



Data Article

A multidisciplinary and interoperable dataset to understanding the dialogue between humans and the environment in Southern Umbria, emphasising sustainable management and valorisation of cultural and landscape heritage

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ABSTRACT

This article presents an integrated digital tool for the documentation, reconstruction, and interpretation of ancient Umbrian landscapes, developed within Spoke 8 (Sustainability and Resilience of Tangible Cultural Heritage) of the CHANGES Partnership (Cultural Heritage Active Innovation for Next-Gen Sustainable Society). The research aims to create a system of interoperable datasets that connect archaeological, cartographic, topographical, geo-environmental and documentary sources within a unified CAD-GIS environment.

The proposed system is structured into multiple, interrelated datasets that organize complementary information: geospatial and documentary sources, historical cartography, archaeological and topographical records, georeferenced graphical data, and thematic deliverables. Together, these components form a scalable digital infrastructure that ensures metadata standardization, interoperability, and adherence to FAIR principles.

Applied to the Valnerina area, with a focus on the Municipality of Arrone (Terni, Umbria) as a pilot case study, the framework supports the reconstruction of the cultural landscape

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and the analysis of relationships between human settlement, environment, and territorial transformations. The resulting model provides both a methodological reference and an operational tool for managing Tangible Cultural Heritage, promoting sustainable data integration, reproducibility, and open access. It establishes a transferable approach for future regional studies, combining scientific rigor, spatial analysis, and heritage conservation within an interoperable digital ecosystem. In summary, the study proposes a shared, interoperable, and sustainable model for the knowledge and enhancement of Umbria's cultural-historical landscapes, providing a methodological framework applicable to other territorial and research contexts.

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Specifications Table

Subject	Social Sciences
Specific subject area	Landscape Archaeology, Topography, Geography, Digital Humanities.
Type of data	Table; Categorical data; Numerical data; References; Graphic materials; Vector data; Raw data; Secondary data.
Data collection	Data collection was conducted with the objective of building an interoperable digital system capable of integrating heterogeneous sources related to the Tangible Cultural Heritage and Ancient Landscapes of Umbria. The process combined bibliographic, archival, cartographic, archaeological, and geospatial resources, harmonized within a unified CAD-GIS environment. The resulting framework is organized into a system of four interconnected datasets (A-D), each designed to serve a specific function within the integrated model. • Dataset A compiles geospatial, and documentary resources derived from institutional repositories and geoportals. • Dataset B gathers historical maps from the 16th-17th centuries, documenting the territorial and environmental perception of Umbria, particularly the Valnerina and the area of Municipality of Arrone (TR). • Dataset C structures archaeological and topographical information, establishing the core relational framework for territorial and chronological analysis. • Dataset D compiles georeferenced graphical and cartographic data, linking descriptive records to their spatial representations.
Data source location	All datasets were harmonized through metadata normalization and spatial referencing, forming a multi-layered digital framework used for analytical and reconstructive purposes within the project. Materials: Repository station, Stanza 10 of Ex Vetriere Sciarra. Via dei Volsci 122, 00185 – Roma. Institution: Sapienza University of Rome. Department of Classics. City: Rome. Country: Italy.
Data accessibility	Geographic coordinates (WGS84): Latitude: 41°53'53"N; Longitude: 12°31'03"E Repository name: Zenodo - Project CHANGES - Cultural Heritage Active Innovation for Next-Gen Sustainable Society Data identification number: https://doi.org/10.5281/zenodo.17444629 Direct URL to data: https://zenodo.org/records/17444629
Related research article	Carafa P., Cecconi N., De Stefano F. (2025), Sharing Assessed Knowledge: Sharing Heritage, «Archeologia e Calcolatori» 36.1, 25–38 doi: 10.19282/ac.36.2.2025.04

1. Value of the Data

- The dataset developed within the Umbrian case study contributes to the objectives of Spoke 8 - “Sustainability and Resilience of Tangible Cultural Heritage”, and to the UN 2030 Agenda, specifically SDG 11 (Sustainable Cities and Communities), particularly Target 11.4, by providing an integrated and interoperable framework for the documentation and analysis of Tangible Cultural Heritage in a regional context. The paper presents a unified digital tool capable of integrating the multiple datasets produced over time by national institutions, regional authorities, and private entities, which are currently scattered across different platforms. These resources constitute a fundamental knowledge base for the historical and environmental reconstruction of the Umbrian landscape, as well as for the conservation, enhancement, and spatial planning.
- The data systematically record architectural, archaeological, topographical, and geo-environmental evidence, integrating historical cartography, archival documentation, and field surveys within a georeferenced digital infrastructure.
- The adoption of standardized metadata schemes and interoperable file formats ensures compatibility with national and European repositories, supporting data sharing, transparency, and long-term preservation.
- Thanks to its replicability and scalability, the methodological framework can be implemented at regional, national, and international levels, supporting comparative analyses of heritage distribution, risk exposure, and resilience in different territorial contexts, while considering the diverse resources and capacities of the administrations involved.
- Open-access dissemination promotes inclusive governance and sustainable management by enabling local administrations, cultural institutions, and communities to reuse and enhance the data for research, planning, and public engagement.

2. Background

This research stems from the methodological and scientific framework developed through previous research conducted between 2019 and 2023 under an inter-institutional agreement between the Lazio Region and Sapienza University of Rome, which focused on the digital documentation, mapping, and analysis of archaeological and architectural heritage across southern Lazio [1,2]. That initiative aimed to consolidate and harmonize a wide range of sources (archival, cartographic, archaeological, and photographic etc.) within a unified geospatial digital system supporting heritage conservation, landscape planning, and regional management. Within the framework of *Spoke 8 – Sustainability and Resilience of Tangible Cultural Heritage* of the CHANGES partnership (*Cultural Heritage Active Innovation for Next-Gen Sustainable Society*), the geographical scope and scientific objectives of the research have been significantly expanded. Building on the methodologies developed within the *Lazio Antico* project, the study now extends beyond southern Lazio to cover part of southern Umbria, encompassing a broader cultural and environmental area corresponding to the historical territories of southern Etruria, Sabina, and the Upper Tiber Valley ([3]; Carafa et alii [4]).

From the *Lazio Antico* project, the *Valnerina Project* has been developed as a case study focused on the territory of lower Valnerina, that is, the portion of the province of Terni including the municipalities of Amelia, Arrone, Ferentillo, Montefranco, Narni, Otricoli, Polino, San Gemini and Stroncone. In this specific case study, the analysis is confined to the administrative boundaries of the municipality of Arrone. The study aims to reconstruct landscapes from prehistory to the Middle Ages, applying and refining the CHANGES methodologies through the integration of geo-environmental, historical, and topographical datasets into an interoperable digital infrastructure.

The resulting dataset enables a diachronic reconstruction of landscape transformations and the analysis of spatial relationships among settlements, infrastructures, and environmental sys-

tems, establishing a methodological framework that links scientific research, digital innovation, and sustainable heritage governance. This work engages not only with regional and national studies but also situates itself within the broader international discourse on the management, interoperability, and integration of Cultural Heritage data and sources (for examples: Barzaghi et alii [5]; Ducatteeuw et alii [6]; Kong et alii [7]; Larsson et alii [8,9]; Sá et alii [10]), contributing to ongoing debates on best practices for harmonizing heterogeneous datasets and promoting FAIR, reproducible, and open-access approaches.

3. Data Description

3.1. Dataset A: Geospatial data sources and services

Dataset A serves as an interoperable dossier or checklist, designed to enable access, download, and coordinated use of tools, services, and digital resources relevant to the territorial analysis of the Umbria region. This framework promotes semantic and technical coherence among diverse raw data sources, fostering reproducibility, interoperability, and the sharing of results within research practices and in the management of Umbria's cultural and landscape heritage.

Dataset A is provided in Microsoft Excel (.xlsx) format and includes two worksheets: one dedicated to metadata, which describes the dataset's structure, fields, and sources, and a main worksheet containing 69 records organized into eight descriptive fields. Each record corresponds to a geospatial resource (documentary, cartographic, or digital) used in the Umbrian case study and is linked to a document, dataset, or digital repository published by national or local institutions responsible for Tangible Cultural Heritage management. The dataset is conceived as a tool for the documentation, organization, and systematization of the geographical sources employed in the study, with the objective of supporting the mapping, classification, and accessibility of territorial and cultural resources.

This dataset includes a worksheet containing metadata and a worksheet with the following columns:

- **Id_Source**: a unique alphanumeric identifier assigned to each resource to ensure traceability and cross-referencing with other datasets.
- **Title**: the official title or designation of the resource, corresponding to publications, archival documents, digital datasets, or visual materials.
- **Year**: the year of publication or creation of the resource, allowing chronological organization and filtering of the materials.
- **Author**: the author, editor, or institutional body responsible for producing or maintaining the resource.
- **Type of file**: the typological classification of the material.
- **The resources include**:
 - **Shapefile (.shp)**: vector geospatial datasets used to represent archaeological sites, boundaries, and infrastructures within GIS environments.
 - **GeoTIFF (.tif, .tiff)**: raster images and orthophotos containing georeferenced topographical or environmental data.
 - **KML (.kml)**: Keyhole Markup Language files used to visualize and share geospatial data in applications such as Google Earth or web-based GIS platforms.
 - **GeoJSON (.geojson)**: lightweight format for encoding a variety of geographic data structures, commonly used in web mapping and open-data environments.
 - **PDF (.pdf)**: textual and graphic documents such as scientific publications, technical reports, and historical maps.
 - **WMS (Web Map Service)**: online map layers provided by institutional or regional geoportals, enabling visualization and integration of spatial data.
 - **TIFF/JPEG/PNG**: photographic and visual documentation of heritage assets.

- Other formats: additional materials (e.g., .csv tables, .doc reports) used as auxiliary documentation.
- Link: the digital access path or URL indicating the online repository or storage location of each file.
- Copyright: information on intellectual property rights, usage restrictions, and license type (e.g., proprietary).
- Accessibility: the accessibility level (open access, restricted, or institutional), defining the degree of availability for consultation and reuse.

All fields are standardized using controlled vocabularies to ensure metadata harmonization and interoperability. The dataset classifies heterogeneous resources, ranging from spatial data to archival documents, within a unified digital structure, facilitating their integration into georeferenced analytical environments developed under the CHANGES framework.

3.2. Dataset B: historical cartographic objects

Dataset B was developed to analyze and document ancient landscape features that have since disappeared but were still clearly represented in historical maps, providing crucial evidence for the diachronic reconstruction of Umbria's territorial and environmental transformations. Each record corresponds to a unique historical map (mainly printed maps, engravings, or illustrated charts) produced between the 16th century and the Italian Unification (1861), and documented in libraries, archives, or digital repositories. These maps represent key historical sources for understanding the environmental, geographical, and settlement dynamics of Umbria, offering valuable insights into landscape configurations, infrastructures, and territorial perceptions over time.

The dataset is provided in Microsoft Excel (.xlsx) format and consists of two worksheets: a metadata sheet and a sheet named "MAPS", containing 49 records and 18 descriptive fields.

This second worksheet includes the following columns:

- Id_Map: a unique alphanumeric identifier assigned to each map, ensuring traceability and cross-referencing with other datasets in the CHANGES framework.
- Technique: the printing or drawing technique used in the map's production.
- Year: the year or time span of production.
- Title: the original title or caption of the map as reported in the source document or atlas.
- Author: the name of the mapmaker, engraver, or publishing authority.
- A textual summary describing the map's content, historical context, and bibliographic notes. The information included in this field corresponds to the descriptive entries provided in the Dossier of the Istituto per la Storia dell'Umbria Contemporanea (ISUC), compiled by Valentina Mariani and entitled "Immagini, percezioni e realtà dell'Umbria tra età moderna e contemporanea (secoli XVI-XX)". The original dossier is accessible and downloadable at the following link: <https://consiglio.regione.umbria.it/isuc/archivio/dossier>
- Material: the physical medium of the artifact.
- Dimension: the physical size of the map, expressed in millimeters.
- Colour: indicates whether the map is printed in color or black and white.
- Conservation: the preservation status.
- Place of conservation: the institution or archive currently holding the map.
- Inventory: the archival or library inventory number, where available.
- Bibliography: references to bibliographic sources describing or citing the map.
- Link: the online access path or permanent URL to the digital version of the map.
- Copyright: information on ownership, reproduction rights, and usage permissions.

All data fields are standardized and curated to ensure interoperability and cross-dataset integration with other Cultural Heritage and spatial information systems. The dataset provides a harmonized digital catalogue of historical cartographic sources documenting the environmental and territorial evolution of Umbria.

It supports research on mapmaking techniques, authorship, and regional representation, facilitating the integration of historical and cartographic evidence into geospatial analytical frameworks developed within the CHANGES project, and promoting the preservation and digital accessibility of historical maps as Cultural Heritage assets.

3.3. Dataset C: archaeological-topographical database

Dataset C is a database of processed data provided in Microsoft Excel (xlsx) format and compiles structured information related to Tangible Cultural Heritage, focusing on archaeological sites, topographical units, chronological periods, and phases, together with their associated metric and reference data. This dataset was specifically developed for the pilot case study presented in this article and therefore encompasses only the archaeological and topographical sources that can be directly associated with the territory located within the administrative boundaries of the Municipality of Arrone (TR).

The compilation of Dataset_C derives from an extensive review of the published bibliography on the subject, the consultation of archival sources, and, most importantly, from the systematic analysis of a selection of repositories classified in Dataset_A:

- AID_1: Vincoli diretti beni archeologici
- AID_2: Beni culturali – archeologici – Tratturi MT art. 10 DLgs. 42/2004.
- AID_3: Beni culturali – aree archeologiche art. 10 DLgs. 42/2004.
- AID_4: Beni culturali – archeologici – Tratturi art. 10 del D.Lgs. 42/2004.
- AID_5: Vincoli indiretti beni archeologici.
- AID_6: Beni archeologici.
- MIC_1: Catasto Gregoriano.
- MIC_2: Catalogo – Vincoli in rete.
- MIC_3: Catalogo Generale dei Beni Culturali.
- MIC_4: Geoportale Nazionale per l'Archeologia.
- MIC_5: Cantieri in Umbria.
- UMB_25: Ricognizione dei centri storici e viabilità storica.
- UMB_26: Siti archeologici ed elementi del paesaggio antico.
- UMB_27: Beni paesaggistici.
- UMB_28: Abbazie e principali siti benedettini.
- UMB_29: Ville e dimore storiche.
- UMB_30: Principali siti di architettura militare e religiosa.

The file consists of seven worksheets, one dedicated to the metadata, one to the bibliography and the other five dedicated to a specific category of archaeological-topographical information, designed to ensure interoperability and to support integrated spatial and temporal analyses.

These classification and structuring procedures were developed within the research activities of the Chair of Classical Archaeology at the Department of Classics, Sapienza University of Rome, under the scientific coordination of Professor Paolo Carafa [11].

- The 0_AGER sheet contains the basic information about the territorial area under analysis. In this case, the *ager* corresponds to the territory within the boundaries of the Municipality of Arrone (TR).
- The 1_SITE sheet contains the basic information on archaeological sites, defined as portions of the territory where coherent sets of material and structural evidence related to one or more human activities have been identified. Each site represents a coherent spatial unit, defined based on the distribution, density, and nature of the archaeological and architectural remains. A site may correspond, for example, to a sanctuary (including temples, altars, and accessory structures), a productive system (residential complex with oil press, basins, and channels), an urban or rural settlement (public and private buildings), or a necropolis (tombs and funerary structures).

- The 2_TU sheet describes the Topographical Units (TUs), which represent the internal spatial subdivisions of sites. Each TU corresponds to a homogeneous portion of space characterized by a specific morphological, functional, or structural configuration. TUs can be analyzed from both a topographical perspective—since they define the shape and position of the evidence in space—and a chronological one, as each unit may have undergone transformations or modifications over time.
- TUs are organized into distinct chronological levels, recorded in the 3_PERIOD and 4_PHASE sheets. Periods represent broad temporal intervals during which a building or context maintained a substantially unified architectural layout, while Phases correspond to shorter intervals marked by minor interventions or secondary modifications that did not alter the main architectural scheme.
- The 5_DATUM sheet contains references used for geolocation and spatial integration of information across the dataset. Each ID_DATUM uniquely corresponds to the identifier of a graphic element contained in the Dataset_D, allowing for a direct association between descriptive data and their corresponding geometric representations.

This relationship ensures consistency between the alphanumeric (Dataset C) and geographical (Dataset D) components of the information system. The collection of Sites and their associated Topographical Units define the Territory, understood as the sum of all TUs and Sites encompassed within a single geographic framework. In this case study, the territory corresponds to the administrative boundaries of the Municipality of Arrone (TR).

This hierarchy: TU → Site → Territory (Ager), provides the structural basis for the organization and management of data within the Territorial Information System developed for the project.

Each TU is identified through an integrated system of information and is classified according to its temporal articulation in periods and phases.

Every TU is assigned a unique alphanumeric code that synthesizes its main identifying elements, ensuring both traceability and interoperability.

For example, the code Arr1_2_1_2_V_P_o_del_arc corresponds to:

- Arr = Ager/Territory (Municipality of Arrone).
- 1 = Site identifier (Sanctuary on Mount Arrone).
- _1 = progressive number of the TU within the site (rock cavity).
- _1 = corresponding Period.
- _2 = Phase referring to the rearrangement of the cavity through the construction of a plastered wall.
- First uppercase letter (Visibility): V = Visible; NV = Not Visible.
- Second uppercase letter (State of preservation): P = Preserved; NP = Not Preserved; U = Unknown.
- Third lowercase letter (Localization): o = Original position; u = Uncertain position.
- Fourth element (Representation): del = Delimited; ndel = Not Delimited.
- Final group of letters (Type of source): arc = Archaeological; let = Literary.

This coding system enables the immediate linkage of each record to its territorial context, site, specific TU, chronological framework, and the type of source from which it derives.

The dataset thus supports integrated spatial and diachronic analyses, ensuring coherent and scalable management of archaeological data within a unified information framework.

3.4. Dataset D: spatially referenced graphical sources

Dataset D consists of a georeferenced DWG file created using AutoCAD Map 3D 2025 in the EPSG:3004 coordinate reference system (Monte Mario / Italy Zone 1). The dataset is also replicated in KML and Shapefile format; however, in these last two versions the WMS connections

and rasters images are not directly loaded and must be accessed separately through their corresponding service URLs listed in Dataset A.

This file integrates:

- WMS connections to major national and regional geoportals (only DWG).
- Georeferenced raster layers that enable the direct visualization of selected cartographic and topographical sources (only DWG).
- Archaeological vector elements, corresponding to Topographical Units (TUs), are represented as spatial features in Dataset_D. Each of these features is linked to its descriptive record in Dataset_C through the unique identifier ID_DATUM, which establishes a one-to-one correspondence between the alphanumeric data stored in Dataset_C and their geometric representations in Dataset_D.
- Geomorphological vector elements were created using georeferenced geomorphological layers derived from GIS analysis of the file: INGV_1 (DTM_Tinitaly).

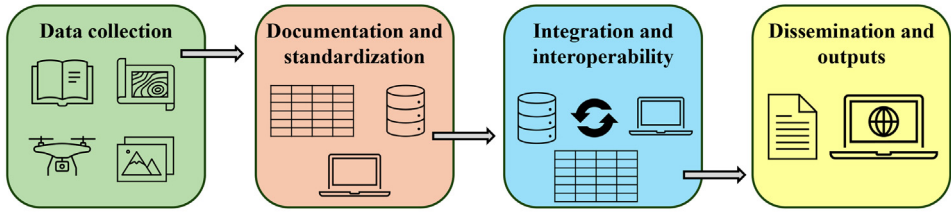
The Dataset_D contains the following geospatial georeferenced sources and services (see Dataset_A):

- MASE_1: Uso del suolo - Corine Land Cover anno 1990.
- MASE_2: Uso del suolo - Corine Land Cover anno 2000.
- MASE_3: Uso del suolo - Corine Land Cover anno 2006.
- MASE_4: Uso del suolo - Corine Land Cover anno 2012.
- MASE_5: Prodotti LiDAR - Regione Umbria.
- MASE_7: Unità amministrative regionali, provinciali e comunali 2020.
- UMB_2: Carta Fitoclimatica 1:200.000.
- UMB_3: Carta Geobotanica 1:50.000.
- UMB_5: Mosaico delle mappe catastali (edizione 1985).
- UMB_6: Carta Tecnica Regionale formato raster a scala 1:10.000.
- UMB_7: Carta Tecnica Regionale formato raster a scala 1:5.000.
- UMB_8: Ecografico Catastale Regionale - 2005–2010
- UMB_15: Morfologia del suolo, singolarità geologiche e reticolo idrografico.
- UMB_16: Zone di elevata diversità floristico vegetazionale.
- UMB_17: Zone di particolare interesse naturalistico ambientale.
- UMB_18: Uso del suolo. Copertura forestale.
- UMB_19: Uso del suolo. Copertura agricola.
- UMB_20: Sistema insediativo e rete delle infrastrutture.
- UMB_21: Siti di interesse naturalistico.
- UMB_22: Rete ecologica regionale.
- UMB_23: Rete di mobilità ecologica di interesse regionale.
- UMB_24: Attività estrattive.
- UMB_25: Ricognizione dei centri storici e viabilità storica.
- UMB_26: Siti archeologici ed elementi del paesaggio antico.
- UMB_27: Beni paesaggistici.
- UMB_28: Abbazie e principali siti benedettini.
- UMB_29: Ville e dimore storiche.
- UMB_30: Principali siti di architettura militare e religiosa.
- UMB_32: Carta geologica.
- UMB_36: Zonizzazione del Parco Fluviale del Nera.

The file contains the georeferenced traces of the raster datasets, but not the raster files themselves. To correctly visualize the geospatial data within the DWG file, the corresponding raster files must be downloaded from Dataset A and re-uploaded into Dataset D. Once this operation is completed, the images will be automatically displayed. Please note that, for files originally in PDF format, the images must first be converted into TIFF, PNG, or JPG format before being loaded.

Table 1

Workflow of the Experimental Design.



The WMS connections, configured according to OGC standards, enable dynamic access to these and other external datasets, such as orthophotos, cadastral layers, and environmental data, allowing users to retrieve, visualize, and overlay multiple sources directly within the georeferenced environment.

The dataset maintains sub-kilometer planimetric accuracy for regional maps, with accuracy oscillating around one meter for territorial units (TU), and sub-metric accuracy for WMS services, is interoperable with major GIS formats (DXF, SHP, GeoPackage), and can be accessed or edited using AutoCAD, QGIS, or equivalent CAD/GIS software.

The dataset environment is fully interoperable and can be converted or reprojected into other coordinate reference systems, such as WGS84 (EPSG:4326) and RDN2008 / UTM Zone 32 N (EPSG:7791), ensuring compatibility with additional datasets and compliance with international mapping standards. Coordinate transformations from EPSG:3004 (Monte Mario / Italy Zone 1) to RDN2008 / EPSG:7791 and WGS84 / EPSG:4326 were carried out using the VertoOnline service provided by the Italian Military Geographic Institute (IGM; <https://www.igmi.org/it/descrizione-prodotti/elementi-geodetici-1/verto-on-line>), which applies the official national grid transformations between Monte Mario and RDN2008 or WGS84. This guarantees both the traceability and reproducibility of the results.

The significance of Dataset D lies in the georeferencing and harmonization process, which enables the spatial contextualization of a representative selection of sources from Dataset A. This provides a geometric and analytical framework for analyzing the historical evolution, spatial organization, and environmental dynamics of the Valnerina and Arrone territories, supporting future activities in heritage conservation, landscape interpretation, and sustainable spatial planning.

4. Experimental Design, Materials and Methods

The methodological workflow of this study has been organized as a four-stage workflow, explicitly linking datasets A-D to concrete actions of data collection, processing, integration, and dissemination. This structure aims to provide clarity, reproducibility, and ease of adaptation for other researchers and heritage professionals working on archaeological and Cultural Heritage data (Table 1).

1. Data collection: bibliographic sources, archival records, institutional geoportals, and historical maps are gathered and catalogued, with particular attention to the integration and reuse of archaeological, historical, topographical, and cartographic legacy data, forming the basis of Datasets A, B, and C.

2. Documentation and standardization: metadata are normalized, controlled vocabularies are defined, and relational tables (Datasets A, B, and C) as well as geospatial datasets (Dataset D) are created. Harmonization of temporal, topographic, and typological fields ensures semantic consistency and prepares heterogeneous sources for integration into a structured, machine-readable system.

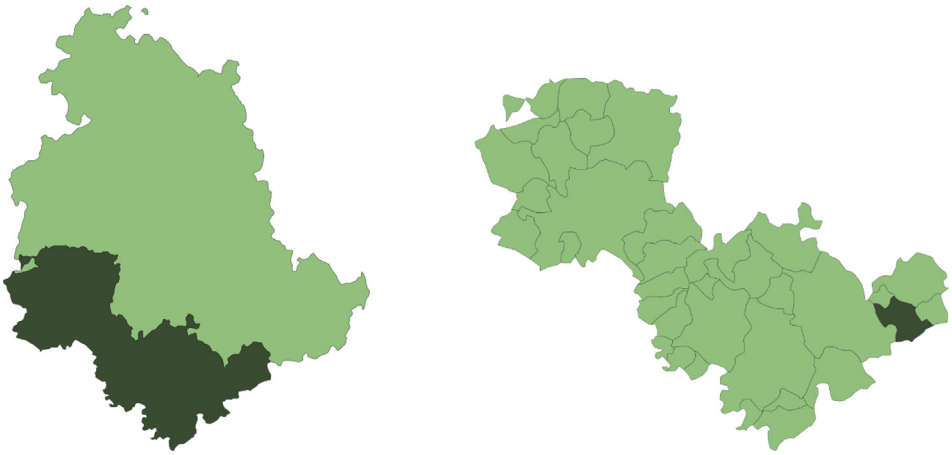


Fig. 1. Left: Umbria region with the territory of Terni Province highlighted in dark green.
Right: Terni Province with the territory of the Municipality of Arrone (TR) highlighted in dark green.

3. Integration and interoperability: Interoperability among Datasets A–D is primarily conceptual and semantic, supported by semi-automatic procedures that still require manual validation. It relies on the consistent use of unique identifiers (ID_Ager, ID_Site, ID_TU, ID_Datum) present across all datasets. These identifiers serve as linking keys between descriptive data, images, and vectorized geometries, ensuring traceability, consistency, and data integrity.

In practice:

Dataset D integrates data by loading Dataset A as raster files or through WMS services, with each layer named according to its corresponding ID.

Images from Dataset B are linked to Dataset C using ID_Ager, ensuring consistent association between images and descriptive data.

Data from Dataset C are incorporated into Dataset D as vectorized geometries, classified and organized into layers labeled with their corresponding ID_Ager, ID_Site, ID_TU and ID_Datum.

This approach allows each dataset to remain independent while enabling coherent combination, querying, and visualization of the information.

The datasets have been structured and harmonized so that they can be directly loaded into GIS environments such as ArcGIS and QGIS. In these platforms, operators can reconstruct a comprehensive Territorial Information System, integrate descriptive, archival, and geospatial data, and perform visualization, querying, and advanced analytical operations. Examples include investigating the spatial distribution of sites, generating phase-specific plans, analyzing relationships between geological contexts and areas of archaeological and cultural interest, examining proximity to hydrological or infrastructural features, assessing patterns of landscape use over time, and supporting predictive modeling to identify areas with potential archaeological significance.

4. Dissemination and outputs: building upon the integration of Datasets A, B, C, and D, a series of interpretative maps can be developed as final visual outputs of the Valnerina Project, focusing on the territory of the Municipality of Arrone (Fig. 1).

- Geological Map and related landscape elements, representing lithostratigraphic units and Quaternary deposits (based on Dataset A: MASE_7, UMB_3, UMB_32; Datasets B and C).
- Geomorphological Map of the Ancient landscape, reconstructing the ancient paleoenvironment by depicting geomorphology and hydrography (based on Dataset A: MIC_1, INGV_1, MASE_1–5, 7, UMB_5–8, 15, 31; Datasets B and C).

These two thematic maps are presented as examples of visual syntheses of the integrated analytical process (Fig. 2); additional deliverables can be generated, depending on the specific

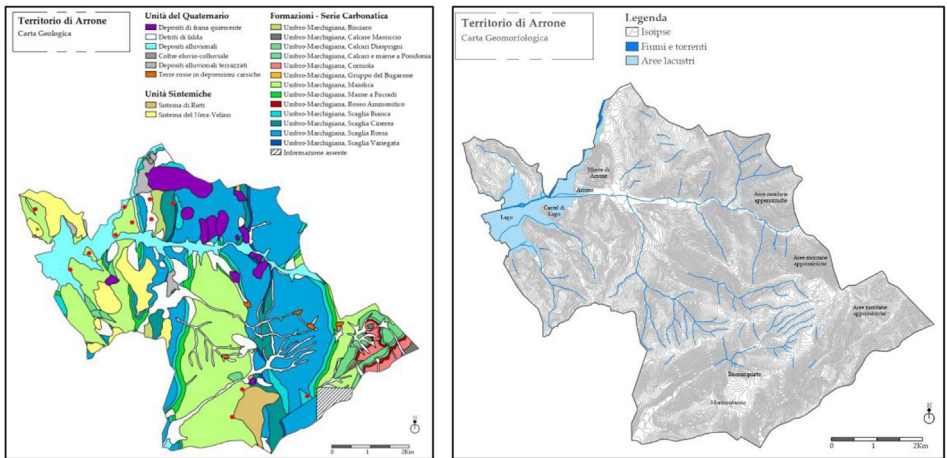


Fig. 2. Left: Geological Map and related landscape elements.
Right: Geomorphological Map of the Ancient landscape.

research questions and data available, supporting both interpretation and communication of results.

All such outputs and interpretative images are continuously uploaded to the open Zenodo repository of the CHANGES community, ensuring immediate accessibility and preservation. Furthermore, a dedicated Web GIS platform conceived as a Territorial Information System (developed by the Department of Classics of Sapienza University of Rome in collaboration with Vision-Lab and Digital Media Agency), will host data from both Southern Umbria and Ancient Latium, enabling broader access and integration. This platform was presented at the recent workshop “Mappe e scenari per il futuro del patrimonio culturale. Tre anni di ricerche del partenariato PNRR CHANGES”, held in Rome between 14 and 16 January 2026, and is scheduled to be made publicly available by the end of 2026.

By explicitly associating each stage of the workflow with the relevant datasets, actions, and the ID-based linkage system, this model provides a transparent, reproducible, and adaptable framework for documenting, processing, and disseminating Cultural Heritage data. At all stages, metadata structures consider international standards such as ISO 19,115 and Dublin Core, extended with fields specifically designed for territorial, historical, and geospatial analyses, while spatial visualization is supported via OGC-compliant services (e.g., WMS). This ensures semantic consistency and interoperability across datasets, enhancing the potential for cross-referencing. Its applicability extends beyond the Umbria region, being designed to support future territorial analyses in national and international contexts, enabling highly effective cross-comparison and integrated analysis of heterogeneous datasets.

Limitations

Although the dataset and methodological framework developed in this study provide a coherent and replicable model for integrating and analysing Tangible Cultural Heritage data, some limitations remain, reflecting the current stage of implementation and suggesting directions for refinement.

- The workflow has so far been applied to a single pilot area: the Municipality of Arrone (TR) in southern Umbria. While this context proved representative for testing data integration, spatial harmonization, and analytical procedures, the scalability of the model to larger,

more heterogeneous, or administratively complex territories (such as metropolitan areas or multi-regional contexts) has yet to be fully validated. This limitation is particularly relevant given that the intended users of the dataset include a wide range of public administrations (ministries, regions, provinces, municipalities) as well as private entities (companies, foundations, and professional organizations), each characterized by different mandates, decision-making scales, technical capacities, and data needs.

- The current system operates within a two-dimensional CAD–GIS environment focused on planimetric integration. While this approach is adequate for territorial overview, comparative analysis, and initial decision-support, three-dimensional modelling, volumetric reconstruction, and predictive or scenario-based simulations are not yet implemented. This limits the applicability of the dataset for advanced architectural analysis, structural assessment, and risk modelling, which are particularly relevant for professionals such as architects, engineers, and conservation specialists.
- Data interoperability among Datasets A, B, C, and D is conceptually defined but still relies on manual or semi-automated integration processes. As a result, the effective use of the dataset currently requires a certain level of technical expertise in GIS and heritage data interpretation, potentially restricting accessibility for non-specialist users or smaller administrations with limited technical resources. To address this issue, the CHANGES research group, and specifically the Sapienza team within Spoke 8, is developing a GIS-based Territorial Information System aimed at automating dataset relationships, enabling dynamic cross-referencing, and supporting advanced spatial and chronological analyses.

Finally, while the dataset is designed to support multiple professional profiles involved in heritage management (including archaeologists, historians, architects, engineers, cultural managers, planners, and policymakers) its current structure primarily addresses analytical and planning-oriented needs. The translation of complex heritage data into simplified or narrative forms suitable for the public, educational purposes, or participatory governance processes remains a challenge and represents an area for future development.

Overall, these limitations underline the evolving and experimental nature of the project. At the same time, they define a clear roadmap for future improvements aimed at increasing automation, scalability, interoperability, and usability across a broad spectrum of institutional actors, professional users, and public audiences.

Ethics Statement

This study did not involve human participants, animals, or the collection of personal or sensitive information. All data presented in the datasets were obtained from publicly accessible bibliographic, archival, and institutional sources, in full compliance with Italian and European regulations on data protection, copyright, and Cultural Heritage management. The research activities were conducted within the CHANGES Partnership (Cultural Heritage Active Innovation for Next-Gen Sustainable Society), Spoke 8 – “Sustainability and Resilience of Tangible Cultural Heritage”, under the coordination of the Sapienza University of Rome, adhering to the ethical guidelines for responsible research and open data dissemination

Data Availability

[Interoperable Datasets for Assessing, Reconstructing, and Valorising the Landscape and Tangible Cultural Heritage of Southern Umbria - Deliverable of the Spoke 8 Project \(Original data\)](#) (ZENODO - Project CHANGES - Cultural Heritage Active Innovation for Next-Gen Sustainable Society).

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary Materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.dib.2026.112555.

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