitemporal Landsat imagery in the city of Erbil (Iraq)

Shwan O. Hussein*

Faculty of Science and Informatics, Department of Physical Geography and Geoinformatics, University of Szeged, Szeged, Hungary

Received: July 31, 2017; accepted: May 7, 2018

Most cities in the world have experienced major developments in the past 20–25 years. However, research has showed that the development aspect of these cities has led to a decrease in green areas. This paper aims to assess the spatiotemporal variations of urban green areas during the period 1990–2015 with special regard to city of Erbil. The study uses a mix of fuzzy functions, linear spectral mixture analysis, and maximum likelihood classification for the classification of Landsat imagery from 1990 to 2015 to extract the four main classes of land use, namely agricultural land, vacant land, built-up land, and green vegetation. Both the classification approaches used in this research produced excellent and reliable results, as an overall accuracy of more than 80% was able to be obtained. The spatiotemporal analysis of land use within the city of Erbil shows a series of major changes between 1990 and 2015. Therefore, the results of the spatiotemporal evolution of urban greenness assessment in the Erbil region can be used both for spatial planning purposes and as an urban greenness assessment method in dry climate areas.

Keywords: Erbil, linear spectral mixture analysis, maximum likelihood classification, multitemporal Landsat, subpixel classification, urban greenness assessment

*Corresponding address: Faculty of Science and Informatics, Department of Physical Geography and Geoinformatics, University of Szeged, Egyetem u. 2–6, H-6722 Szeged, Hungary
E-mail: shwan.huseen1@su.edu.krd

ISSN 1788-2281 © 2018 *The Author(s)*

Introduction

In the past 20–25 years, many cities around the globe have experienced major trends in development. The knowledge of the spatial distribution of green areas within urban areas is vital for decision makers, since the latter have significant influence on urban environmental setups. Having detailed information about the spatial distribution and size of green areas would benefit Erbil's local authorities, since according to Erbil Tourism (2014), green areas cover 12% of the city's built-up area, and the authorities would like to increase it to 15%, which is the minimum ratio provided by the International Organization for Standardization (ISO).

Statistical reports from the United Nations show that the global urban population had increased from 746 million in 1950 to 3.9 billion in 2014. This means that the urbanization process has experienced an acceleration process like never before, with interest in the study of greenness within cities undergoing a directly proportional increase.

The process of urbanization is significantly influenced by a number of socioeconomic factors, the main ones are population growth, built space, and the underlying levels of economic development. The concept of urban greenness ratio and distribution are some of the most important changes that urban centers experience due to the basic process of urbanization. Tang et al. (2012) argued that decision makers and urban planners should have the ability to manage these changes and use remote sensing as a basic tool in this endeavor.

The distribution and ratio of urban greenness is some of the most important factors of urban life equality-assessment processes. As such, having different functions such as recreational facilities or carbon sinks are essential factors to foster inclusivity and pride toward the city. Furthermore, the green areas offer the required base for higher standards by enhancing the quality of life of the people in the city. In cities with dense populations, green spaces are now considered to be more valuable than in the past due to the high pressure caused by the construction of new buildings and structures (Rafiee et al. 2009).

Vegetation in urban setups greatly determines the rate of evapotranspiration and the speed at which solar radiation is absorbed. If this is the case, then vegetation monitoring in urban ecosystems is an important endeavor and simultaneously, is a valuable tool in the reduction of atmospheric pollution and in the mitigation of heat island effect.

One of the first studies using remote sensing on Landsat imagery to assess the urban greenness areas was conducted in 1987; it focused on defining the spatial patterns of urban vegetation and separate woody and herbaceous vegetation (Sadowski et al. 1987). It was during the period 1990–2000, two other studies focused on the use of remotely sensed data for the evaluation of urban greenness. As a matter of fact, these studies were carried out in the year 1997. They used Landsat data to derive vegetation indices as one of the multiple variables used for the assessment of quality of life in urban areas. However, since the year 2000, the number of studies that involved in urban greenness has increased exponentially, with a record of 124 studies in 2016. Many of these studies have tried to correlate the impact of urban greenness with other urban variables, such as crime, health, life expectancy, and household income, among others. However, the most relevant studies regarding the use of remotely acquired data are those of Chang and Ji (2006), Dawelbait and Morari (2011), Gupta et al. (2012), Lu et al. (2002), Mozaffar et al. (2008), Rhew et al. (2011), Sakti and Tsuyuki (2015), Song (2005), Tang et al. (2012), and Wang et al. (2013). A large number of the aforementioned studies were focused on the basic concepts of subpixel classification techniques and endmember extraction. However, other studies have used vegetation indices in land-use change analysis, such as Buyantuyev et al. (2007) and Farooq (2009), who derived indices like Normalized Difference Vegetation Index, Soil-Adjusted Vegetation Index, and also used spectral mixture analysis (SMA), whereas Tooke et al. (2009) used the SMA and decision tree classification methods. There are also numerous other studies that focused on the subject matter and consequently provided distinctive results. These include research carried out by Abd El-Kawya et al. (2011), Dewan and Yamaguchi (2009), Rawat and Kumar (2015), and Suribabu et al. (2012).

The main aim of this study is to assess the spatiotemporal urban greenness evolution within an arid region by combining the linear SMA (LSMA) and fuzzy functions for the evaluation of Landsat imagery, in order to extract four main classes of land use: agricultural land, vacant land, built-up land, and green vegetation. These land-use classes were extracted using maximum likelihood classification (MLC) as well. Small (2001) argued that spatiotemporal analysis is a pillar for urban environment studies. The decision to carry out this analysis was motivated by the need to bring new data into the analysis of evolution of urban greenness in Erbil during the past 25 years.

Materials and methods

The study area is the capital of Iraqi Kurdistan Region (Erbil city) (Fig. 1), which has experienced huge population growth in the past 11 years (2004–2015), due the economic prosperity after the liberation of Iraq in 2003. The Iraq City Population (Central Statistical Organization, Iraq 2014) shows that the number of people in Erbil had increased by 210%, from 485,968 in 1987 to 1,025,000 in 2011.

Being one of the fastest growing cities in Iraq, the city of Erbil is perfect for a spatiotemporal evolution assessment of urban greenness within an arid region, due to the fact that it is located in a region characterized by a hot-summer Mediterranean Climate where urban greenness plays an important role.

For the spatiotemporal assessment of urban greenness, a set of three cloud-free Landsat images were used. In order to avoid seasonally derived errors, it was decided to use scenes from the same season. The images were acquired in the summer months, which represent the same vegetation condition of green areas in the city (Table 1). In addition, the selection of specific periods reflects spatial distributions and temporal changes due to significant economic and urban development.

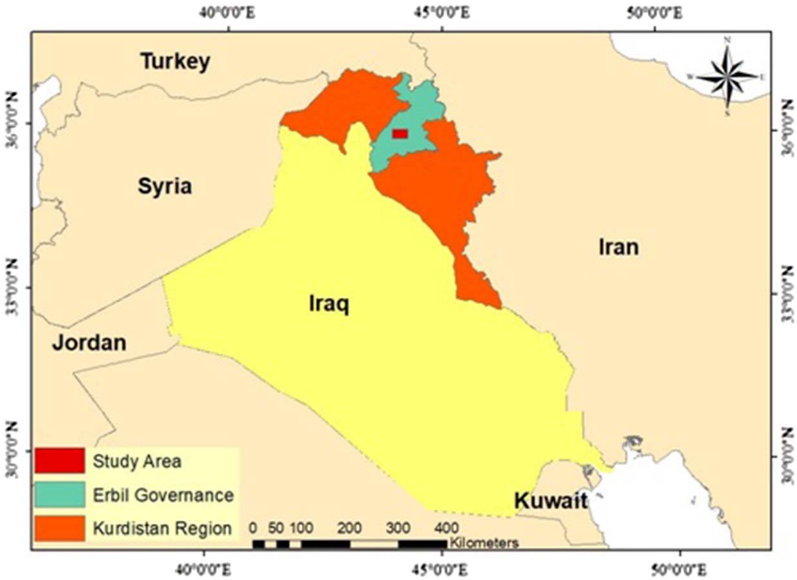


Fig. 1
Study area, Erbil City, covered by one Landsat scene in patch/row 169/36

Table 1
Description of the satellite imagery used in this study

Characteristics/sensor	LANDSAT TM4	LANDSAT TM5	LANDSAT OLI_TIRS8
Date of acquisition	July 10, 1990	August 14, 2000	August 8, 2015
Pixel size (m)	30	30	30
Number of bands	6	6	6
Time	7:08:31	7:16:37	7:38:38
Path and raw	P: 169; R: 35	P: 169; R: 35	P: 169; R: 35
Projection	UTM Zone 38	UTM Zone 38	UTM Zone 38
Ellipsoid	WGS 84	WGS 84	WGS 84

A number of corrections such as orthorectification and the conversion of the digital numbers to normalized at sensor reflectance were made, based on the methodology described by Markham and Barker (1987), using ENVI's preprocessing tools.

The methodology involves a three-step framework as presented in Fig. 2.

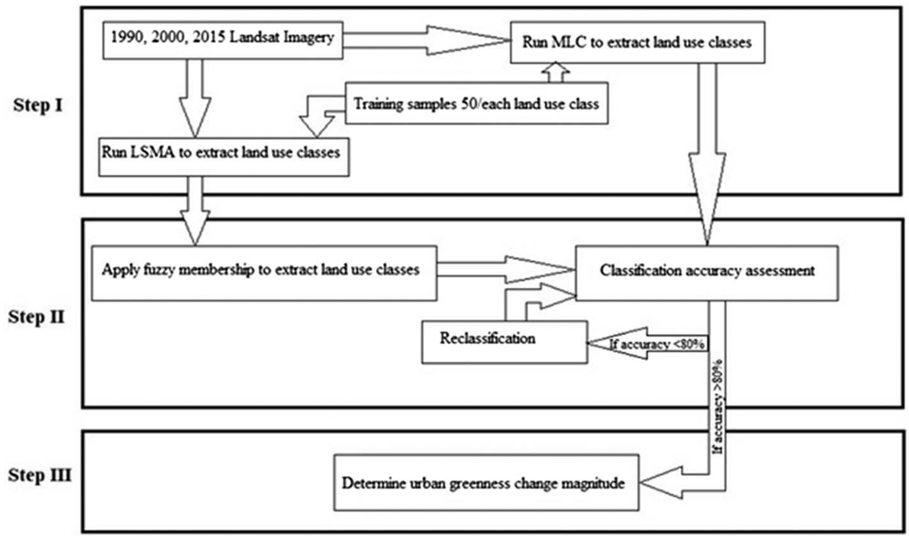


Fig. 2
Work methodology flowchart

Step I: This entailed the use of LSMA and MLC to classify the three Landsat scenes; Step II: Here, the results from the LSMA are fuzzified to extract the land-use classes (Appendices 1 and 2), after which both LSMA and MLC results undergo a classification accuracy assessment, which must be greater than 80% for the classification to be used; Step III: The green vegetation change magnitude was to be determined.

The accuracy levels for both methods were assessed using a series of 50 random trust points for each class; historical maps, current Google Earth images, Quickbird images from 2005, spot images from 2013, field surveys, interviews, and local knowledge and experience of the study area were used as reference data for the assessment, providing a confidence level of 95% and a confidence interval of ±10% for both classification methods, resulting in an overall accuracy of over 85%.

Based on the results from the LSMA, the large type of membership was chosen for the fuzzification process, resulting in a raster file with values ranging from 0 to 1 (Appendix 1), where the pixels with values close to 1 have the highest probability of representing that specific land-use class.

The trial and error method was used to identify the smallest value representing that specific land-use class. After multiple trials, the value of 0.92 was identified as the lower limit for each type.

The urban greenness change magnitude was determined by considering 1990 as T0, 2000 as T1, and 2015 as T2. Furthermore, both T1 and T2 would be compared with T0 to assess the magnitude change for each period.

Results and discussions

The two classification approaches used in this research produced reliable results, as they obtained an accuracy of over 80%. However, the LSMA classification gave more accurate results, since all the three classifications had an accuracy of more than 92% (92.08% in 1990, 95.12% in 2000, and 92.28% for the 2015 image). On the other hand, the MLC approach was inconsistent, as its accuracy value dropped from 95.81% to 80.78% in 1990 and 2000, respectively.

In most cases, the percentages obtained using both MLC and LSMA were similar for the same year with a slight difference of between 2% and 3%, which represents a difference of 200 ha for built-in land in 2000, 523 ha for the same land use in 2015, or 313 ha for vacant land in 2000 (Table 2).

Land use within the city of Erbil had undergone a series of major changes, especially between 2000 and 2015, when the city's built-up land area increased by about 3,800 ha (229%) as per the LSMA classification. However, the MLC classification put the value at 3,572 ha (225%; Fig. 3).

The expansion of the built-up area prompted the diminishing of agricultural land within the city. Unlike in other cases where green vegetation areas have been significantly reduced due to urbanization, the case of Erbil was different, since there is a direct link between the process of urbanization and an increase in green vegetation from 590 ha in 1990 to 1,002 ha in 2015.

Other studies also show an increase in vegetation areas. For example, the study conducted by Suribabu et al. (2012) showed an oscillating increase in the greenness

Table 2
The area (hectares) and the percentage covered by different categories of land use according to MLC and LSMA classification methods in 1990, 2000, and 2015

Land use	MLC 1990		LSMA 1990		MLC 2000		LSMA 2000		MLC 2015		LSMA 2015	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Green vegetation	889	6	590	4	550	4	325	2	815	6	1,002	7
Built-up land	3,394	24	3,589	26	3,575	25	3,752	27	8,077	57	8,590	61
Agricultural land	1,182	9	1,299	9	992	7	548	4	0	0	0	0
Vacant land	8,564	61	8,558	61	8,913	64	9,413	67	5,136	37	4,449	32
Grand total	14,029	100	14,036	100	14,029	100	14,038	100	14,029	100	14,041	100

MLC: maximum likelihood classification; LSMA: linear spectral mixture analysis

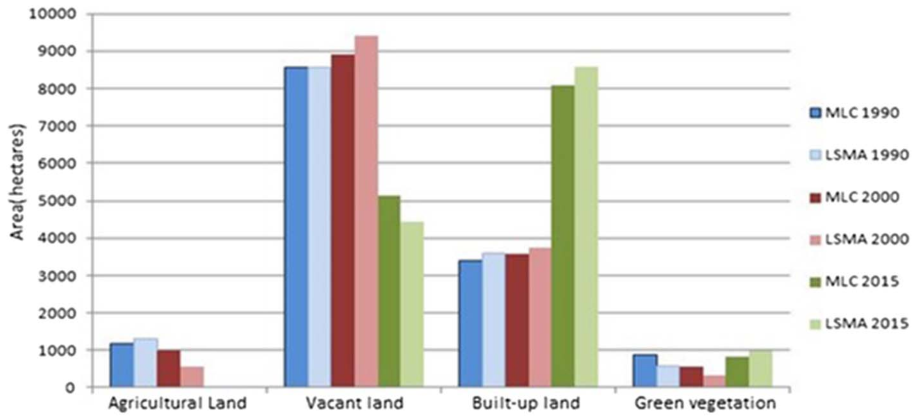


Fig. 3
1990–2015 land use evolution in the city of Erbil

within Tiruchirappalli City in India. In the case of Erbil, there was a decrease in the volume of green vegetation between 1990 and 2000. This could have been caused by the subsequent increase in built-up land, which has reached almost the same surface area as the one lost by the green vegetation land use. However, the spatial comparison between the maps as shown in Fig. 4 demonstrates that the area covered by green vegetation had been converted into vacant land, with the concept of seasonal drought used as the overall explanation. The 2% decrease in area covered by green vegetation between 1990 and 2000 was offset by a 5% increase in area covered by green vegetation between 2000 and 2015, covering 7% of the city's total area.

This is despite the fact that the LSMA classification found that the green vegetation surface had increased up to 1,002 ha (308%) during the same period. In Fig. 3, it can be observed that the area of green vegetation is considerably smaller than the area of built-up land.

However, it is important to note that both the built-up land and the green vegetation areas had significantly increased to the detriment of vacant land, which has seen the reduction in area from more than 9,000 ha in 2000 to about 4,500 ha in 2015, and of agricultural land, which has completely disappeared from Erbil in 2015, according to the results of the study (Fig. 3).

The increase in area covered by green vegetation can be explained by the construction of green areas, such as the Sami Abdulrahman Park, which was built in 1998, covering about 200 ha (Kurdistan Regional Government, Iraq 2007). Therefore, the construction of this park alone accounted for about half of the increase in green vegetation area within the city. The Sami Abdulrahman Park was accurately identified by both classification methods, representing the largest and the most compact area covered by green vegetation, as can be seen in the northwest part of the maps presented in Fig. 4c and f.

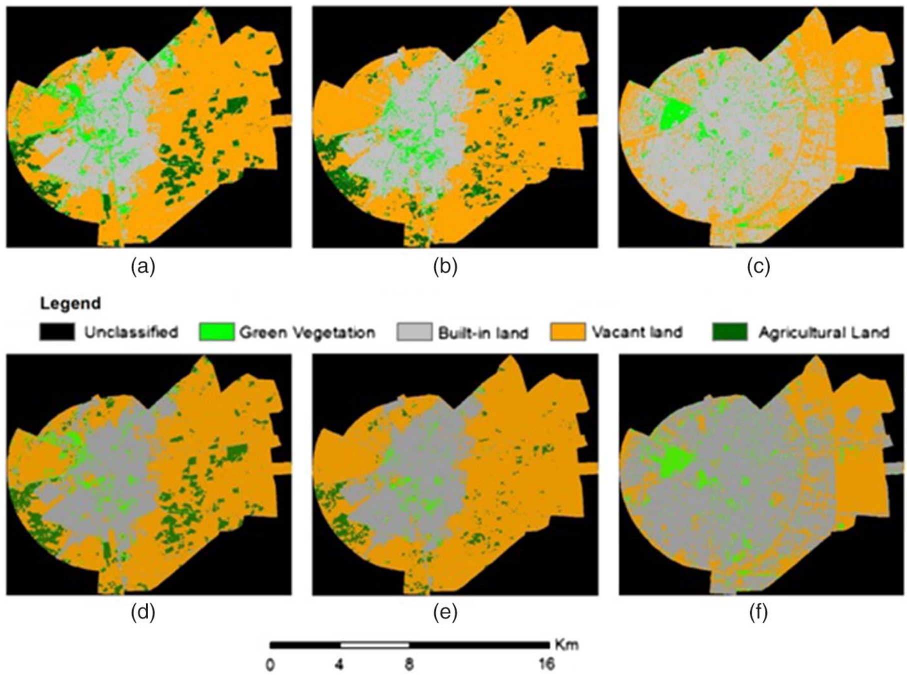


Fig. 4
Landsat imagery classification results (a: MLC 1990, b: MLC 2000, c: MLC 2015, d: LSMA 1990, e: LSMA 2000, f: LSMA 2015)

The spatiotemporal analysis of the green vegetation distribution reveals a continuous migration of the green vegetation clusters from northwest in 1990 to southeast in 2000 and then back to northwest again.

The fact that the area covered by green vegetation had tripled in the past few years depicts some unimaginable benefits for the city. However, the ratio of built-up area to green vegetation is still small, considering the fact that the area covered by green vegetation only accounts for 7% of the city's surface. This is contrary to the international standards set up by the United Nations, which specify a minimum of 15% of area covered by green vegetation within cities.

After the evaluation of the results from a spatial perspective, it can be noted that by 2015, the agricultural land has totally disappeared in both the MLC and LSMA classifications. This is despite the fact that the built-up land had considerably increased in a concentric aspect, with further developments in the suburban areas. Green vegetation has also increased in size, but it can be observed that most of the areas are small "islands" in the middle of built-up areas, with the exception of the Sami Abdulrahman Park, which is a large green area in the northwest of the city.

Conclusions

This research project provides critical information regarding the spatiotemporal evolution of the urban greenness in the city of Erbil over the past two and half decades (1990–2015), highlighting the increase in urban greenness by approximately 308%. The accuracy of the results proves the usefulness of LSMA in extracting endmembers from satellite imagery to provide an accurate quantitative analysis of land-use change within arid regions.

From the results obtained in this research, it can be argued that although the built-up areas have considerably increased in the past 25 years, the green areas have also increased as the process of urbanization unfolds. The overall consequence of this increase in built-up areas is represented by the changes in the location of these green areas.

The analysis of the greenness dynamics in the city of Erbil is helpful for urban planning and environmental management, since it provides an overall image regarding the changes in urban setups in the past 25 years, with special regard to the basic issue of vegetation dynamics. Small and Lu (2006) argued that urban vegetation studies can be used in urban planning, parks and natural areas management, and the spatial distribution of green areas within the city.

A deeper understanding of greenness within the urban setup in arid regions could help in the sustainability of the city and raise the living standards of the citizens (Tooke et al. 2009), considering the fact that different arid regions have different wet seasons, and that some cities use irrigation for the green areas and some do not. Therefore, this is the main limitation of the current approach. Liu and Yang (2015) affirmed that greenness studies can help to mitigate concerns over environmental degradation and consequently spur the economic sustainability.

References

Abd El-Kawya, O.R., J.K. Rød, H.A. Ismail, A.S. Suliman 2011: Land use and land cover change detection in the western Nile delta of Egypt using remote sensing data. – Applied Geography, 31, pp. 483–494.

Buyantuyev, A., J. Wu, C. Gries 2007: Estimating vegetation cover in an urban environment based on Landsat ETM+ imagery: A case study in Phoenix, USA. – International Journal of Remote Sensing, 28/2, pp. 269–291.

Central Statistical Organization, Iraq 2014: Population Statistics. – http://cosit.gov.iq.

Chang, C.-I., B. Ji 2006: Fisher's linear spectral mixture analysis. – IEEE Transactions on Geoscience and Remote Sensing, 44/8, pp. 2292–2304.

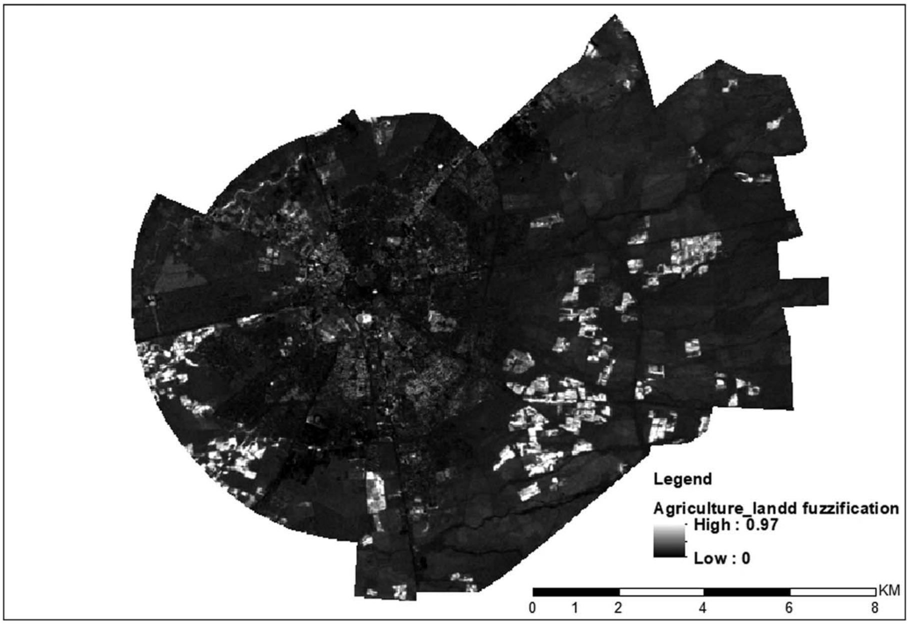
Dawelbait, M.A., F. Morari 2011: LANDSAT, spectral mixture analysis and change vector analysis to monitor land cover degradation in a Savanna Region in Sudan (1987–1999–2008). – International Journal of Water Resources and Arid Environments, 1/5, pp. 366–377.

Dewan, A.M., Y. Yamaguchi 2009: Land use and land cover change in Greater Dhaka, Bangladesh: Using remote sensing to promote sustainable urbanization. – Applied Geography, 29/3, pp. 390–401.

Erbil Tourism 2014: Erbil Seeking Access to International Standards of Green Areas. – http://www.erbiltourism2014.com/en/erbil/news/113-erbil-seeking-access-to-international-standards-of-green-areas.

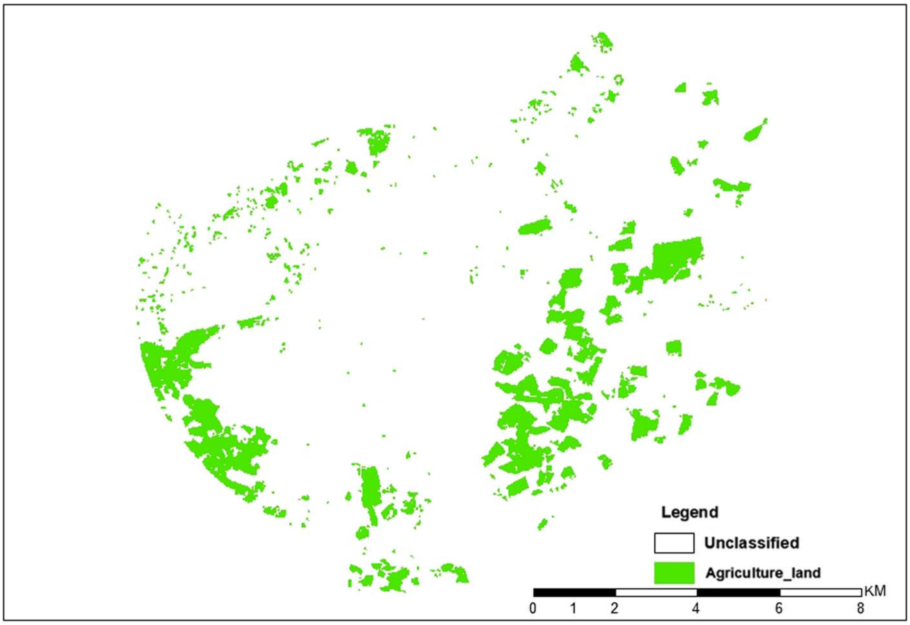
Farooq, A. 2009: Detection of change in vegetation cover using multi-spectral and multi-temporal information for District Sargodha, Pakistan. – Revista Sociedade & Natureza, 24/3, pp. 557–572.
Gupta, K., P. Kumar, S.K. Pathan, K.P. Sharma 2012: Urban neighborhood green index – A measure of green spaces in urban areas. – Landscape and Urban Planning, 105/3, pp. 325–335.
Kurdistan Regional Government, Iraq 2007: Homepage of the Kurdistan Regional Government, Iraq. – http://www.gov.krd/a/d.aspx?a=18843&l=14&r=81&s=010000.
Liu, T., X. Yang 2015: Monitoring land changes in an urban area using satellite imagery, GIS and landscape metrics. – Applied Geography, 56, pp. 42–54.
Lu, D., M. Batistella, E. Moran 2002: Linear spectral mixture analysis of TM data for land-use and land cover classification in Rondônia, Brazil Amazon. – In: Armenakis, C., Y.C. Lee (Eds): Proceedings of the ISPRS Commission IV Symposium: Geospatial Theory, Processing and Applications. Natural Resources Canada, pp. 557–562.
Markham, B.L., J.L. Barker 1987: Thematic Mapper bandpass solar exoatmospheric irradiances. – International Journal of Remote Sensing, 8/3, pp. 517–523.
Mozaffar, M.H., M.V. Zoej, M. Sahebi, Y. Rezaei 2008: Vegetation endmember extraction in hyperion images. – The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 37/B7, pp. 409–412.
Rafiee, R., A.S. Mahiny, N. Khorasani 2009: Assessment of changes in urban green spaces of Mashad city using satellite data. – International Journal of Applied Earth Observation and Geoinformation, 11/6, pp. 431–438.
Rawat, J.S., M. Kumar 2015: Monitoring land use/cover change using remote sensing and GIS techniques: A case study of Hawalbagh block, district Almora, Uttarakhand, India. – The Egyptian Journal of Remote Sensing and Space Sciences, 18/1, pp. 77–84.
Rhew, I.C., A. Vander Stoep, A. Kearney, N.L. Smith, M.D. Dunbar 2011: Validation of the normalized difference vegetation index as a measure of neighborhood greenness. – Annals of Epidemiology, 21/12, pp. 946–952.
Sadowski, F.G., J.A. Sturdevant, R.A. Rowntree 1987: Testing the consistency for mapping urban vegetation with high-altitude aerial photographsand Landsat MSS data. – Remote Sensing of Environment, 21/2, pp. 129–141.
Sakti, A.D., S. Tsuyuki 2015: Spectral mixture analysis (SMA) of Landsat imagery for land cover change study of highly degraded peatland in Indonesia. – International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-7/W3, pp. 495–501.
Small, C. 2001: Estimation of urban vegetation abundance by spectral mixture analysis. – International Journal of Remote Sensing, 22/7, pp. 1305–1334.
Small, C., J.W.T. Lu 2006: Estimation and vicarious validation of urban vegetation abundance by spectral mixture analysis. – Remote Sensing of Environment, 100/4, pp. 441–456.
Song, C. 2005: Spectral mixture analysis for subpixel vegetation fractions in the urban environment: How to incorporate endmember variability? – Remote Sensing of Environment, 95/2, pp. 248–263.
Suribabu, C.R., J. Bhaskar, T.R. Neelakantan 2012: Land use/cover change detection of Tiruchirapalli City, India, using integrated remote sensing and GIS tools. – Journal of Indian Society of Remote Sensing, 40/4, pp. 699–708.
Tang, J., F. Chen, S.S. Schwartz 2012: Assessing spatiotemporal variations of greenness in the Baltimore-Washington corridor area. – Landscape and Urban Planning, 105/3, pp. 296–306.
Tooke, T.R., N.C. Coops, N.R. Goodwin, J.A. Voogt 2009: Extracting urban vegetation characteristics using spectral mixture analysis and decision tree classifications. – Remote Sensing of Environment, 113/2, pp. 398–407.
Wang, H.-F., J.-X. Qiu, J. Breuste, C. Ross Friedmand, W.-Q. Zhou, X.-K. Wang 2013: Variations of urban greenness across urban structural units in Beijing, China. – Urban Forestry & Urban Greening, 12/4, pp. 554–561.

APPENDIX 1



Example of fuzzification of the LSMA results

APPENDIX 2



Example of land-use extraction from fuzzified LSMA