

Article

Preventive Archaeology Based on Open Remote Sensing Data and Tools: The Cases of Sant'Arsenio (SA) and Foggia (FG), Italy

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Abstract: Sentinel-2 data have been used in various fields of human activity. In cultural heritage, their potential is still to be fully explored. This paper aims to illustrate how remote sensing and open source tools are useful for archaeological investigations. The whole issue revolves around the application of satellite (Sentinel-2) and accessory tools for the identification, knowledge and protection of the cultural heritage of two areas of southern Italy: Sant'Arsenio (SA) and Foggia (FG). Both study cases were selected for a specific reason: to demonstrate the usefulness of open data and software for research and preservation of cultural heritage, as in the case of urban sprawl, development of public works (gas- and oil-pipelines, etc.) or intensive use of land for agricultural purposes. The results obtained are relevant for the knowledge improvement and very useful to operate in the field of preventive archaeology, for the evaluation and management of risk, the planning of city-expansion or infrastructures that could damage the buried heritage.

Keywords: remote sensing; satellite; risk monitoring; archaeology; cultural heritage preservation; open data; Sentinel-2; GIS

1. Introduction

Interest in Cultural Heritage (CH) has increased in the 21st century, as communities have come to better appreciate the productive role that heritage can play in our vision of a better future. The result of this awareness is the entry of CH in the UNESCO (United Nations Educational, Scientific and Cultural Organisation) SDGs (Sustainable Development Goals).

The Agenda 2030, in fact, includes explicit references to CH, concerning sustainable development and the promotion of cultures and diversity. Furthermore, it stresses the need to preserve, protect, and promote cultural and natural heritage (4.7, 8.9, 11.4, and 12b).

This recognition has been the basis for the use of economic and technological resources as never seen before, with continuous incentives for research and development. The result of the combination of interest, use of resources and tools has certainly played a fundamental role in the development of a multidisciplinary approach for the protection and preservation of CH. In addition, the 21st century is the time when open source and open data issues are important for world community, also thanks to the technological developments including Earth Observation (EO) and Information and Communication Technologies (ICT).

Moreover, the availability of open databases and free data processing tools has exponentially increased the use of EO and ICT in diverse fields, including CH. Among the open source tools, those provided by the Copernicus Programme are excellent for Earth monitoring and, potentially, also for CH.

1.1. Copernicus Programme and Tools for Cultural Heritage

The Copernicus Programme is coordinated by the European Commission. It was created through collaboration between Member States, the European Space Agency (ESA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the European Centre for Medium-Term Weather Forecasts (ECMWF), EU agencies and Mercator Océan. The idea was born from the need to monitor and safeguard the Earth's resources, for the benefit of all citizens, in several fields with a totally open source policy.

The Copernicus Programme uses the Sentinels: dedicated satellites owned by the European Union. The aim of the project, started in 2014, is to send more than twelve Sentinels with different sensors into space. Each satellite has its own characteristics and sensors. Detailed information on the Copernicus Programme and the status of Sentinel missions can be found directly on the ESA website (<https://sentinel.esa.int/web/sentinel/home>).

Sentinel-2 provides multispectral data that are very useful for several applications ranging from environmental monitoring to risk estimation and also offers great potentiality for archaeological investigation thanks to its multispectral capability and spatial resolution (up to 10 m/pixel). Actually, the detection of buried archaeological remains depends on the spatial resolution of the sensors as well as on the geophysical contrast between the archaeological features and their surroundings [1].

The presence of buried remains causes anomalies in the spectral response of soil and vegetation and, therefore, can be revealed by the so called proxy indicators (generally known as crop and soil marks). For example, buried remains (walls, pits and ditches) affect the state of vegetation and soil, thus causing differences in the spectral behaviour well evident in some bands and emphasised by several spectral combinations [2].

1.2. Purpose

The 20th and 21st are centuries of technological development as well as of unprecedented urban and infrastructural expansion. This phenomenon is a serious risk for CH. To prevent this, specific archaeological surveys (generally known as “rescue” and/or “preventive” archaeology) are requested to prevent damages and increase knowledge of areas that should be involved in urban and infrastructural expansion, or licensed for oil exploitation or other activities which can adversely affect CH. This is a pressing issue in Italy (the country that holds the record for UNESCO sites, 54 in 2018) where CH and archaeological sites have an enormous density compared to its extension. The rules of preventive archaeology in the case of large public and private buildings are relatively new (<http://www.sbap-pr.beniculturali.it/index.php?it/206/verifica-preventiva-interesse-archeologico>).

The state and superintendencies claim an “Archaeological Risk Assessment” for the protection and preservation of the CH [3] based on specific (rescue and preventive) archaeological surveys based on investigations and in situ analysis and documentation.

In this framework, protection, sustainability and research are the issues of this paper, which provides an overview on the potentiality of Copernicus data along with free national/international services such as Google tools for archaeological investigations. All of these tools can be promptly combined with traditional approaches, integrated with ancillary information, and, in the case Sentinel 2 data systematically available and weekly updated for the whole globe.

To assess the potentiality of Sentinel 2 data for archaeological investigations, two significant test sites have been selected: the municipality of Sant’Arsenio (SA) and some areas located in the Foggia (FG) province.

For Sant’Arsenio, scarce archaeological information is available due to the lack of systematic archaeological investigations. This is extremely counterproductive for the creation of an urban development plan and for the tourist enhancement of the territory. Instead, over the years, starting from the 1940s, Foggia area has been largely investigated also using remote sensing tools. Therefore, in the first case, the aim was the improvement of archaeological knowledge through a multidisciplinary approach mainly based on remote sensing technologies. In the second case, the main aim was to assess the potentiality of

Sentinel 2 data for the identification of large-scale archaeological evidence while also exploiting the rich information today promptly available for validation purposes.

2. Materials and Methods

2.1. Sant'Arsenio

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

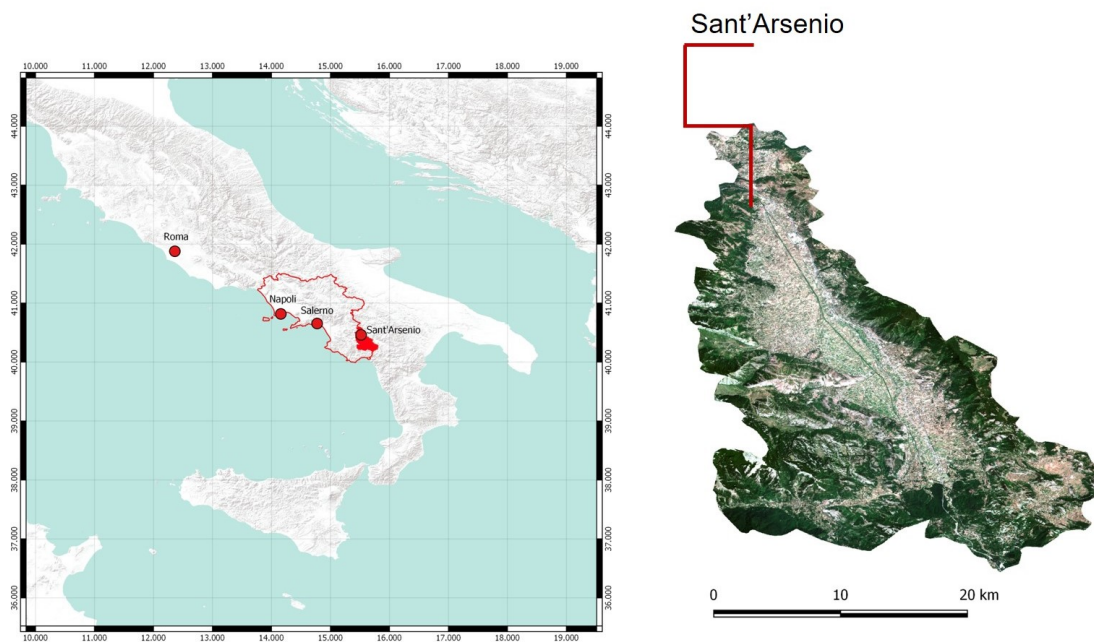


Figure 1. Sant'Arsenio (Salerno, Campania, Italy).

The valley, located on the border between Campania and Basilicata, dates back to the beginning of the Pleistocene and it was as a large lake basin. The Vallo di Diano shows archaeological traces of human occupation from prehistory to the Iron Age and was reclaimed in the Roman period for farmland [4–9]. S. Arsenio is a medieval small town, whose “importance” increased during the 12th century when it was under the Abbey of Cava de’ Tirreni.

Up to now, the most ancient archaeological evidences were identified 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) and Prof. A. Cazzella (University of Rome La Sapienza), and coordinated in the field by Dr. F. Nomi (University of Rome 3), in the years 2012, 2013 and 2014 [6,7]. The researchers conducted in the framework of these projects found materials and remains of inhabited areas from the Eneolithic (3800 BC) to the Bronze Age (1700 BC) and fragments of cups dating back to the 8th–6th century BC, in an area known for the discovery of Archaic tombs and traces of a Roman settlement.

The remains preserved on the Cornaleto (593 m above sea level) are datable to the Middle Bronze Age and are 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 archaeological remains identified. Materials dating back to the protohistoric phase emerged during the surveys carried out on the heights of the Alburni (S. Vito, Cerri, and Costa di S. Maria). Sestieri mentioned the finding of some fragment of figurative ceramics dating back to the time of the Magna Grecia colonies [10].

Some sources mentioned a Roman settlement, just to the north of the hill of S. Vito, and a boundary/mile stone in the place seems to confirm the data.

The information about Sant'Arzenio town are conspicuous for the medieval and post-medieval centuries. The settlement dates back to the early medieval period, between the Greek-Gothic war and the Lombard conquest of southern Italy [11], by some Byzantine settlers, in the 6th/early 7th century AD, near the locality called Serrone [12]. Nevertheless, other hypotheses suggest the foundation of the village in the 9th/10th century AD, a period in which the southern part of the peninsula is crossed by a multitude of Italian–Greek religious from Sicily and Calabria [12–14].

During the period of Norman expansion (12th century), the story of Sant'Arzenio was 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 [15,16]. The first mention of a church and of a monastery of Sant'Arzenio was in a pontifical privilege of Eugene III (1149) [13]. Twenty years later (1186), the church of Sant'Arzenio was mentioned, with information about the presence of a prior, Cipriano, in a donation made by Andreas [17].

Probably, 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'Arzenio was still mentioned within some imperial documents, which confirm its ownership to the Cavensian abbots (1221–1231). The last twenty years of the 13th century represented a turning point in the management policy of its dependencies by the Abbey of Cava due of the crisis of the great monastic orders and the war of Vespers (1282–1302).

During 1381–1382, the abbot of Cava, Antonio, imposed on his vassals the oath of loyalty, given in the name of the community of Sant'Arzenio by the judge Cirone di 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'Arzenio in the dowry. Between the 14th and 15th centuries, the village of Sant'Arzenio was flourishing with high population, and a large number of mills and ovens as well as the expansion of cultivated land lands and pastures [13].

2.2. Foggia and Its Territory

The territory of Foggia (Figure 2), in Apulia (south Italy) is very well studied and known.

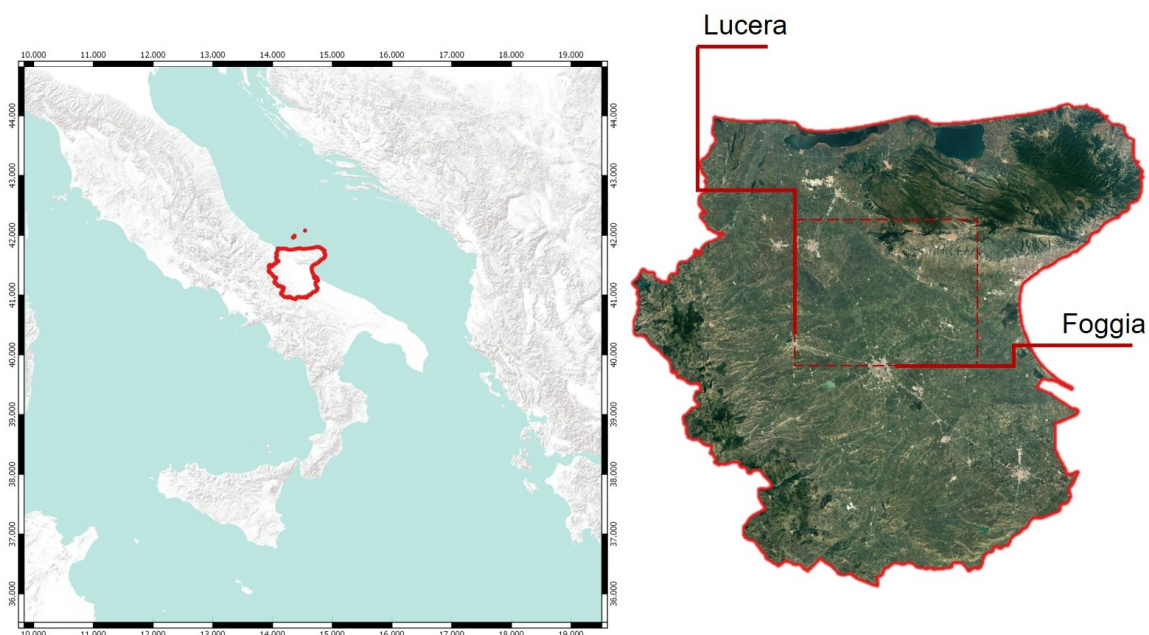


Figure 2. Foggia (Apulia, Italy).

Archaeological evidences in the area had already been investigated in the past by excavation and survey and are already the subject of publications of remote sensing and geophysical applied to CH [18–20].

The study area is enclosed by Lucera, Foggia, San Giovanni Rotondo and San Severo. Foggia is famous for the presence of many Neolithic settlements, dating from the 6th to 4th millennium BC.

A fortuitous mixture of geological, climatic and agricultural elements allows us to see the traces of buried structures (villages, huts, roads, etc.) thanks to the abundant presence of crop-marks.

In fact, after World War II, John Spencer Purvis Bradford, stationed at the air base of San Severo, observed the aerial photos of the RAF (Royal Air Force) and understood the relationship between visible anomalies in the growth of vegetation and the presence of buried archaeological remains [21].

Bradford discovered one of the largest Neolithic settlements in the world: Passo di Corvo. The evidences that were noticed by Bradford are typical for Neolithic sites. Some previous studies have analysed the presence of archaeological indicators on a time basis and the response to remote sensing surveys of circular and sub-circular anomalies [18].

The area of Foggia is considered the cradle of agriculture in Italy and Europe. The area has other Neolithic settlements; some examples are: Masseria Pantano (Foggia) [22], Masseria Acquasalsa, San Rocco-Guadone (San Severo), Piano Morto (Candela-FG), Biccari (FG) [23], Masseria Schifata and Masseria Palmori (Lucera) [24]. In addition to the Neolithic settlements, the area shows abundant traces of other civilisations. The archaeological sites of Arpi (in Greek Argos Hippium) date back to the 2nd millennium B.C. [25].

In ancient times, the region was divided into three parts: (i) Daunia in the north, which in the Middle Ages was called Capitanata; (ii) Peucezia/Terra di Bari, in the middle; and (iii) Salento, or Terra d'Otranto, in the south. The city of Lucera is considered one of the most important cities of Daune. For the Greek geographer Strabo (58 B.C.–24 A.D.), the origins of the city are attributed to Diomedes, after his escape from Troy [26].

Leaving aside the myth, Lucera was an important city during the Roman period. It was placed at the head of one of the four “province questorie” [27]. The events of the whole area continued in the early Middle Ages. The Byzantines, the Lombards, and the Saracens left traces in the culture and in the architecture [28].

Moreover, the region was one of the favourites of Frederick II. In 1230, at the time of the promulgation of the Liber Augustalis and the great administrative reforms, Frederick II completed the division of the territory of the kingdom into provinces, each entrusted to a Giustiziere. He created two new provinces, alongside the Land of Bari and the Land of Otranto, already existing in the 12th century: Capitanata and Basilicata. Within the Capitanata, Frederick II was the promoter of a fervent building activity that involves the territory of Foggia with the construction of farmhouses, castles and fortresses [29,30].

The history of the territory of Foggia is complex. We cannot outline detailed picture in these short lines. As described, Apulia is as a territory strongly permeated by archaeology and historically stratified over the centuries. In a piece of land, we are witness of thousands of years of history hidden in a few metres below the surface [18].

2.3. Sentinel-2

Since their launches in 2015/2017, Sentinel-2 (A and B) satellite data have probably represented one of the best free tools available until today. Sentinel-2 is currently the only orbiting device that provides free data at high resolution (HR) and, above all, acquired on a regular frequency (every five days). Sentinel data can be downloaded free from the Copernicus Open Access Hub platform. In addition, the ESA has made available for free the SNAP software tool to process the data.

The usefulness of the Sentinel tool for the recognition, study and safeguarding of CH has been preliminarily explored or experimentally proposed in several papers [31–39].

One of the strengths of Sentinel-2 images is linked to their spatial resolution and multispectral capability. The Blue (B2), Green (B3), Red (B4) and NIR (B8) bands have a spatial resolution of 10 m. The other bands have a spatial resolution of 20 m (B5–B7, B11 and B12) or 60 m (B1, B9 and B10) (Table 1).

Spatial resolution is important in the case of remote sensing for the discrimination of targets (in term of physical size). The acquisition of multispectral bands is equally important because it allows observing the different reflectances of the elements of the image and to work on multi-channel images. This, as shown below, is useful for archaeological investigations [31,39].

Table 1. Spectral bands of Sentinel-2A images (from ESA website/userguide/spatial).

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

In this study, Sentinel-2 data were processed for two selected study cases: Sant’Arsenio and Foggia. Sentinel-2 images of Sant’Arsenio cover a period from 23 May 2016 to 25 October 2018. The images of Foggia cover a period from 12 June 2016 to 08 January 2018. For both case studies, the same data processing was used.

In all cases, the images have a cloud coverage of less than 10% and clouds do not cover the area of interest.

After downloading, SNAP software was used for image processing, which was done automatically, thanks to the “graph builder” option.

The workflow is made up of the following steps: read, resampling, subset, bandmath, time series analysis, principal component analysis and write.

The first function is the resampling: It is a native function in SNAP software useful for re-scaling the pixel resolution and benefit from all Sentinel-2 bands [40–42]. We used B4 (10 m) as reference band from source product for each Sentinel-2 file and the nearest neighbor as method.

After the resampling, a subset function was used to crop the images on the areas of interest and make faster the processing phase. Subset allows choosing the border using a polygon shape file or a latitude/longitude corners system. The subset areas on Sant’Arsenio and Foggia are 4.123 ha and 95.730 ha, respectively.

SNAP software offers different images processing tools. One of them is the possibility to combine different bands in a Red–Green–Blue (RGB) colour composite. RGB colour composite is a common practice in remote sensing for CH and it provides us with a multi-channel image using each band in a different channel. The number of RGB composite combinations is equal to the number of possible mathematical combinations of the spectral bands [2].

After resampling process, SNAP gives the possibility to create different RGB images thanks to pre-set options, based on Sentinel-2 bands attributes. Different RGB composite images can enhance different type of features. We used three type of composition to observe the areas: 4–3–2; 8–4–3; and 8–11–2 (Table 1). The first is a simple RGB image. The second and the third are false colour infrared

and healthy vegetation images. While the first is very close to the human eye's perception, the other two are useful to see anomalies in vegetation and farmland, based on reflectance response [43].

Another fundamental tool in SNAP is the BandMath, which allows us to process the different bands to calculate multiple indices for each Sentinel-2 image, following the most recent bibliography [31,39,44,45].

Two types of indices, vegetation health monitoring and soil analysis (Table 2), were focalised because they are the most commonly used in archaeology. They are useful to enhance crop and soil anomalies on the basis of spectral signature characteristics [46–48].

Table 2. Calculated indices.

Index	Equation	Reference
Burned Area Index (BAI)	$\frac{1}{(0.1-B4)^2 + (0.06-B8)^2}$	[49]
Difference Vegetation Index (DVI)	$B8 - B4$	[50]
Enhanced Vegetation Index (EVI)	$2.5 \times \frac{(B8-B4)}{(B8+6 \times B4-7.5 \times B2+1)}$	[51]
Green Difference Vegetation Index (GDVI)	$B8 - B3$	[52]
Green Normalised Difference Vegetation Index (GNDVI)	$\frac{(B8-B3)}{(B8+B3)}$	[52]
Green Ratio Vegetation Index (GRVI)	$\frac{B8}{B3}$	[52]
Normalised Difference Vegetation Index (NDVI)	$\frac{(B8-B4)}{(B8+B4)}$	[53]
Normalised Archaeological Index (NAI)	$\frac{(B7-B5)}{(B7+B5)}$	[31]
Modified Chlorophyll Absorption in Reflectance Index	$((B5 - B4) - 0.2 \times (B5 - B3)) \times (\frac{B5}{B4})$	[54]
Soil band	$0.09 \times B2 + 0.27 \times B3 - 0.71 \times B4 - 0.65 \times B8$	[54]
Crop band	$-0.38 \times B3 - 0.71 \times B2 + 0.2 \times B4 - 0.56 \times B8$	[54]
Normalised Difference Moisture Index (NDMI)	$\frac{(B8-B11)}{(B8+B11)}$	[55]
Soil Adjusted Vegetation Index (SAVI)	$\frac{1.5 \times (B8-B4)}{(B8+B4+0.5)}$	[56]
Simple Ratio Nir/Red	$\frac{B8}{B4}$	[57]

In both cases (Sant'Arsenio and Foggia), the indices highlighted spots related to the probable presence of archaeological evidence.

The software also allows “tracking” the spectral signature of the pixels [58,59].

The different indices enhanced the differences in vegetation and soils, thus facilitating the identification of buried structures and areas of potential archaeological interest.

The anomalies in vegetation and soil, usually denoted as crop- and soil-mark, are closely linked to several factors and, for this reason, during different periods of the year may vary [18].

The tool “Time Series Analysis” (TSA) was used to overcome this problem and understand the intra- and inter-year trends of crop marks. TSA is a native function on SNAP that allows us to see

the spectral signature of a pixel in different Sentinel-2 tiles. The signature is represented in a graph where on the abscissa is the time and the ordinate is the reflectance value [59–62].

After the temporal analysis, Principal Component Analysis (PCA) was computed using the different indices. PCA is useful to reduce data redundancy providing a new series of less correlated bands, limiting the loss of information [63–65]. Spectral discrimination between surface components is more visible in the PCA than in individual bands. For example, in the case of Foggia, we have 10 Sentinel-2 tiles multiplied by the sum of processed indices and bands, plus three RGB colour composites for each tile. Thanks to PCA, we created an RGB colour composite using: R, first PCA band; G, second PCA band; B, third PCA band. The same procedure was done for the images of Sant’Arsenio.

Obviously, the work on a single file is easier than the simultaneous management of dozens of images. Each image was exported in geo.tiff format to be analysed in the Qgis and Saga GIS software.

2.4. Other Tools

In addition to Sentinel-2 images, research was conducted using other data and tools available for free. The aim was to acquire as much information as possible, in a relatively short time.

2.4.1. Google Tools

The first tool is Google Earth (<https://www.google.it/intl/it/earth/>), which was made available free by the technology giant Google in 2005 [66,67].

Google Earth (GE) is the most popular 3D visualisation software for the globe and is currently also free in its Pro version. GE allows us to observe the globe and shows RGB images. The user can zoom in and out on images with a very high detail and, above all, can observe images acquired on different dates. The images are acquired from satellites or planes and have an excellent spatial resolution (VHR) [68]. The use of GE is excellent for CH, and in the case of Sant’Arsenio (SA) and Foggia (FG). The access to historical images [68] allows us to observe the variation of the crop-marks in time, even after years.

In addition to Google Earth, another free Google portal, Google Maps, is useful in remote sensing for CH. Google tools can easily be linked to GIS software for an immediate comparison between Google data and satellite data.

2.4.2. National Service Tools

In the same way, another fundamental tool is the National Geoportal viewer (<http://www.pcn.minambiente.it/viewer/>).

The viewer provides a series of really useful data and images. The best data are certainly the optical data. The images, in fact, have a high resolution and a time scale that goes from 1988 to 2012. Moreover, the services allows us to superimpose different thematic maps or other data on the cartographic layer, such as: LiDAR 1 m × 1 m, LiDAR 2 m × 2 m, risk zones (water, fire, etc.), Corine Land Cover, IGM (cartography of the Italian Military Geographic Institute), DEM (Digital Elevation Model), etc. An added value to the viewer of the National Geoportal is the ability to connect the different layers directly to the Qgis software through the use of WMS layers.

The mentioned tools are a fundamental part of the study of the areas of Sant’Arsenio and Foggia. In addition, only for the province of Foggia, there is the WebGis CARTApulia (<http://www.cartapulia.it/>) that is the “Archaeological Map of the CH of the Apulia Region”. Thanks to the WebGis information system, we could consult a map containing sites from prehistory to the modern age.

2.4.3. UAV for Cultural Heritage

In the case of Sant’Arsenio, to better understand the archaeological evidence found in the satellite images, a Phantom 3 Professional (UAV) was used to survey Mount Carmelo from above. In total, 99 photos were acquired in 25 min of flight and the data processing was done through

the software Agisoft Photoscan. Thanks to this, we created a dense point cloud, a mesh model and a textured model. The software Cloud Compare allowed us to create a DEM (Digital Elevation Model), contour lines, and orthophotos.

All the data thus obtained and described (historical sources, modern bibliography, surveys, Sentinel-2 images, images from Google Earth/Maps, data from the National Geoportal, etc.) were integrated using a Gis (Qgis) platform

3. Results

The following results are a summary of the considerations taken from the processed dataset.

3.1. Sant' Arsenio

The main purpose of the research conducted on Sant' Arsenio was the knowledge improvement for a future enhancement of the territory. As mentioned above, the information about Sant' Arsenio is scarce if compared with that of other places in the area and thanks, to the use of remote sensing and ancillary data, the knowledge gap was partially filled.

According to the information reported in the bibliography of the last century, Sant' Arsenio has been characterised by a long human frequentation, characterised by Neolithic settlements, archaic necropolis, Roman remains and medieval settlements on the top of hills. Actually, the data show a complex and articulated situation from an archaeological point of view, with an abundance of sources associated with a lack of investigations and in situ confirmations.

The analysis of Sentinel-2 images allowed us to identify some areas that seem to be of archaeological interest for the CH (Figure 3).

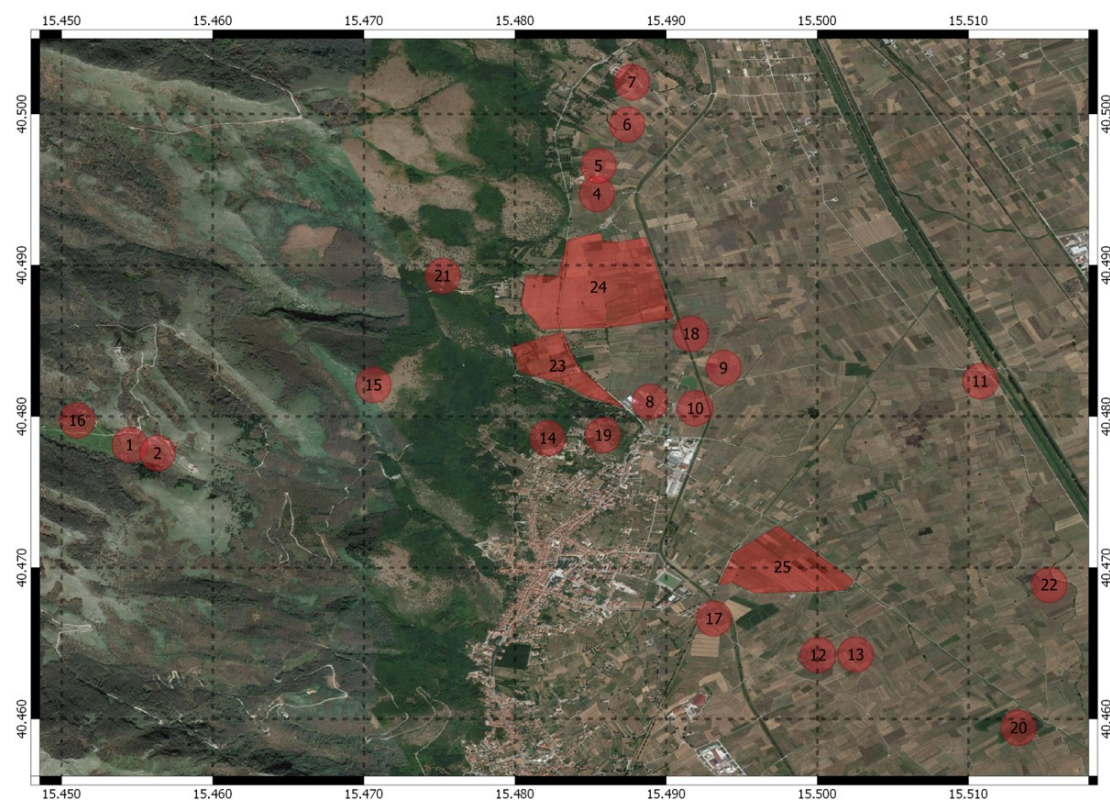


Figure 3. Areas of archaeological interest in Sant' Arsenio.

The different indices used (Table 2) well fit with the available bibliography. The AOIs are located inside or on the borders of the municipality of Sant' Arsenio.

To the west/northwest, on the heights, some “spectral” anomalies have highlighted possible archaeological sites: on the San Vito hill (Figure 3, No. 19); on the Cornaleto (Figure 3, No. 14); on the top of Serra la Compra (Figure 3, No. 15; Figure 4); and behind Monte Carmelo in a place called Il Lago (Figures 3 and 5, Nos. 1, 2, and 16).

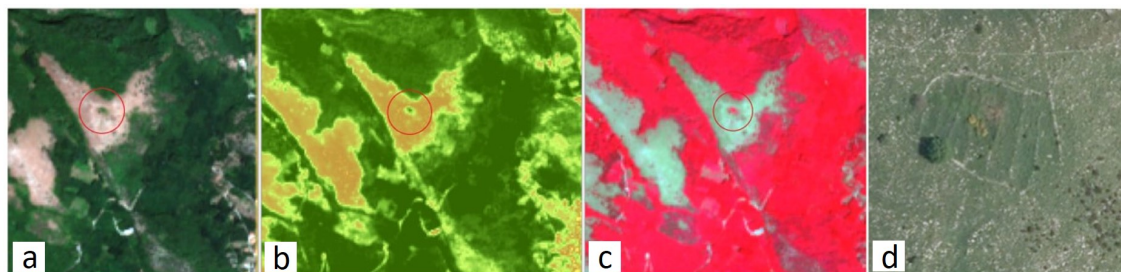


Figure 4. Site of Serra la Compra: (a) RGB Sentinel-2; (b) NDVI Sentinel-2; (c) NRG Sentinel-2; and (d) National Geoportal).

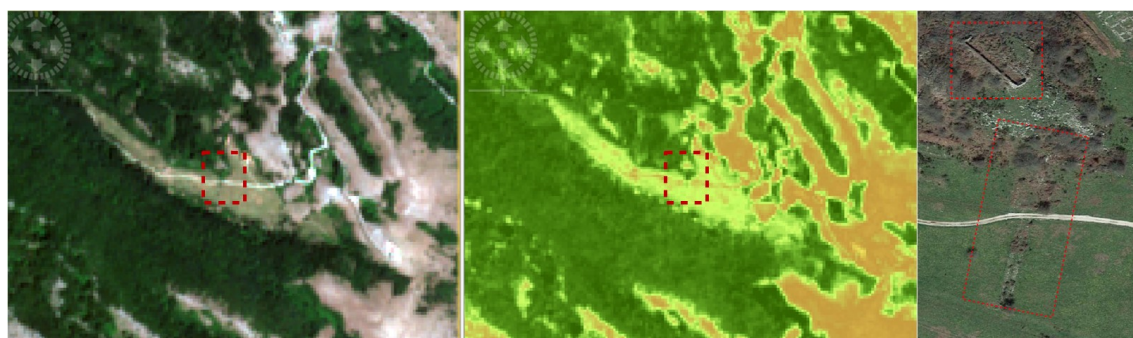


Figure 5. Site on Mount Carmelo (RGB Sentinel-2, NDVI Sentinel-2, and National Geoportal).

3.1.1. Serra la Compra

On the height of Serra la Compra, we found an archaeological feature similar to that found on the Cornaleto. This feature is clearly visible within Sentinel-2 images, on a multitemporal scale, from the various indices and in the analysis of the spectral signatures of the examined pixels [2].

The feature on the hill could be another Neolithic settlement. However, further investigations will be conducted in the future.

3.1.2. Mount Carmelo

The analysis of the data revealed a small anomaly on the top of Mount Carmel. From above, a rectangular structure, associated with other structures that cut across the main road, is clearly visible. Field and Unmanned (UAV) surveys were conducted to verify the presence and typology of these structures [60,69–71]: old buildings useful for water management (Figure 6).

3.1.3. Remote Sensing, Historical Sources and Archaeological Data

To the north, the bibliography mentions the presence of an Archaic necropolis and a Roman settlement. Hypothetically, these sites may be located in Contrada Parisi and Contrada Priore, in the area known as Pozzo (Figure 3, Nos. 23 and 24), for which a fairly large anomaly is reported.

To the west, along the course of the river, there are evidences that could be of archaeological interest (Figure 3, No. 21). Other features to consider are located in the locality called Foce, near the border with the municipality of Polla (Figure 3, Nos. 4–7).

This place is currently called “Via fosso del Mulino” and could take its name—as for other places in Sant’Arsenio—from the presence of mills during the Middle Ages (Figure 3, Nos. 11–13, 17, 20, 22, and 25).

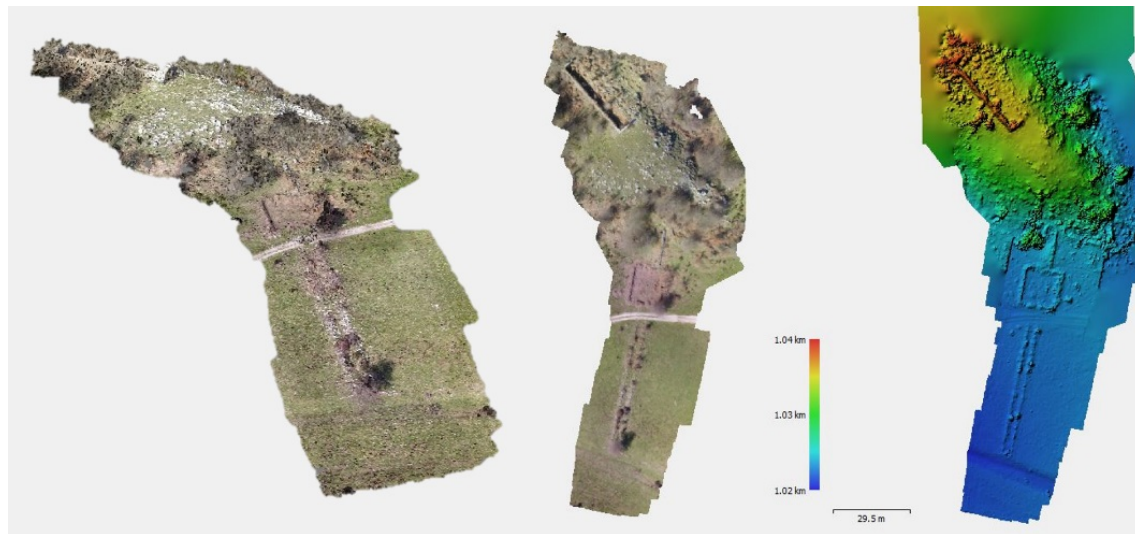


Figure 6. Mount Carmelo (point cloud and DEM).

3.2. Foggia

For Foggia, the aim of the investigation was mainly to assess the capability of Sentinel 2 for archaeological investigations. We are aware of the complicated network of settlements, roads and other structures hidden by the soil.

The analysis of multi-temporal series of Sentinel-2 allowed us to highlight the different periods in which the proxy indicators of the presence of archaeological remains are visible. The indicators seem to be clearly visible at certain times of the year such as spring, late summer and autumn. Obviously, the analysis of the spectral signature of the anomalies, observed from the different indices, varies on the basis of the bands involved in the creation of the index itself. The most performing indices for the identification of crop-marks and traces in agriculture are certainly those defined as crop-band, soil-band and SR (NIR/Red) (Table 2). The images were processed in different ways, giving different results each time.

We identified anomalies in most cases and used unsupervised classification to automatically track areas of interest. The k-means cluster analysis method was used for the classification. The unsupervised classification gave satisfactory results: it showed that the areas of archaeological interest are red areas surrounded by green spots. The correspondence of the points marked by these colours is quite faithful to that provided by other tools (Figure 7).

However, even if very satisfactory, the results are not enough good to judge the map as valid, clean, and precise. In fact, the image has a lot of noise.

The RGB on the PCA provided an excellent image for the optical identification of buried elements. This image allowed us to see in blue the traces of buried elements, related to settlements, roads, paleorivers, and paleocanals (Figure 8). It was compared with what was known by CARTApulia and from the previous studies on the area and the feedback is impressive. In addition, thanks to the presence of excellent photos on Google Earth and on the National Geoportal, we can have an immediate view in VHR for a direct feedback of the data.

Many of the already known sites (e.g., Masseria Palmori, Masseria Schifata, and Masseria Villano) are visible (Figure 8). In addition, we can easily identify ancient rivers, old roads and communication routes, even if not surveyed by the accessory tools described above (Figure 9).

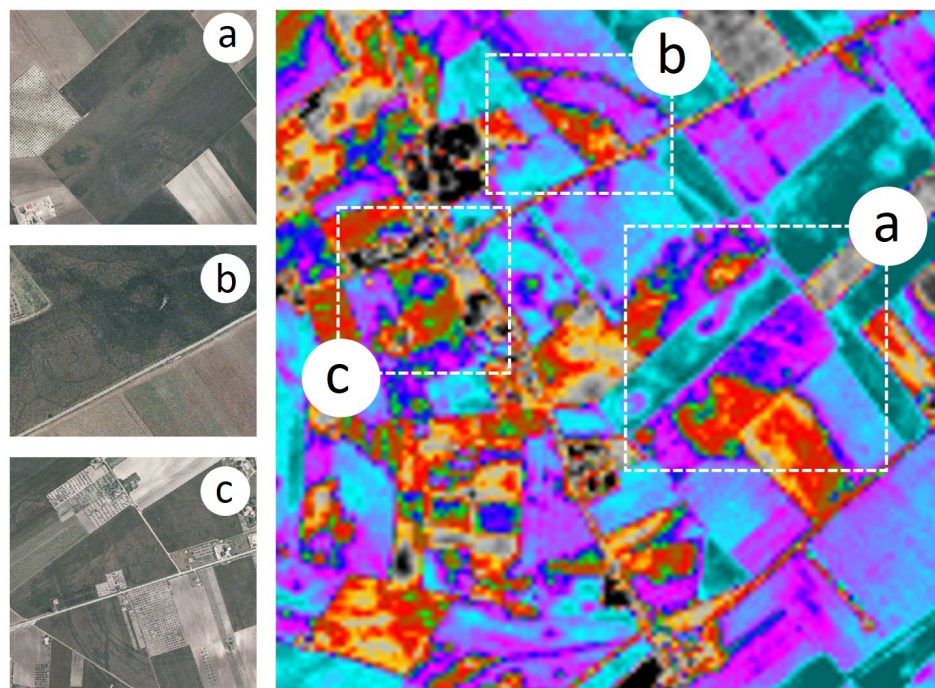


Figure 7. Unsupervised Classification. Archaeological ROIs are in red. Some examples: (a) M. Villano; and (b,c) M. Palmori.

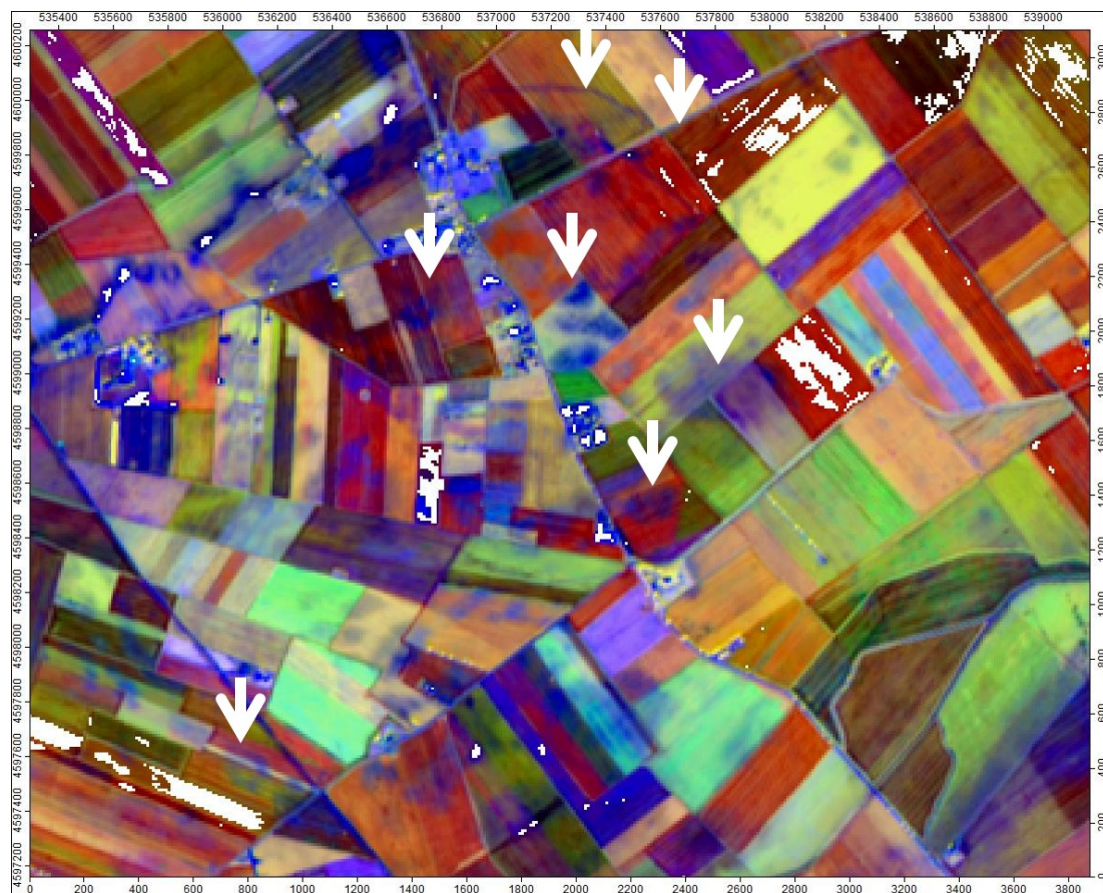


Figure 8. RGB obtained from the first, second and third PCs.

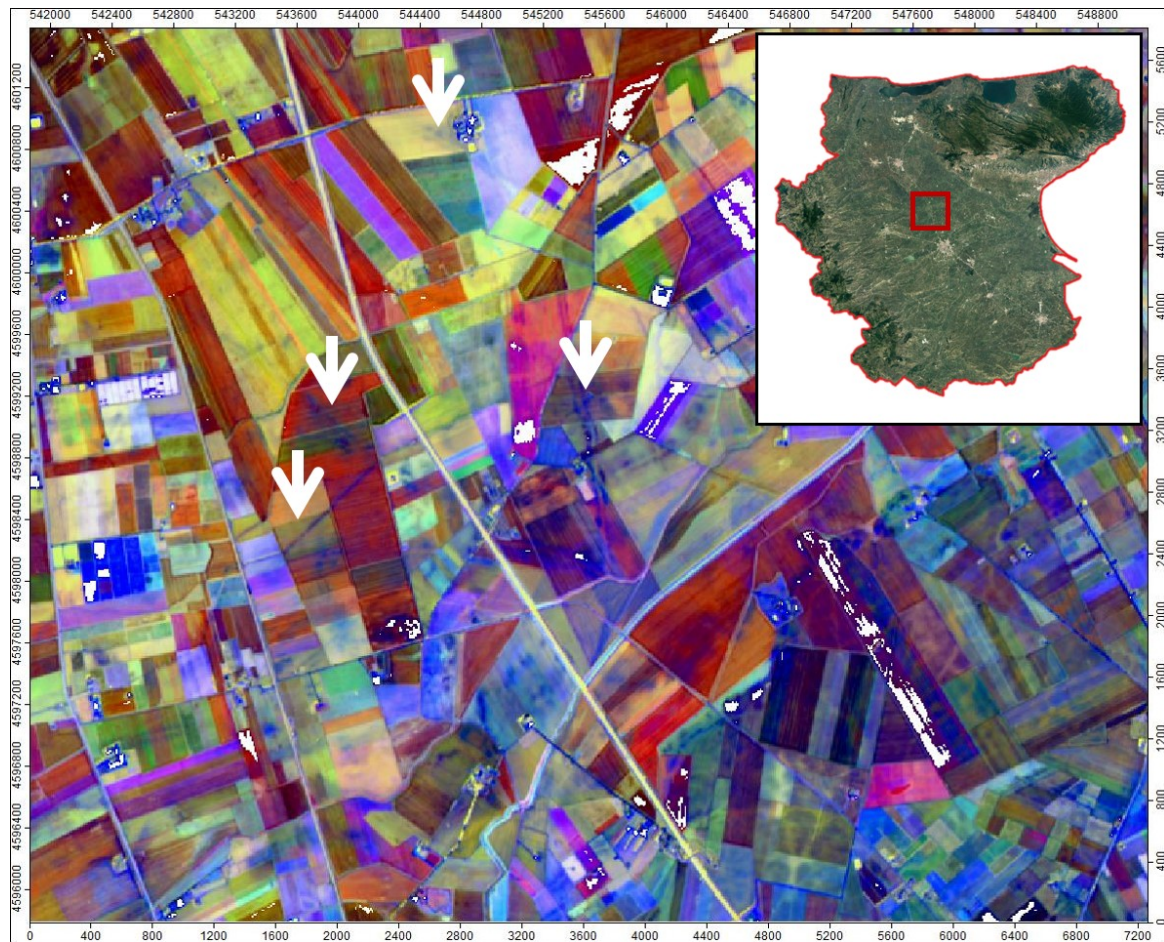


Figure 9. ROIs present in other areas. Neolithic settlements, ancient roads and paleo-rivers are clearly visible.

Even well-known sites, such as the Passo di Corvo, can be investigated with these methodologies and the result can always surprise. In fact, the images show the entire perimeter of the Neolithic settlement, well beyond the small excavated area. The results are only a small part of those observed and for us it would be, in this case, impossible to describe them individually.

4. Conclusions

The use of EO tools in archaeology can be linked to different purposes, as research and preservation. 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. Obviously, the use of satellite images has its pros and cons. In the case of buried archaeological remains, one of the main limitations of Sentinel-2 images is the spatial resolution. In fact, below 10 m, the evidence is not visible or distinguishable. This is the case of much archaeological evidences (burials, structures, and walls) that have a sub-pixel resolution. Of course, Sentinel-2 images do not enable us to record and discriminate these features. In addition, archaeological proxy indicators (crop- and soil-marks) are not always visible due to the specific vegetation phenology, the meteorological conditions or the state of the soil (vegetation, type of agriculture practiced, etc.).

Sentinel-2 offers many potentialities linked to multispectral capability and weekly systematic data acquisition. The multispectral capability of Sentinel-2 enables the user to range over the non-visible, using the individual bands (B4 and B8) to observe the particular spectral response of some targets or to combine them to obtain additional information from the various indices. In particular, the analysis of those related to the state of health of vegetation, crop and humidity has been significant.

In addition, the repeated acquisition every few days is a great advantage. However, the importance of Sentinel-2 is mainly related to systematic monitoring for supporting a sustainable land development and planning potential land-use changes. The study on the municipality of Sant'Arzenio was an experimental application devised in the framework of the Memorandum of Understanding (MoU) signed by the Municipality and the Institute of Methodologies for Environmental Analysis of the National Research Council (CNR-IMAA).

The research activities were mainly addressed to a preliminary investigations to estimate the archaeological potential of the territory. Knowledge about the presence of potential archaeological areas is very useful to interact directly with the superintendence and to protect the heritage in case of urban expansion or new infrastructure construction. The municipal administration has expressly requested an estimation on the potential archaeological areas as support for the PUC (Municipal Urban Plan). The usefulness of having a municipal urban plan is forced by the current administration to plan a development of the municipality mainly promoting cultural heritage. Thanks to this MoU, the municipality of Sant'Arzenio has now begun to structure an urban development plan based on the archaeological data that improved significantly the knowledge about the territory. Obviously, the data collected still needs to be further studied in depth, integrated and enriched with other data sources, bibliography field surveys and excavations.

The study on Foggia was conducted with the aim to assess the archaeological potentiality of Sentinel-2 for a very large area in a relatively short time. This case study was a methodological exercise in the hypothesis of having to use free data to approach the production of an archaeological risk assessment. The territory of Foggia has proved to be excellent for the use of remote sensing techniques applied to cultural heritage. The images have returned many archaeological evidences, well differentiated from the background. Many of the evidences identified are already known in CartApulia or in the bibliography, however others are absolutely new. The nature of the evidence is a more complex issue. In some cases, comparing the features, it is easily imaginable. However, here again, additional investigations and even excavations can provide more information.

In any case, the procedure has proved extremely useful and could be included in the practices for the creation of the archaeological risk documentation to be handed over to the superintendencies. The methodological approach herein proposed is only based on open data and free tools and this is an important issue being that economic resources and time are often scarce compared to the extension of the territory to be investigated.

The case of Foggia is different and also the starting idea behind the study is different. The study on Foggia was conducted with the aim of being able to evaluate in advance the archaeological potential of a very large area in a relatively short time. The choice, as already specified, fell on this area for the presence of an abundant bibliography and other useful tools to immediately confirm the validity of our data.

The evaluation was a methodological exercise in the hypothesis of having to use free data to approach the production of an archaeological risk assessment. The territory of Foggia has proved to be excellent for the use of remote sensing techniques applied to cultural heritage. The images have returned a large number of archaeological evidence, well differentiated from the background. Many of the evidences identified are already known in CartApulia or in the bibliography, however others are absolutely new. The nature of the evidence is a more complex issue. In some cases, comparing the features, it is easily imaginable. However, here again, only other instruments can provide more information.

In any case, the procedure has proved extremely useful and could be included in the practices for the creation of the archaeological risk documentation to be handed over to the superintendencies. Adding another tool to those already available to the archaeologist could help. In addition, each tool is free and easy to use. This is important in a field where economic resources and time are often scarce.

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