Prospects and Limitations of Vegetation Indices in Archeological Research: The Neolithic Thessaly Case Study

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ABSTRACT

Vegetation indices have been widely used for the detection of archaeological traces, based on crop marks, during different phenological stages. Such indices can be used in order to enhance interpretation performance of multispectral and hyperspectral satellite data, for identification of buried archeological remains. Although a variety of indices exists in the literature, research is still limited and only a small group of these indices have been explored. This paper aims to highlight the prospects as well the limitations of several broadband vegetation indices for the detection of Neolithic tells in the Thessalian plain (Greece). Several multispectral Landsat 5 TM and Landsat 7 ETM+ satellite images have been used for evaluating the effectiveness of such indices. In addition, new developed algorithms and hyperspectral narrowband indices, specially designed for archaeological research, have been also used and compared using hyperspectral satellite data (EO-Hyperion). Indeed, the Normalized Archaeological Vegetation Index (NAVI) as well as a linear transformation of the Landsat 5 TM were applied to satellite data. The above were also compared to other processing algorithms such as Tasseled – Cap algorithm and Principal Component Analysis. The results have shown that several indices and new algorithms may be used for the enhancement of crop marks, while some no-widely used indices can be successfully used for archaeological purposes.

Keywords: remote sensing archaeology, vegetation index, archaeological crop mark, Archaeological Index, linear transformation

1. INTRODUCTION

Since the beginning of the 20th century, aerial photography has been used in archaeology primarily to observe landscapes which are difficult if not impossible to visualize from ground level [1]. As [2] argue, the application of Earth Observation (EO) techniques has exhibited great potential for archaeological investigations, even if in an experimental stage. It has accounted for a number of important archaeological discoveries and has provided manifold capabilities starting from the detection of cultural features through archaeological prospecting in regional surveys, to palaeo-ecosystem studies and paleo-landscape reconstructions. Indeed, many studies have shown that satellite images of medium or high spatial resolution can be used for the detection of buried archaeological studies [3-5]. However, as [6] mention, although a number of different satellite sensors have been employed in a variety of archaeological applications spanning the identification of spectral signatures within archaeological sites, such techniques have their merits and their disadvantages.

Vegetation indices are widely used for the detection of buried archaeological remains. However, as literature review has shown, only a small number of existing indices are applied to archeological research. As [7] have recently demonstrated, more than 70 vegetation indices exist, ranging from the visible to the near infrared part of the spectrum. The outcomes of this study have shown that different indices, can be successfully applied for archaeological research. Thus, some not widely indices tend to give better results compared to other traditional indices (e.g. NDVI). In addition, a hyperspectral archaeological index, for the enhancement of crop marks has been also reported [8]. This index is able to distinguish crop marks which are related with buried archaeological remains using the 700nm and 800nm wavelengths.

This paper aims to apply and quantify different existing broadband indices for the detection of archaeological remains. For this purpose more than 15 different indices have been applied in 5 multi-temporal medium resolution satellite images

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in the Thessalian plain (central Greece). In addition, other known image analysis has been carried out using Hyperion data.

2. METHDOLOGY AND RESOURCES

Numerous studies in the past have considered using remote sensing data to detect potential archaeological remains. Recent studies make use of remote sensing data and vegetation indices, supporting for the detection of subsurface archaeological remains. Although vegetation indices provide valuable information on archaeological exploration, it is critical to estimate their accuracy and their performance. This paper presents the results for the detection of a Neolithic settlement ("*Almyros II"*), located in the Thessalian plain, central Greece. In this study 15 multispectral vegetation indices (see Table 1) have been applied and evaluated for their ability to detect subsurface archaeological remains on land covered by vegetation.

Table 1: Vegetation indices used in this study [7]

no	Vegetation Index	Equation
1	EVI (Enhanced Vegetation Index)	$2.5\ (p_{NIR} - p_{red})\ /\ (p_{NIR} + 6\ p_{red} - 7.5\ p_{blue} + 1)$
2	Green NDVI (Green Normalized Difference Vegetation Index)	$(p_{NIR} - p_{green})/(\ p_{NIR} + p_{green})$
3	NDVI (Normalized Difference Vegetation Index)	$(p_{NIR} - p_{red})\ /\ (p_{NIR} + p_{red})$
4	SR (Simple Ratio)	$p_{NIR}\ /\ p_{red}$
5	MSR (Modified Simple Ratio)	$p_{red}\ /\ (p_{NIR}\ /\ p_{red} + 1)^{0.5}$
6	MTVI2 (Modified Triangular Vegetation Index)	$[1.5(1.2^*(\ p_{NIR} - p_{green})-2.5(p_{Red} - p_{green})]\ /\ [(2\ p_{NIR}+1)^2 - (6\ p_{NIR} - 5\ p_{Red}{}^{0.5})-0.5]^{0.5}$
7	RDVI (Renormalized Difference Vegetation Index)	$(p_{NIR} - p_{red})\ /\ (p_{NIR} + p_{red})^{1/2}$
8	IRG (Red Green Ratio Index)	$p_{Red} - p_{green}$
9	RVI (Ratio Vegetation Index)	$p_{red}\ /\ p_{NIR}$
10	MSAVI (Modified Soil Adjusted Vegetation Index)	$[2\ p_{NIR}+1-[(2\ p_{NIR}+1)^2-8(p_{NIR} - p_{red})]^{1/2}]/\ 2$
11	ARVI (Atmospherically Resistant Vegetation Index)	$(p_{NIR} - p_{rb})/(\ p_{NIR} + p_{rb})$, $p_{rb} = p_{red} - \gamma\ (p_{blue} - p_{red})$
12	GEMI (Global Environment Monitoring Index)	$n(1-0.25n)(\ p_{red} -0.125)/(1- p_{red}\ )$ $n = [2(p_{NIR}{}^2 - p_{red}{}^2)+1.5\ p_{NIR}+0.5\ p_{red}]\ /\ (p_{NIR} + p_{red} + 0.5)$
13	OSAVI (Optimized Soil Adjusted Vegetation Index)	$(p_{NIR} - p_{red})\ /\ (p_{NIR} + p_{red} + 0.16)$
14	DVI (Difference Vegetation Index)	$p_{NIR} - p_{red}$
15	SR × NDVI (Simple Ratio x Normalized Difference Vegetation Index	$(p_{NIR}{}^2 - p_{red})\ /\ (p_{NIR} + p_{red}{}^2)$

Five multispectral satellite images of Landsat 5 TM and Landsat 7 ETM+ have been used (image overpass: 26/07/2007; 15/07/2009; 24/07/2009; 31/07/2009; 20/09/2010). The results were based on reflectance values, after the necessary atmospheric and radiometric corrections of all images. The final results are presented through tables and diagrams. In detail the darkest pixel method was applied to satellite images. As [9] have shown, this method is very simple to be applied for archaeological research since it requires no axillary data. Therefore, archive images can be also atmospheric corrected. In these way all multispectral dataset is radiometric calibrated.

3. CASE STUDY AREA

The Thessalian region is located in north Greece and is considered as the primary agricultural area of Greece. At this plain many of Neolithic settlements/tells called magoules were established from the Early Neolithic period until the Bronze Age (6,000 – 3,000 BC). The magoules are typically low hills of 1–5 meters height above the surrounding area and they mainly consist of loam and mud based materials. Hundreds of magoules are located all over Thessaly and can be found within different kinds of vegetation. Due to the intensive cultivation of the land in the past and their low elevation, a major number of them are not clearly visible from the ground [5; 10].

The area of Thessaly is ideal for the detection of possible crop marks related to archaeological sites using remote sensing techniques and spectroradiometric measurements due to the presence of barley and wheat crops cultivated over known archaeological sites. These crops eliminate the error of the background soil (for example, in Vegetation Indices) since they are characterized by a high Leaf Area Index (over 3) [7].

Researchers have recently examined the area using multi-spectral and hyper-spectral images [5;7;10-11]. Different algorithms were evaluated for their accuracy while filters for the detection of magoules from various Digital Elevation Models were examined. These studies reached the conclusion that magoules can be detected using the at-satellite reflectance during specific periods of time. *Almyros II* site (Figure 1) revealed a high density of ceramics at the top of the magoula (≈10 ceramics/m^2) based on foot surveys.

Figure 1: *Almyros II*, case study area in the Thessalian plain, central Greece (left) and a photo from the site (right)

4. RESULTS

4.1 Vegetation Profiles

Vegetation profiles for the Neolithic tell *Almyros II* were created in order to examine if the tell tends to give a different spectral profile compared to the surrounding cultivated area. In Figures 2 and 3, the results from two satellite images are shown (image overpass: 26/07/2007 and 15/07/2009). Similar outcomes (not shown here) have also been recorded for the rest of the satellite dataset. As recorded, a decrease of the reflectance at all bands (visible and VNIR) is observed in the top of the tell (located in around 70-90 m in the X-axes of the diagrams.). Several vegetation profiles can identify this difference observed between the *Almyros II* and the surrounding area. Such differences were also reported in [10]. Both images tend to give similar results, although some differences are also observed (e.g. OSAVI index). It is also noticeable that vegetation indices tend to give different patterns along the section that passes through the tell. Such differences were expected since many VIs are developed, in order to enhance specific vegetation biophysical parameters, or to minimize~~d~~ external factors affecting canopy reflectance [7;12].

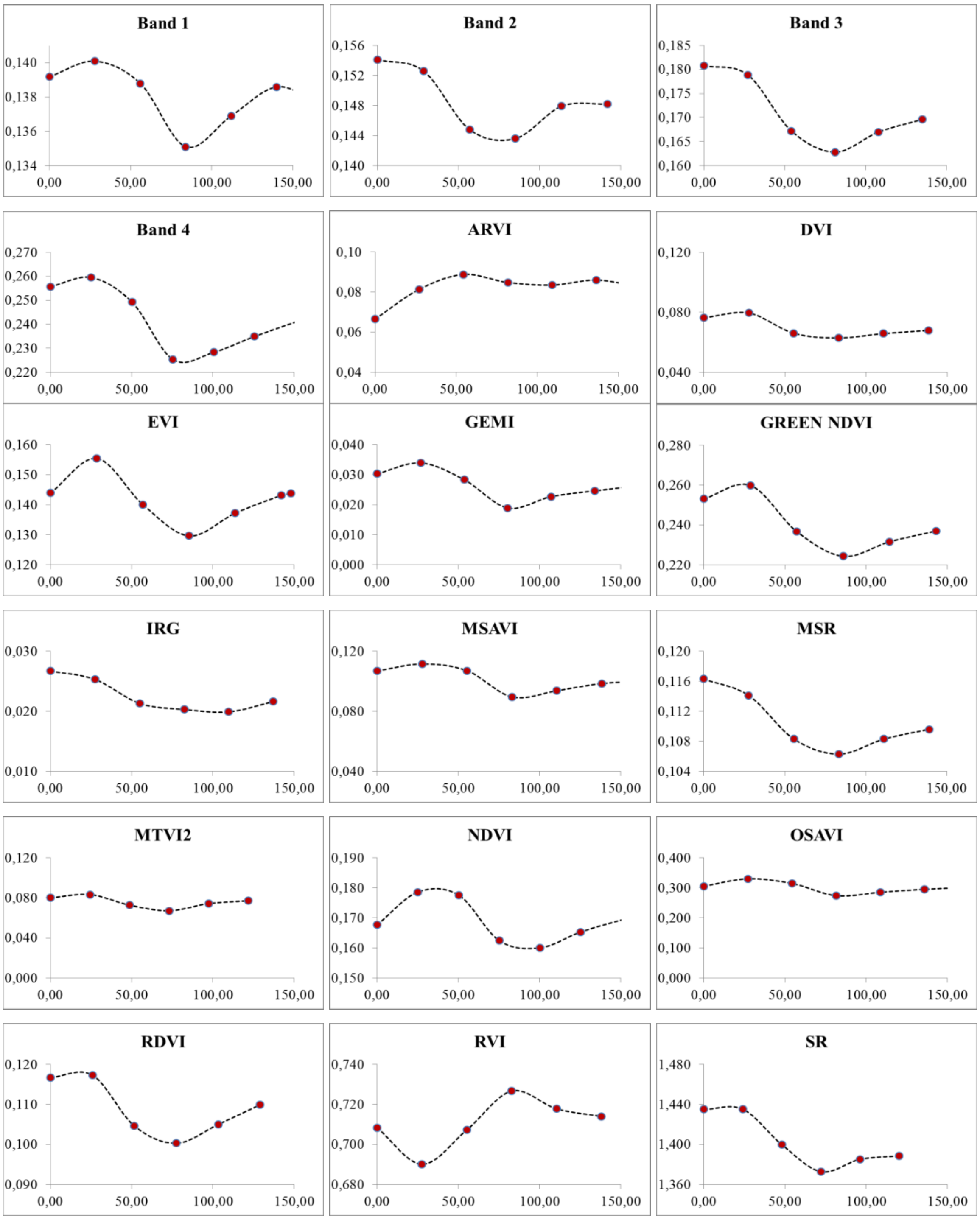

Figure 2: Vegetation profiles over the Almyros II site (Image:26/07/2007)

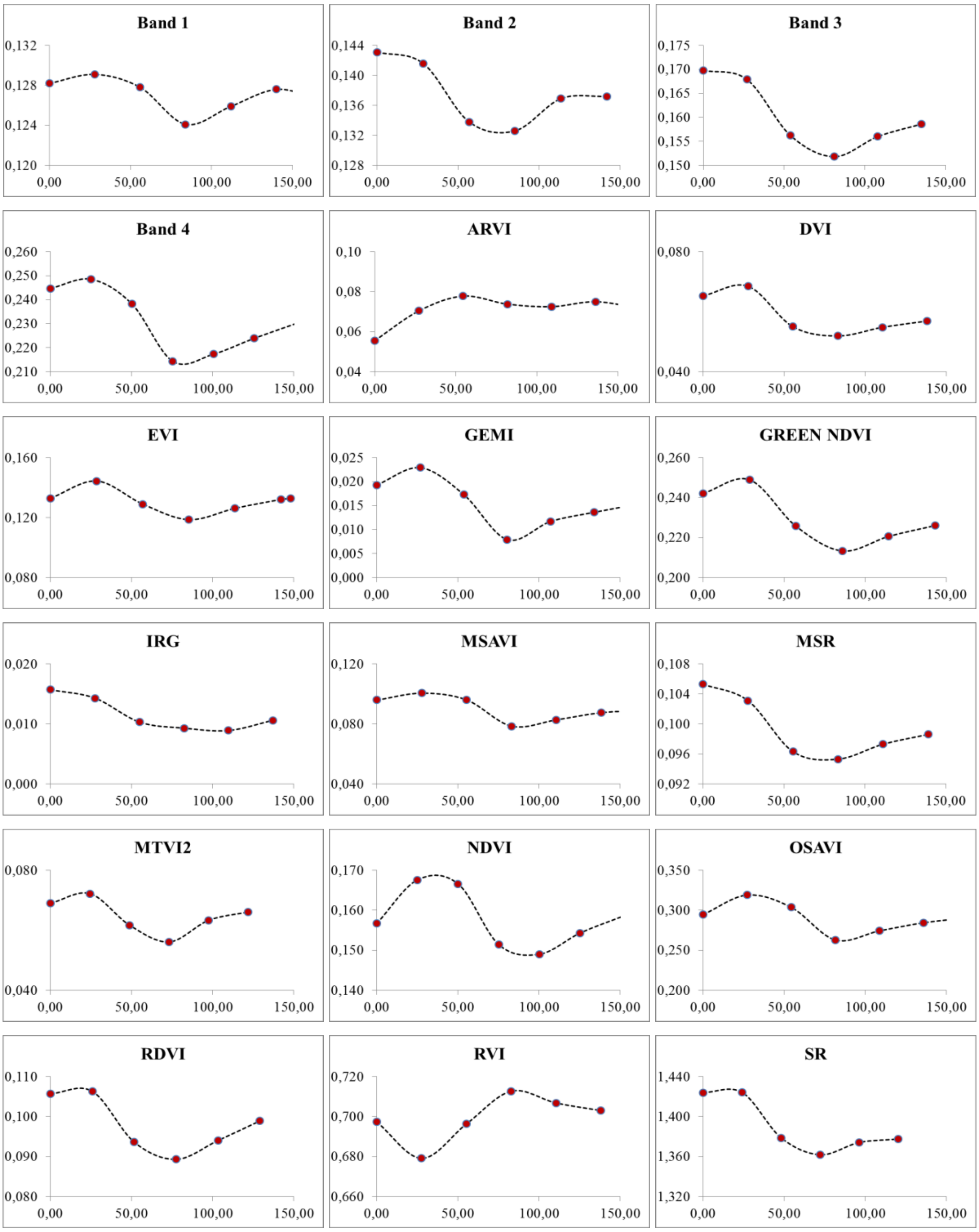

Figure 3: Vegetation profiles over the Almyros II site (image:15/07/2009)

In an effort to quantify these changes observed between the archaeological site and the surrounding area, regions of interest near and on the top of the tell were analyzed. Figure 4, presents the relative difference between these areas. All indices mentioned in Table 1 have been able to distinguish the magoula and its surrounding area. However, the most promising index with more than 25% relative difference was GEMI index for all dataset. In contrast, other indices widely applied (e.g. NDVI) tend to give lower relative difference (less than 10%). MSAVI and OSAVI indices were the next most promising indices compared to the rest examined in this paper. It is also noticeable that these relative differences observed in this study are quite similar with the one performed by [7]. In their study [7], the relative difference for GEMI was estimated up to 42%, while for MSAVI and OSAVI the difference was calculated up to 14% and 19% respectively.

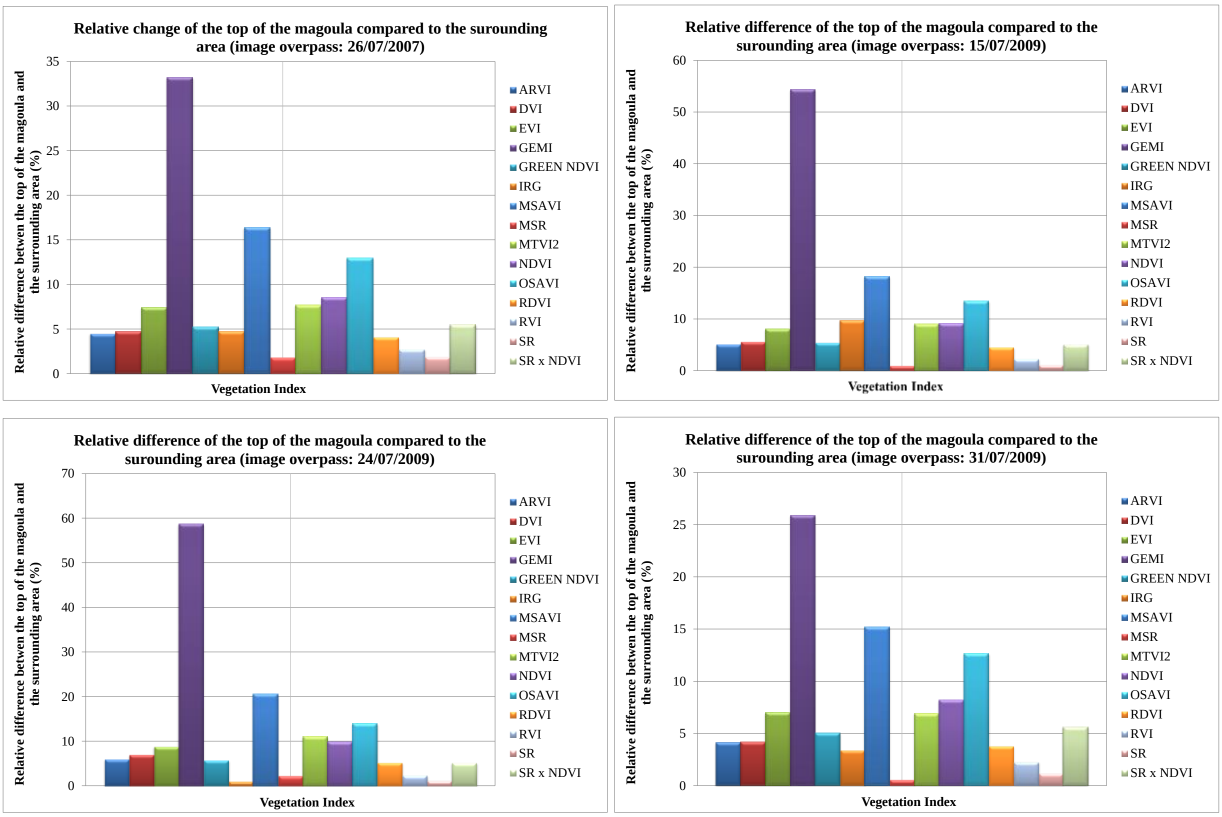

Figure 4: Relative difference of vegetation indices for several satellite images observed between the top of the tell and the surrounding area.

4.3 Image analysis

Vegetation indices were applied to the whole dataset of the Landsat 5 TM and 7 ETM+ images selected in this paper. As shown in Figure 5, spatial resolution can be problematic for the interpretation of the images. However, despite the medium resolution of these images, some interesting crop marks can be found.

Interpretation of *Almyros II* site based on true and false composites (R-G-B; VNIR-R-G) as well as in grayscale band reflectance images, tends to give very poor results.. However, after the application of the vegetation indices (shown in Table 1), a circular crop mark is visible to some images. GEMI index (Figure 5) was found to be the most promising since a circular crop mark is visible despite image's medium resolution. In contrast, NDVI index did not reveal any significant changes of the tell compared to the surrounding area.

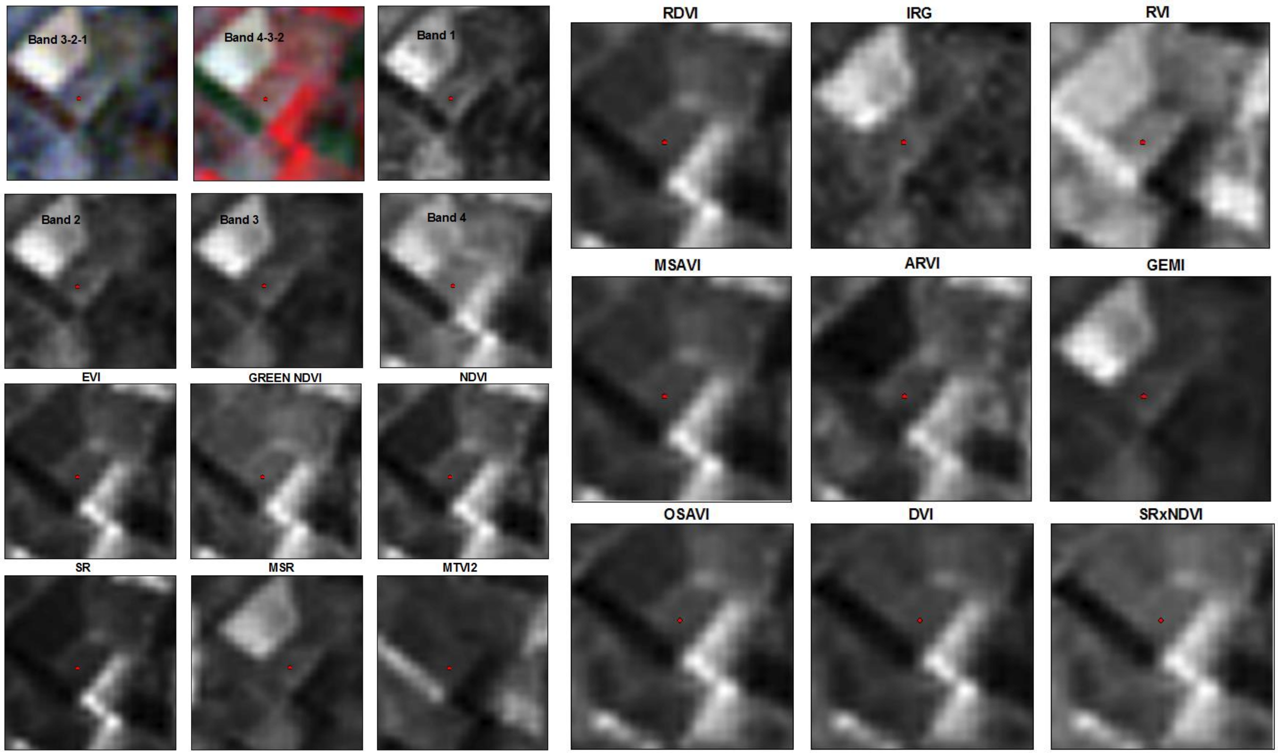

Figure 5: Vegetation indices applied to Landsat image (20/09/2010), over the *Almyros II* site.

In addition to the VIs, several image processing techniques were also applied. Specifically, the Tasseled Cap algorithm and the Principal Component Analysis were applied to the dataset. Tasseled Cap transformation is used to enhance spectral information for Landsat images and it was specially developed for vegetation studies. The first three bands of the Tasseled Cap algorithm result are characterized as follow [13]: Band 1: brightness (measure of soil); Band 2: greenness (measure of vegetation) and Band 3: wetness (interrelationship of soil and canopy moisture). In detail the Tasseled Cap algorithm is a linear combination of the initials bands of the Landsat image. The first three parameters of the T-K are calculated as shown in Eq. 1-3:

Brightness = 0.3037(TM1) + 0.2793(TM2) + .4743(TM3) + 0.5585(TM4) + 0.5082(TM5) + 0.1863(TM7) (Eq. 1)

Greenness = -0.2848(TM1) - 0.2435(TM2) - 0.5436(TM3) + 0.7243(TM4) + 0.0840(TM5) - 0.1800(TM7) (Eq. 2)

Wetness = 0.1509(TM1) + 0.1973(TM2) + 0.3279(TM3) + 0.3406(TM4) - 0.7112(TM5) - 0.4572(TM7) (Eq. 3)

Principal Component Analysis (PCA) is a well-known linear transformation where the image information is re-projected into a new n-dimensional space of linearly uncorrelated variables. The first PCA component has the largest possible variance of the overall data, and each succeeding component (i.e. PCA2; PCA3 etc) has the highest variance possible under the constraint that it is orthogonal.

Further to the above, the Normalized Archaeological Vegetation Index (NAVI) was also applied [8;14]. This index, as proposed by [8;14] aims to enhance the archaeological crop marks using hyperspectral images. The reflectance values at around 700nm and 800nm are used, since, as it was found, in these regions the difference between vegetated areas and areas with archaeological interest (i.e. crop marks) is maximized. The NAVI is given in equation 4. Finally, linear transformations of the Landsat 5 images using the first four bands of the images (visible – VNIR bands) were also applied as shown in [15]. These equations aim to re-project the initial bands to three new un-correlated axes related with vegetation; soil and crop marks. These transformations are shown in equation 5-7

$$NAVI = (\rho_{800}-\rho_{700}) / (\rho_{700}+\rho_{800}) \qquad \text{(Eq. 4)}$$

$Vegetation = -0.04* \rho_{Band\ 1TM} + 0.02*\rho_{Band\ 2TM} -0.04*\rho_{Band\ 3TM} +1.00*\rho_{Band\ 4TM}$ (Eq. 5)

$Soil = -0.47* \rho_{Band\ 1TM} - 0.67*\rho_{Band\ 2TM} -0.57*\rho_{Band\ 3TM} -0.03*\rho_{Band\ 4TM}$ (Eq. 6)

$Crop\ mark = 0.19* \rho_{Band\ 1TM} + 0.56*\rho_{Band\ 2TM} -0.81*\rho_{Band\ 3TM} -0.04*\rho_{Band\ 4TM}$ (Eq. 7)

Results from the above analysis area are shown in Figures 6 and 7. The *Almyros II* site is able to be detected both in T-K algorithm, at the brightness component (Figure 6; a) as well as with the vegetation component (Figure 6; f) of the linear transformation. The latest seems to be able to enhance better the archaeological site from the surrounding area. Since Hyperion images were not obtained over the *Almyros II* site, another two interesting crop marks were evaluated using the NAVI and Hyperion images. These sites are *Stavros 2* and *Stavros 3* located northern to *Almyros II* site. As shown in Figure 7, both tells were able to be detected after the NAVI application.

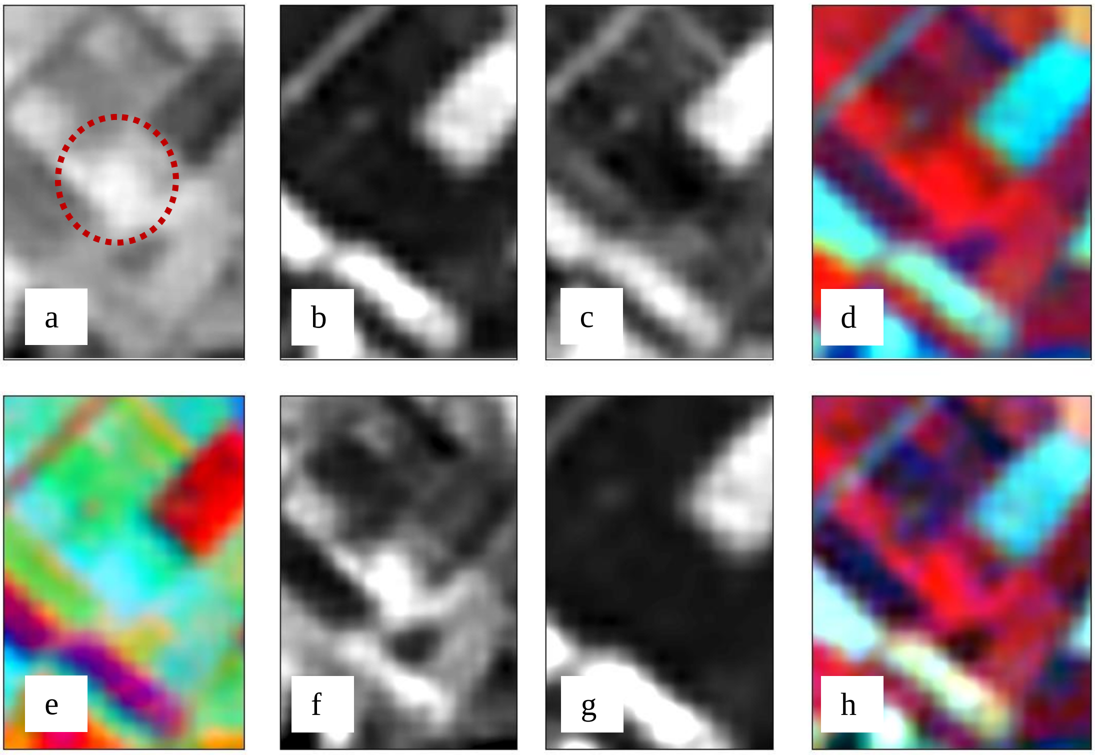

Figure 6: Above: Tasseled Cap results for *Almyros II site* (a) Brightness, (b) greenness, (c) wetness and (d) RGB of the first three components of the T-K algorithm. Below: PCA false composite (e); vegetation and soil composite (f and g respectively) and false composite of the linear transformation (h).

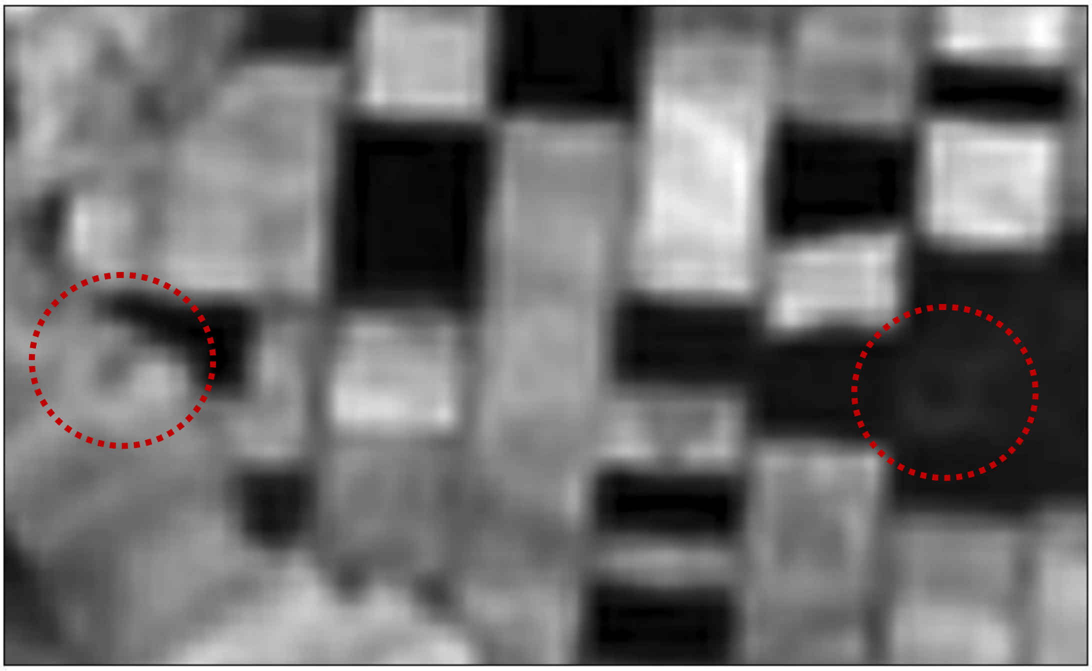

Figure 7: The Stavros 2 and Stavros 3 tells as shown in the Hyperion images after the NAVI application

5. DISCUSSION

Remote sensing has made a great contribution to archaeological research. The detection of buried archaeological features has been successfully applied using a variety of data and algorithms. However, regarding the vegetation indices only a small number have been evaluated and quantified. In this paper more than 15 vegetation indices have been applied to a buried Neolithic settlement in the Thessalian plain. Quantifications of the results have revealed that NDVI index can be problematic for the detection of the magoula, compared to other indices. The results have shown that many indices not widely applied such as GEMI, MSAVI and OSAVI can be efficiently used for the detection of Neolithic settlements.

Sections over the *Almyros II* site have also revealed very interesting results. A small decrease or increase of the index value was noticeable at the top of the magoula compared to the surrounding area. Further to vegetation indices, other existing algorithms were also applied. PCA and T-K algorithm show that may be used for archaeological purposes. However, the use of equations intended for the detection of buried archaeological features, such as NAVI index or the 3D-linear transformation may enhance better the interpretation of the image.

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