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Abstract In 1980s a significant boom in construction industry was witnessed in Cyprus. This paper explores the changes of land use that have occurred over the past 30 years around the historical capital of Nicosia, in particular around the core of the historic city defined by the Venetian walls. Further to some Open geospatial Data available within the national and regional geo-portals, the research has focused on the use and exploitation of freely accessible satellite imagery (such as Landsat and Sentinel imagery) and other archive aerial datasets in order to observe the most recent modifications of the urban landscapes. The changes occurred over time were observed using multi-spectral multi-temporal dataset with main aim to create thematic maps for further interpretation. The changes were hence identified, mapped and structured so as to emphasise different types and density of urban development affecting the surrounding landscapes

and potential “hot-spots”. Such observations could be a valuable input to the future urban development of Nicosia.

Keywords
(separated by '-')

Historical cities - Nicosia - Cyprus - Earth observation - Landsat - Changing landscape

Observing Landscape Changes Around the Nicosia Old Town Center Using Multi-temporal Datasets

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Abstract. In 1980s a significant boom in construction industry was witnessed in Cyprus. This paper explores the changes of land use that have occurred over the past 30 years around the historical capital of Nicosia, in particular around the core of the historic city defined by the Venetian walls. Further to some Open geospatial Data available within the national and regional geo-portals, the research has focused on the use and exploitation of freely accessible satellite imagery (such as Landsat and Sentinel imagery) and other archive aerial datasets in order to observe the most recent modifications of the urban landscapes. The changes occurred over time were observed using multi-spectral multi-temporal dataset with main aim to create thematic maps for further interpretation. The changes were hence identified, mapped and structured so as to emphasise different types and density of urban development affecting the surrounding landscapes and potential “hot-spots”. Such observations could be a valuable input to the future urban development of Nicosia.

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1 Introduction

Geo-spatial information is increasingly being used for purposes of territorial management as it has been recognized to be crucial when it comes to informed decision making processes that regard landscapes and environment. The nature of geo-information is in fact twofold - on one side the elaboration of such data is capable to describe phenomena that has already occurred (i.e. impact assessment purposes) and on the other side to provide us with simulations of possible further effects or occurrence (scenario modelling). In this paper authors opted for a combined and integrated use of multi-spectral, multi-temporal and multi-source data available over Cyprus in order to explore the contribution of freely available satellite imagery for monitoring of changes around the city of Nicosia and to suggest possibilities offered by such data for implementing the Open geospatial information available through national and EU repositories. Open geospatial Data approach was also of interest due to the recently established national INSPIRE platform, implemented by the Department of Land and Surveying of the Republic of Cyprus [1]. In the framework of Open Government

initiative, experts consider geospatial data to be significantly important category [2]. The possibility to access publicly collected and available data is retained crucial for the development of new and innovative applications useful for a variety of social domains [3]. Such approach that promotes the use and re-use of publicly collected data is actually encouraged by public policies for economic purposes [4].

This paper investigates the contribution of satellite imagery to non-space sectors such as built environment and urban development. The interaction between urban (built) environment and the surrounding landscapes was observed applying a combined and integrated use of multi-spectral and multi-temporal data (Sect. 2). Section 3 illustrates the methodology applied on the satellite remote sensing data with focus on change detection, with illustration of the results in Sect. 4. A discussion on the method and its use for purposes of decision making in urban contexts is provided in Sect. 5. Paper concludes with inputs on the land use changes around the city of Nicosia and on possible contribution of the information deriving from the satellite imagery in the future decision-making processes that regard the island's capital.

2 Datasets

The main data used to observe the changes in landscape around Nicosia's walls were freely available satellite imagery Landsat (LT), described in Table 1.

Table 1. Landsat imagery used in the study

Year (date-month)	Satellite (Sensor)	Spatial resolution (m)		Spectral resolution (nm) (only VIS-VNIR listed)
		Panchromatic	VIS	
1987 (22-April)	LT5 (Thematic Mapper – TM)	15	30	450–900
2003 (25-Sept)	LT5 (Thematic Mapper – TM)	15	30	450–900
2016 (5-April)	Landsat8 Operational Land Imager (OLI)	15	30	433–885

The images were accessed and downloaded from the geo-portal of the Geographical Survey of United States (USGS) for the years 1987, 2003 and 2016. This choice was made in order to investigate changes in the period of 80s and 90s (years of construction sector “boom” recorded in Cyprus) [5] and to observe possible modifications in urban fabric in the years after Cyprus accession to the European Union in 2004. PCA methodology was applied as it is frequently used to understand interactions between landscape and urban sprawl. In 2015, for example, Agapiou et al. [5], use PCA to determine areas of Paphos municipality that have undergone dramatic change in their land use for the period 1984–2010.

Figure 1 above shows Nicosia observed in all three images in Red – Green – Blue (RGB) bands i.e. the band combination that corresponds to the human vision. Below the same area as seen in band combination NIR – R – G that enhances the presence of vegetation (in red). This paper concentrates on the changes occurred in the part of Nicosia under administration of Republic of Cyprus, south of the buffer zone area.

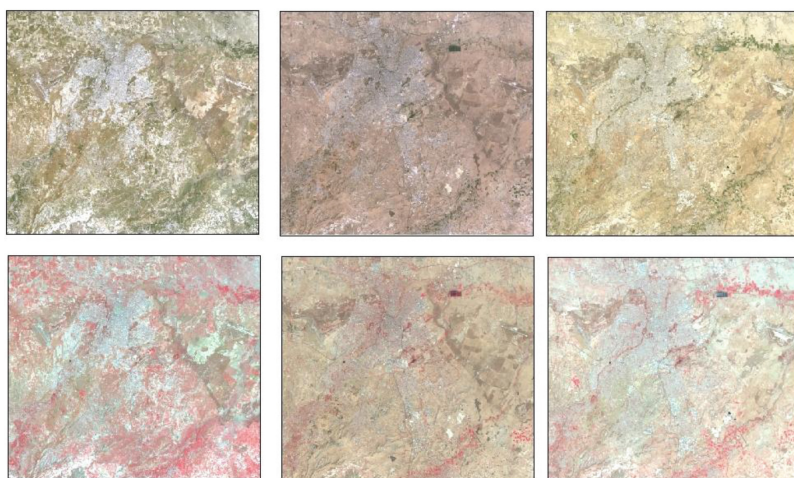


Fig. 1. Nicosia Municipality seen in RGB (above) and as NIR – green – blue (below). (Color figure online)

3 Methodology

3.1 Creation of Multi-spectral Multi-temporal Imagery Using Landsat Data

In order to observe the land changes using this multi-spectral imagery over a period of time, first it was necessary to build “stack layers” composed of two images. This was performed for three pairs (1984–2003; 1984–2016 and 2003–2016) using ERDAS Imagine 2010 software©. The images obtained in such a way are hence referred to as multi-spectral multi-temporal imagery. However, it is important to mention that a selection of bands for every image was made, according to their suitability for observing changes of construction and vegetation areas i.e. the urban development and possible landscape changes around inhabited spaces. Table 2 reports these combinations for all three pairs used.

For experiment purposes an additional image combining all three images was built following the same procedure. In this case, a composite image of 19 bands was obtained, as illustrated in Table 3.

Figure 2 shows two scenarios A and B with hatched buffer zone (left) and with buffer zone show as outline (right). The couple of images A refer to a stack image pair 1987–2016 observed with a combination 1,8, 14 i.e. showing the blue bands of both

Table 2. Landsat satellite imagery and respective bands used for creation of multi-spectral multi-temporal pairs.

Image pair	Single satellite image per year	Band number in the original image (wavelength)	Band number in multi-temporal image		
Pair 1987–2003	LT5 1987	Band 1 – blue (0.45–0.52)	1		
		Band 2 – green (0.52–0.60)	2		
		Band 3 – red (0.63–0.69)	3		
		Band 4 – Near Infrared (0.77–0.90)	4		
		Band 5 – short-wave Infrared (1.55–1.75)	5		
		Band 6 – Thermal Infrared (10.40–12.50)	6		
		Band 7 – red (2.09–2.35)	7		
	LT5 2003	Band 1 – blue (0.45–0.52)	8		
		Band 2 – green (0.52–0.60)	9		
		Band 3 – red (0.63–0.69)	10		
		Band 4 – Near Infrared NIR (0.77–0.90)	11		
		Band 5 – short-wave Infrared SWIR (1.55–1.75)	12		
		Pair 1987–2016	LT5 1987	Band 1 – blue (0.45–0.52)	1
				Band 2 – green (0.52–0.60)	2
Band 3 – red (0.63–0.69)	3				
Band 4 – Near Infrared (0.77–0.90)	4				
Band 5 – short-wave Infrared (1.55–1.75)	5				
Band 6 – Thermal Infrared (10.40–12.50)	6				
Band 7 – red (2.09–2.35)	7				
LDCM 8 2016	Band 2 – blue (0.45–0.51)	8			
	Band 3 – green (0.53–0.59)	9			
	Band 4 – red (0.64–0.67)	10			
	Band 5 – NIR (0.85–0.88)	11			
	Band 6 – short-wave Infrared (1.57–1.65)	12			
	Band 7 – SWIR (2.11–2.29)	13			
	Band 8 Panchromatic (0.50–0.68)	14			

(continued)

Table 2. (continued)

Image pair	Single satellite image per year	Band number in the original image (wavelength)	Band number in multi-temporal image
Pair 2003–2016	LT 5 2003	Band 1 – blue (0.45–0.52)	1
		Band 2 – green (0.52–0.60)	2
		Band 3 – red (0.63–0.69)	3
		Band 4 – Near Infrared NIR (0.77–0.90)	4
		Band 5 – short-wave Infrared SWIR (1.55–1.75)	5
	LDCM8 2016	Band 2 – blue (0.45–0.51)	6
		Band 3 – green (0.53–0.59)	7
		Band 4 – red (0.64–0.67)	8
		Band 5 – NIR (0.85–0.88)	9
		Band 6 – short-wave Infrared (1.57–1.65)	10
		Band 7 – SWIR (2.11–2.29)	11
		Band 8 Panchromatic (0.50–0.68)	12

images and using panchromatic band to enhance the spatial resolution. Couple B refers to a stack of all three images (Table 2) observed with a band combination 1, 8, 13 i.e. the blue bands in all three years. Such visualization criteria was chosen because man-made structures (and materials such as cement) are more easily distinguished in this range of spectrum.

3.2 3.1 Principal Component Analysis of Multi-spectral Multi-temporal Data

In order to analyze these first observations, a spectral enhancement technique was performed using a Principal Component Analysis (PCA). The parameter of 5 elements was used in order to have a significant qualitative gradient of changes in a range from 1 to 5 (with 1 referring to the most and 5 referring to least significant changes, respectively). Equivalent analysis was made for a multi-temporal image combining all three datasets. The image obtained however results in a complicated set of information that regards almost 30 years. In order to comment such image a more thorough background in terms of historical information and documentation is needed (Fig. 3).

Table 3. Landsat satellite imagery and respective bands used for creation of a composite multi-spectral multi-temporal image.

Composite image	Single satellite image per year	Band at the origin and its wavelength domain	Band number in the multi-temporal image
1987 – 2003 – 2016	LT5 1987	Band 1 – blue (0.45–0.52)	1
		Band 2 – green (0.52–0.60)	2
		Band 3 – red (0.63–0.69)	3
		Band 4 – Near Infrared (0.77–0.90)	4
		Band 5 – short-wave Infrared (1.55–1.75)	5
		Band 6 – Thermal Infrared (10.40–12.50)	6
		Band 7 – red (2.09–2.35)	7
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		Band 3 – red (0.63–0.69)	10
		Band 4 – Near Infrared NIR (0.77–0.90)	11
		Band 5 – short-wave Infrared SWIR (1.55–1.75)	12
	LDCM8 2016	Band 2 – blue (0.45–0.51)	13
		Band 3 – green (0.53–0.59)	14
		Band 4 – red (0.64–0.67)	15
		Band 5 - NIR (0.85–0.88)	16
		Band 6 – short-wave Infrared (1.57–1.65)	17
		Band 7 – SWIR (2.11–2.29)	18
		Band 8 Panchromatic (0.50–0.68)	19

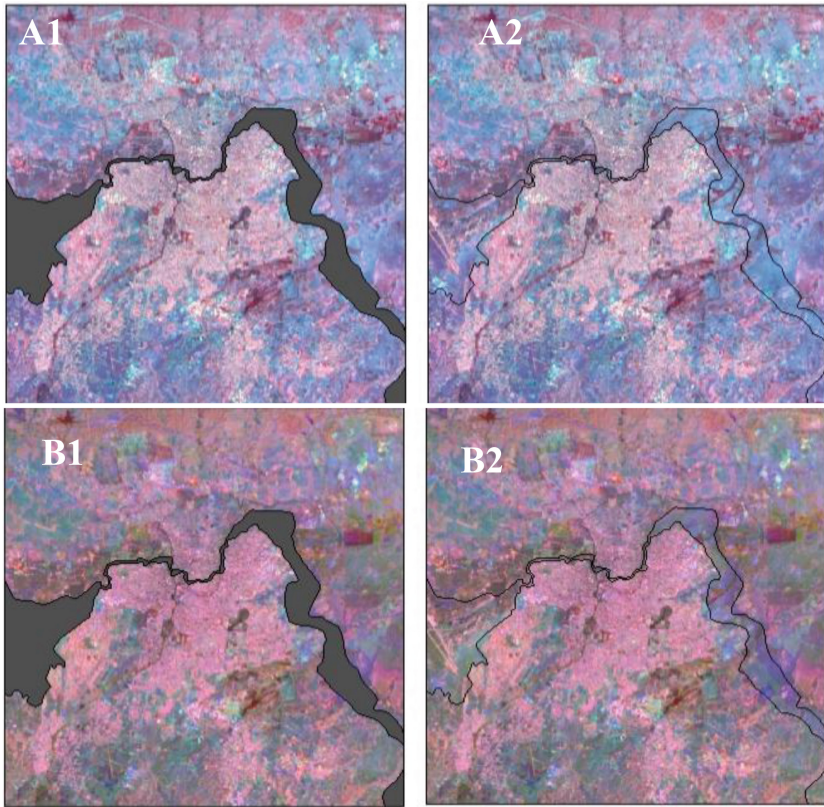


Fig. 2. Blue band combinations: (A) 1987–2016 image observed in band combination 1, 8 and 14 (above) and (B) 1987–2003–2016 image observed in band combination 1, 8, 13 (below). (Color figure online)

4 Results

The results obtained using the PCA is illustrated in Fig. 4. It is to be noted that such images appear in false-colour meaning that RGB channels are attributed to single elements of the PCA. Here the band combination used was 1, 2, 4 meaning that higher changes are observed in channels of Red and Green (1 and 2 respectively) while milder changes are observed in Blue channel (4 on the scale of 1–5).

Hence, the colours seen on the image do not have an absolute value but are an indication of landscape change in the cover (and hence use) observed and it requires further qualitative and quantitative interpretation. A closer look on the walled city of Nicosia and its southern area within the PCA image 1987–2016 (Fig. 5) show some significant changes around the city walls (white dashed lined), just out of the walls and along the main transport arteries of the city (red colour).

Such observations were identified as ‘hot-spots’ and were further examined observing the values of sample pixels across all the bands used in both images.

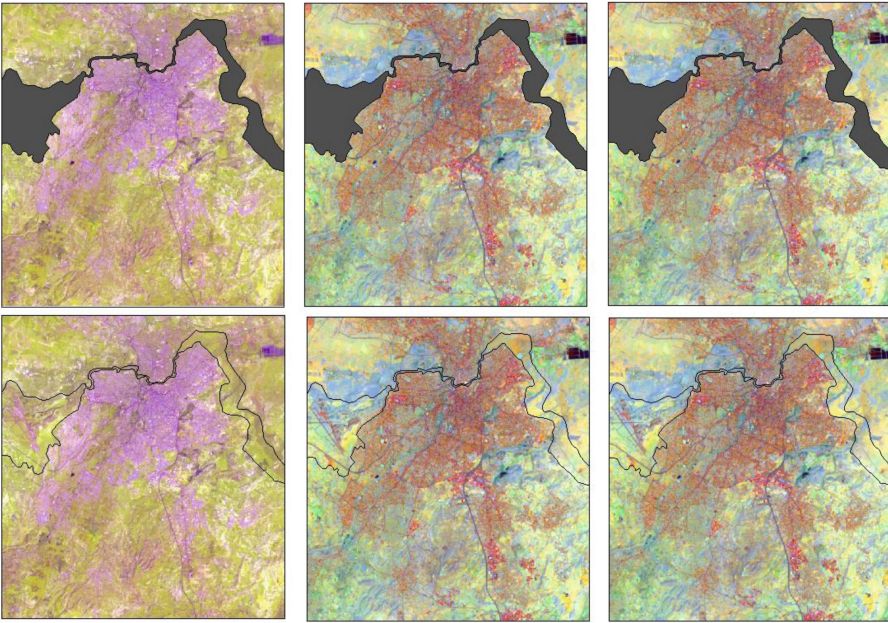


Fig. 3. Principal Component Analysis for image pairs: 1987–2003 (left); 2003–2016 (middle) and 1987–2016 (right). Buffer zone is shown as hatched (above) and as outline only (below).



Fig. 4. PCA of the image pair 1987–2016, a close-up on southern Nicosia. (Color figure online)

Using 1987–2016 PCA image as a reference, a sample of 9 points was selected (points within the walled city, on the walls and out of the walls on ‘hot-spots’ and on areas with medium and low change-rate). Choosing the blue band as the most suitable one for observations of changes in construction, the absolute differences in reflectance values were observed in bands 1 and 8 of the image pair 1987–2016 (Table 2), shown in Fig. 5. The difference value is not steady but shows fluctuation: such behavior could indicate changes in the urban environment (such as demolition or new construction) for example in point 3 (around Venetian walls) or in point 6 (hot-spot 3). Further, the four pixel samples corresponding to ‘hot-spots’ were examined for their reflectance values in Near Infrared (NIR) band in both years (i.e. bands 4 and 11 from Table 2). Figure 6 shows that differences in reflectance of ‘hot-spots’ 1, 2 and 3 have a similar trend, while it is different for ‘hot-spot’ 4. NIR range of the spectrum this band is particularly suitable for detecting changes in vegetation. This observation could hence be an indication of change in vegetation cover in the ‘hot-spot 4’.

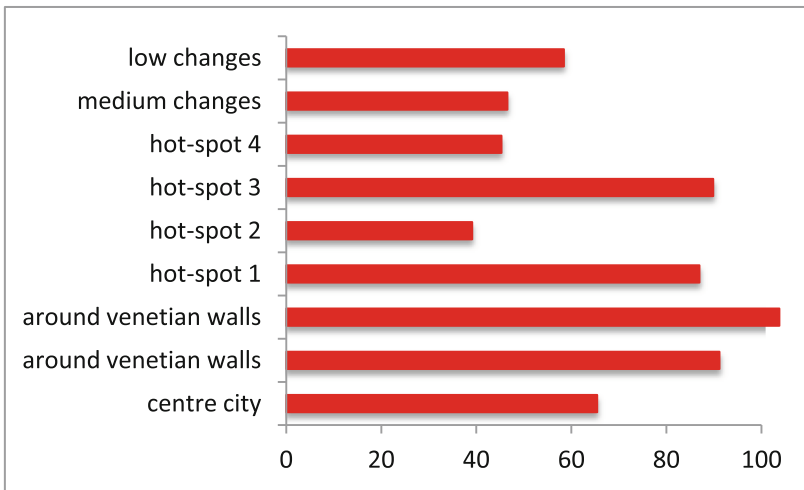


Fig. 5. The absolute difference in blue bands in 1987 and in 2016 for all 9 sample points

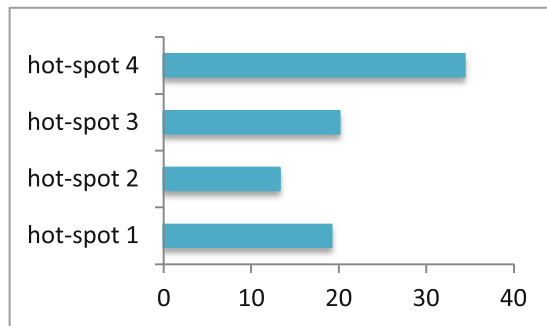


Fig. 6. The absolute difference in NIR bands in 1987 and in 2016 for all ‘hot-spots’

5 Discussion

The results illustrated show that quite a few areas in Nicosia have been subject to land cover change and hence probably their land use. The PCA seems to be an adequate method for qualitative analysis and useful for identification of ‘hot-spots’ i.e. areas mostly subject to change. The limits of this approach is that areas cannot be assumed as ‘hot-spots’ only upon the investigation of satellite imagery but they need to be further examined using urban masterplans or technical maps. In addition to reflectance pixel values, the assumptions made on the type of land cover change are to be further elaborated using historic data and in-situ measurements, also due to the limit of the image spatial resolution. The method proposed can be however suitable for two reasons: (1) it can provide an overview of the changes on a territorial scale of entire municipalities (or even larger areas) and (2) it can help to identify specific areas of the city that have been subject to change and that require further investigation.

6 Conclusions

The study here illustrated was an attempt to observe changes in urban environment of the Nicosia municipality, in particular in the southern area around the walled historic city. The methodology employed regards the use of freely available satellite imagery that was examined using multi-spectral multi-temporal pairs of images. Further to the visual interpretation, the study illustrates a spectral enhancement method using a PCA. The results show some clear changes in the urban fabric in southern area of the walled city of Nicosia, helping to identify several significant ‘hot-spots’. Possible use of such result could be seen in the development and implementation of the urban masterplans or planning the construction works that could have high impact on the historic urban structure e.g. new high speed transport connections, proximity of larger constructions to sensitive areas such as Venetian walls and so forth. However, it is important recall that in order to quantify and describe the changes more precisely, further in-situ measurements and comparison with historic information such as maps and aerial images needs to be performed. In such a way, it would be possible correlate in an even more significant manner the observations coming from satellite imagery with changes in the urban scenario that have occurred over the past three decades.

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