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The *RESEARCH* project. Soil-related hazards and archaeological heritage in the challenge of climate change

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Abstract. Archaeological Heritage, naturally endangered by environmental processes and anthropogenic pressures, is today increasingly at risk, because of intense human activities and climate change, and their impact on atmosphere and soil. European research is increasingly dedicated to the development of good practices for monitoring archaeological sites and their preservation. One of the running projects about these topics is RESEARCH (Remote Sensing techniques for Archaeology; H2020-MSCA-RISE, grant agreement: 823987), started in 2018 and ending in 2022. RESEARCH aims at testing risk assessment methodology using an integrated system of documentation and research in the fields of archaeology and environmental studies. It will introduce a strategy and select the most efficient tools for the harmonization of different data, criteria, and indicators in order to produce an effective risk assessment. These will be used to assess and monitor the impact of soil erosion, land movement, and land-use change on tangible archaeological heritage assets. As a final product, the Project addresses the development of a multi-task thematic platform, combining advanced remote sensing technologies with GIS application. The demonstration and validation of the Platform will be conducted on six case studies located in Italy, Greece, Cyprus, and Poland, and variously affected by the threats considered by the Project. In the frame of RISE (Research and Innovation Staff Exchange), RESEARCH will coordinate the existing expertise and research efforts of seven beneficiaries into a synergetic plan of collaborations and exchanges of personnel (Ph.D. students and research staff), to offer a comprehensive transfer of knowledge and training environment for the researchers in the specific area. This paper aims at illustrating the results of the activities conducted during the first year of the Project, which consisted in developing an effective risk assessment methodology for soil-related threats affecting archaeological heritage, and defining the scientific requirements and the user requirements of the Platform. The activities have been conducted in synergy with all the Partners and were supported by the possibility of staff exchange allowed by the funding frame MSCA-RISE.

1. The project RESEARCH (Remote Sensing techniques for Archaeology)

Nowadays, Europe's Archaeological Heritage (AH) is increasingly at risk, endangered by environmental processes and anthropogenic pressures, acting in both the short and the long term. Climate-related and natural hazards, either acting alone or combined with anthropic pressure, pose several threats to the preservation of archaeological assets, amplifying the natural deterioration of materials and reducing the ability of soil to preserve them [1]. Standing structures and excavated areas, being exposed to the open air, directly interact with atmospheric phenomena, such as rain, wind, and temperature variation, able to produce damages to materials and structural stability. In particular in case of abandon, these artifacts are also predisposed to the attack of uncontrolled vegetation growth, that can lead to a weakening of the structure due to the penetration of root systems. Another part of the archaeological heritage is still unexcavated and lies underground forming the so-called archaeological deposits, composed by structures and stratigraphy. The main role in the preservation of this portion of archaeological heritage is played by soil, so that every change in it, due to intensive human activities or increased by the effects of climate change, can also produce damage for archaeological features. In this scenario, authorities in charge to AH preservation have a strong requirement for systematic, effective, usable and affordable tools and services to monitor the degradation process, in order to enable preventive maintenance, and to reduce restoration costs.

RESEARCH (*Remote Sensing techniques for Archaeology*) is a four-year project (2018-2022), funded by the European Union under the Horizon 2020 framework, *Marie Skłodowska Curie Action, Research and Innovation Staff Exchange* (MSCA-RISE) (Grant Agreement n. 823987). The project addresses the design and development of a multi-task platform, combining advanced remote sensing technologies with GIS application for mapping and long-term monitoring of AH endangered by soil related threats, in particular land movement, soil erosion, and land use change. The platform is designed on end-user requirements. It supports a risk assessment methodology specifically designed on the threats considered and their possible impact on AH, calculated on a medium-large scale (regarding land movement and land use), and on a smaller scale (in particular for soil erosion).

RESEARCH will coordinate the existing expertise and research efforts of seven partners into a synergic plan of collaborations and exchanges of personnel through secondments, to offer a comprehensive transfer of knowledge and training environment for the researchers in the specific area.

The consortium is composed by academic organizations and SME: *Università degli Studi della Tuscia* (IT, project coordinator), *Technologiko Panepistimio Kyprou* (CY), *Alma Sistemi Srl* (IT), *Foundation for Research and Technology Hellas* (GR), *Space Systems Solutions Ltd* (CY), *Geosystems Hellas it kai Efarmogesgeopliroforiakon Systimaton Anonimietaireia* (GR), *Uniwersytet Im. Adama Mickiewicza W Poznaniu* (PL).

RESEARCH risk assessment methodology will be tested on case studies from Italy, Greece, Cyprus and Poland. Case study areas have been selected looking at the specific soil-related risk considered by the project and affecting archaeological areas in the different countries involved.

The following table (table 1) shows the case studies and the hazard/s considered in each of them.

Table 1

Case Study		**Land Movement**	**Soil Erosion**	**Land Use Change**
ITALY	Falerii Novi	X	X	X
CYPRUS	Amathous	X	X	X
GREECE	Almiriotiki		X	
	Vaitsi Mill			X
	Itanos	X		
POLAND	Darłowo			X
	Cisowo		X	X
	Dzierżęcin		X	X

This paper aims at illustrating the results of the activities conducted during the first year of the Project, which consisted in developing an effective risk assessment methodology for soil-related threats affecting archaeological heritage, and defining the scientific requirements and the user requirements of the Platform. The activities have been conducted in synergy with all the Partners and were supported by the possibility of staff exchange allowed by the funding frame MSCA-RISE.

2. RESEARCH risk assessment methodology

On a technical base, risk can be defined as the product of three factors that are hazard, exposure and vulnerability [2, 3]. The hazard is anything (tangible or intangible) that can cause harm to some assets. It is the threat itself, considered in its magnitude and its spatial and temporal aspects. The objects considered at risk are instead described by the concepts of exposure and vulnerability. Exposure is related to the asset exposed to a given hazard (people, objects, economic asset, cultural heritage -tangible and intangible-), while vulnerability indicate the degree in which the exposed objects are predisposed to be damaged by a specific threat.

RESEARCH risk assessment methodology is designed in order to assess the possible impact of land movement, soil erosion, and land-use change on standing and buried archaeological heritage. In order to do so, specific data processing chains have been designed for the estimation of hazard levels, while the elements of the archaeological landscape exposed to the hazards (identified and mapped using available and newly acquired data) will be classified in a vulnerability ranking.

All the products (maps) of external processing chains will be then managed in a specifically designed GIS Platform (see paragraph 3), that will be able to produce hazard, exposure and vulnerability maps, and to correlate them in order to produce final risk maps. The intermediate (hazard, exposure and vulnerability maps) and final products (risk maps) will be then available on a Web-GIS Platform.

The following sections explain more in detail the nature of the hazards considered by RESEARCH, also describing the specific RS data processing chains that will be implemented by Partners for their assessment, and, above all, the principles followed to indicate the vulnerability and the exposure of archaeological features.

2.1. Land movement

Land movements are natural phenomena influenced by geological and environmental conditions. They typically occur along hillsides and mountains, and can naturally happen or being the consequence of human actions. They can suddenly occur or be very slow, depending on the characteristics of both the area and the hazardous event. Land movements can impact on the archaeological heritage preserved in an area by damaging and destroying standing and buried structures, as well as archaeological stratigraphy. Damages potentially increase in absence of an effective strategy of risk analysis, monitoring of the area, and maintenance.

RESEARCH designed an EO data processing chain based on the use of medium/high-resolution Synthetic Aperture Radar (SAR) data, putting together existing and newly developed modules: differential interferograms generation, deformation map calculation through specific algorithms, surface velocity map generation as input to the structure stability risk model. Differential SAR interferometry (D-InSAR) and Persistent Scatterer Interferometry (PSI) methods are used to assess the stability of the ground and identify ground motion caused by processes as subsidence and landslides at, and near, archaeological sites.

2.2. Soil erosion

Soil erosion is the natural phenomenon of soil loss manly due to water runoff and wind. The process can be accelerated and intensified by climate change and by some human activities, such as intensive agricultural and pastoral activities, inefficient or inadequate irrigation systems, and deforestation. The soil degradation by erosion influence in many ways the use of space and land, and these actions can be threatening for the preservation of natural and cultural heritage, especially in the challenge of climate change. Soil erosion can impact in different ways on the archaeological features exposed to it. In case of standing structures, the presence of rills in their proximity can excise the soil on which they are positioned, or the area around them, or can expose archaeological sections, with loss of stratigraphy and potentially favouring structure instability. Effects are even more urgent on archaeological buried structures and stratigraphy because, when soil is eroded, the effective soil thickness above them, that represent a protection, is reduced. Buried archaeological features and stratigraphy, in fact, are quite vulnerable to threats acting on soil, such as agricultural activities, especially ploughing, which impact over time on structures and stratigraphy, destroying contexts and spreading sherds of building materials and artifacts on soil surface, out of their original context.

Currently, the soil erosion issue is classified at low scale by field investigation or at more large scale using numerical and empirical erosion models. These models enable to predict the potential of soil erosion. In this regard, RESEARCH aims at exploiting a soil erosion remote sensing processing chain, by testing and enhancing existing soil erosion estimation models (such as RUSLE, SIMWE, USPED) in order to provide soil erosion hazard assessment. The methodology is based on the estimation of soil loss and soil accumulation per unit area, taking into account specific parameters such as rainfall factor, topography and land cover management. For these data, multispectral satellite images of high spatial resolution will be analysed simultaneously with the development and processing of a high spatial resolution Digital Elevation Model (DEM), derived from SAR data or UAV. Remote Sensing and GIS techniques will be integrated in order to estimate long-term average annual soil loss and accumulation, and to map erosion hazard. In order to validate the results obtained from the soil erosion data processing chain, in some case studies, specific tools of remote sensing, as mini-LIDAR on UAV, will be used. This will allow a more precise monitoring and a more detailed quantification of the phenomena of soil erosion and accumulation, which results will be compared with those of the data processing chain.

2.3. Land use change
Environmental factors and human activities influence in many ways the use of space and land, and these actions can be threatening for the preservation of natural and cultural heritage, especially in the challenge of climate change. Beside local environmental conditions and climate change, in fact, most of the factors potentially dangerous for AH are related to intensive land use and land use changes. AH preservation can be threatened by urban sprawl, building and mining activities, pollution, agriculture and pasture related activities, which all imply physical impacts influencing the preservation of archaeological records. Land use and land use change can be today assessed by using remote sensing and various types of land use classification.

In order to assess land use change, RESEARCH will process optical datasets at different resolutions, in function of the scope and spatial extent of the analysis. Categories of land use/land cover, defined specifically for each test case, will be studied for the monitoring of important changes in a given span of time. In order to conduct these analyses, satellite and aerial images (multispectral and hyperspectral), terrain attributes, and data collected in field investigation will be used.

The Multispectral RS satellites capture the electromagnetic energy reflected from the Earth’s surface, so that Visible (Vis), Near Infrared (NIR) and Shortwave Infrared (SWIR) can be used to calibrate site-specific datasets, in order to offer information about the physical and chemical properties of the soil surface, such as the topsoil matrix, the presence and type of vegetation cover, urban areas and water sources. The digital processing of satellite data provides tools for analysing the image through different algorithms and mathematical indices, so allowing to identify features with various methodological approaches, using techniques such as pixel-based (image classification, regression, etc.), sub-pixel-based (linear spectral mixing, imperviousness as the complement of vegetation fraction etc.), object-oriented algorithms, and artificial neural networks. RESEARCH, by comparing diachronic set of images, aims at determining the change occurring through time in archaeological areas. In order to do so, RESEARCH will apply object-based mapping using existing experience, available data and learned methodology in “Trimble eCognition” software.

2.4. The vulnerability and the exposure of archaeological features: a proposal

In order to actually calculate the risk, it is fundamental to evaluate the vulnerability of the elements exposed to the hazards.

The parameters used to calculate the **vulnerability** differ from one research to another, depending from the specific research questions and from the scale of investigation.

RESEARCH works on a medium-large scale, not focusing on single archaeological remains or structures, rather analyzing large archaeological areas, possibly characterized by the presence of a broad variety of archaeological features. Therefore, it is not possible to assess the vulnerability on a detailed scale, looking at different types of buildings, construction techniques, materials, or preservation condition. For this reason, RESEARCH considers all the ascertained archaeological features on a same high level of importance for the reconstruction of the past, both referring to standing structures and unexcavated contexts, starting from the point of view that as much as we are sure that an archaeological feature exists, as much it can be potentially vulnerable to a given hazard.

The vulnerability level will therefore follow the level of knowledge reached on single features, that depends, case by case, from the types of investigations conducted in order to identify them and ascertain their archaeological value. For this reason, RESEARCH vulnerability ranking is based on the distinction among four main types of features (standing structures/monuments, buried features/contexts (*i.e.* archaeological deposits), areas of scattered materials, soil/crop/shadow marks), that are the results of different data acquisition methodologies and techniques (as described in table 2).

Table 2

Type of features	Description	Vulnerability value
Standing structures and monuments	Features exposed above the ground level, have an evident archaeological value and they can be studied in detail through the application of various approach.	3
Buried archaeological contexts (*i.e.* archaeological deposits)	They include structures and stratigraphy, even if hidden underground, can be today surveyed and mapped thanks to geophysics. The interpretation of the results obtained through geophysics, even with a lower level of detail than the one of features preserved above ground level, usually allowed an ascertained archaeological value (that can be further detailed through stratigraphic excavation), that brings to a consequent high level of vulnerability.	3
Areas of scattered archaeological materials	They consist of sherds of building and other types of materials visible on the surface, that can be collected and studied after field surveys. They result from the partial or complete destruction of archaeological deposits, but only when other technics are put in practice (such as geophysics or stratigraphic excavation) it is possible to estimate the level of conservation of the archaeological deposit, therefore its consistence.	2
Soil, crop and shadow marks	They are mapped only from satellite and/or aerial (airborne, UAV) observation. Their actual archaeological value can be estimated only after other techniques are put in practice (such as field survey, geophysics or stratigraphic excavation) in order to verify their correspondence to archaeological features because they can also result from other types of environmental and anthropic actions.	1

Features can move from a class to another, following the results of further investigations conducted in order to ascertain their archaeological value and consistency.

Finally, in order to actually calculate the risk, it is fundamental to evaluate the **exposure**, that indicates the level of exposition to a given hazard of a certain asset (people, objects or economic asset).

The asset considered by RESEARCH consists in archaeological features, therefore their presence, effective or supposed, and their archaeological value imply an equal high exposure to an occurring hazard, independently from their level of vulnerability. Consequently, in theory, a standard value of exposure of 1, as a maximum value, can be assigned to any archaeological area and feature.

However, in the case of soil erosion, the exposure of buried features follows another principle. As much as a preserved archaeological context is buried deep, the more it is protected from superficial erosion of soil. Therefore, wherever the burial depth of the archaeological deposit is known, it can be applied a coefficient able to represent the differences in the exposure of the features, that reduce the final risk level. Given a maximum exposure 1, the gradient will be comprised between, 0.01 (corresponding to the deeper structures surveyed using geophysics) and 0.99 (indicating the structures visible on the surface or very close to it).

In respect to land movement and land use change, instead, the value will be always 1, because they act on soil in depth, potentially damaging all the features existing in the area with no distinction.

3. The RESEARCH System

The RESEARCH System is intended as the combination of the external data processing chains for soil-related threats assessment and archaeological features mapping, the archaeological database, and the WebGIS Platform, composed by the GIS Desktop Platform and the WebGIS Portal (figure 1). The System has been designed on the base of the methodology adopted, elaborated by the authors of this contribution and described above. In particular the GIS Desktop Platform is thought to be used to transform the products of external data processing chains first in hazard, vulnerability and exposure maps (intermediate products), and then in risk maps (final products), by combining hazard and relative vulnerability maps.

The data processing chains (light-blue boxes) designed for the modelling of the threats considered by the Project will be carried out outside the Platform, by using specific software. The final products of these data processing chains (*Land Movement, Soil Erosion*, and *Land use/cover Change Maps*) will be uploaded inside the Platform, respecting specific requirements in terms of file format. The GIS Desktop Platform produced by RESEARCH, in fact, will be able to manage the procedures of risk assessment and also to carry out the task of being a repository for all the data used in the processing chains, all the output data of the processing chains, and all the intermediate and final products of the Platform.

The GIS Desktop Platform will transform land movement, soil erosion, and land use/cover change maps in proper hazard maps (*Land Movement, Soil Erosion*, and *Land use/cover Change Hazard Maps*) through the application of specific hazard values. The hazard rankings for land movement and soil erosion will have hazard values comprised between 0 and 3. Being quantifiable phenomena, they allow to quantify the hazard, so that the results obtained from the specific processing chains can be ordered in range of intensity, corresponding to null (0), low (1), medium (2), and high (3) level of hazard, by taking into account the local environmental characteristics of each site considered. Differently, land use/cover change hazard ranking will indicate only the areas where changes occurred. Therefore, it will be 0, where no change occurred, or 1, when a change is registered.

At the same time, for each case study, the archaeological data coming from archaeological investigations will be collected and processed with specific processing chains outside the GIS Desktop Platform, and then uploaded in the Data Storage inside the GIS Desktop Platform (shapefiles) and in a database specifically designed (metadata). Inside the database, features will be case-by-case registered as pertaining to their proper vulnerability class (*i.e.* soil/crop/shadow marks (1), areas of scattered materials (2), standing structures/monuments, buried features (3)), and their exposure value (≤ 1).

For each case study, features related shapefiles, in combination with their metadata, will be then shown in archaeological *Archaeological Features Maps*, which will be transformed by the GIS Desktop

Platform in *Absolute Vulnerability Maps*, by applying the values 1, 2 or 3, following the principles explained above.

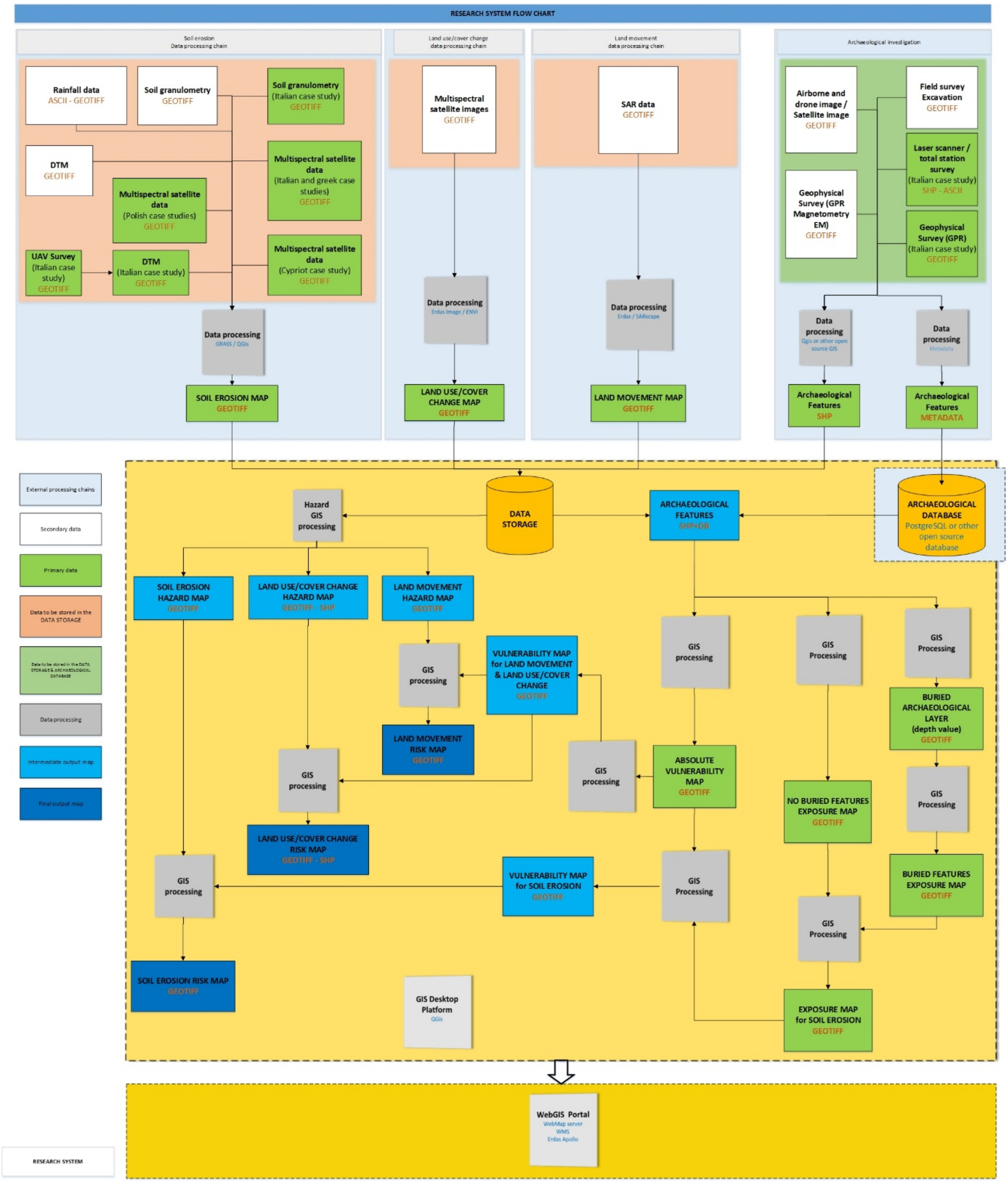

Figure 1. RESEARCH System workflow.

As the exposure values of archaeological features in respect to land movement and land use/cover change is considered equal to the maximum value 1, the GIS Desktop Platform, by using the exposure value 1, will transform the *Absolute Vulnerability Maps* in *Vulnerability Maps for Land Movement* and *Land use/cover Change*, substantially confirming the values 1, 2, 3.

As explained above, in the case of soil erosion, the exposure value for features preserved above or at the level of soil surface (standing structures, areas of scattered materials, soil/crop/shadow marks) will be at its maximum (1), so the GIS Desktop Platform will produce an exposure map of these features (*No Buried Features Exposure Map*). On the other side, in respect to archaeological deposits, wherever the burial depth is known, as instance from GPR data, it will be produced a layer of the underground superior surface of the archaeological deposit (*Buried Archaeological Layer*). On this base, it will be applied a coefficient able to represent the differences in the exposure of the features. Given a maximum exposure 1, the gradient will be comprised between, 0.01 (corresponding to the deeper structures surveyed using geophysics) and 0.99 (indicating the structures visible on the surface or very close to it). Its application to the *Buried Archaeological Layer* will produce the exposure map for the archaeological deposit (*Buried Features Exposure Map*). Then, in order to produce the final *Exposure Map for Soil Erosion*, the GIS Desktop Platform will combine the *No Buried Features Exposure Map* and the *Buried Features Exposure Map*. The final *Exposure Map for Soil Erosion* will be processed together the *Absolute Vulnerability Map*, in order to produce a *Vulnerability Map for Soil Erosion*. This operation will imply, for the archaeological deposit areas, a more shaded vulnerability value, included between 2.1 (for deeper points), and 3 (for points at the soil surface level).

These vulnerability maps will be then combined with soil erosion hazard maps producing final soil erosion risk maps. Similarly, the *Vulnerability Maps for Land Movement* and *Land use/cover Change* will be combined with the *Land Movement* and *Land use/cover Change Hazard Maps*, producing *Land Movement* and *Land use/cover Change Risk Maps*.

By its side, the WebGIS Portal will showcase:

- the input data used in data processing chains and related intermediate output data (*Land Movement Maps, Soil Erosion Maps, Land use/cover Change Maps*, and *Archaeological Features Maps*);
- the primary data produced by the GIS Desktop Platform for the elaboration of *Exposure Map for Soil Erosion* (*Buried Archaeological Layer*, *No Buried/Buried Features Exposure Maps*);
- the intermediate products (*Land Movement Hazard Maps, Soil Erosion Hazard Maps*, *Land use/cover Change Hazard Maps*, the related *Archaeological Vulnerability Maps*, and the *Exposure Map for Soil Erosion*) produced by the GIS Desktop Platform;
- final products (*Land Movement Risk Maps, Soil Erosion Risk Maps*, *Land use/cover Change Risk Maps*) produced by the GIS Desktop Platform.

4. Conclusions

This brief contribution aimed at presenting the purpose of RESEARCH project and the results of the first year of Project activities, in particular the study of the state of the art about soil related threats and their assessment, the design of the data processing chains, the selection of case studies, and, above all, the definition of risk assessment methodology, and the related requirements of the RESEARCH GIS Platform. With regard to these latter activities, the far more important result was the design of a GIS Platform able of managing the data outputs of the various processing chains (both those relating to the hazard assessment and those relating to the processing of data deriving from archaeological investigations), and to automatically generate from them hazard maps, absolute and relative vulnerability maps, and exposure maps. By combining hazard and relative vulnerability maps, it will be finally possible to generate, always through an automatic processing, specific risk maps for soil erosion, land use/cover change and land movement.

At the moment, the Platform is under construction, input data acquisition is in course, and the single data processing chains designed by partners are starting to be tested. After completing the data collection, partners will proceed with the evaluation of hazards and with the mapping and cataloguing of archaeological features. At the same time the platform will be completed and its functioning will be

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tested with the products of the external processing chains. All these activities will be carried on as much as possible through secondments.

During the first year, researchers were seconded among Partners, so achieving new competences and allowing a more effective communication. Partners also met in multiple occasions such as for meetings, and for the First Summer School organized by RESEARCH, held in Limassol (Cyprus) in May 2019. Other three summer schools will be organized (one per year), conveying partners and externals at the same table in order to share knowledge and enrich their participation to the Project. Two conferences are scheduled for January 2021 and October 2022. They will be organised by the coordinator and will be held in Rome, in order to reach a wider public.

RESEARCH progress can be followed on the official website at www.re-se-arch.eu, or on Facebook (*Research - Remote Sensing techniques for Archaeology*), with updates about milestones and dissemination activities.

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