

Old Methods and New Technologies: A Multidisciplinary Approach to Archaeological Research in Sant'Arsenio (Salerno, Italy)

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Abstract. This contribution is part of a project for the identification, research and protection of archaeological evidence in the village of Sant'Arsenio (SA), through the use of new technologies applied to archaeological research. In particular, the activity combines typical Remote Sensing tools (satellite data and UAVs), with a preference for open source software and open access databases, and common archaeological research practices (study of ancient and modern bibliographic sources, field survey, topographic analysis, etc.). Sant'Arsenio is a small town in the western part of Vallo di Diano, a large plain surrounded by mountains, between 450 and 480 m above sea level, located on the border between Campania and Basilicata. Information about the archaeological potential of the Sant'Arsenio appear to be relatively scarce compared to those available for the surrounding municipalities (Polla, Atena Lucana, Teggiano, Sala Consilina). This lack is due to the absence of systematic studies and planned archaeological research activities in the municipality. This paper presents the data collected between the end of 2018 and the beginning of 2019 by IMAA-CNR (Istituto di Metodologie per l'Analisi Ambientale del Consiglio Nazionale delle Ricerche). In particular, the satellite data (Sentinel-2), assisted by archaeological research, allowed to identify some anomalies of archaeological interest.

Keywords: Remote Sensing · Cultural Heritage · Open data

1 Introduction

This paper is part of a project developed by Consiglio Nazionale delle Ricerche – Istituto di Metodologie per l'Analisi Ambientale (CNR-IMAA), about the use of Remote Sensing and new technologies for research, monitoring and protection of national and international Cultural Heritage.

The municipality of Sant'Arsenio (Salerno, Italy) is the object of this work as subject of an agreement between the CNR-IMAA and the municipality itself.

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The aim of the study is to combine archaeological research with new non-invasive technologies (Remote Sensing) and, above all, open data, such as the Sentinel-2 images of the Copernicus program, to expand the knowledge of a specific place and protect any evidence, for a conscious urban development.

Sentinel-2 images are optimal for archaeological research, as evidenced by several works published in recent years [1–3]. The ability to download free data at a good resolution is essential in archaeology. Moreover, the archaeological data for the municipality of Sant'Arsenio are scarce and the Sentinel-2 images have quickly provided an overview of a large territory, allowing us to isolate areas of interest (AOIs) for further research as will be seen in the following pages.

2 Materials and Methods

Research in Sant'Arsenio concerns the use of the traditional archaeological method associated with the use of Remote Sensing techniques.

To identify a range of potentially AOIs, an overlap was made between the bibliographic/archaeological sources (geo-referenced and transposed into a GIS platform), Sentinel-2A multispectral satellite data [1], acquired through the Copernicus platform (https://scihub.copernicus.eu), IGM cartography (1: 25.000), multi-temporal images present on the National Geoportal Viewer (http://www.pcn.minambiente.it/viewer/) and Google Earth [2].

2.1 Methodology

Sentinel-2 data are fundamental to increase the knowledge of the study area. In fact, the images are free and see beyond the visible spectrum (*see* Table 1). Furthermore, Sentinel-2 data have a good resolution in the RGB and NIR bands (10 m) [3].

Table 1. Spectral bands of Sentinel-2A images.

Bands	Central wavelength (nm)	Spatial resolution
Band 1 – Coastal aerosol	0.443	60 m
Band 2 – Blue	0.490	10 m
Band 3 – Green	0.560	10 m
Band 4 – Red	0.665	10 m
Band 5 – Vegetation Red Edge	0.705	20 m
Band 6 – Vegetation Red Edge	0.740	20 m
Band 7 – Vegetation Red Edge	0.783	20 m
Band 8 – NIR	0.842	10 m
Band 8A – Vegetation Red Edge	0.865	20 m
Band 9 – Water vapour	0.945	60 m
Band 10 – SWIR – Cirrus	1.375	60 m
Band 11 – SWIR	1.610	20 m
Band 12 – SWIR	2.190	20 m

Multispectral images are useful in archaeological studies to easily recognize and categorize surfaces and their spectral response (spectral signatures), analyzing variations during the time of vegetation, soil, humidity, etc. The images allow to identify possible archaeological evidences, thanks to the integration with other sources [4].

Archaeologists use the analysis of multispectral images to identify buried or hidden structures, observing different indices (combination of bands) and anomalies in vegetation and soil (crop-marks, soil-marks) [5].

The images used for the study of Sant'Arsenio come from the Copernicus platform, with a percentage of clouds less than 10% per image and an acquisition period from 05/23/2016 to 10/25/2018.

The open source software ESA SNAP (http://step.esa.int/main/download/) processed all the images.

We have created an automated process to generate indices and images, thanks to SNAP's "graph building" function, speeding up all operations.

The workflow is simple and operations on Sentinel images follow this order: Read, Resampling (on Red Band or 10 m), Subset (reduces the file size), BandMaths (*see* Table 2), BandMarge (joins the Sentinel bands with indices), Write.

Table 2. Indices used for the identification of possible archaeological areas (referred to Sentinel-2 bands).

Index	Equation	Reference
Burned Area Index (BAI)	$\frac{1}{(0.1-B4)^2+(0.06-B8)^2}$	[6]
Difference Vegetation Index (DVI)	$B8-B4$	[7]
Enhanced Vegetation Index (EVI)	$2.5\times\frac{(B8-B4)}{(B8+6\times B4-7.5\times B2+1)}$	[8]
Green Difference Vegetation Index (GDVI)	$B8-B3$	[9]
Green Normalized Difference Vegetation Index (GNDVI)	$\frac{(B8-B3)}{(B8+B3)}$	[9]
Green Ratio Vegetation Index (GRVI)	$\frac{B8}{B3}$	[9]
Normalized Difference VegetationIndex (NDVI)	$\frac{(B8-B4)}{(B8+B4)}$	[10]
Normalized Archaeological Index (NAI)	$\frac{(B7-B5)}{(B7+B5)}$	[3]
Modified Chlorophyll Absorption in Reflectance Index	$((B5-B4)-0.2\times(B5-B3))\times\left(\frac{B5}{B4}\right)$	[11]
Normalized Difference Water Index (NDWI)	$\frac{(B8-B11)}{(B8+B11)}$	[12]

We have used the software to "trace" the spectral signature of the different pixels and make a physical and optical distinction between them [13–15].

We have used the Qgis Software for the last phase of processing and for the interpretation, loading into a single project the entire dataset from Sentinel-2 (bands, images and indices), IGM cartography, historical photos from WMS National Service and ancillary data acquired during the preliminary research phase.

In one case, aerial shots (UAV - DJI Phantom 3 Professional), photogrammetry software (Agisoft Photoscan) and data processing software (Cloud Compare, MeshLab) were used to expand the knowledge of one of the identified sites.

Approximately 99 aerial shots were acquired in 25 min of flight. The entire set of images was processed using the Agisoft Photoscan software and the point clouds (sparse and dense), the polygon mesh and the textured model were created. Each data is geo-referenced thanks to the metadata contained within the pictures. Cloud Compare and MeshLab software provided DEMs, contour lines, orthophotos and other useful data.

2.2 The History of Sant'Arsenio Through Archaeological Sources and Data, from Prehistory to the Late Medieval Period

Sant'Arsenio is a small town near Salerno, located on the western slope of the Vallo di Diano, a wide valley, between 450 and 480 m above sea level (*see* Fig. 1).

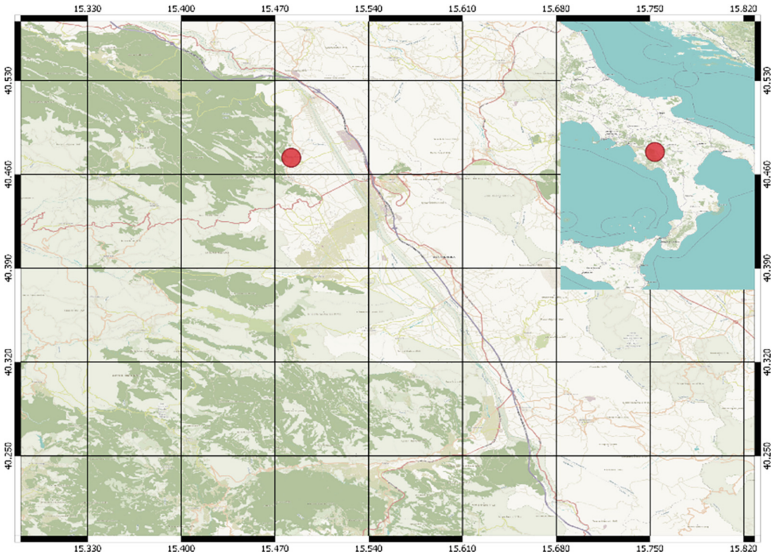

Fig. 1. Sant'Arsenio (Salerno, Italy).

The valley - which extends longitudinally - is located on the border between Campania and Basilicata. It is a natural link between the territory of Salerno and Lucania.

The valley dates back to the beginning of the Pleistocene and appeared as a large lake basin. Around 200,000 years ago, it became a large swamp, then modified - in historical times - by land reclamation and canalization work, starting from the "Roman period", for urban development and agricultural land use [16].

Excavations and archaeological research have shown traces of frequentation within the caves of Pertosa, Zachito, Castelcivita, of Ausino and Polla, with rare cases of *sub divo* evidences in the cases of Buccino, Atena Lucana and Sala Consilina [17].

The Bronze Age represents, for the area, a clear change within the settlement forms and economic vitality [18, 19].

The Iron Age (950 BC) is a very important moment for the Vallo di Diano. Villanovan culture groups penetrate the valley and occupy the heights.

For the archaic period (6th century BC) and the classical period (5th-4th century BC), data are scarce due to systematic archaeological operations.

Most of the information in our possession comes from the excavation of some sepulchral contexts. The 6th century shows similar characteristics to the previous one, as shown by the funeral goods and artifacts found during the excavation of the necropolis of Sala Consilina and Atena Lucana [20].

The presence of roads and passes through the Apennines greatly favors connections with areas such as the Val d'Agri, the Ionian Cost of Basilicata and the Tyrrhenian Cost, through the Sella di Corticato (Teggiano) and Monte Pruno (Roscigno) passes. In these places, a fortified site has been identified and excavated, probably datable to the 6th century BC [21].

For the Roman period, although still incomplete, the archaeological investigations and documentary sources (texts and epigraphs) are able to clearly delineate the situation of the Vallo di Diano.

One of the first points of contact between Rome and the populations of the Vallo happens, certainly, in the 3rd century. BC (272), with an alliance. This agreement ends at the end of the 3rd century, with the Annibalic wars, when the Lucanians of the Apennines supported Hannibal, paying - subsequently - the duty of defeat with heavy dispossession of territory in favor of the *ager publicus populi Romani* [22, 23].

The importance of the centers along the Capua-Regio route must certainly have increased at this time. Atena Lucana, Polla, Sala Consilina and Teggiano show a remarkable and constant urban growth up to the Augustan age, confirmed by inscriptions and inscriptions [24].

The late republican age and the imperial age saw the formation of a class of middle landowners who left the place, between 3rd and 4th centuries AD, to a landowner aristocracy [25].

During the medieval period the Vallo continues to play the role of crossroads for goods and people. This is very clear inside a letter of Cassiodorus (485–580 ca.) (*Variae, 8, 33*) of 527 AD when the author describes an important annual fair in a place identified as San Giovanni in Fonte, where the ruins of an early Christian baptistery are kept [26].

The Municipality of Sant'Arsenio is located on the western side of the Vallo di Diano, below the Alburni Mountains, in a natural basin formed by the heights, called, from south to north, Costa Masturso, Costa di S. Maria, the Cerri, Serra the Compra e Cornaleto.

It is widely believed that the origins of the town are to be found in the centuries of the Middle Ages and that the "importance" of the center in the economy of the territory

remains marginal until the passage of the village to the Abbey of Cava de' Tirreni (12th century).

The most ancient evidences identified in the place are those found by the S.t.A.r.S. (Sant'Arsenio Survey) and V.A.L.L.O. (Valorizzazione Archeologica di un Lago non Lago Onnicomprensivo) projects, directed by Prof. A. Guidi (University of Rome 3), by Prof. A. Cazzella (University of Rome La Sapienza), coordinated in the field by dr. F. Nomi (University of Rome 3), in the years 2012, 2013 and 2014 [18, 19].

The work of the archaeologists has deepened the knowledge about the occupational dynamics, with materials and remains of inhabited areas from the Eneolithic (3800 BC) to the Bronze Age (1700 BC) and fragments of cups or olla dating back to the 8th-6th century BC, in an area famous for the discovery of tombs from the Archaic period and possible traces of settlement from the Roman period.

The remains preserved on the Cornaleto (593 m above sea level) could be dated to the Middle Bronze Age and could be part of a defensive system of masonry and terracing.

The excavations took place between 2013 and 2014, with the aim of understanding the extent and nature of the evidence identified in the previous year during the survey phase. Above the Cornaleto three excavation trenches were opened (A3 on the top and two A1, A4 at a lower altitude).

Materials dating back to the protohistoric phase also emerged during the surveys carried out on the heights of the Alburni (Collina di S. Vito, the Cerri, Costa di S. Maria).

Some fragments of figurative ceramics and a crater date back to the time of the Magna Graecia colonies, mentioned by the Sestieri [27].

Some sources mention a Roman settlement, just north of the hill of S. Vito, and a boundary stone in the place, although - as often happens in the places of our peninsula - the overlap of the settlements in later times complicates the understanding of place.

The news on the town of Sant'Arsenio are, certainly, more conspicuous for the medieval and post-medieval centuries.

The foundation of the primitive settlement dates back to the early medieval period; precisely, between the Greek Gothic war and the Lombard conquest of southern Italy [28], by some Byzantine settlers, in the 6th/early 7th century AD, near the locality called Serrone [29].

Otherwise, other hypotheses see the foundation of the village dating back to the 9th–10th century AD, a period in which the southern part of the peninsula is crossed by a multitude of Italian-Greek religious who, starting from Sicily and Calabria, move towards the north to found new monasteries [30–32].

With the collapse of the Lombard power in southern Italy, the construction of the Norman Kingdom of Sicily and the rise of Roger II (1145) who, in a climate of strong political instability, local lordships and religious congregations expand their properties. The history of the Vallo di Diano, in this period (12th century) is closely linked to the Abbey of Cava de' Tirreni and the development of the *Ordo Cavensis*. In fact, information in our possession comes from the Cavense Archive and from the homonymous code [33].

The document provided the Abbey of Cava with concessions mainly in the civil sphere (exploitation of pastures, forests, men etc.) with the donation of the Church of

Santa Maria, the village of Sant'Arsenio and all the men and income connected to it. The donation appears rather punctual in the description of the boundaries of the territory of the church of Santa Maria [34].

The first mention of a church and a monastery of Sant'Arsenio is about a decade after the donation of Santa Maria, in a pontifical privilege of Eugene III of 1149 [30].

About twenty years later (1186), there is explicit mention of the church of Sant'Arsenio, with information about the presence of a prior, Cipriano, in a donation made by Andreas [35].

It is not to be excluded that the management of the monastery was entrusted to Greek monks at least until 1186 when for the first time the prior Cipriano was appointed, sent directly by Cava. The village of Sant'Arsenio is still mentioned within some imperial documents which confirm its ownership to the Cavensian abbots (1221–1231).

The last twenty years of the thirteenth century represents a turning point in the management policy of its dependencies by the Abbey of Cava. With the crisis of the great monastic possessions and the devastation brought to Vallo di Diano by the Vespro war (1282–1302) priorates, farmhouses and appliances pass or are destroyed.

In 1310–1320 Roberto d'Angiò, on behalf of his father Carlo II, started an investigation to ascertain the ability to pay of the houses, following the war events, revealing a very impoverished reality for Sant'Arsenio. In 1381–1382 the abbot of Cava, Antonio, imposed on his vassals the oath of loyalty, given in the name of the community of Sant'Arsenio by the judge Cirone of Gargano. In 1394, Pope Boniface IX raised Cava as the seat of the diocese, giving the Cavense abbots the episcopal jurisdiction and including the church of Sant'Arsenio in the dowry. Between the 14th and 15th centuries the village of Sant'Arsenio appears to be flourishing with about 200 fires, vegetable gardens, cultivated lands, mills, ovens and various pastures [30].

3 Results: An Agreement Between Literary Sources, Materials and Technology

The information in our possession about the archaeological potential of the territory of Sant'Arsenio appears relatively poor if compared to those available for the municipalities in the district (Polla, Atena Lucana, Teggiano, Sala Consilina).

This lack is to be attributed to the absence of systematic studies and archaeological research activities in the area.

The place presents, from a strictly archaeological point of view, pros and cons.

Like most small towns in Campania, in fact, it is a multi-layered village. Some "historic" places have maintained unchanged toponyms and connotations and they are still identifiable today (a clear example is represented by the places called Fontanella, Lamato, Secchio, Foce, Serra La Compra and Costa Santa Maria). Furthermore, life continued uninterruptedly from the medieval period to the present and urbanization seems to have only partially involved the surrounding fields and the western highlands.

The information reported in the bibliography of the last century has exposed for Sant'Arsenio a fairly variegated picture with archaic necropolis and Roman elements placed in the plain, near the present cemetery, and an occupation of the heights during

the middle ages, which has given life to the current historic center and the expansion of the village, later, inside the Vallo di Diano.

The data reported in the previous pages show a complex and articulated situation from an archaeological point of view, to which an abundance of sources is associated with a lack of material elements.

The analysis of Sentinel-2 images, visible and non-visible, has allowed us to identify some areas that, according to the sources, with archaeological data and with an anthropological *ratio*, seem to be of interest for the Cultural Heritage (*see* Fig. 2).

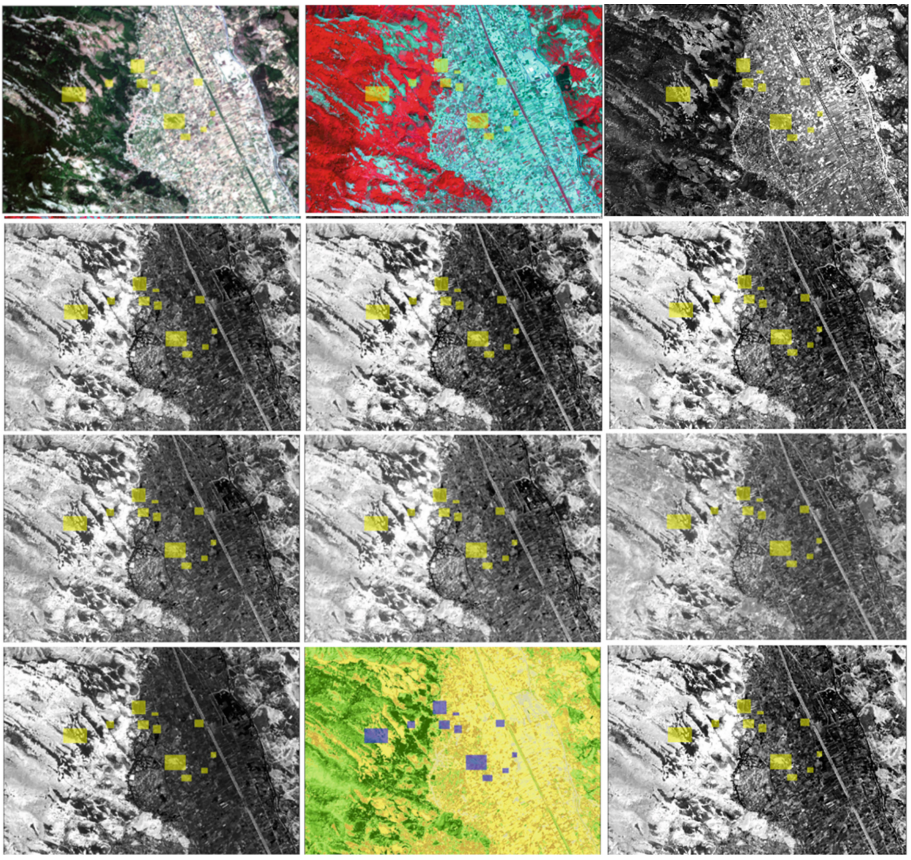

Fig. 2. From the top left corner to the bottom right corner: RGB, NIR-RG, BAI, DVI, EVI, MCARI, GDVI, GNDVI, NDWI, GRVI, NDVI, NDI.

The different indices used, shown in Table 2, in agreement with the present bibliography, show variations in vegetation and plowed fields.

The AOIs, for which further study is proposed in the future, are located within or on the borders of the municipality of Sant'Arsenio.

To the West/North-West, on the heights, some "spectral" anomalies have highlighted possible archaeological sites on the San Vito hill (*see* Fig. 3, n. 19) and of the Cornaleto (*see* Fig. 3, n. 14), supported from the multi-temporal images present within the National Geoportal; on the top of Serra la Compra (*see* Fig. 3, n. 15; *see* Fig. 4); behind Monte Carmelo in a place called Il Lago (*see* Fig. 3, nn. 1, 2, 16; *see* Fig. 5).

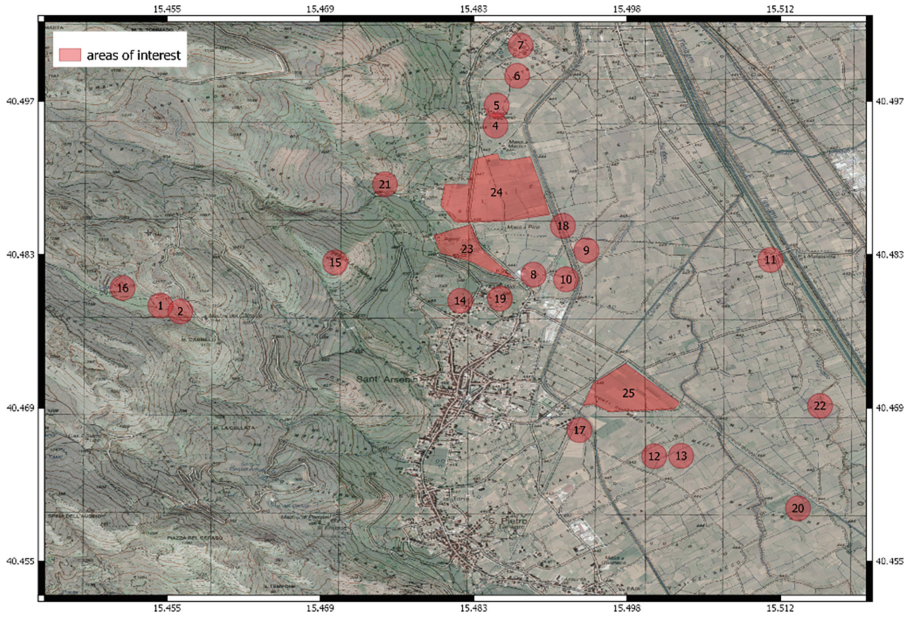

Fig. 3. Areas of interest.

On the height of Serra la Compra, the anomaly found - identified as a possible site of prehistoric age, similar to that found on the Cornaleto - appears as a patch of abundant vegetation, which detaches clearly from the barren landscape of the surrounding area. This evidence is clearly visible within the Sentinel-2 images, on a multitemporal scale, within the various indices and in the analysis of the spectral signatures of the examined pixels, in accordance with what established by the modern bibliography [36].

The survey improved knowledge of the site on Mount Carmel, in a place called Il Lago.

The site is a large rectangular structure and, from Sentinel-2 images, looks like a church. Furthermore, not far from this structure, an anomaly orthogonal to the road is clearly visible.

A thorough investigation was conducted for these anomalies thanks to the use of a drone [37] and 3D photogrammetry [38–40].

The analysis allowed us to understand the nature of the buildings. These are not religious buildings but could be old buildings useful for water management (*see* Fig. 6).

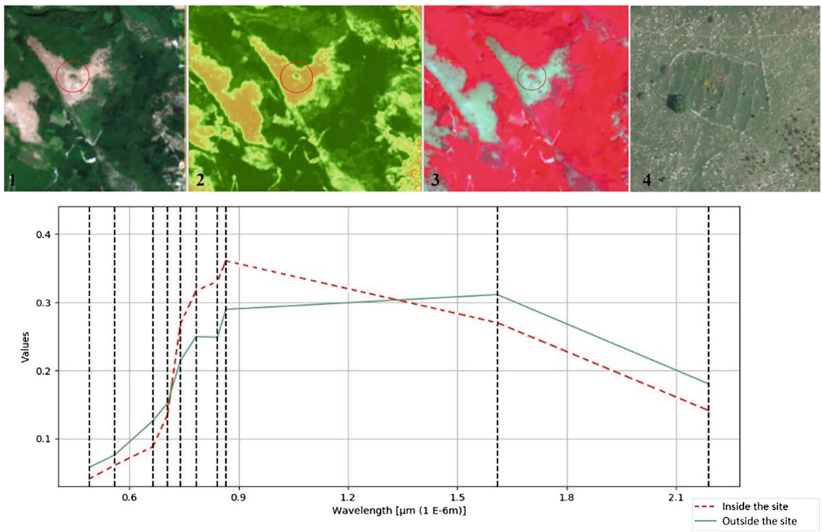

Fig. 4. Serra la Compra through the use of Sentinel 2 satellite images and image from the National Geoportal (1. RGB; 2. NDVI; 3. NIR-RG; 4 RGB from NG).

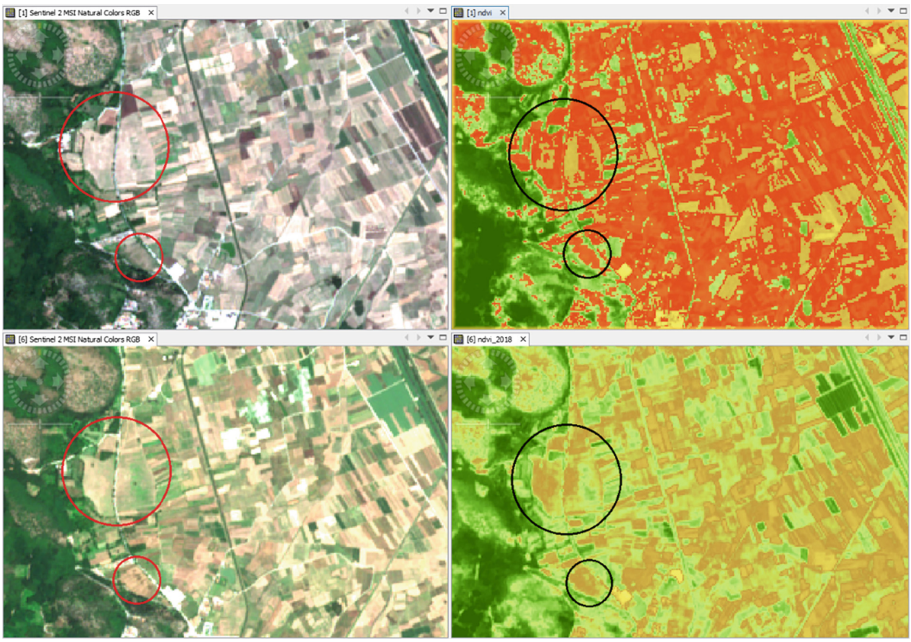

Fig. 5. AOIs north of the town (Sentinel 2 images: RGB and NDVI).

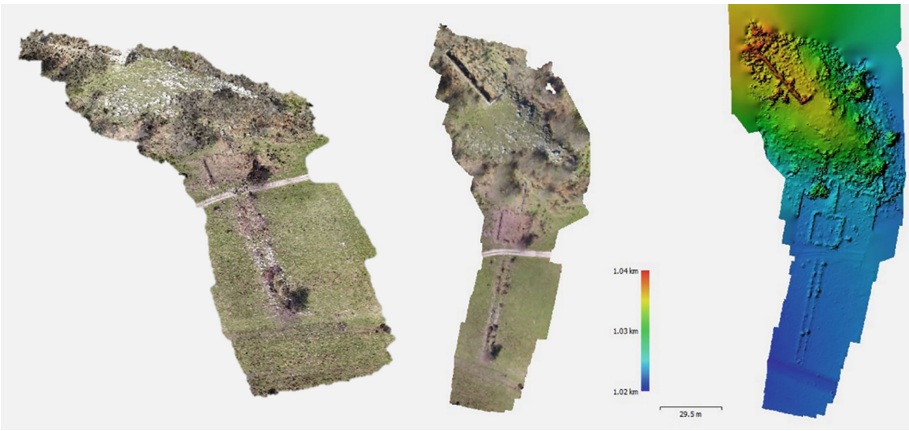

Fig. 6. Results obtained through the use of a UAV on Mount Carmelo.

To the north towards Polla, the bibliography speaks of a possible necropolis of the Archaic period and a Roman settlement. Hypothetically, it is possible that the sites mentioned may be located in Contrada Parisi and Contrada Priore, in the area known as Pozzo (*see* Fig. 3, nn. 23–24), for which a fairly large anomaly is reported.

Slightly to the west, along the course of the river, there are evidences that could be of archaeological interest (*see* Fig. 3, n. 21); while other spots to consider are located in the locality called Foce and in Petrosa, near the border with the municipality of Polla (*see* Fig. 3, nn. 4–7).

In the East some anomalies lead to the signaling of some places that could prove interesting - traces of ancient canalizations interrupted by large circular anomalies - arranged along the medieval border of the municipality of Sant'Arsenio in the Lamato locality and Fossa locality, close to the current road "Via fosso del Mulino" (*see* Fig. 3, nn. 11–13, 17, 20, 22, 25).

4 Conclusions

Although in a preliminary way, the synergy between archaeological research and data acquired through Remote Sensing appears to be useful for the study, knowledge, research and protection of visible and non-visible structures. In particular, the use of data and software freely provided by the European Space Agency (ESA) through the Copernicus program and the "sentinels" greatly facilitates the retrieval of information and its processing.

The Sentinel-2 images, in fact, have the advantage of providing a fairly good resolution for preliminary analysis (10 m) and are systematically acquired, allowing data to be processed on a time series.

The multispectrality made available by Sentinel-2 also allows the user to be able to range over the non-visible, using the individual bands (B4, B8) to observe the particular spectral response of some elements or to combine them to obtain additional

information from the various indices. In the case of archeology, profits turned out to be the indices listed above; in particular, the analysis of those related to the state of health of vegetation and humidity was significant (EVI, NDVI, NDWI).

Although the territory of Sant'Arsenio is not optimal for the use of satellite images with a resolution of over ten meters, the comparative analysis of archaeological data and multispectral images Sentinel-2A allowed the identification of different areas of interest archaeological.

This study is a proof of how a multidisciplinary approach is now the very essence of research. The cognitive potential of the archaeological method is, in fact, exponentially increased thanks to the contribution of Remote Sensing. The practical demonstration is that provided by the example of the sites identified on the heights of Serra La Compra and in Locality Lago, practically never identified by the human eye but clearly visible within the satellite images.

Furthermore, the satellite data allows to give strength to only advanced ideas thanks to the archaeological studies as in the cases of the anomalies identified north of the municipality, where the existence of an archaic necropolis/Roman settlement is assumed.

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