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Detecting Underground Military Structures Using Field Spectroscopy

George Melillos, Kyriacos Themistocleous, Athos Agapiou, Silas Michaelides and Diofantos Hadjimitsis

Abstract

Satellite remote sensing is considered as an increasingly important technology for detecting underground structures. It can be applied to a wide range of applications, as shown by various researchers. However, there is a great need to integrate information from a variety of sources, sent at different times and of different qualities using remote sensing tools. A SVC-HR1024 field spectroradiometer could be used, and in-band reflectance's are determined for medium- and high-resolution satellite sensors, including Landsat. Areas covered by natural soil where underground structures are present or absent can easily be detected, as a result of the change in the spectral signature of the vegetation throughout the phenological stages; in this respect, vegetation indices (VIs) such as the normalized difference vegetation index (NDVI), simple ratio (SR), and enhanced vegetation index (EVI) may be used for this purpose. Notably, the SR vegetation index is useful for determining areas where military underground structures are present.

Keywords: spectroscopy, military underground structures, vegetation indices, Landsat

1. Introduction

For decades, research on the detection of buried targets has led to the development of a variety of techniques for identifying buried structures [1, 2]. These techniques use a variety of geophysical instruments [3–6] that involve the use of ground-penetrating radar (GPR). Ground-penetrating radar is a sensitive technique for detecting even small changes in the subsurface dielectric constant. Consequently, the images generated by GPR systems contain a great amount of detail, much of it either unwanted or unnecessary for purposes of surveying for underground objects. A major difficulty, therefore, in using GPR for locating an underground structure concerns the present inability in the art to correctly distinguish return signals reflected by an underground object of interest from all of the signals generated by other subsurface features; the latter signals are collectively referred to as clutter [7].

Nowadays, a lot of attention is being paid to the development of new methods and instrumentation for the detection of buried targets. The detection of military underground structures is a major concern for military and national security agencies, as this is evident from the large budget [8] allocated for the detection and monitoring underground structures. National security agencies use human intelligence (HUMINT)

as one of the currently used information collection methods. HUMINT refers to the collection of information by a trained HUMINT collector (military occupational specialty) [8], from people and their associated documents and media sources for the identification of elements, intentions, composition, strength, dispositions, tactics, equipment, personnel, and capabilities. Additionally, technology such as imagery intelligence (IMINT) can also be used for gathering information via satellite and aerial photography. Remote sensing techniques are quick, are easily manageable, and involve a wide variety of techniques where valuable information can be accessed remotely [9, 10].

Buried underground structures are difficult to detect, especially when they are fully covered by soil [11]. It is possible to detect such military underground structures by means of satellite images and aerial photographs. The concern about underground facilities (or “hard and buried” targets) is evident from the establishment of several purpose-dedicated components within various intelligence and defense agencies [12].

Underground structures such as military constructions and archaeological remains can affect their surrounding landscapes in different ways, such as localized soil moisture content and drainage rates [13], soil composition, and vegetation vigor [7]. Vegetation vigor could be observed on the ground as a crop mark, a spot which can be used to indicate the presence of underground structures [14]. Crop marks can be formed both as negative marks above concrete foundations and as positive marks above the damper and more nutritious soil of buried pits and ditches [14].

During the last decade, the improvement of sensor characteristics, such as higher spatial resolution and hyperspectral data, as well as the technological achievements in space technology, offers new opportunities for future applications [15].

Additionally, in some cases, researchers seek not to find the target itself but rather to identify symptoms related to the topography (relief), crop characteristics (crop marks), soil characteristics (soil marks), or even changes in snow cover (snow marks). For instance, archaeological structures buried beneath the soil (i.e., still un-excavated sites) can be detected through remote sensing images as stressed vegetation (crop marks) which can be used as a proxy for the buried archaeological relics. Crop marks may be formed in areas where vegetation grows over near-surface archaeological remains. These features modify the moisture retention compared to the rest of the crop coverage of an area. Depending on the type of the feature, crop vigor may be enhanced or reduced by buried archaeological features [16].

In comparing the two different kinds of marks, the positive crop marks are normally taller with darker green and healthy foliage than the negative crop marks, while negative crop marks tend to be paler green with lighter-colored appearance when monitored from the air [17]. Indeed, spectral remote sensing is widely used in several occasions for the detection of underground structures, such as agricultural remains [18].

In addition, spectral remote sensing for the detection of underground military structures is considered to be very precise in detecting subsurface remains. Different geophysical processing techniques and equipment, such as GPR, magnetometer, and resistivity, are usually integrated to maximize the success rate of uncovering underground remains [19–22]. Moreover, the use of unmanned aerial vehicle (UAV, popularly known as a drone) for environmental remote sensing purposes has increased in recent years. Although the military has used UAVs for defense applications for decades, the scientific environmental sector increasingly takes advantage of the application of UAVs [23].

Also, this chapter investigates the possibility of applying satellite data using Landsat 8 sensor and comparing it with field data in an effort to distinguish between buried structure area (existence of underground structure) and vegetated area (lack of underground structure).

It is noted that in the literature, there is a gap in the monitoring of vegetation over military underground and ground structures throughout the plants' phenological development cycle; this paper aspires to contribute to the filling-in of this gap. Indeed, this chapter aims at presenting the results obtained from ground spectroradiometric campaigns, using an SVC-HR1024 field spectroradiometer, carried out in a specific area in Cyprus. For in situ observations, field spectroradiometric data were collected and analyzed to identify (known) underground structures using the spectral profile of the vegetated surface over the underground target and the surrounding area. Crop marks demonstrate the variations between the presence and the absence of military underground structures. The in situ measurements were resampled to the Landsat 8 sensor using the appropriate relative spectral response (RSR) filters.

2. Materials and methods

This study proposes a methodology for detecting underground targets using remote sensing techniques. The basis of this methodology is the combination of the study of the vegetation phenology as a proxy for buried underground structures of significance to defense. Data acquisitions were used to identify any variations between the area over an underlying structure and over a reference area.

For this study, certain assumptions have been adopted. In the case of this project, phenological field observations were conducted in two test sites from 2016 to 2017 to determine the dates of completion of different phenological phases. For actual defense purposes, the characteristics of the area of interest are often not known. Furthermore, the cultivation of barley in the area is for investigative purposes and part of the experimental work for studying the impact of underlying structures on vegetation. Under real scenarios, different types of vegetation (if any) will be present.

2.1 Study area

The proposed methodology has been applied in Cyprus over a specific geographical area. The area is situated on a hill which provides clear viewing from airborne and spaceborne platforms, making the area ideal for remote sensing applications (**Figure 1**, left). Also, it is located within a fenced, abandoned military area (due to security and confidentiality issues, the specific area cannot be reported herein). The soil type of the area is leptosol which contains small amounts of gravel and with a very shallow depth.



Figure 1.
Overview of the study area (left); an example of a military bunker (right).

Figure 1 (right) shows a military storage bunker similar to the one that is in the focus of this research. The horizontal dimensions of the underground structure are 13 m × 5 m; it is a concrete storage bunker, located ~2 m below the ground surface.

2.2 Methodology

Spectral data are increasingly incorporated into process-based models of the Earth’s surface and the atmosphere. The area of interest was determined first by identifying plots with a high probability of buried targets. Such areas can be determined from various sources, such as on-site irregular activities, personal communication, surveys, and crop marks.

In situ measurements were taken at two test areas: (a) vegetation area covered with vegetation (barley), in the presence of an underground military structure [hereafter denoted as area (a)], and (b) vegetation area covered with vegetation (barley), in the absence of an underground military structure [hereafter denoted as area (b)].

An SVC-1024 spectroradiometer of the Spectra Vista Corporation (SVC) with a spectral range of 350–2500 nm was used to measure reflectance values. The spectral resolution of the spectroradiometer is 1.0 nm. The measurements were taken between 11:00 AM and 13:00 PM (local time), under clear and overcast skies for diffuse light to minimize any variation of the incoming solar electromagnetic radiance. In addition, a calibrated Spectralon panel (with reflectance ≈99.996%) measurement was used as a reference, while the measurements over the crops were used as a target [12].

Then, the waveband reflectance values were used to calculate three vegetation indices (VIs), the normalized difference vegetation index (NDVI), enhanced vegetation index (EVI), and simple ratio (SR), as shown in **Table 1**. The waveband reflectance’s were calculated from the RSR filter of the Landsat 8 sensor. The vegetation indices were plotted and statistically cross compared between the two areas of interest, namely, the “buried military structure” and the “nonmilitary structure.”

In situ measurements were taken in a grid format which is the same as the dimension of the underground structure (13 m × 5 m), over the two study areas, and systematic targets were collected at each time to compile a representative sample that is statistically reliable. Due to the very close proximity of the two sites (<20 m), the analysis was based on the following two criteria: both study areas have similar soil and climatic characteristics [28]. Area (a) is the area over the underground structure itself and the area around it. Area (b) is the reference area in the absence of an underground military structure. The measurements were also made when the underground structure was covered with the existing natural soil which was subsequently cultivated and covered with vegetation (barley) in order to study possible differences of the spectral signature of vegetation, as a result of the existence of underground structures. During the campaign, 1740 measurements were taken using the SVC-1024 field spectroradiometer, with an average reference spectral signal as given for each of the six campaigns (random sampling) in **Table 2**.

No.	Vegetation index	Equation	Reference
1.	NDVI (Normalized Difference Vegetation Index)	$(p_{NIR} - p_{RED}) / (p_{NIR} + p_{RED})$	[25]
2.	EVI (Enhanced Vegetation Index)	$2.5 (p_{NIR} - p_{RED}) / (p_{NIR} + 6 p_{RED} - 7.5 p_{BLUE} + 1)$	[26]
3.	SR (Simple Ratio)	p_{NIR} / p_{RED}	[27]

Table 1.

Vegetation indices used in this study, where p_{NIR} , p_{RED} , and p_{BLUE} represent the atmospherically or partial-atmospherically corrected surface reflectance values of the near-infrared (NIR), red (RED), and blue (BLUE) wavelengths, respectively [24].

No.	Date	Phenological stage	Number of measurements
(a)	30-10-2016	Cultivation stage	120
(b)	11-12-2016	Tilling stage	120
(c)	23-01-2017	Flag Leaf Emerging stage	120
(d)	25-02-2017	Boot stage	460
(e)	05-03-2017	Head Emerging stage	460
(f)	16-03-2017	Flowering stage	460

Table 2.
 Number of measurements in each phenological stage.

3. Results

3.1 Vegetation indices

Figures 2-4 show the results for the vegetation indices shown in Table 1 with reference to the phenological stages. The vegetation indices were applied to the barley crop over area (a) (red line) and area (b) (blue line). The response of VIs with respect to barley growth was evaluated by contrasting the minimum to the abovementioned areas. The results show that VIs display a distinct variation corresponding to the barley development and they could be used as cultivar-independent phenological indicators. It can be observed that there is a high correlation between the results of VIs. Indeed, VIs could be used in field spectroscopy for the detection of buried structures. The use of more than one VI for the detection of crop marks is suggested in order to enhance the final results. Furthermore, it is clear from these graphs that VI values vary from one phenological stage to another. Although the same dataset was used for all these vegetation indices, each of the VIs demonstrates

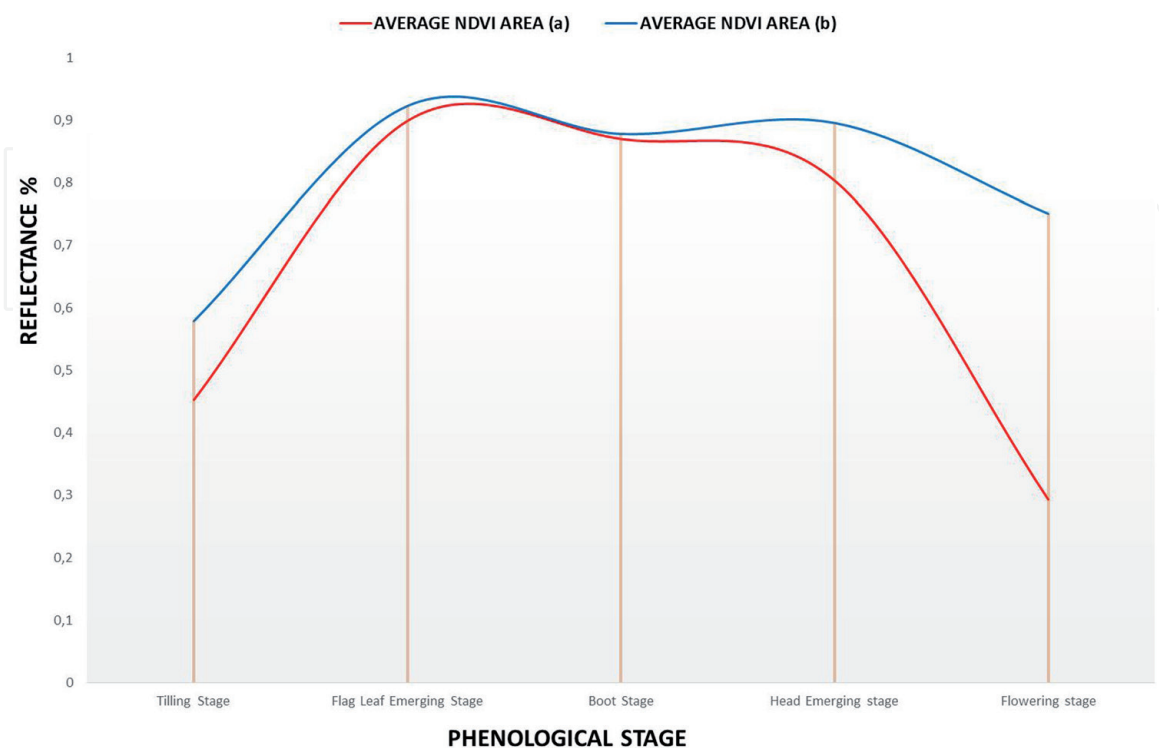


Figure 2.
 Vegetation values for area (a) for (buried structure, red dots) and area (b) for (vegetated area, blue line) during phenological cycle for NDVI.

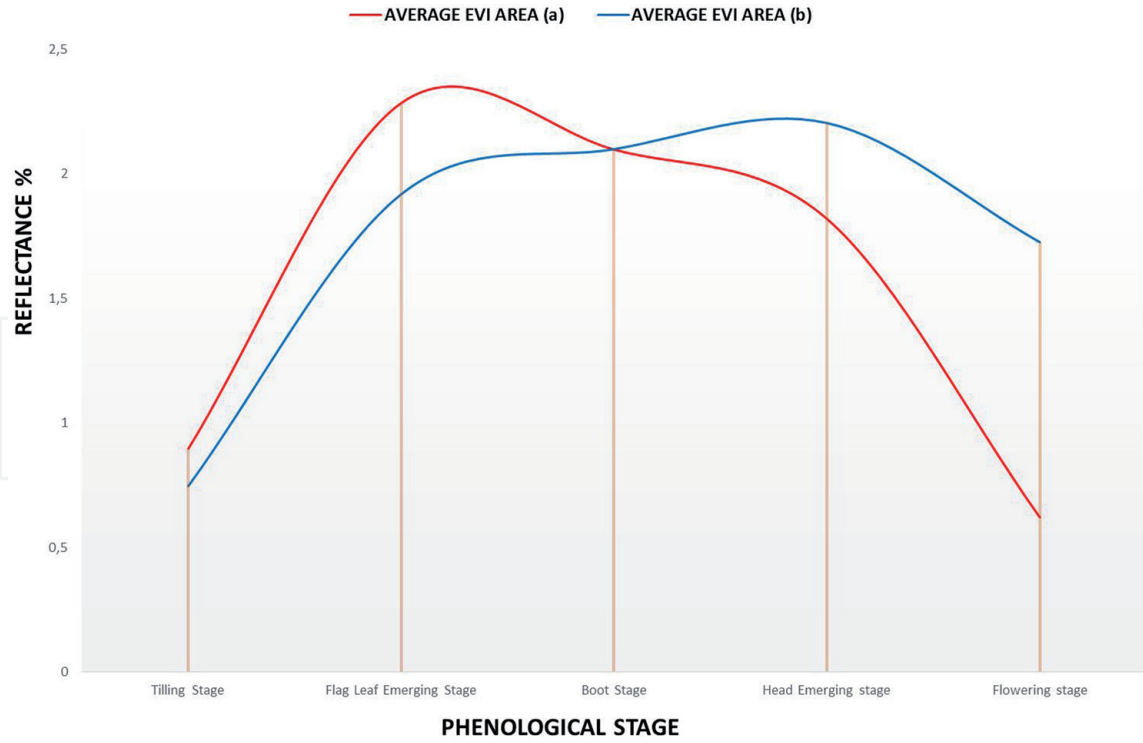


Figure 3. Vegetation values for area (a) for (buried structure, red dots) and area (b) for (vegetated area, blue line) during phenological cycle for EVI.

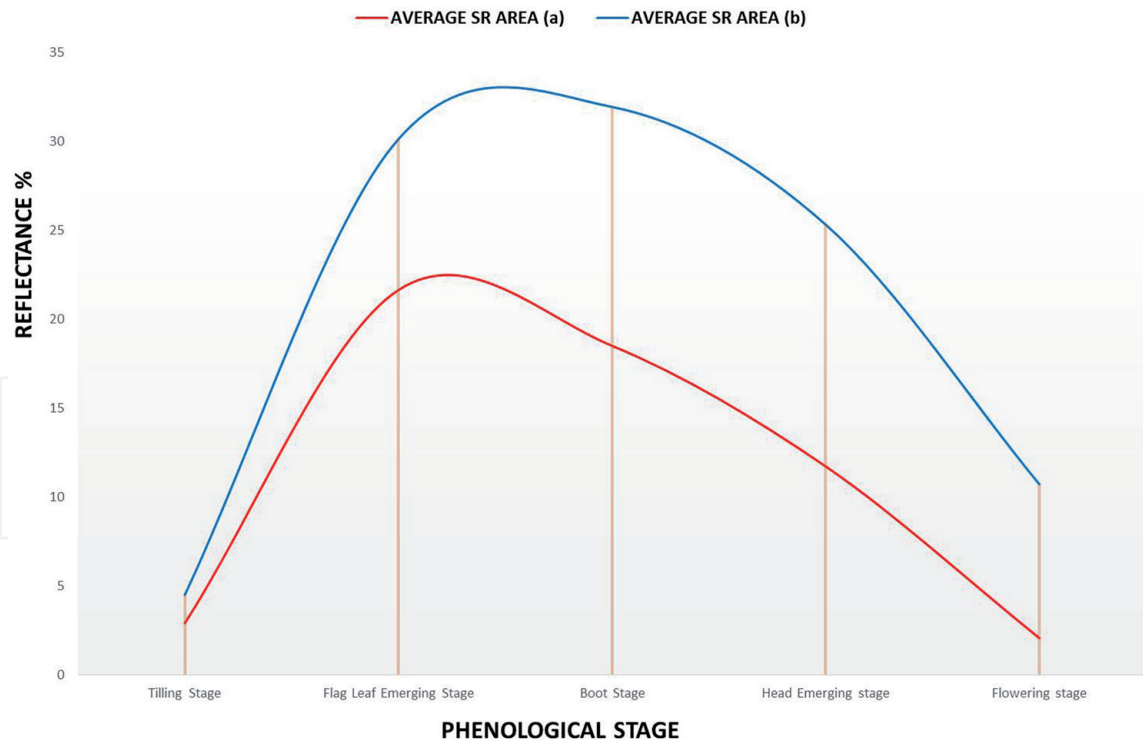


Figure 4. Vegetation values for area (a) for (buried structure, red dots) and area (b) for (vegetated area, blue line) during phenological cycle for SR.

a different response at different phenological stages. It may be seen clearly in the Flowering stage that there is a distinction between area (a) and area (b). **Figure 2** presents a typical example of the spectral profile of area (a) and area (b) using the NDVI. There is an upward trend of area (b) (blue line) compared with area (a) (red line) in which there is a downward trend, throughout the phenological

cycle. Evidently, this happens using the SR vegetation index. Moreover, it is remarkable to note that for the SR vegetation index (**Figure 3**), in test area (b) (blue line), the reflectance response is higher than test area (a) (red line), throughout the phenological cycle. Obviously, the reflectance response in test area (b) (blue line) follows a steeper upward path in the Tilling and Flag Leaf Emerging stages. In the Boot stage, the reflectance of area (b) (blue line) increases dramatically. In the Head Emerging and Flowering stages, the reflectance decreases, but there is a differentiation between the two test areas. This differentiation is not arbitrary but reinforces the diagnosis of existence/nonexistence of military underground structures. In addition, for the EVI (**Figure 4**), the reflectance response changes over time. Specifically, there is an upward trend in area (a) (red line) in the Tilling and Flag Leaf Emerging stages. In contrast, there is an upward trend in area (b) (blue line) in the Head Emerging and Flowering stages.

3.2 Image maps

Ground spectroradiometric measurements can provide the spectral response of the vegetation in detail [29]. The analysis of the spectral data shows the maps of vegetation indices (NDVI, EVI, and SR) for area (a) (**Figure 5**) and area (b) (**Figure 6**), during Flag Leaf Emerging stage. Comparing area (a) with area (b) using NDVI (**Figure 5**), it appears that area (b) obtains lower values due to the nonexistence of underground structures, while area (a) has similar vegetation but higher NDVI values due to the existence of underground structures. In addition, using the EVI (**Figure 6**), area (a) has higher values due to the existence of underground structures, while area (b) has lower values due to nonexistence of structures. Similarly, using the SR vegetation index (**Figure 6**), area (b) has clearly lower values due to the existence of underground structures, while area (a) (**Figure 5**) has higher values due to nonexistence of structures. The green color illustrates high value of indices that distinguish the existence of structures. The existence of underground structure can be clearly seen by comparing area (a) with area (b), during the Head Emerging stage. The analysis of the spectral data shows the maps of vegetation indices (NDVI, EVI, and SR) for area (a) (**Figure 7**) and area (b)

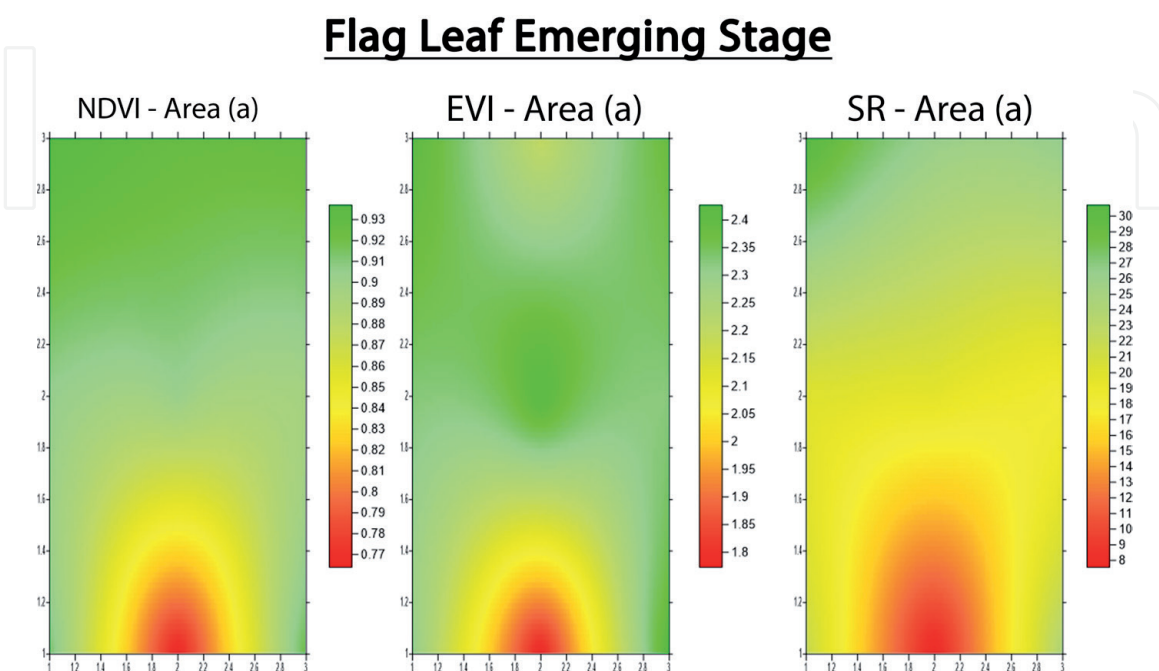


Figure 5.
Image maps showing NDVI, EVI, and SR field data for area (a) during Flag Leaf Emerging stage.

Flag Leaf Emerging Stage

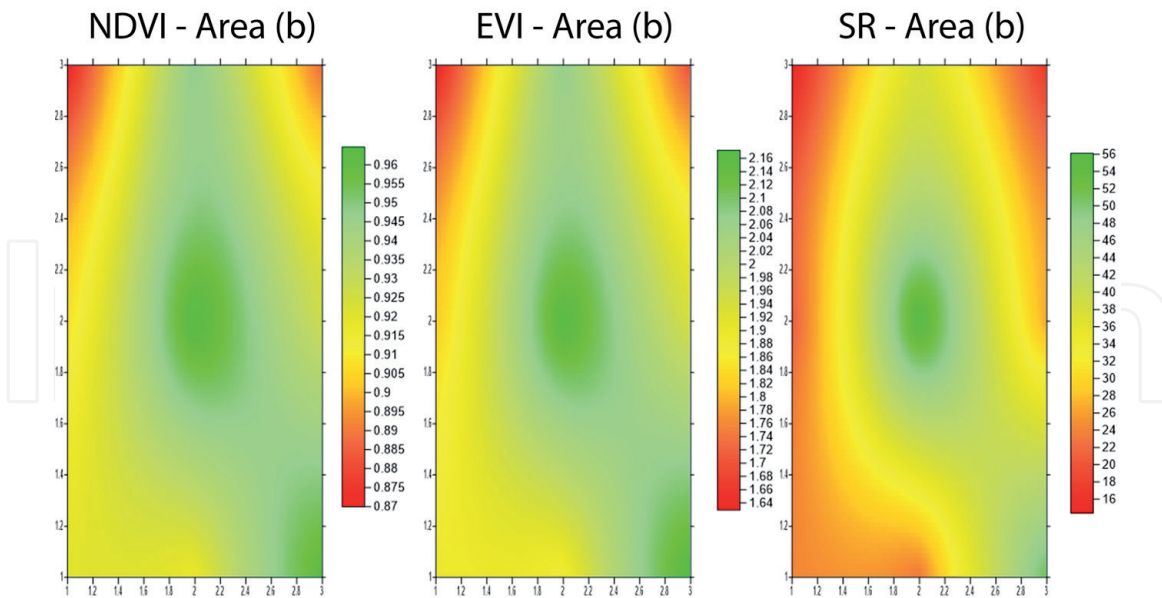


Figure 6.
Image maps showing NDVI, EVI, and SR field data for area (b) during Flag Leaf Emerging stage.

Head Emerging stage

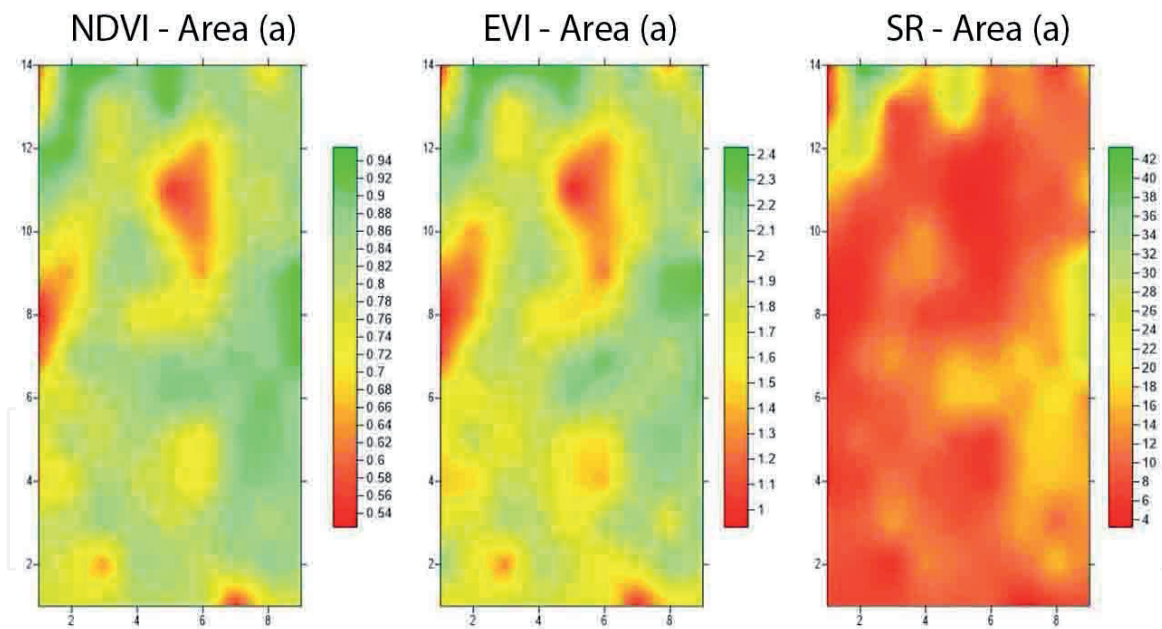


Figure 7.
Image maps showing NDVI, EVI, and SR field data for area (a) during Head Emerging Stage.

(**Figure 8**). In comparing area (a) with area (b) using the NDVI (**Figure 8**), area (b) has higher values due to the nonexistence of underground structures, while area (a) (**Figure 7**) has similar vegetation but lower NDVI values due to the existence of underground structures. Likewise, using the EVI, area (a) (**Figure 7**) has lower values due to the existence of underground structures, while area (b) (**Figure 8**) has higher values due to nonexistence of structures.

Using the SR vegetation index (**Figure 7**), area (a) tends to exhibit a difference with respect to area (b) (**Figure 8**). More specifically, in target area (a) (**Figure 7**), the reflectance response is lower than area (b) (**Figure 8**), which indicates that the

Head Emerging stage

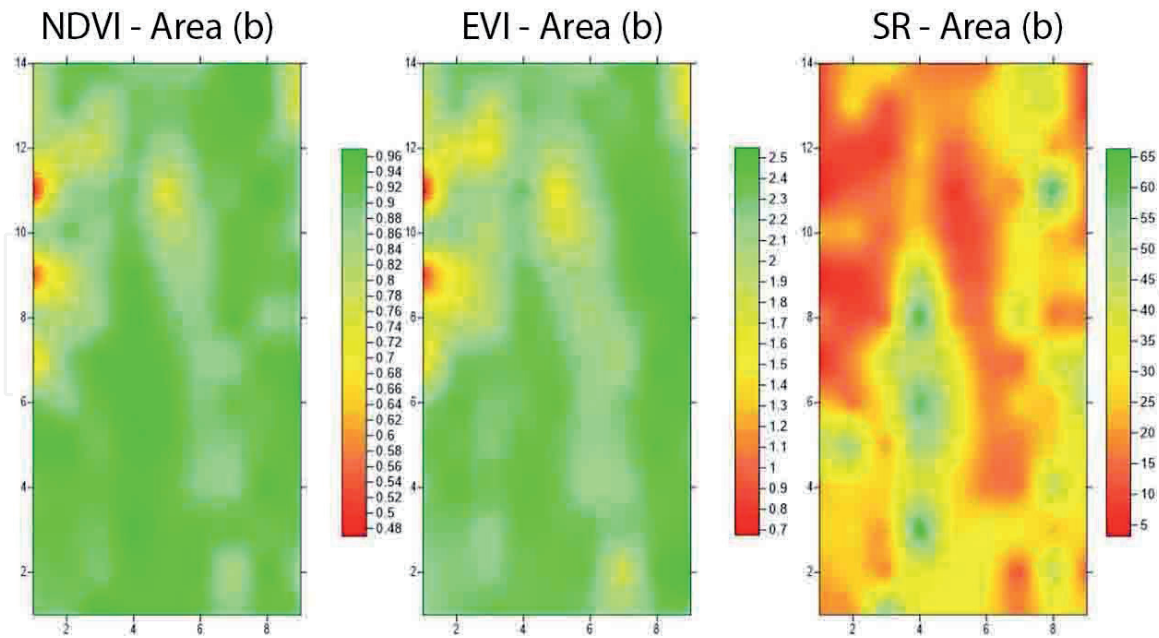


Figure 8.
Image maps showing NDVI, EVI, and SR field data for area (b) during Head Emerging Stage.

resulting differences reinforce the existence/nonexistence of underground structures. It can be argued that soil also contributed to the reflectance measurements. The variations between the two cases, namely, in the presence and in the absence of military underground structures, can result in better interpretations of images for the detection and identification of crop marks.

4. Conclusions

Field spectroscopy can support satellite remote sensing studies for monitoring systematically critical areas of interest including the detection of underground bunkers.

The application of remote sensing in defense and security merges the technological improvements of remote sensing sensors with military needs to improve the quality of information retrieved from remote sensing data. Indeed, decision-making authorities can benefit from such efficient space imaging technology of underground targets.

The advantages of using vegetation indices as proxy variables for intercalibration among existing sensors are the low sensitivity to the uncertainties in atmospheric correction and the variation in the satellite viewing angle [30]. As shown in this paper, vegetation indices can corroborate areas of possible military underground structure.

In comparing the two areas, the spatial distributions of VIs exhibit no table differences (**Figures 7 and 8**). This is clear in **Figure 8**, where image maps illustrate the differences between the two areas using NDVI, EVI and SR Vegetation Indices. Mostly SR vegetation index is used for defining areas where military underground structures are present.

Consequently, the near-infrared (NIR) band of Landsat 8 sensor could be useful to identify the underground structure. It is apparent that the waveband analysis of the Landsat 8 sensor distinguishes between the two study sites. Monitoring variations of the NIR spectrum during the life cycle of vegetation is a key parameter for the field spectroscopy for the detection of military underground structures using remote sensing techniques.

In this chapter, it was demonstrated how remote sensing can be exploited as a monitoring and decision-making tool by any agency in tackling military and security issues related to the presence of underground military structures. Field spectroscopy measurements were used to detect underground military structures through variations in vegetation indices. Indeed, vegetation indices can be used to develop a suitable vegetation index for detecting military underground structures.

Areas covered by natural soil where underground structures are present or absent can easily be detected as a result of the change in the spectral signature of the overlying vegetation; in this respect, vegetation indices, such as the NDVI, SR, and EVI, may be used for this purpose.

It is recommended to collect field spectroradiometric measurements to other types of military underground structures to evaluate the above results and the satellites' spectral sensitivity. The development of a standard model/methodology framework to be produced through the stages of the study for locating military underground structures is an innovation in military operations research. Additionally, an unmanned aerial vehicle (UAV) may be used to survey the area with visible and near-infrared cameras to generate vegetation indices for comparison to the in situ spectroradiometric measurements [31].

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Conflict of interest

The authors declare no conflict of interest.

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