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Integrated use of multi-temporal multi-sensor and multiscale Remote Sensing data for the understanding of archaeological contexts: the case study of Metaponto, Basilicata.

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Abstract. This paper is focused on the archaeological area of Metaponto (Μεταπόντιον) and its territory, located in southern Italy. The area played an important role for the agricultural economy and the traffic of goods and people, from the south of Italy towards the central regions, starting from the Neolithic period, and reaching the zenith with the Greek polis of Metaponto and its hinterland. The site is herein analyzed through an integrated use of several Earth observation and remote sensing technologies and ancillary data produced over the years by archaeologists and scholars. The aim was to identify new buried elements of archaeological interest, for the reconstruction of the historical-archaeological landscape. Through the combined use of optical and radar satellite images, high-resolution images obtained by Unmanned Aerial System (visible, multispectral, and thermal infrared), geophysical data, and archival data, it was possible to deepen the knowledge of the area, in particular the “Castrum” area, identifying new buried evidence (structures, roads, and elements of the ancient landscape).

1. Introduction

The analysis of archaeological contexts on a landscape scale for the protection, preservation and knowledge of cultural and natural heritage (CNH) is, of course, a central issue in an era where the development of large infrastructures for functional, commercial or tourist purposes (e.g. aqueducts, methane pipelines, railways, roads, buildings, etc.) occurs every day, with a strong impact on the landscape. Earth observation technologies, combined with data collected by archaeologists and scholars in field activities, certainly play a key role in preventing heritage from being destroyed or damaged by incessant and frenetic human activity.

This paper is focused on the archaeological area of Metaponto (Μεταπόντιον) and its territory, located in southern Italy. The area played an important role for the agricultural economy and the traffic of goods and people, from the south of Italy towards the central regions, starting from the Neolithic period, and reaching the zenith with the Greek polis of Metaponto and its hinterland (4th century B.C.)[1–3].

During the 3rd century B.C., the Greek colony changed radically in morphology and management. After the events of the Punic wars (218–202 B.C.), the so-called "Castrum" was created on the south-eastern side of the city, above a part of the Greek agorà and other buildings, and was connected by

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roads and canals to what must have been a harbour establishment, near the Località Mele, one kilometre inside the present coastline [4–6]. The first excavation in this part of the site, was carried out in 1973; further excavations were carried out in 1975 and 1976. Starting from 2019, the granting of excavation in the "Castrum" area has been entrusted to the School of Specialization in Archaeological Heritage of Matera (SSBA-Unibas) of the University of Basilicata, in collaboration with the CNR. The polis of Metaponto has been of interest since the 18th century, subject of a prolific humanistic [7–11] and scientific [12–15] literary production. The site is herein analyzed through an integrated use of several Earth observation and remote sensing technologies and ancillary data produced over the years by archaeologists and scholars. The aim was to identify elements of archaeological interest for the reconstruction of the historical-archaeological landscape, in an area covering about 140km^2 between the Bradano and Basento rivers, through the use of multitemporal, multisensor and multiscale data.

2. Material and Methods

The analyses carried out in the Metaponto area involved several remote sensing and Earth Observation (EO) technologies: (i) medium- and high-resolution multispectral optical sensors; (ii) zoom-in and validation on areas of in-depth study with RGB, multispectral, and thermal UAS (Unmanned Aerial System) and (iii) geophysics, including geomagnetometry; and (iv) historical aerial photos. These data were combined with those collected by archaeologists (Figure 1).

Figure 1. Survey area with reference to the extent of the survey for each tool used.

The analyses started with the lowest resolution (10m/pixel) and largest scale (landscape) data. Multi-temporal data in the years 2017-2020 (400 satellite images approx.) from Sentinel-2 (multispectral) were used. These data were complemented by a single very high resolution (0.5 m) satellite data obtained from the Pleiades constellation (2013-08-17).

The processing of the Sentinels [16,17] was done using Google Earth Engine (GEE) platform [16,17]. GEE is an open-source tool made available by Google through registration. It is a portal that allows to work simultaneously with petabytes of different datasets for a collection of over forty years of data on a global scale. GEE is a powerful computing tool, accessible via application programming interface (API) [18]. Using GEE, all images from 2017 to the end of 2020 (400 approx.) were processed and annual NDVI's averages were calculated, according to the methodology described in [16,19]. The used methodology was addressed to feature enhancement and data-reduction to capture archaeological proxy indicators. The identification of proxy indicators of archaeological presence is a necessary activity in the field of RS applied to cultural heritage. These are visible within the images as zonal differences in the reflectance value in different bands. The reflectance takes on different values due to the presence of elements in the subsoil that favour (cisterns, gullies etc.) or prevent (structures, floors etc.) the development of vegetation and/or the accumulation of moisture in the soil. The values recorded are in fact due to (i) differences in the state of health of the vegetation, with consequent irregular production of chlorophyll and carotenoids, and (ii) retention of moisture in the soil [20–22]. A PCA (Principal Component Analysis) [23,24] was then applied to the data produced, as a data-reduction method, and the resulting transformations were used for final considerations and improve the visibility of the macro-elements of the ancient landscape such as roads, channels, etc. The PCA is a technique of data reduction, and it is a common practice in the field of Remote Sensing applied to Cultural Heritage. It was used in the past to enhance the presence of archaeological proxy indicators, for hyperspectral and multispectral images, due its capacity to reduce significative information in few outputs. The high-resolution satellite image, on the other hand, was pre-processed and the low-resolution multispectral bands were processed by a Gram-Schmidt pansharpening method, using ENVI 5.6 software [25], and vegetation indices were produced to enhance the visibility of archaeological proxy indicators.

Data from UAS were acquired using a Dji Matrice 210 drone equipped with (i) DJI Zenmuse X5S RGB-visible camera, (ii) Sentera agx710 multispectral camera, and (iii) DJI Zenmuse XT2 high-resolution thermal camera. The acquisition was carried out on the "Castrum" area and the images were processed separately, by type (visible, multispectral, thermal infrared) using the Agisoft Metashape software, for the creation of high-resolution orthophotos. The data in the visible spectrum were used without modification, while those in the multispectral and thermal infrared were used either as a single band, or in RGB (e.g. False Colour Infrared) and vegetation index combinations, to increase the visibility of crop- and soil-marks [26].

The geomagnetic survey represent one the most relevant non-destructive techniques for investigating the archaeological sites and widely applied as geophysical techniques [27].

This method of investigation consists in measuring the intensity values of the earth's magnetic field and subsequently analyzing its variations or anomalies. From the analysis of these anomalies it is possible to identify the presence of buried elements of archaeological origin. Obviously, in order for a significant change in magnetic measurements to be observed, there must be a corresponding contrast between the magnetic properties of the various buried archaeological elements and the soil that contains them. The archaeological elements that can give evident contrasts in the magnetic properties and that can therefore be an interesting object for magnetic prospecting, are concentrated elements such as wells, ovens, tombs, etc. or linear elements that extend in one direction such as ditches, roads or remains of masonry. The possibility to scan large areas in a short time, the easy field operations and the relative intuitive data processing, make the MAG investigation an optimal tool for a preliminary survey of an area of potential interest. For the these reasons, it has been widely applied in archeology, from the small-scale site characterization to the surveying of large scale areas [28].

The magnetometric method used in this work is the differential or gradiometric one, it is based on the use of a differential magnetometer or gradiometer, where the space between the sensors is fixed and is small compared to the distance from the sources whose gradients are being measured. The information relating to the gradient is particularly useful in the search for surface anomalies since it allows to remove the effects due to the local regional magnetic field. In fact, gradient anomalies tend to "solve" (break down) complex anomalies into their individual constituents; moreover, it allows to eliminate the effects of diurnal variations or magnetic storms, without resorting to the aid of a second magnetometer as a base station.

The magnetometer used for the surveys conducted in Metaponto is Bartington's Grad601. It is a high resolution fluxgate gradiometer, used to measure minute variations in the magnetic field that are caused by hidden anomalies in the ground, such as archaeological features, pipes, cables or unexploded ordnance. The gradiometric survey was carried out according to pre-set grids of side 40 and spacing of the profiles at 1 meter. The investigated area consists of a 40x20m rectangular area adjacent to the current excavation area. This area was identified as a priority for evaluating the spatial distribution of some wall structures and their continuation in adjacent areas.

All the data obtained from the described processes were loaded into a GIS (Geographic Information System) platform and used in combination with archaeological data from studies and excavations, to increase the knowledge on the archaeological site of Metapontum.

3. Results and Conclusions

The study allowed to identify several signs of archaeological interest, visible as crop- and soil-marks, i.e. traces visible in the vegetation or in the retention of moisture in the soil. In particular, significant information has been obtained: (i) for the urban development of the ancient city of Metapontum for which the boundaries and regular road axes not yet excavated are clearly visible by remote sensing; (ii) about the development of elements of archaeological interest distributed in the chora of Metapontum (e.g. secondary roads, ditches, buried structures); (iii) for the area of the so-called "Castrum" of Metaponto; and (iv) the area of the lake of Santa Palagina; (iv) for the reconstruction of the ancient landscape thanks to the evidence of palaeo-rivers, palaeo-shorelines and main ancient roads. The results are summarized in Figure 2.

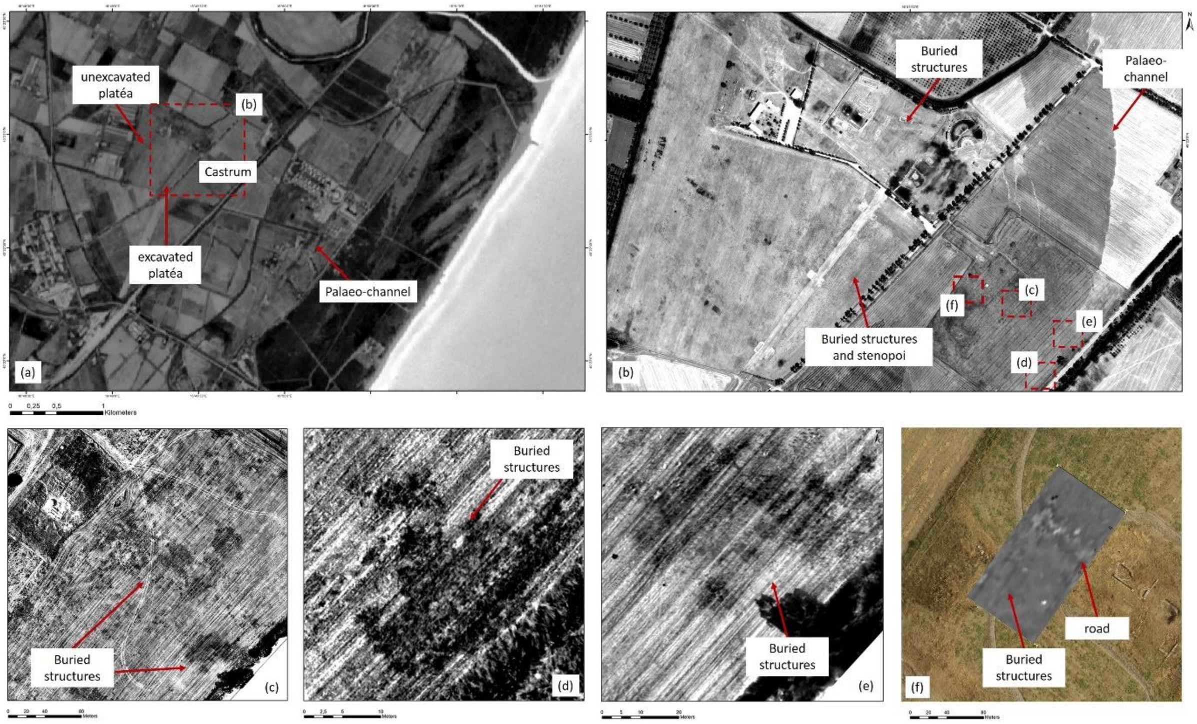

Figure 2. Features identified by multiscale-multisensor RS analysis: (a) Sentinel-2 1st PC obtained by applying PCA to the 2017-2020 annual averages of NDVI indices where macro elements of archaeological interest are clearly visible, such as a platéa and the canal near the so-called Lago di Santa Palagina; (b) Single NDVI at very high resolution (VHR) where features produced by buried structures are visible; (c) GRDVI index produced with multispectral imagery from UAS showing

features of archaeological interest related to buried wall; (d) NDVI index produced with multispectral images from UAS showing a buried three-apse structure; (e) Thermal infrared showing features of several buried structures; (f) MAG results showing features related to a road and buried structures.

The remote sensing and Earth observation data proved to be complementary to each other.

Analysis on a landscape scale (Sentinel-2 and Pleiades satellite images) revealed elements of the ancient landscape. In particular, elements of the road system (roads) and watercourses (canals and palaeo-rivers). On the other hand, the processed very high resolution satellite images also highlighted several micro-features of archaeological interest related to buried environments and structures, proving to be of very similar usefulness to UAS acquisitions.

The drone data provided very high resolution images, which identified many features related to buried structures, especially in the so-called "Castrum" area. The visible data, useful for a general overview of the area, were supplemented by high resolution multispectral and thermal data (2 cm/pixel), which allowed the identification of crop-marks and soil-marks of regular geometric shape (rectilinear or quadrangular), which opened the archaeological interpretation to several new hypotheses and provided new information on the development of the "Castrum" area.

From the analysis of the results obtained through gradiometry, several surface anomalies emerge. First of all, the most evident structure is connected to the pre-existing structure aligned in the NW-SE direction of the baths in fact the magnetic anomalies portend the existence of a continuation of the underground walls as there are significant anomalies in the same direction as structures already excavated.

In addition, secondary structures are present in adjacent areas, such evidence will have to be confirmed in the future through the use of other geophysical techniques (GPR) and with a more expanding geophysical survey campaign.

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