Integrated Archaeological Investigations for the Study of the Greater Aquileia Area

Arianna Traviglia
Department of Ancient History, W6A 338 Macquarie University,
NSW 2019, Australia
arianna.traviglia@mq.edu.au

Abstract. A large number of technologies, such as Geographic Information Systems (GIS), Global Positioning Systems (GPS), Remote Sensing (RS), geophysical instruments, allows nowadays for fast and reliable automated capture, management and analysis of archaeological data. *Beyond the City Walls* (BCW) is a landscape archaeology project based in the countryside of the Roman *municipium* of Aquileia (Italy) that applies and integrates these technologies for the reconstruction of peripheral settlement dynamics in antiquity, trialling concurrently tools that operate as hubs for acquisition of disparate field data.

Keywords: Archaeological remote sensing, Aerial photography, Multispectral and hyperspectral data, Historical maps image processing, GIS, GPS.

1 Introduction

From its ‘official’ inception in the second part of the 19th century, the archaeological research on Aquileia has mainly concentrated on the analysis of building and planning aspects of the Roman city, focussing on issues related to the urban sector [1-3]. The surrounding countryside has by comparison received little consideration, with just a limited number of projects focussed on the reconstruction of the suburban settlement system, or the functional distribution of suburban spaces being performed during the last decades [4-8]. The systematic detection of the landscape spatial organisation using remotely-sensed data and topographic survey has been scarcely undertaken in the area, and where this has occurred it has not been followed by consistent ground-testing to verify the nature and scope of the detected traces. These attempts were based in turn either on aerial photography [9] and multi and hyperspectral data [10-13]; however, some of these pioneering efforts in remote sensing-based landscape reconstructions have not always found complete support within the archaeological discourses [5].

1.1 Beyond the city walls

Against this background, the 'Beyond the City Walls (BCW): the landscapes of Aquileia' project[1] aims to provide a timely study of Aquileian landscapes to understand trends of peripheral occupation at different scales and times.

The study seeks to illuminate the landscape settlement dynamics of Aquileia's periphery in antiquity, as seen through the layers of subsequent reorganisation of the land, and to re-orient the discussion from an exclusive focus on the city to a broader understanding of the city's relationship with the periphery and surrounding landscape. These goals are being pursued using a combination of traditional archaeological research together with a flexible data modelling system, automated data collection in the field and the employment of geomatics (including the use of Geographic Information Systems (GIS), multi and hyper-spectral remote sensing, and geophysical methods). Remote sensing plays here a fundamental role in the identification of the Roman spatial signature on the Aquileian landscape, contributing efficiently in the detection of the elements of the built and natural environments that are constituents of the past landscape.

1.2 The case study area

The BCW project includes a vast portion of the peripheral territory of Aquileia, namely the Communes of Aquileia, Terzo di Aquileia, Fiumicello, Villa Vicentina, Cervignano, Grado, Marano Lagunare, Ruda, Torviscosa, and Turriaco (Fig.1). To properly assess the dynamics of landscape transformation, large areas and multiple locations need in fact to be holistically investigated. Examination of a single location, unrelated to its broader landscape and cultural context, would provide only a limited view of the functional characteristics of the investigated landscape.

The area, ranging from a coastal tract to a primarily flat, fertile plain, was altered in the past by geomorphic processes related to rising sea levels [14] and the migration of rivers [15] as well as human-induced change.

---

[1] BCW is a Macquarie University (Sydney, Australia) research project directed by the Author and performed in collaboration with the Superintendence of the Archaeological Heritage of Friuli Venezia Giulia.

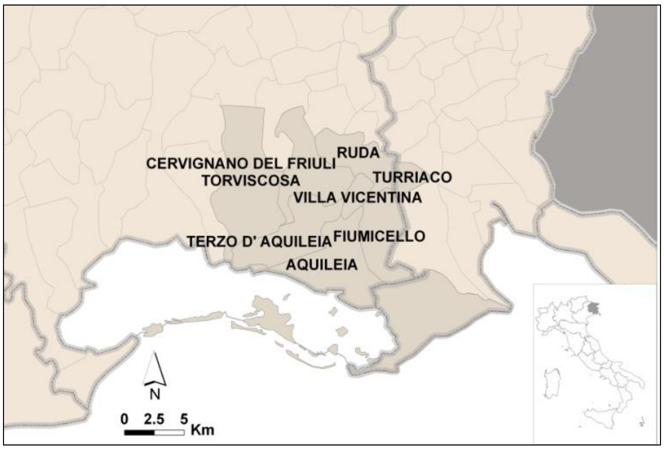

Fig. 1. The extent of the case study area.

2 Sensing the Aquileian landscapes

Remote sensing in landscape studies holds a key role in the identification of data on the ground that is unobtainable using traditional archaeological fieldwork techniques. The imagery has the potential not only to disclose a substantial amount of information related to isolated anthropogenic features but also to elucidate landscape transformations connected to ancient human modifications of the environment.

Multi-sourced and multi-temporal remote sensing imagery coverage is needed in order to collect as much information as possible in relation to a territory that has undergone major transformations in the past 80 years. For this reason a large acquisition campaign has been undertaken resulting, at the current state of research, in a holding of around 350 images, whose number increases exponentially once we consider the processed images[2]. Aerial, multi and hyperspectral data are included in this material. In addition, digital topographic data from radar systems (Shuttle Radar Topography Mission -SRTM-) and satellite-borne sensors (Advanced Spaceborne Thermal Emission and Reflection Radiometer -ASTER- GDEM) have been acquired to be used as reference datasets in the interpretive process.

2.1 The remote sensing imagery

Aerial photos. A vast survey of available past and recent aerial photographs has been undertaken (and is still in progress) in several regional and national institutions to achieve the most comprehensive coverage of the investigated area and provide a wide temporal span. The available imagery includes historical and modern photos spanning from vertical photos dated 1938 to recent orthophotos dated 2007, with an average of at least one aerial

[2] Each image can in fact undergo up to 10 or more different processes creating new imagery that requires separate examination [18].

coverage every ten years. Historical photos[3] hold an incredible documentary value since they document the state of the Aquileian landscape in a period preceding the massive reclamation works started in 1933. It is therefore a straightforward procedure to detect anthropogenic features, land partitions and outdated tracks that are no longer traceable in the current territorial configuration.

Modern aerials[4] (Fig. 2) provide important insights into the transformation of the territory and are a vital reference for identifying recent traces of territorial changes that may be easily mistaken as ancient.

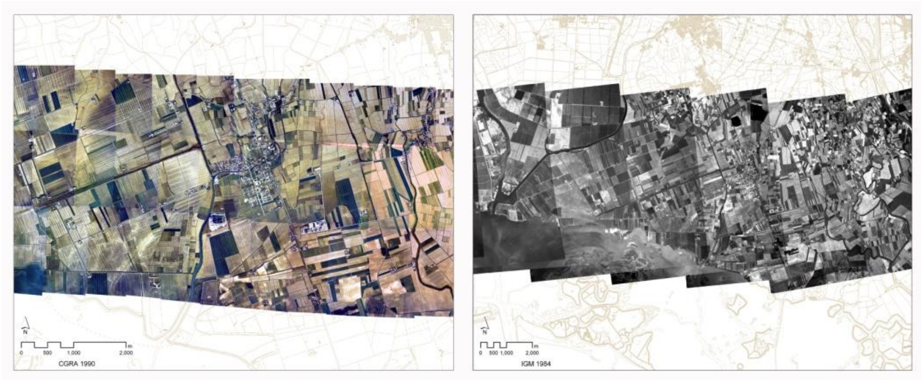

Fig. 2. Geo-referenced aerial photos (CGRA 1990 left, IGM 1984 right).

Multispectral and hyperspectral data. The current provision of multi- and hyperspectral data includes Landsat TM5, ASTER, GeoEye Ikonos and Daedalus Multispectral Infrared and Visible imaging Spectrometer (MIVIS) imagery, with GeoEye GeoEye-1 and DigitalGlobe Quickbird in the process of acquisition. While the poor resolution of Landsat TM and ASTER (respectively 30m and 15/30/90m according to the band) make them mainly suitable for detection of broad environmental features, MIVIS and Ikonos (with a surface resolution respectively of 3m and 4m -multispectral-) are demonstrably effective in the remote recognition of anthropogenic and natural traces of medium-small size, having a minimum average area of 40m^2 or a length of at least 15/20m (Fig. 3). MIVIS and Ikonos resolution is limited in comparison to some of the latest HR multispectral products, such as Quickbird and GeoEye-1, but the amplitude of the portions of the electromagnetic spectrum they cover (especially with regard to the IR band) makes them highly suitable imagery for archaeological goals.

[3] The holding includes IGM (Military Geographic Institute) coverage from 1938, 1945, 1954.

[4] Modern aerials include IGM coverage from 1974 and 1984, CGRA (Compagnia Generale Riprese Aeree, Parma) coverages from 1990 and Orthophotos from 2000, 2003, 2007.

Fig. 3. Linear traces evident on a TC display of a MIVIS run, located east of the Aquileia *Circus* [18]

DEM data. In order to define an objective framework for assessing the interpretations of traces, a SRTM3 DEM (90 m nominal resolution) and a ASTER GDEM (30 m nominal resolution) are systematically being used as a reference dataset and compared to the remotely sensed data, providing important information that contributes to a better understanding of the feature patterns.

2.2 Image processing

Image processing of remote sensing data is a fundamental step in the enhancement of the visibility of traces. The goal of the enhancement techniques is to increase and improve the optical distinction between features and traces recorded in the scene by generating a new image where the useful information is more easily detectable and measurable.

Currently 1/3 of the acquired aerial images have been already processed for routine image restoration and enhancement[5] as well as ortho-rectified and geo-referenced, while the completion of the procedure is expected by the end of the year.

A vast range of procedures has been applied to multi and hyperspectral imagery according to the type of environmental settings represented in each image or in portions of it. Among them, Vegetation Indices (VI), Principal Components Analysis (PCA) and Soil Line Index (SLI) have proved to be extremely useful to augment the visibility and definition of traces.

Vegetation Indices. Vegetation indices provide critical information of variability in the amount, development and vigour of vegetation, and have thus proven extremely valuable in archaeological research for detecting natural and archaeological deposits that augment or limit the growth of the plants [16-17]. The presence of extraneous elements (such as construction debris) in the composition of the subsoil can have a strong impact on the growth of the vegetation, determining the manifestation of “marks” over the vegetation.

[5] Image enhancement of aerial includes common procedures such as contrast enhancement, histogram equalisation, interactive grey-level slicing (thresholding).

The vegetation becomes, in this way, the mediating element of the subsurface heterogeneity.

Vegetation Indices are particularly efficient when computed over hyperspectral data, such as MIVIS, due to their fine quantisation of spectral information, which allows for accurate definition of absorption features. As part of the standard procedure of VIs application to the MIVIS data available for Aquileia, an average of 5 to 7 different VIs have been trialled [18] on each MIVIS scene, including indexes like DVI, NDVI, MSAVI2[6]. As a result, a substantial number of potential archaeological features, made visible through alteration over the vegetation, have been identified and mapped (Fig. 4).

Fig. 4. The use of MSAVI2 (right) allows for visualising linear traces that are not visible in the True colour (left) MIVIS data.

PCA and Selective PCA. Principal Component Analysis has found substantial usage in archaeological research since it can improve the differentiation of dissimilar surfaces, landform and geomorphic features, which thus become more distinguishable during visual inspection. PC transformation is particularly suitable for MIVIS hyperspectral data since starting from MIVIS original and redundant 102 bands it generates a new, limited series of bands (the Principal Components), where the information content is concentrated. The transformed bands can then be used for visual analysis in lieu of the original, numerous MIVIS bands. Principal Components 1, 2 and 3 of MIVIS data have demonstrated to hold virtually all of the variance in the scene (on average 99.6 %) and, as a consequence, of the

[6] Difference Vegetation Index (DVI) is a subtraction operation involving Red and NIR pixel values: DVI=NIR-R; RVI [19]; Normalized Difference Vegetation Index (NDVI) is the difference of the Red and Near Infrared band combination divided by the sum of the Red and Near Infrared band combination: NDVI = (NIR – Red)/(NIR + Red) [20]; 2nd Modified Soil Adjusted Vegetation Index (MSAVI2) is a recursion of MSAVI: MSAVI2 = (1/2)*[2(NIR+1) - √ (2(NIR+1) 2- 8(NIR- Red)] [21]. See [22] for a discussion on their application to archaeological contexts.

total information, although valuable information can occasionally be found in higher-order Principal Components [22].

To overcome the inevitable loss of details entailed in the PCA[7], a SPCA (Selective Principal Components Analysis), which is a PCA computed for groups of bands belonging the same spectral region or to a single spectrometer of the sensor, is routinely applied to Aquileia's MIVIS scenes and Selected Components are then displayed in composites using a dedicated correlation matrix in order to identify the minimum set of SPCs able to provide most complete information [22].

Soil Line Index. A Soil Line Index was defined to provide support in the identification of archaeological traces on bare soil using MIVIS data [23]. The SLI produces a new image where the optical distinction between the wetness or the dryness of the top soil is increased. By accentuating the dry-wet discrimination, the index facilitated the distinction of linear or areal features from the surrounding ground.

2.3 From remote sensing to remote mapping

Raw and processed RS datasets are being managed into a GIS environment. The remotely sensed traces holding an archaeological potential identified on the processed images are converted to vector coverage. The process is accomplished via heads-up digitising, tracing on-screen the outlines of traces deemed to have an archaeological interest. The detected anthropogenic features and the topographical anomalies are being mapped at a nominal scale of 1:1000 and being given a series of attributes to encapsulate pertinent information. Among the attributes being retained in this process are metadata about the image process(es) that facilitated identification, the degree of visibility of the trace, the likely interpretation of the feature and the photo-interpretation factor (dimension, alignment, orientation, shape, texture, pattern, size) which supported its detection.

At the current state of advancement, over 700 features have been identified and tagged (Fig.5) using less than 1/3 of the available imagery. The identified features concur to create a preliminary repository map, which is then tested by contrasting the mapped traces against available datasets (see par. 3) suitable for the trace validation process. Experience shows that a high number of these features will be discounted when contrasted with those ancillary data as well as during and after the ground check. The trace crosscheck procedure is one of the steps for the creation of a final ‘Map repository of remotely sensed anthropogenic traces’.

[7] Many details that are visible when analysing the original separate bands cannot always be recognised in the PCs because they are concealed by the overlaying information from other bands.

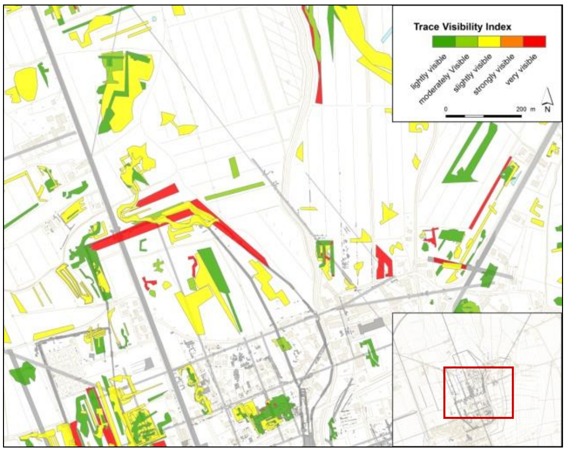

Fig. 5. Detail of remotely detected traces plotted against Aquileian ancient topography (modern topography in background). In this visualisation, they are colour coded based on their visibility.

3 Assessing the image detection procedure

One of the most challenging steps of every remote sensing project is the trace assessment and substantiation i.e. the procedure of validating through auxiliary datasets the traces, features and anomalies detected during the visual analysis of remote sensing imagery. Although ground truthing activities for verification of remotely obtained trace datasets (see below par. 4) assume vast relevance, the constant cross-reference to ancillary datasets (cartographic -modern and historical-, archival, archaeological) is an essential stage of the process of validation or discounting of the detected traces, reducing time consumption during the interpretation process and providing the basis for a prioritised strategy of ground verification.

3.1 A GIS for the Aquileian territory

The BCW GIS (©ESRI ArcGIS 10) manages a vast range of pre-existing topographical and cultural datasets as well as project generated survey and remote sensing datasets that concur to build an understanding of the landscape transformation. The datasets incorporate modern geospatial information, historical mapping, archaeological and cultural records.

Contrasted against these comprehensive data assets, the traces repository map can be refined by assigning each feature a value of ‘archaeological reliability’ [18, 22], i.e. an evaluation (expressed as a percentile) of the potential of such feature to have an archaeological nature.

3.2 Modern cartography

The Region Friuli Venezia Giulia holds a substantial asset of digital cartography including a complete regional digital coverage in scale 1:5000 and 1:25000[8]. The available coverage serves as a topographical base layer both for mapping features and surveying activities on the field, providing a high level of detail and accuracy as well as constant update.

Pre-digital cartographic materials, produced between 1970 and 1990, have been likewise acquired by scanning and geo-referencing them, since they retain a significant number of useful information related to landscape changes that occurred in recent times.[9]

A vast assortment of thematic maps[10] are also available to the project, making available a substantial body of environmental information supporting the reconstruction of the past landscape evolution.

3.3 Historical cartography

The Aquileian landscape is depicted in a large number of small and large-scale historical maps from a period spanning nearly 400 years. Such documentation provides key insights on landscapes arrangements, changing settlement patterns, and landscape elements preserving relics of ancient activities.

Historical maps have been -and are still being-collected from regional and national archives[11]. Currently approximately 90 maps representing the Aquileian countryside and the peri-urban area, have been identified suitable for this project. A systematic semantic and conceptual analysis, for the purpose of data modelling, is being conducted on the already acquired maps. As part of their acquisition in the data modelling system, all the maps undergo geo-referencing procedure, although many of the earliest ones exhibit planometric distortions that make them too complex to use directly (Fig. 6). To overcome this deficiency, the maps are processed manually after the geo-referencing in order to map elements that provide insight on the settlement dynamics and at the time of their drafting. This procedure captures nearly all map-specific information, and is well suited for data mining and more sophisticated visualisations of the results.

---

[8] A 1:10000 scale coverage, obtained through photo-reduction of the 1:5000 coverage, is also available.

[9] A primary use is the fact that the orientation of the irrigation ditches can be and often has been changed in past decades. These previous water channels are clearly visible in remote sensing imagery and can easily been mistaken for centuriation markers or other ancient features.

[10] The collection includes the Geologic Map of Friuli Venezia Giulia (scale 1:150.000), and the Technical-Geological Map (scale 1:5.000) incorporating the Geomorphological Map, the Subsoil Map, and the Structural Map.

[11] Namely the State Archives of Triest, Venice and Gorizia, the *Capitolo* Archive of Udine, the Provincial Archive of Gorizia and a number of libraries, including the *Biblioteca Joppi* of Udine, the *Biblioteca Statale Isontina* of Gorizia and the *Marciana* National Library of Venice.

Fig. 6. A Napoleonic Cadastral map (1811) geo-referenced against the modern topographic maps. On the right: the zoom shows the Napoleonic map plotted against the modern topographic map.

3.4 Archaeological and cultural datasets

A comprehensive archaeological map in vector format of the Aquileian countryside has been created by digitisation of published archaeological cartography[12] and a systematic collection and plotting of archaeological literature. Location of past casual finds, excavations, and surveys have been recorded with the best possible level of accuracy, although this was not always achievable in reference to decades old information. The inclusive map supplies contextualisation for remote sensing and survey obtained data as well as historical mapping datasets, allowing comparison with the elements that compose the past landscape and their interpretation.

4 Ground truth activities

A critical part of any archaeological application of remote sensing is the fieldwork component of the project. A large number of cross tests assists in the verification of identified traces and the quality control of image processing techniques, with field walking survey and use of geophysics instrumentation underpinning the substantiation of the ground mapped features.
At the current state of the research the prospective archaeological sites are inspected through systematic field walking survey. In a future stage of the project, the sites with the highest archaeological reliability will be investigated through geophysical methods, namely Ground Penetrating Radar and Electromagnetic survey.

These ground-based methods will support the verification of underground archaeological deposits and will eventually result in the collection of detailed physical dimensions of the detected features.

[12] Archaeological map holdings include [1, 24]. Archaeological maps from 18th and 19th centuries (such as the ones realised from G.D. Bertoli, C. Baubela, E. Maionica and P. Kandler) are included in the historical cartographic dataset.

4.1 Ground survey

Field survey is being carried out following conventional procedure of field-walking in (virtual) grids or line transects, subject to the consent of the local landowners. Current verifications are being conducted in March-April and October-November periods, with repetition of ground-truthing activities at the same location, in order to ensure systematic coverage over the investigated areas and possibility of better visibility of detected features in dissimilar environmental, climatic and seasonal conditions.

The survey activities include differential GPS recordings of transects/grids and on surface visible features, in addition to documentation of surface artefacts using mobile devices by systematically mapping the density distribution of artefacts and their spatial variability. Fieldwork relies heavily on automated procedures of mobile data recording because of a number of practical issues related to fast data collection, connected to the opportunity to access large fields only for limited periods.

Fieldwalker App. Fieldwalker is a custom-made Android App developed for this project in order to speed up the field data collection. The App runs on a Samsung Galaxy tablet and is remotely connected via Wi-fi to the GPS to receive positioning and geo-locate field-recorded data in real time. By entering the relative positions of the surveyors and tracking the walking path via GPS, it is possible to store textual, photographic and graphic information on the field for each positions of the surveyors. The App also works in fact as a hub for automated acquisitions of geo-located photo shots on the field and manual drawing. Although mobile GIS products are commercially available, the App expands considerably the capabilities of those products providing more flexibility and customisation, and the possibility to import disparate types of data.

5 Forthcoming research

The BCW project is currently at its first stage, with three complete field campaigns and two per year, planned for the next years. As a result of the preliminary ground verifications, a number of sites holding a very high archaeological potential have been identified and will be further investigated using non-invasive geophysics methods.

Indicators of past human presence and activities, such as potsherds and other surface artefacts, are being identified, counted, sampled and plotted against the topography of the investigated areas. The count data collected on the field are being used for the creation of distribution and density maps (Fig. 7) of archaeological deposits on the plough soil surface. One of the current focuses is to distinguish assemblages that reflect the anthropogenic use of the site, from others that are just the results of different interventions, such as, for example, the terrain transfer from one location of the Aquileian countryside to another site, a common practise adopted in the area until fairly recent times as part of reclaiming the land. The goal is being pursued by the analysis of soils on which the artefacts are deposited. At the current stage of results, it appears sufficiently clear that the original stratigraphy in sections of the territory S of the Aquileia have been heavily reworked and altered, and that natural phenomena contributed to significantly modify the original deposits. Notwithstanding it is still possible to identify portions of agricultural fields, where later modifications have not changed the surface sites in a substantial way (both manifestations of covered strata or phenomena existing only on the present surface with no relationship to a stratified deposit), that retain substantial evidence of spatial distribution created by past cultural activities. The prosecution and widening of this study of high-density and low-density artefact scatters, preserving information about past human activities, will provide in turn a better understanding of the settlement dynamics and land management of the Aquileian landscapes.

Fig. 7. Distribution and density of artefacts on the ploughsoil surface (M. Chang).

Acknowledgments. The author wishes to thank the '*Servizio pianificazione territoriale*' of Regione Friuli Venezia Giulia, the Consorzio di Bonifica Bassa Friulana, the Arts eResearch at The University of Sydney, Mr D. Busato, Dr M. Chang and all the students and volunteers participating to the 2010 and 2011 surveys. Special thanks also to *Soprintendenza Archeologica del Friuli Venezia Giulia* and the National Museum of Aquileia, in the persons of Dr L. Fozzati, Dr M. Novello and Dr P. Ventura, for their kind support and assistance.
Regione Friuli Venezia Giulia data authorisation: P.M.T./1295/2100, 25-01-05.

References

1. Bertacchi, L.: Nuova pianta archeologica di Aquileia. Edizioni del Confine, Udine (2003)
2. Verzar-Bass, M. (ed): Scavi ad Aquileia, I. L'area ad est del Foro II. Rapporto degli scavi 1989-1991. Quasar, Roma (1994)
3. Strazzulla, M.J.: In paludibus moenia; problemi urbanistici di Aquileia in età Repubblicana alla luce della documentazione archeologica e delle fonti scritte. AAAd. 25, 187-228 (1989)
4. Muzzioli, M. P.: Aspetti della pianificazione della colonia di Aquileia. AAAd 59, 121-150 (2004)
5. Prench F.: Le pianificazioni agrarie di età romana nella pianura aquileiese. Editreg, Trieste (2002)
6. Maggi, P., Oriolo, F.: Dati d'archivio e prospezione di superficie: nuove prospettive di ricerca per il territorio suburbano di Aquileia. AAAd 45, 99-123 (1999)
7. Bottazzi, G., Buora, M.: Nuovi dati sul territorio di Aquileia romana. AAAd 45, 61-79 (1999)
8. Oriolo, F.: Nuovi dati sulle vie sepolcrali di Aquileia. Xantener Berichte 7, 177-180 (1998)
9. Schmiedt, G.: Contributo della fotografia aerea alla conoscenza del territorio di Aquileia. AAAd 15(1), 145-188 (1979)
10. Coren, F., Visintini D., Fales, F.M., Sterzai, P., Prearo, G., Rubinich, M.: Integrazione di dati laserscanning ed iperspettrali per applicazioni archeologiche. In: Atti della 9a Conferenza Nazionale ASITA, Catania 2005, vol. 1, pp. 793-798. ASITA, Catania (2005)
11. Sugan, M., Pipan, M., Mogorovich, P.: Integrazione di metodologie d'analisi per la ricerca di beni archeologici sepolti. In: Atti dell'8ª Conferenza Nazionale ASITA,Verona, Italy, vol. 2, pp. 1777-1782 (2003)
12. Baggio, P., Sigalotti, G.B.: Recupero dei sistemi fisico e antropico antichi mediante interpretazione da telerilevamento. In: Cantino Wataghin, G. (ed.) Antichità e Altomedioveo tra Livenza e Tagliamento, pp.11-24. Amministrazione Provinciale, Pordenone (1999)
13. Marcolongo, B., Mascellani, M.: Immagini da satellite e loro elaborazione applicata all'individuazione del reticolo romano nella pianura veneta. Arch. Veneta 1, 131-146 (1978)
14. Gaddi, D.: Approdi nella laguna di Grado. AAAd 46, 261-275 (2001)
15. Arnaud-Fassetta, G. et al.: The site of Aquileia (Northeastern Italy): Example of fluvial geoarchaeology in a Mediterranean deltaic plain. Géomorphologie 4, 227-246 (2003)
16. Traviglia, A.: Archaeological usability of hyperspectral images: successes and failures of image processing techniques. In: Campana, S., Forte, M. (eds.), From Space to Place. Proceedings of the 2nd International Conference on Remote Sensing in Archaeology, Rome, December 4-7 2006, pp. 123-30. Archaeopress, Oxford

17. Lasaponara, R., Masini, N.: Identification of archaeological buried remains based on Normalized Difference Vegetation Index (NDVI) from Quickbird satellite data. IEEE Geosci. Remote Sens. Lett. 3, 325-328 (2006)
18. Traviglia, A.: Integration of MIVIS hyperspectral remotely sensed data and GIS to study ancient landscape: the Aquileia case study. Agri Centuriati 2, 139-170 (2005)
19. Tucker, C. J.: Red and Photographic Infrared Linear Combinations for Monitoring Vegetation. Remote Sens. Environ. 8, 127- 150 (1979)
20. Rouse, J.W.J., Haas, R.H., Schell, J.A., Deering, D.W.: Monitoring Vegetation Systems in the Great Plains with ERTS. In Freden, S.C., Mercanti, E.P., Becker, M.A. (eds.), 3rd Earth Resources Technology Satellite, vol.1, pp. 309-317. NASA, Washington DC (1973)
21. Qi, J., Chehbouni, A., Huete, A.R., Kerr, Y.H.: Modified Soil Adjusted Vegetation Index (MSAVI). Remote Sens. Environ. 48, 119-126 (1994)
22. Traviglia,A.: Identificazione di tracce archeologiche sul territorio tramite sensore aviotrasportato MIVIS: L'esempio di Aquileia. Archeologia Aerea 3, 69-92 (2008)
23. Traviglia, A.: A semi-empirical index for estimating soil moisture from MIVIS data to identify subsurface archaeological sites. In: Atti della 9a Conferenza Nazionale ASITA, Catania 2005, Vol.2, pp. 1969-1974. ASITA, Catania (2005)
24. La Carta Archeologica del Friuli-Venezia Giulia. Università degli studi di Trieste. Dipartimento di Scienze dell'Antichità, Trieste (1996).