Contribution of Satellite imagery and DEMs to the Detection of Neolithic Settlements in Thessaly, Greece

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ABSTRACT: Thessaly is a region of low relief in Greece where hundreds of Neolithic settlements/tells called magoules were established from Early Neolithic period until Bronze Age. Multi sensor remote sensing was applied to the study area in order to evaluate its potential to detect Neolithic settlements.

Moreover, different kinds of digital elevation models were used such as SRTM, DEM constructed by interpolation of contours from topographic maps, DEM constructed by aerial photos and DEM constructed by Aster images, where tells can be identified as small contrasting spots within the elevation pattern of the natural variation of the land surface.

A range of image processing techniques such as colour composite, principal components analysis, decorrelation stretch, followed by visual interpretation, were originally applied to the hyperspectral imagery in order to detect the settlements and validate the results of GPS surveying. The next step was to collect spectral signatures of these tell sites, to correlate them within the same spectral range of the different sensor systems and finally to proceed with their statistic analysis. Various filters were applied to all images to explore the high spectral and spatial variability of the settlement patterns, such as Sobel 3*3 right diagonal and Laplace filter. Classification of all the images using different hard and soft classifiers and application of vegetation index NDVI was followed. To cope with the difficulties of pixel based methods, object–oriented classification techniques were also applied to Ikonos imagery to classify tells according to their shape and geometry.

In addition, sophisticated filters were applied to each DEM in order to detect the settlements. After validating the results with real altitude data, we concluded which of them are more reliable either for general topographic studies of the area or more specifically for the detection of the settlements. The final step was the application of fuzzy algorithms for the classification of the possibility of settlement existence.

Although there are specific difficulties encountered in the classification of archaeological features composed by a similar parent material with the surrounding landscape, the results of the research suggested a different response of each sensor to the detection of the Neolithic settlements, according to its spectral and spatial resolution. Moreover, the integrated use of remote sensing imagery and the digital elevation models produced an important enhancement to the design of a predictive model of the Neolithic settlements of Thessaly by combining the spectral, spatial and topographic attributes of the tells.

1 INTRODUCTION

The spectral capability of early satellite sensors opened new perspectives in the field of archaeological research. The recent availability of hyperspectral and multispectral satellite imageries has established a valid and low cost alternative to aerial imagery in the field of archaeological remote sensing. The high spatial resolution and spectral capability can make the VHR satellite images a valuable data source for archaeological investigations ranging from synoptic view to small details (Masini and Lasaponara, 2007). In this study the satellite data have been statistically analysed together with other environmental parameters to examine any kind of correlation between environmental, archaeological and satellite data.

2 RESEARCH METHODS AND MATERIALS

The study involved satellite image detection of Neolithic Settlements in Thessaly by incorporating the following satellite and digital spatial data: 4 ASTER images, 1 LANDSAT ETM image, 1 HYPERION image, 4 IKONOS images, 5 airphotos, GPS surveying measurements of more than 342 Neolithic settlements of Thessaly and a digitized DEM of 20 m pixel size of the study area.

3 SATELLITE IMAGE PROCESSING

The image processing of satellite data was carried out in two steps. Initially, we started with the preprocessing procedures and then we continued with the main image processing steps.

3.1 *Preprocessing of Satellite images*

Before starting the image processing we masked the sea, the clouds and the snow areas of all the images. Then we proceeded to the construction of image mosaics and transformation of the projection systems to a common projection system (EGSA87/HGSR87). In the end, the DN values of the images were converted to reflectance values.

3.2 *Composition of RGB composites*

Several RGB composites were constructed in an effort to examine their efficiency in the detection of the Neolithic settlements. For the ASTER image with acquisition date 19-03-2003, where most of the magoulas are registered, the RGB→1,2,3, RGB→3,2,5 and RGB→2,3,7 composites have been the most successful for the detection of the Neolithic settlements (39 out of 239 settlements were highly visible, 49 average visible and 151 poorly visible). Similarly, RGB composites of IKONOS images were able to detect 27 in a total of 48 settlements. It is worth mentioning that 19 of the detectable magoulas, namely the highest of all corresponding to an average altitude of 4.6m, were highly visible in all RGB composites. On the other hand, RGB composites of Landsat and HYPERION images were not very promising (for HYPERION composites only 5 settlements were detected in a total of 21). Finally, average altitude aerial images contributed to an excellent detection of all the 5 settlements that were inside the spatial limits of the airphoto mosaic. As a general conclusion however, the most crucial factors for the detection of magoules proved to be the acquisition date of the image due to the fact that the terrain of the majority of the settlements is cultivated (mainly soft/shallow cultivation).

3.3 *Spectral Profile Comparison and Classification*

The identification of spectral signatures was considered to be a crucial task for the detection of Neolithic settlements especially for the classification process. Signatures were collected from all the tells and were divided in to two categories: Those collected from plain areas and those collected from mountainous areas due to different soil cover.

3.4 *Principal Component Analysis*

We applied PCA to ASTER, Landsat and Hyperion Images. PCA of ASTER images provided the best results where 39 settlements were highly discriminated and 47 medium discriminated in a total of 247.

3.5 *Image Fusion*

Image fusion is a standard satellite image procedure of combining images of different spatial resolution to obtain a single final composite image. Various fusion combinations were tried, such as ASTER (15 m) visible channels with the PCA product of HYPERION (30m) or the high resolution (1m) bands of IKONOS with the PCA product of HYPERION. The results were highly promising for the cases of fusion between high spatial resolution and high spectral resolution images.

3.6 *Spectral Mixer Utility*

In order to exploit the high spectral resolution of HYPERION images, we applied a spectral mixer utility of Erdas Imagine 9.1. Spectral Mixer produces three bands to be assigned to the red, green, and blue color guns, but in this case instead of just assigning each band to a color gun we could select a weighted average of spectral bands to be assigned to a color gun (Erdas Field Guide, 2006). For HYPERION images only the bands that have reflectance values above 0.3 were used and we assigned a weighting coefficient of 0.14 for each band. The new RGB that was created (RGB1) employed the mixing of the bands (38, 42, 48, 49, 50, 51, 52), (85, 86, 87, 88, 89, 90, 91, 92,) & (93, 94, 108, 109, 110, 111, 113, 114).

3.7 *Radiometric Enhancement*

Radiometric enhancement was vital for the appearance of the images. After applying radiometric enhancement to ASTER images (acquisition date of 19-03-2003) we managed to detect 57 settlements. A non-linear radiometric enhancement of the HYPERION PCA image, followed by an inversion of brightness was able to highlight 8 settlements from a total of 9. Similar type of non-linear radiometric enhancement of the high resolution Ikonos images through the modification of the histogram was able to outline the round shape of known magoules, as well as to identify 10 more targets of similar geometry that need to be verified by the ground truthing activities that will follow (Fig 1).

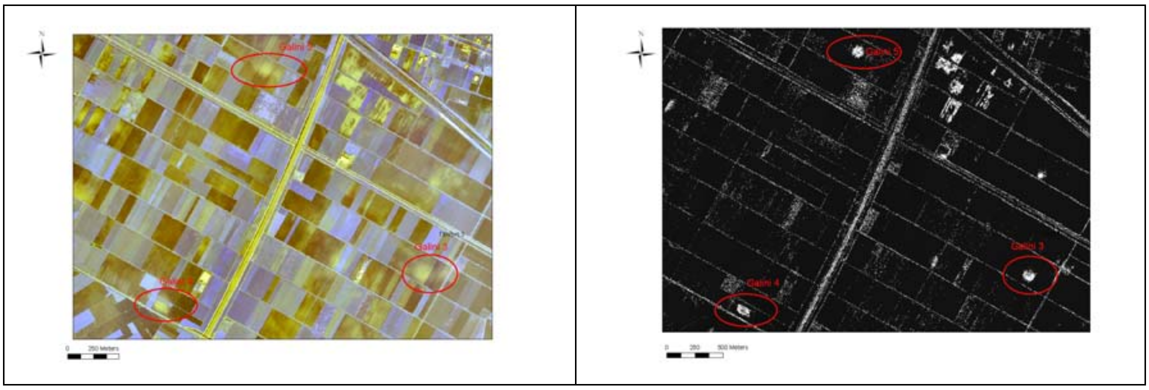

Fig. 1. Appearance of 3 settlements in the original IKONOS image (left) and the radiometrically enhanced image where three Neolithic settlements are highlighted (right). To the north of Galini-3 settlement, shown at the lower right of the image), another smaller potential magoula is suggested.

3.8 *Land Classification and Vegetation Indices*

In the domain of predictive modeling, the specification of the environmental attributes that correlate to the location of the archaeological sites is of importance. For this reason, in order to investigate the regime of the land use surrounding the magoules, several methods of supervised classification were applied to Landsat and ASTER images. Mahalanobis classification proved to be the most efficient one in terms of the overall accuracy assessment compared to all the classification algorithms that were applied (8 in total). The Normalised Difference Vegetation Index (NDVI) was computed to analyse the difference of vegetation during various acquisition dates. As expected, the NDVI of the spring ASTER image was higher than the summer Landsat image.

3.9 *De-correlation Stretch*

The de-correlation stretch is a process that is used to enhance (stretch) the color differences found in the input pixels. After we applied de-correlation stretch to the ASTER images, we managed not only to detect easily 36 Neolithic settlements, but also to obtain estimates of their extent.

3.10 *Spatial Enhancement*

Spatial enhancement of images is considered to be a standard satellite image enhancement. Of the several types of filters that were applied in the specific study, only two of them, Sobel Right Diagonal 3x3 and Laplace 3x3, proved to be very useful for the detection of Neolithic settlements (Fig 2).

3.11 *Predictive Modeling*

The results of land use classification, NDVI estimates and those from the spectral signatures and classification of the ASTER image (acquisition date 19-03-2003) were combined together with a DEM constructed by digitization of 1:50.000 scale topographic maps. All data were reclassified and a certain weight factor was applied to each of the raster layers. After constructing the final map we estimated that 92 of the known settlements are laid on areas of high probability and 23 in areas of medium probability.

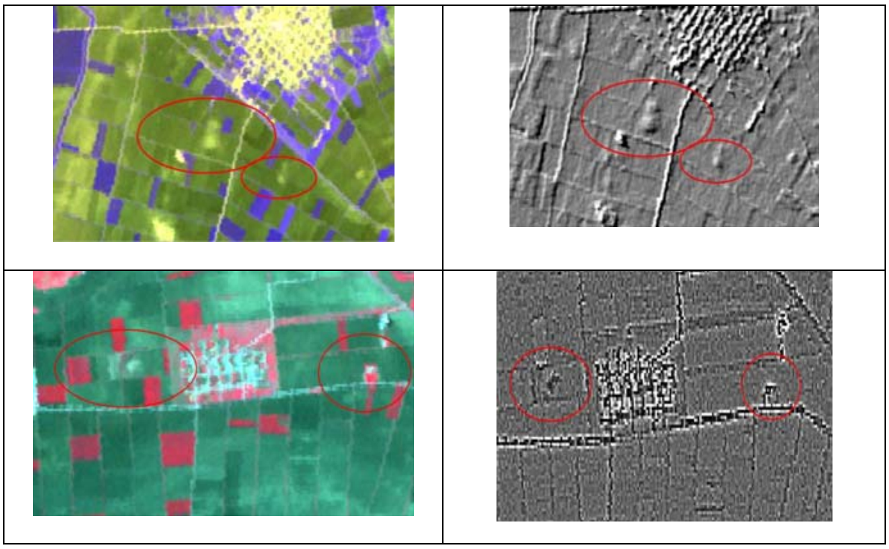

Fig 2. Original ASTER image (RGB→ 1,2,3) around Halki area (Top Left) and the corresponding image after the application of Sobel Right Diagonal filter (Top Right). Original ASTER image (RGB→ 1,2,3) around the settlements of Elliniko 1 and Elliniko 2 (Bottom Left) and the corresponding image after the application of Laplace Filter (Bottom Right)

4 APPLICATION OF SOPHISTICATED FILTERS TO DEM.

The study involved detection of Neolithic Settlements through the use of Digital Elevation Models (DEM). For this purpose we used three different kinds of DEM: SRTM DEM of 90 m pixel size, ASTER DEM of 30 m pixel size and the DEM from digitized contours of 20 m pixel size.

For the detection of the Neolithic settlements we used three different methodologies to the above DEMs. The first methodology involved the estimation of the index of convexity according to Fry et al (2004). The second methodology had to do with the creation and application of customized filters similar to those used by Menze et al (2006). The third methodology followed the approach of Iwahashi and Kamiya (1995) for the estimation of geometric signatures of DEM which involved the integrated study of slope gradient, surface convexity and texture of the study area. To the final results of the filtered DEM, algorithms of fuzzy logic were applied in order to obtain better classification results.

5 CONCLUSIONS

ASTER images proved to be the most reliable and efficient for the detection of Neolithic settlements. In contrast, Landsat images did not produced satisfactory results, mainly due to the summer acquisition date of it. The high spectral abilities of HYPERION, especially after merging it with the high resolution images of Ikonos, seem to have an increased potential not only for detecting but also for outlining the particular features. The image processes that proved to be more effective were the spatial filtering, the process of de-correlation stretch and the radiometric enhancement. In addition the results of the analysis of DEMs, especially the application of the three different filters to SRTM DEM, proved to be very promising.

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