12

Archaeological site monitoring and risk assessment using remote sensing technologies and GIS

Stefano De Angeli and Fabiana Battistin

Threatened archaeological heritage: climate change and soil-related hazards

Archaeological heritage includes all the moveable objects, structures, earth-works, monuments and developed sites created, transformed and left by people through time, whether located on land or under water; both preserved standing above the soil surface and still buried (see Valletta 1992). All this legacy, together with all other heritage resources, is nowadays at risk, endangered by different natural and anthropogenic factors that can cause the physical degradation and destruction of ecofacts and materials. Being made of matter and depending on their environmental setting, any feature interacts with atmospheric and soil processes – natural or human-induced – that can lead to the degradation of materials and to other types of damage to ancient remains. The effects of those processes are today exacerbated by the action of climate change, which can contribute to accelerating them and, therefore, to the damaging of standing and buried archaeological features (UNESCO 2007; also Caneva et al. 1991; Sabbioni et al. 2010).

In the last 15 years, European research has focused on possible climate change effects on historical built heritage. Examples include the ‘Noah’s Ark Project’, which aimed at determining the meteorological parameters and changes most critical for the conservation of European historical built heritage (Brimblecombe et al. 2011; Sabbioni et al. 2010), or the more recent projects STORM (www.storm-project.eu/en) and HERACLES (www.heracles-project.eu), mostly concerned with the health of standing structures and their sta-

bility. Looking at these experiences, it appears that the same attention has not yet been systematically dedicated to investigating the level of risk for the preservation of archaeological heritage, in particular for areas of buried remains, regarding the impact of human actions and climate change.

The preservation of buried archaeological features, including structures and stratigraphy (Harris 1979; Carandini 1991; Renfrew and Bahn 1991), is strictly connected with soil nature and condition, which contribute to their protection. In this regard, it is no coincidence that among the various ecosystem functions of soil, recognized by the European Soil Framework Directive as worthy to be protected, there is also the cultural function of soil, as an archive of historical and archaeological heritage and as a fundamental part of landscape (COM 2006, 231; see also van Zanten et al. 2014). If the health of soil is compromised, there can be consequences for the balance reached through time between materials and soil, which can cause the damaging, and even the loss, of archaeological traces and evidences.

Based on this awareness, the CLIMA project was designed and developed with the aim of promoting highly interdisciplinary soil-oriented research, involving a wide variety of experts: archaeologists, soil scientists, geomorphologists, geologists, botanists, experts in geographic information system (GIS) and remote sensing technologies (terrestrial, aerial and satellite). The project specifically focused on some of the most prominent soil-related threats, such as soil erosion, land movement, land use change and vegetation. It aimed at the monitoring and estimation of such specific hazardous phenomena and at the detection and mapping of archaeological features, as well as at the definition of an effective methodology of risk assessment, culminating in the creation of a GIS Platform able to help in the preservation of archaeological heritage. CLIMA's case study sites were the Roman town of Falerii Novi (Italy), the Graeco-Roman city of Nea Paphos (Cyprus) and the Antonine Wall in Scotland (UK).

This chapter illustrates the main results of the project with respect to the monitoring and assessment of soil erosion, which can well exemplify the mutual impact of climate change and anthropic pressures on buried archaeological heritage. Through the example of the procedure adopted, it will also highlight the importance of carrying on research in this field and how, in this sense, cooperation with public authorities might be fruitful both for knowledge and for the actual protection of archaeological heritage.

Soil erosion and archaeological buried heritage: the CLIMA risk assessment methodology

Together with urban sprawl, infrastructure development, intensive exploitation of natural resources and sociocultural misuse of heritage, agriculture and other intensive land management schemes are the principal cause of damage to archaeological features (Trowl and Holyoak 2014: limited to the phenomenon in England). Doubtless, intensive agricultural activities pose a range of immediate and future threats to sensitive cultural landscapes and to the historical, archaeological and environmental archive they preserve. They can produce an increase in natural processes such as soil erosion (Nearing et al. 2004) and disturb the near-equilibria between archaeological materials and soil, reducing the ability of soil to preserve buried heritage, affecting structural stability and amplifying the natural deterioration of exposed structures.

The impact of agriculture on landscape formation processes increased at an enormous scale from the 1950s onwards because of large-scale mechanization of agricultural practices (Binswanger 1986; Kienzle et al. 2013; van Zanten et al. 2014). Since then, tillage erosion has increased conspicuously, becoming dominant over natural water erosion (Van Oost et al. 2005) and leading to a heavy negative impact on archaeological heritage. Intensive ploughing practices produce tillage erosion of topographical features and truncation of soil profiles; they have reduced numerous archaeological sites to 'ploughsoil scatters', bringing the physical destruction and degradation of buried structures, stratigraphy, artefacts and ecofacts. Nowadays, the situation is made worse by climate change, in particular by extreme weather phenomena such as flooding, drought and intense rainfall, which contribute to amplifying the impact of natural water erosion on soil (Nearing et al. 2004).

In the 1980s and the early 1990s there were some studies regarding the relationship between soil erosion and buried archaeological sites (Reynolds and Schadla Hall 1985; James et al. 1994; Wainwright 1994). These stimulated the academic debate on the topic, with the aim of overcoming the broadly shared idea that the further a structure is buried, the more it is protected from hazards acting on soil. Today there is a widely shared awareness that the erosion of archaeological stratigraphy causes material loss, like mould attacking archival documents and so making them illegible. The destruction of archaeological stratigraphy, even partial, determines a definitive loss of invaluable information, in which respect any scale of supposed importance assigned to the type of artefact would be inadequate to illustrate the severity of the loss (Milanese 2007; see also Davidson and Wilson 2006).

In 2006, the UNESCO report *Predicting and Managing the Effects of Climate Change on World Heritage*, presented to the World Heritage Committee, highlighted that soil erosion is one of the most serious consequences of climate change affecting archaeological heritage, both exposed above ground level and buried (UNESCO 2007). More recently (2008), a specific conference was organized about these issues: ‘The Erosion of Archaeology, the Archaeology of Erosion’ (Meylemans et al. 2014a). The conference showcased some significant European experiences, focusing not only on the occurrence of the soil erosion phenomenon in archaeological sites but also on a more detailed quantification of it towards the creation of decision support systems for cultural heritage management (Ducke 2014).

Even if there is great potential for integrating archaeological heritage management aspects within national and international agro-environmental schemes, as for instance in relation to soil erosion prevention and heritage management stewardship, the topic does not seem to have found a suitable space within European research regarding the protection of cultural heritage. Despite a few exceptions on the national scale (see e.g. Oxford Archaeology 2002; DEFRA 2005), European policies and guidelines regarding the use of soil (e.g. in the Common Agricultural Policy, ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/cap-glance_en) are still lacking in attention to these cultural and archaeological issues, contrasting also with developer-funded archaeology as stipulated in Article 5 of the Valletta Convention on the Protection of the Archaeological Heritage (Valletta 1992).

The development and growing availability of GIS technology, and the possibility to create geospatial data such as high-resolution digital terrain models (DTM), allow today for the production of erosion and sedimentation maps, which can help vastly in surveying, assessing and visualizing the risk to archaeological heritage at regional and local scales. Moreover, in the last three decades, some important tools have become available for quantitative erosion and sediment transportation modelling, ranging from very simple empirical to highly complex, process-based models (Meylemans et al. 2014b).

In the context of CLIMA, soil erosion has been evaluated via two different methods: the Revised Universal Soil Loss Equation (RUSLE), which gives an estimated amount of soil loss per year that can be visualized as a map of the area (Cuca and Agapiou 2017, 2018); and the Gamma Spectrometer, a tool implemented by the project in order to calculate lateral soil movement in ploughed fields (Varley et al. 2017; Varley et al. 2018).

RUSLE was chosen because it is a simple and cost-efficient empirical model that considers soil and terrain properties, vegetation cover and rain parameters. All these data, mostly produced through remote sensing applications (optical/multispectral images from satellite and Unmanned Aerial Vehicle (UAV)), allow reliable predictions of the magnitude of erosion threat to fields. A limit of RUSLE is that it can carry on averaged per-field erosion assessments, but cannot model sediment deposition, another important and critical component for heritage management.

In order to compensate for this limitation of the RUSLE, instead of using other soil erosion models, it was deemed appropriate to test the Gamma Spectrometer. This tool using large-volume NaI mobile and in situ detectors, enables real-time, non-destructive drive-over surveys to map soil erosion and vertical disturbance depths across buried archaeological sites. Utilizing patterns of anthropogenically derived and atmospherically deposited ^{137}Cs in the soil, the tool is able to give a complete mapping of the lateral soil disturbance phenomenon as it formed during the late twentieth century, identifying areas of soil removal and thinning, and areas of soil deposition and deepening.

Both the RUSLE and the Gamma Spectrometer were applied to the sites of the Antonine Wall and Falerii Novi. Both sites are characterized by the presence of wide areas of buried archaeological features, which are affected by agricultural activities that generate soil erosion. For its part, the case study of Nea Paphos, as it is an archaeological park, presents different management conditions: it is not affected by agricultural activities and tillage erosion. For this reason, it was not a suitable case for testing the Gamma Spectrometer; therefore, project activities concerned only water soil erosion assessment through RUSLE.

The combined application of the two methods was meant to compare at least the results regarding soil erosion areas. This was possible in the case of the Antonine Wall, but unfortunately, in Falerii Novi, the results of Gamma Spectrometer were compromised by the intensity of natural radioactive substances inside the soil, which created a disturbance in the measuring of ^{137}Cs deposited. However, those activities produced a large amount of data regarding soil erosion, which was used to generate specific hazard maps.

Nevertheless, evaluating the threatening phenomenon is only a part of a proper risk assessment. In this regard, CLIMA followed a consolidated methodology (applied to all the hazards analysed by the project), considering the risk as the result of hazard and vulnerability interaction; that is to say, between the threat and the object potentially at risk, because it is exposed to the hazard (see in particular Cardona et al. 2012).

Regarding soil erosion risk assessment, the output data coming from the RUSLE and the Gamma Spectrometer processing chains were stored in the GIS platform and then processed to translate the data into specific *hazard maps*, where the intensity of the erosive phenomenon was expressed by a simplified ranking from 0 to 3.

At the same time, in order to produce archaeological *vulnerability maps*, archaeological data were collected, and then aerial/satellite and terrestrial remote sensing technologies were applied for further detection. A degree of vulnerability from 1 to 3 was then assigned to each feature.

The parameter used to define the scale of vulnerability was the level of the available knowledge of archaeological features because the high variability of weaknesses that any archaeological feature presents required a more general approach. In this scale, the minimum value is assigned to soil marks (only identified on aerial and satellite images and *not verified* on soil), a medium value to areas of fragments of archaeological materials scattered on the soil surface (observed through a field walking survey, but *not yet verified* through geophysical survey or excavation), and a maximum value to standing structures and excavated areas (*visible*), and buried structures (*ascertained* and mapped through geophysics).

Regarding the effect of soil erosion on buried structures, an index of exposure was added. This was applied in order to take into consideration that structures can be more or less at risk from superficial erosion depending on their burial depth.

In Falerii Novi, this procedure was applied to the south-east sector of the town, characterized by the underground presence of the Roman theatre. To identify the actual depth of archaeological structures, the area was surveyed with Ground-Penetrating Radar (GPR). For the Antonine Wall, a fairly detailed assessment of the underlying archaeological features existing in the test area was held by Historic Environment Scotland (HES). It provided data regarding the spatial extents of individual features (such as the ditch, wall and forts) and their average burial depth. In the case of Nea Paphos, the entire area of the archaeological park was considered. This was assigned an average burial depth of buildings of 30 cm, based on direct observations of excavated areas and buried structures visible in section.

In all three case studies, the combining of hazard and vulnerability maps using GIS led to the production of *risk maps*, able to show not just the areas of more

intense soil erosion, but also the degrees of risk for archaeological buried structures and contexts.

Concluding remarks and research perspectives

From the point of view of soil-related threats, the project represents an initial step towards a more extensive analysis of soil processes threatening archaeological remains. The aim, in the future, is to refine the soil erosion risk assessment methodology and to consider not just physical soil threats, but also soil biochemical processes induced by climate change and affecting the material preservation of buried archaeological artefacts.

The risk assessment methodology adopted in CLIMA represents a concrete innovation because it is not limited to simply highlighting the presence and intensity of a certain threat but aims at quantifying the possible impact of the threat on buried archaeological structures, based on the evaluation of a major or a minor exposition to it, as shown in the case of soil erosion.

The possibility of quantifying the intensity of a threat in action, and relating it with accuracy to buried archaeological structures, can also allow for the application of mitigation measures to contain or slow down the phenomenon and therefore its impact on archaeological heritage.

With regard to soil erosion, if soil is not used for agriculture, it is possible to adopt land-covering solutions that include the planting of vegetal species with non-invasive root systems. Conversely, if there are agricultural activities, it is possible to choose methods that allow cultivation with less pressure on the soil, as, for example, the no-tillage agriculture. This technique requires lightly working the soil only once. It reduces the number of actions usually needed to plough up and sow, and therefore the production of CO₂, the impact on soil and, as a consequence, on everything contained in it.

Further research aims at improving the platform. A new project (RESEARCH – REMote SENSing techniques for ARCHaeology – H2020-MSCA-RISE – grant agreement No. 823987 – www.re-se-arch.eu) is carrying on the work started with CLIMA to reach complete automation of the generation process of hazard and vulnerability maps from output data of the different environmental (related to soil erosion, land movement and land use change) and archaeological data processing chains. The ultimate aim is to produce comparable hazard

and vulnerability maps from which to automatically generate specific risk maps (Battistin and De Angeli 2020).

For all these reasons, it is of paramount importance to promote the GIS platform and the related risk assessment methodology among public authorities responsible for the protection and management of private and public archaeological heritage. Such tight cooperation between public authorities and research groups will allow the testing and validation of the procedure on other sites, proving its degree of replicability and its limits, thus improving the methodology itself and enlarging the number of sites for which risk maps will be available.

Furthermore, wider knowledge and application of the risk assessment methodology and the platform will contribute to addressing regular activities of research, and to the protection and promotion of a site for the collection of both archaeological and environmental data. This is needed for a risk assessment adequate for the application of specific mitigation measures and the safeguarding of sites.

References

- Battistin, F. and S. De Angeli (2020), 'Da CLIMA a RESEARCH. Monitoraggio e valutazione del rischio nei siti archeologici mediante l'applicazione di tecnologie di *remote sensing* e GIS', in A. Russo and I. Della Giovampaola (eds), *Monitoraggio e manutenzione delle aree archeologiche. Cambiamenti climatici, dissesto idrogeologico, degrado chimico-ambientale. Atti del Convegno Internazionale di Studi* (Roma, Curia Iulia, 20–21 Marzo 2019), Bibliotheca Archaeologica 65, Roma: L'Erma di Bretschneider, 275–9.
- Binswanger, H. (1986), 'Agricultural mechanization: a comparative historical perspective', *The World Bank Research Observer*, 1 (1), 27–56.
- Brimblecombe, P., C.M. Grossi and I. Harris (2011), 'Climate change critical to cultural heritage', in H. Gökçekus, U. Türker and J. LaMoreaux (eds), *Survival and Sustainability. Environmental Earth Sciences*, Berlin and Heidelberg: Springer, 195–205.
- Caneva, G., M.P. Nugari and O. Salvadori (1991), *Biology in the Conservation of Works of Art*, Roma: ICCROM.
- Carandini, A. (1991), *Storie dalla terra. Manuale di scavo archeologico*, Torino: Einaudi.
- Cardona, O.D., M.K. van Aalst, J. Birkmann, M. Fordham, G. McGregor, R. Perez, R.S. Pulwarty, E.L.F. Schipper and B.T. Sinh (2012), 'Determinants of risk: exposure and vulnerability', in C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor and P.M. Midgley (eds), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, A Special Report of Working Groups I and II of the

- Intergovernmental Panel on Climate Change (IPCC), Cambridge and New York: Cambridge University Press, 65–108.
- COM 2006, 231: *Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee of the regions. Thematic Strategy for Soil Protection* (2006), Commission of the European Communities, COM, Brussels (231 final), accessed 20 January 2019 at <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52006DC0231>.
- Cuca, B. and A. Agapiou (2017), 'Impact of land use change to the soil erosion estimation for cultural landscapes: case study of Paphos district in Cyprus', *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-5/W1, 25–9, <https://doi.org/10.5194/isprs-archives-XLII-5-W1-25-2017>.
- Cuca, B. and A. Agapiou (2018), 'Impact of land-use change and soil erosion on cultural landscapes: the case of cultural paths and sites in Paphos district, Cyprus', *Applied Geomatics*, December, **10** (4), 515–27.
- Davidson, D.A. and C.A. Wilson (2006), 'An assessment of potential soil indicators for the preservation of cultural heritage', Final report, University of Stirling.
- DEFRA (2005), *Controlling Soil Erosion. A Manual for the Assessment and Management of Agricultural Land at Risk of Water Erosion in Lowland England*, London: Department for Environment, Food and Rural Affairs (DEFRA).
- Ducke, B. (2014), 'An integrative approach to archaeological landscape evaluation: locational preferences, site preservation and uncertainty mapping', in E. Meylemans, J. Poesen and I. In't Ven (eds), *The Erosion of Archaeology, the Archaeology of Erosion. Proceedings of the Brussels Conference (April 28–30, 2008)*, Relicta Monografieën 9, Brussels, 13–22.
- Harris, E.C. (1979), *Principles of Archaeological Stratigraphy*, London: Academic Press.
- James, P.A., Ch. B. Mee and G.J. Taylor (1994), 'Soil erosion and the archaeological landscape of Methana, Greece', *Journal of Field Archaeology*, **21**, (4), 395–416.
- Kienzie, J., J.E. Ashburner and B.G. Sims (eds) (2013), 'Mechanization for rural development', *Integrated Crop Management* (FAO), **20**, Rome.
- Meylemans, E., J. Poesen and I. In't Ven (2014a), *The Erosion of Archaeology, the Archaeology of Erosion. Proceedings of the Brussels Conference (April 28–30, 2008)*, Relicta Monografieën 9, Brussels.
- Meylemans, E., B. Vanmontfort and A. Van Rompaey (2014b), 'The evaluation of archaeological sites using LIDAR and erosion/sedimentation modelling', in E. Meylemans, J. Poesen and I. In't Ven (eds), *The Erosion of Archaeology, the Archaeology of Erosion. Proceedings of the Brussels Conference (April 28–30, 2008)*, Relicta Monografieën 9, Brussels, 23–36.
- Milanese, M. (2007), 'Voci delle cose: fonti orali, archeologia post-medievale, etnoarcheologia', in M. Milanese (ed.), *La Voce Delle Cose. Fonti Orali e Archeologia Post-Medievale*, Atti del convegno di studi (Pisa, 15 March 2002), Firenze, All'insegna del Giglio, 11–30.
- Nearing, M.A., F. Pruski and M.R. O'Neal (2004), 'Expected climate change impacts on soil erosion rates: a review', *The Journal of Soil and Water Conservation*, **59** (1), 43–50.
- Oxford Archaeology (2002), *The Management of Archaeological Sites in Arable Landscapes*, BD1701, CSG15, accessed 20 January 2019 at http://sciencesearch.defra.gov.uk/Document.aspx?Document=BD1701_514_FRA.pdf.
- Renfrew, C. and P.G. Bahn (1991), *Archaeology: Theories, Methods and Practice*, New York: Thames and Hudson.

- Reynolds, P.J. and R.T. Schadla Hall (1985), 'Measurement of plough damage and the effects of ploughing on archaeological material', *Occasional Papers, Department of the Environment, Directorate of Ancient Monuments and Historic Buildings*, **3**, 114–22.
- Sabbioni, C., P. Brimblecombe and M. Cassar (2010), *The Atlas of Climate Change Impact on European Cultural Heritage*, London and New York: Anthem Press.
- Trowl, S. and V. Holyoak (2014), 'The erosion of archaeology: the impact of ploughing in England', in E. Meylemans, J. Poesen and I. In't Ven (eds), *The Erosion of Archaeology, the Archaeology of Erosion. Proceedings of the Brussels Conference (April 28–30, 2008)*, Relicta Monografieën 9, Brussels, 55–62.
- UNESCO (2007), *World Heritage Reports No. 22 – Climate Change and World Heritage*, accessed 20 January 2019 at <https://whc.unesco.org/en/activities/474>.
- Valletta (1992), *European Convention on the Protection of the Archaeological Heritage (Revised)*, European Treaty Series, 143, Valletta, Malta.
- Van Oost, K., W. Van Muysen, G. Govers, J. Deckers and T.A. Quine (2005), 'From water to tillage erosion dominated landform evolution', *Geomorphology*, **72**, 193–203.
- Van Zanten, B.T., P.H. Verburg, M. Espinosa et al. (2014), 'European agricultural landscapes, common agricultural policy and ecosystem services: a review', *Agronomy for Sustainable Development*, **34** (2), 309–25.
- Varley, A., A. Tyler, M. Dowdall, Y. Bondar and V. Zabrotski (2017), 'An *in situ* method for the high resolution mapping of ¹³⁷Cs and estimation of vertical depth penetration in a highly contaminated environment', *Science of The Total Environment*, **605–606**, 957–66.
- Varley, A., A. Tyler, Y. Bondar, A. Hosseini, V. Zabrotski and M. Dowdall (2018), 'Reconstructing the deposition environment and long-term fate of Chernobyl ¹³⁷Cs at the floodplain scale through mobile gamma spectrometry', *Environmental Pollution*, **240**, 191–9.
- Wainwright, J. (1994), 'Erosion of archaeological sites: results and implications of a site simulation model', *Geoarchaeology*, **9**, 173–201.