Monitoring Archaeological Site Landscapes in Cyprus using Multi-temporal Atmospheric Corrected Image Data

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This paper aims to examine the use of satellite remote sensing for monitoring archaeological and more generally cultural heritage sites. For this purpose, multi-temporal data from Landsat 5 TM, Landsat 7 ETM+ and Quickbird images were applied. The paper also discusses the importance of atmospheric correction at the pre-processing step in order to determine true surface reflectance values by removing these effects from satellite images. Atmospheric correction is arguably the most important part of the pre-processing of satellite remotely sensed data and any omission produces erroneous results. The effects of the atmosphere are more severe where dark targets are shown in the satellite image. In the management of cultural heritage sites, since temporal satellite images are required for monitoring purposes, the effect of the atmosphere must be considered. In-situ spectro-radiometric measurements using the GER1500 field spectro-radiometer have been used to assess the reflectance values found after applying the darkest pixel atmospheric correction to the image data. The study area consist the Amathus archaeological site in Limassol and the Nea Paphos archaeological site area located in Paphos district area in Cyprus. Vegetation Index (NDVI) change detection algorithm has been applied to a series of thirteen Landsat TM/ETM+ images of Amathus archaeological site in Limassol. Classification and extraction algorithms have been applied to Landsat TM and Quickbird high resolution images of Nea Paphos archaeological site area.

1. INTRODUCTION

Archaeological studies have a long tradition of aerial photography application [1]. What has changed in recent years in remote sensing application is the development of new sensors (in particular multi-spectral Pavlidis *et al*. [16]; hyper-spectral such as Cavalli *et al*. [4]; microwave) and the availability of new tools for the management and integration of spatial information. Despite good archaeological results, there is a considerable reporting of the inherent limitations of this method of survey. The main problem is the cartographic nature of the data and the impossibility of planning the flights to coincide with "time windows" when conditions for the detection of archaeological features are at their best [3]. Satellite remote sensing can provide a variety of useful data for monitoring and managing archaeological sites [15; 7; 8, 9, 10; 2]. Satellite image data provides a synoptic view which is not available from aerial photography. It takes over 200 aerial mapping photos to cover the same area as a single satellite image.

The importance of applying space technology to cultural heritage and archaeological research has received great attention worldwide, mainly because very high resolution (VHR) satellite data, such as IKONOS (1999) and QuickBird (2001), are able to match with aerial photogrammetric images [12; 6].

The extent of the problem of the changing landscape nearby the archaeological sites is mostly unknown, however, and efficient coping strategies are not developed. In this paper we present an overview of the basics of the application of remote sensing in such tasks. Indeed, change detection method based on the use of the Normalized Difference Vegetation Index (NDVI), classification, image-overlay applied to Landsat TM images with different acquisition dates, followed by image subtraction (differencing) have been also presented. This procedure results in an easily interpretable and extremely quick approach to change detection of land cover as well as change in biomass, and it can be used as a 'first warning' method to indicate archaeological sites threatened by the nearby changing landscape.

Attention is given in the use of green, red and near-infrared spectral bands instead of longer wavelengths, since most of the change detection algorithms make use of such bands [4] and it can be seen in the acquisition of ground spectral data. Vegetation properties, vegetation cover, and types of archaeological features are best retrieved in the near-infrared bands.

2. REMOTE SENSING

2.1. Introduction

Remote sensing covers all techniques related to the analysis and use of data from environmental and earth resources satellites and from aerial photographs. Remote Sensing is the science of deriving information about an object from measurements made at a distance from the object (i.e. without actually coming in contact with it).

With their continuous development and improvement, and free from national access restrictions, satellite sensors are increasingly replacing surface and airborne data gathering techniques. At any one point in time, day or night, multiple satellites are rapidly scanning and measuring the earth's surface and atmosphere, adding to an ever-expanding range of geographic and geophysical data available to help us manage and solve the problems of our human and physical environments. Remote Sensing is the science of extracting information from such images.

Landsat Thematic Mapper (TM) or Enhanced Thematic Mapper (ETM+), SPOT, ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) satellite images are widely used for deriving information about the earth's land. Moreover, the operational availability of high-resolution satellite imagery, (i.e. Quickbird, IKONOS), opens up new possibilities for investigating and monitoring natural resources. Compared with traditional survey techniques, satellite remote sensing is accurate, timely and cost-effective. These data offer a number of advantages:

- Provide synoptic coverage and therefore give an extensive view of vast areas at the same time.
- Images can be acquired for the same area at a high rate of repetition (two to three times a month), thus permitting selection of the most appropriate seasonal data.
- Satellite images are recorded in various wavelengths, visible and non-visible, which provide accurate information on ground conditions.
- They can be obtained for any part of the world without encountering administrative restrictions.

2.2. Pre – Processing of Remote Sensing Data

After remotely sensed data have been received and undergone preliminary correction at the ground receiving station, the next step is to pre-process the data. In the context of digital analysis of remotely sensed data, pre-processing is generally characterised by two types of data correction: (1) radiometric pre-processing which addresses variations in the pixel intensities (digital numbers, DN) and (2) geometric correction which addresses errors in the relative positions of pixels, mainly due to the sensor viewing geometry and terrain variations. Radiometric corrections are distinguished between calibrations, de-striping approaches, atmospheric corrections and removal of data errors or flaws (Mather, 2001). Radiometric correction is more difficult than correction for geometric effects since the distributions and intensities of these effects are often inadequately known. Despite of the variety of techniques which can be used to estimate the atmospheric effect, the atmospheric correction remains an ill-determined step in the pre-processing of image data.

2.3. Multi-temporal Images

The extent of the problem of the changing landscape nearby the archaeological sites is mostly unknown, however, and efficient coping strategies are not developed. In this paper we present an overview of the basics of the application of remote sensing in such tasks. Change detection methods based on the use of the Normalized Difference Vegetation Index (NDVI) and classification, are applied to Landsat TM images with different acquisition dates. This procedure results in an easily interpretable and extremely quick approach to change detection of land cover as well as change in biomass, and it can be used as a first warning method to indicate archaeological sites threatened by the nearby changing landscape.

Time series of satellite remote sensed data acquired at high spatial and temporal resolution provides a potentially ideal source for detecting change and analyzing trends.

2.4. Atmospheric Correction

Any sensor that records electromagnetic radiation from the earth's surface using visible or near-visible radiation will not represent the true ground-leaving radiance at that point [17]. Part of the brightness is due to the reflectance of the target of interest and the remainder is derived from the brightness of the atmosphere itself. The separation of contributions is not known a priori, so the objective of atmospheric correction is to quantify these two components so that the main analysis can made on the correct target reflectance or radiance values.

Since multi-temporal images are often acquired by different sensors under variable atmospheric conditions, solar illumination and view angles, an effective atmospheric correction is required to remove radiometric distortions and make the images comparable using the retrieved true reflectance values [13]. Several operational algorithms for relative and absolute atmospheric correction have been developed as shown by Hadjimitsis et al. [11] and el Hajj [13]. The users of remotely sensed data must be aware about the contribution of the atmosphere to the at-satellite signal especially in the case of time-series images.

3. CHANGE DETECTION TECHNIQUES

Change detection has become a major application of remotely sensed data because of repetitive coverage at short intervals and consistent image quality. The basic premise in using remote sensing data for change detection is that changes in land cover result in changes in radiance values and changes in radiance due to land cover change are large with respect to radiance changes caused by others factors such as differences in atmospheric conditions, differences in soil moisture and differences in sun angles. Several change detection techniques applied to satellite digital images along with GIS techniques have been reported in the literature. Some of these include image overlay, image difference, ratioing, principal component analysis (PCA), and post-classification etc. An important component to change detection is radiometric calibration including atmospheric correction.

3.1. Image Overlay

The simplest way to produce a change image is by making a photographic two-colour composite (of a single band) showing the two dates in separate colour overlays. The colours in the resulting image indicate changes in reflectance values between the two dates. Thus, features that are bright (high reflectance) on date 1, but dark (low reflectance) on date 2, will appear in the colour of the first photographic overlay. Features which are dark on date 1 and bright on date 2 will appear in the colour of the second overlay. Features which are unchanged between the two dates will be equally bright in both overlays and hence will appear as the colour sum of the two overlays (Mather, 2001)

3.2. NDVI

Many techniques have been developed to study quantitatively and qualitatively the status of the vegetation from satellite images. To reduce the number of parameters present in multispectral measurements to one unique parameter, the Vegetation Indexes were developed. Vegetation Indexes are combinations of spectral channels that reflect the contribution of vegetation depending on the spectral response of an area, minimizing the contribution of other factors such as soil, lighting, atmosphere, etc. [17]. The Normalized Difference Vegetation Index (NDVI) is a nonlinear function which varies between -1 and $+1$ but is undefined when RED and NIR are zero. Only the positive values correspond with vegetated zones. The negative values, generated by a higher reflectance in the visible region than in the infrared region, are due to clouds, snow, bare soil and rock.

3.3. Unsupervised Classification

In unsupervised classification, the computer is allowed to analyse all of the spectral signatures of all of the image's pixels and to determine their natural groupings, that is to say, to group the pixels on the basis of their similar spectral signatures [17]. The main advantage of this method is its great speed, for it requires practically no intervention from the user.

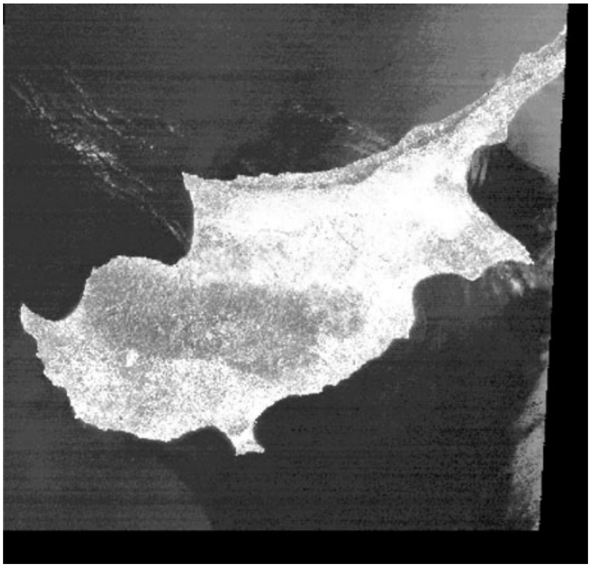
3.4. Image Differencing

Another procedure is to register simply two images and prepare a temporal difference image by subtracting corresponding pixel values for one date from those of the other. The difference in the areas of no change will be very small, and areas of change will reveal larger positive or negative value. In this method, registered images acquired at different times are subtracted to produce a residual image, which represents the change between the two dates. Pixels of no radiance change are distributed around the mean, while pixels of radiance change are distributed in the tails of the distribution.

4. METHODS AND MATERIALS

4.1. Available Satellite Images

The Landsat TM/ETM+ images listed in Table 1 have been used for the Amathus archaeological site area. The ERDAS Imagine 9.3 software has been used for the processing of available images.



► Figure 1. Landsat TM image of Cyprus.

► **Table 1. Satellite image used.**

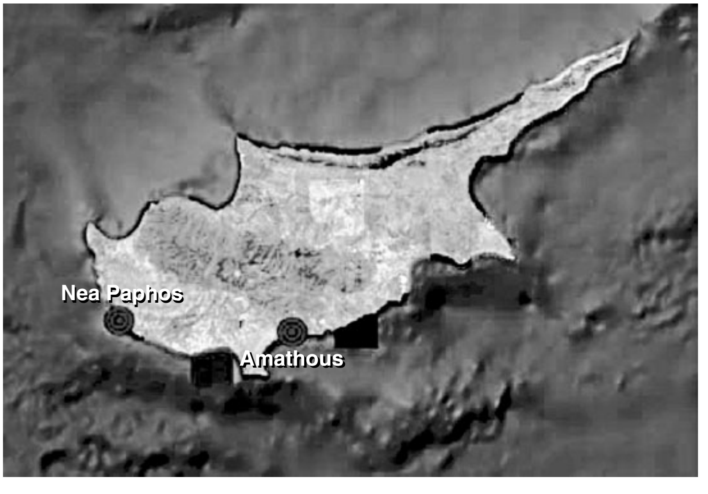
Satellite	Date acquired
Landsat-5 TM	30/01/2001
	11/05/2000
	11/09/1998
	03/06/1985
Landsat-7 ETM+	19/12/2008
	17/11/2008
	01/11/2008
	16/10/2008
	30/09/2008
	14/09/2008
	29/08/2008
	13/08/2008
	28/07/2008
	05/10/2004
	19/09/2004
	30/05/2004
	14/05/2004
	28/04/2004
	12/04/2004
	08/02/2004
	20/11/2003
IKONOS	14/03/2000
Quickbird	23/01/2003

Archived Landsat-5 TM images of the Paphos District area in Cyprus acquired on the 30/01/2001, 11/5/2000, 11/9/98 and 3/6/1985 have been used. Ikonos and Quickbird images acquired on 14/3/ 2000 and 23/1/2003, respectively, were also used to track more easily the spectral targets. The District areas of Paphos and Limassol, which consists of many cultural heritage sites, have been selected to be used as pilot studies.

◀ Figure 2. Quickbird- 0.6m resolution image of Paphos harbour area acquired on 23-12-2003 (castle and House of Dionyssos area).

4.2. Area of Interest

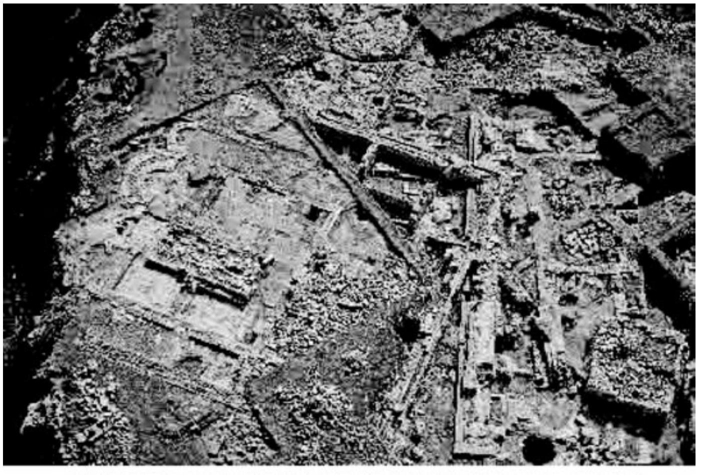
The archaeological sites of Amathous and Nea Paphos have been selected as pilot cases studies (Figure 3). These where selected among other archaeological sites since they cover vast areas and so they were visible and recognizable even from the Landsat satellite images (pixel size 30m × 30 m). Smaller in area archaeological sites and cultural heritage sites could be studied by satellites of higher spatial resolution (e.g. IKONOS).



◀ Figure 3. Amathous and Nea Paphos archaeological site (Google Earth©).

The ancient town of Amathous is situated on the south coast of Cyprus, about 7 km east of the town of Limassol. Traces of the earliest human presence, dating to the Neolithic period, have been detected during archaeological excavations on the hills neighbouring Amathous. However, we do not know with certainty the exact moment of the foundation of the town of Amathous. During the Archaic period the town acquired special wealth as one of the Kingdoms of Cyprus, and had remarkable commercial relations with neighbouring countries. Already in the 8th century B.C. a strong group of Phoenicians settled in Amathous. The abolition of the Kingdom of Amathous, as well as of the other Kingdoms of Cyprus, was sealed during the Hellenistic period due to the annexation of the island by the Ptolemies. The acropolis was almost completely abandoned and the living quarters were concentrated downtown.

► Figure 4. Airphoto of the archaeological site of Amathous and Nea Paphos (Cyprus Department of Antiquities).



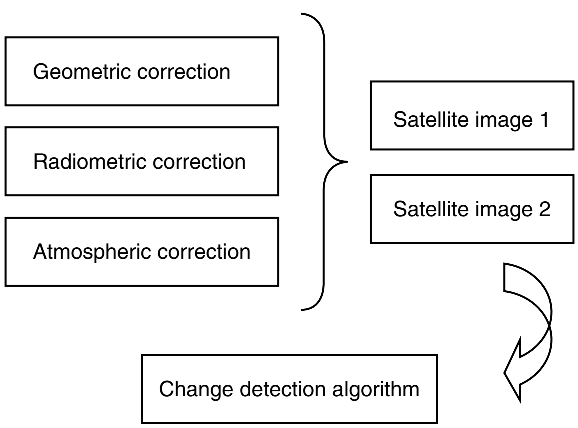
Nea Paphos is situated on a small promontory on the southwest coast of the island. According to written sources, the town was founded at the end of the 4th century by Nicocles, the last king of PalaiPaphos. In the beginning of the 3rd century B.C. when Cyprus became part of the Ptolemaic kingdom, which had its capital in Alexandria, Nea Paphos became the center of Ptolemaic administration on the island. Until the end of the 2nd century B.C., Nea Paphos acquired such an important role as a political and economical centre of the region that the Ptolemies made it the capital of the whole island. Nea Paphos went through a period of decline, which lasted a few centuries, and was thus reduced in size. The town regained some of its importance during the Byzantine and the Medieval periods but from the Venetian period onwards the coastal settlement of Nea Paphos was abandoned and the population began to move further inland where the present town of Paphos developed.

4.3. Methodology

All satellite images were firstly georeferenced at the World Geodetic System '84 (WGS 84 / UTM) using a high resolution digital map of Cyprus. A polynomial geometric model was selected (second order) and the Root Mean Square was lower than 1 pixel. After the necessary radiometric corrections, atmospheric correction using the darkest pixel method was applied for these images.

Finally change detection such as NDVI algorithm was computed for different –in time- satellite images, in order to detect any threatened by the nearby changing landscape.

An overview of the methodology applied is shown in Figure 5.



◀ Figure 5. Methodology.

4.4. Ground Measurements

The Remote Sensing and Geodesy Laboratory of the Department of Civil Eng. and Geomatics at the Cyprus University of Technology supported the ground measurements of this project. A GER1500 field spectro-radiometer was used to retrieve the true reflectance value of several target areas such as bare soil (see Figure 6). This allowed the quantification of the amount of atmospheric effects in different targets in the vicinity of cultural heritage sites.

► Figure 6. Collection of spectral signature data on a whitish bare soil using the GER1500 Field Spectroradiometer.

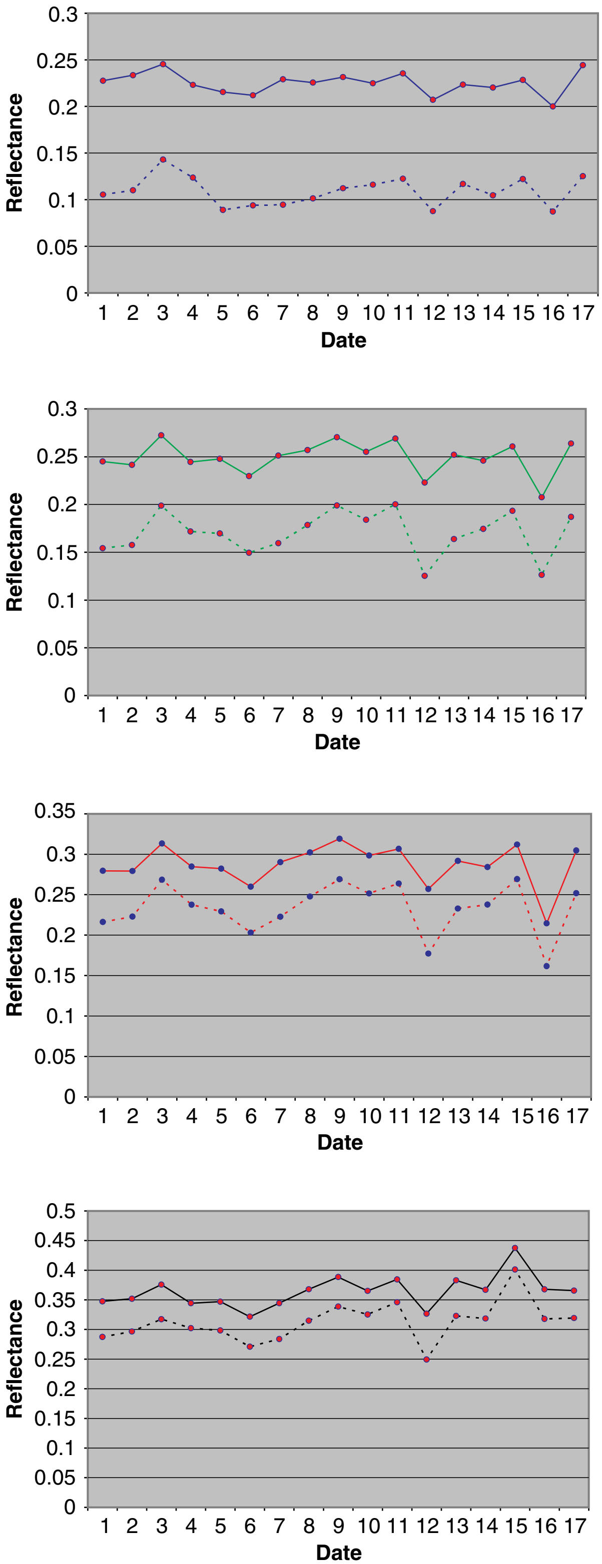
4.5. Application of Atmospheric Correction

Examination of the statistics of multi-temporal images (consisting several cultural sites) provides a tool for deciding whether the images are affected by the atmosphere. Over dark bodies that located in the vicinity of cultural heritage sites any significant temporal variations of DN's (digital numbers), or any high DN's in the near infra-red (TM band 4) indicate that some images are affected by the atmosphere, since dark body has very low reflectance values in the visible bands and has negligible reflectance values at near infra-red.

The darkest pixel (DP) atmospheric correction method, also termed also histogram minimum method was applied to the multi-series satellite images of Cyprus area since it has been found that is the most effective atmospheric correction algorithm [7,11].

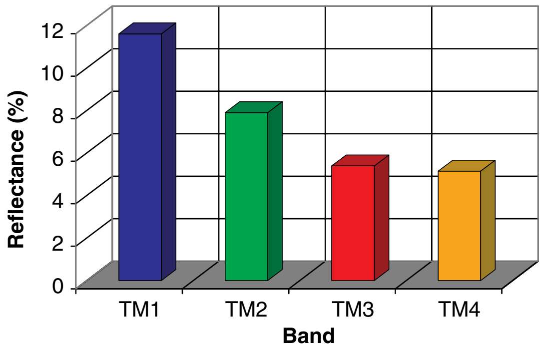
From the time-series images, the average values of the at-satellite reflectances (%) were calculated for the Amathous area. The following diagrams indicate the reflectane (TM1 –TM4 respectively, Landsat 7 ETM+, reversed order) before and after the atmospheric correction (continued and dashed line).

Large variations in at-satellite reflectance values, especially in TM band 1 suggest that atmospheric effect were both variable and significant. For TM1 it has been occurred an average 12% of the at-satellite reflectance due to atmospheric correction, following by 8%, 6% and 5% for TM2, TM3 and TM4 respectively.



◀ Figure 7. Variation of at-satellite reflectance (%) before and after atmospheric correction.

► Figure 8. Average difference at the at-satellite reflectance atmospheric effect for TM1 –TM4.



Using similar ground measurements, from previous studies, which were acquired from the GER1500 field spectro-radiometer a comparison was made between the at-satellite reflectance values and the associated ground reflectance values. The atmospheric corrected image data show good agreement with the ground data.

From the time-series Landsat TM images, the average values of the at-satellite reflectances (%) were calculated for an area of interest which consists also the archaeological site of Nea Paphos and other nearby landscape (e.g. vegetation, dark surfaces etc). Large variations in at-satellite reflectance values, especially in TM band, 4 suggest that atmospheric effect were both variable and significant. By comparing the average at-satellite reflectance in the image time series with the ground measurements, an approximate estimate of the magnitude of atmospheric effects was found. Atmospheric effects were found to account for the following % of the received at-satellite reflectance:

- 80-90 % in TM band 1,
- 40-70 % in TM band 2,
- 50-80 % in TM band 3,
- 90-95 % in TM band 4.

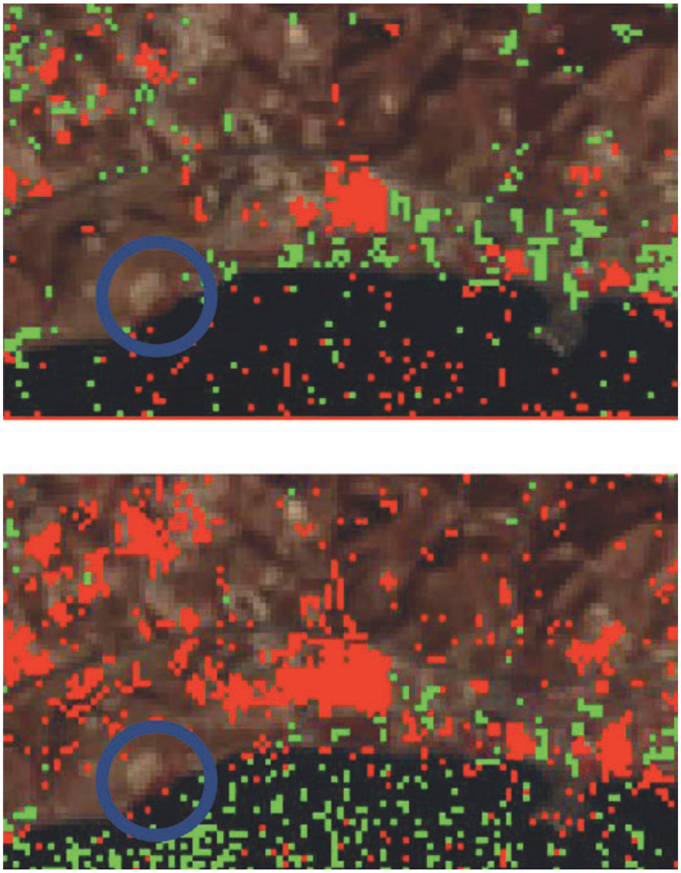
4.6. NDVI Results for the Amathus Archaeological Site Area

In order to detect any changes regarding vegetation which occurred in the last years at the surrounding area of the archaeological site of Amathous (at a distance of 5Km from the archaeological site of Amathous) an NDVI algorithm was applied for the Landsat 7 ETM+ images.

The results found are presented at the following table. Of course, vegetation indices are related with the climate of the region. Although as it was found a significant decreased of the NDVI was detected at the north and east of the archaeological site. This can be seen as a first warning for the surrounding area of the site. During this period, it has been recorded a residential development at the area. At the south of the site, in the sea, an increased of the NDVI was found, which may be caused by algae.

Landsat images	Increased NDVI (in hectares)	Decreased NDVI (in hectares)
19/12/08 - 17/11/08	37.17	10.35
17/11/08 - 01/11/08	11.79	10.53
01/11/08 - 16/10/08	11.16	466.02
16/10/08 - 30/09/08	260.19	0
30/09/08 - 14/09/08	0	31.41
14/09/08 - 28/07/08	7.02	1.35
28/07/08 – 05/10/04	35.91	1.8
05/10/04 - 19/09/04	0.63	0.18
19/09/04 - 30/05/04	10.13	0
30/05/04 - 14/05/04	0	4.5
14/05/04 - 28/04/04	10.53	2716.2
28/04/04 - 12/04/04	4.23	517.59
12/04/04 - 20/11/03	1922.13	0

◀ **Table 2. Change detection of the NDVI at the surrounding of the archaeological site.**



◀ Figure 9. Difference at NDVI values, between 2004 and 2008. Red colour represents a 20% decreased of the NDVI and green colour 20% increase (before and after atmospheric correction).

► Figure 10. Unsupervised classified-5 classes IKONOS pan-sharpened 1m high-resolution satellite image of Katos Paphos archaeological site acquired on 14th of March 2000.

4.7. Classification, Image Extraction Image Subtraction for the Nea Paphos Archaeological Site Area

Unsupervised classification has been applied to Ikonos and Landsat TM image of the Nea Paphos site area and the results are shown in Figure 10.

Further to the application of the change detection algorithms, the processing was carried out using Principle Component Analysis (PCA) (see Figure 11), Tasseled Cap Transformation (TCT), Decorrelation Stretch (DS) and RGB colour composites (Mather, 2001) for site extraction.

5. RESULTS

Upon completion of the image processing, as expected, the best results came from transformations in which the near infrared band plays a primary role, especially in NDVI, Principal Component Analysis, brightness and Wetness Transformation and relative colour composites. In our study, we concluded that bands green, red and near infrared, show the most potential for the identification of archaeological features. Red and near infrared images are less affected by haze and provide good definition for soil marks and crop marks. Despite these promising early results the true potential of this type of imagery is still not fully clear and needs to be further evaluated to test its responsiveness under a broad range of environmental conditions.

By applying the change detection techniques, it has been found that in the nearby area of the Kato Paphos archaeological site area, a 20% difference in the landscape has been occurred (Figure 10). By comparing the results obtained between supervised and unsupervised classification results for the high-resolution satellite images based on the use of the in-situ spectral signatures, it has been found that in the green and red bands the difference between the two methods on the % measured land in each class was 10%.

◀ Figure 11. Principal Component Analysis: Quickbird- 0.6m resolution image of Kato Paphos Paphos archaeological area acquired on 23-12-2003.

◀ Figure 12. Image-Subtraction of Landsat TM images: 2000-1985.

6. CONCLUSIONS

It has been shown that the integration of both post-processing techniques with the in-situ spectroradiometric measurements can improve the effectiveness of such methods especially for monitoring landscape changes in the vicinity of archeological sites.

An overview of the magnitude of the atmospheric effects in satellite imagery of cultural heritage sites in Cyprus have been presented by comparing at-satellite values with ground measurements. It can be seen from the use of NIR band that atmospheric affects can be both large and variable for the archaeological site landscapes that consists vegetation and dark targets. It is therefore essential that they are taken into account before attempts are made to ground conditions on the basis of multi-spectral reflectance values.

NDVI application to time series images show that such algorithm can present the 'landscape' changes associated with vegetation impact changes in nearby the archaeological site area.

We concluded that bands green, red and near infrared, show the most potential for the identification of archaeological features.

By applying the change detection techniques, it has been found that, in the nearby area of the Kato Paphos archaeological site area, a 20% difference in the landscape has been occurred.

Future work consists of further validation and assessment of every post-processing algorithm for such task in conjunction with simultaneous measurements of the following: image overpass, spectral signature measurement and atmospheric conditions measurements.

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