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DATA DESCRIPTOR

An interoperable catalogue of Middle and Late Bronze Age settlements in western Anatolia (c. 2000–1200 BCE)

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This dataset offers a comprehensive digital catalogue of 483 archaeological settlement sites in western Anatolia dating to the Middle and Late Bronze Age (c. 2000–1200 BCE). Compiled over a decade, it brings together evidence from excavation reports, systematic surveys, historical sources, and remote sensing. Each site is georeferenced and described through a standardized set of metadata, including chronological attribution, site function, material culture, bibliographic references, and associated ancient mineral resources. The dataset is published on Zenodo as a collection of openly accessible files, structured with consistent keys that ensure integration across records. To enhance semantic interoperability, settlement entries are linked to external reference datasets such as open knowledge bases, enabling opportunities for comparative, geospatial, and interdisciplinary research spanning archaeology, digital humanities, and historical geography. By combining standardized metadata with semantic linking, the resource facilitates reuse within broader digital infrastructures. It thereby provides a transparent, openly licensed foundation for analyzing regional settlement systems and encourages more comprehensive approaches to the study of Bronze Age Anatolia.

Background & Summary

The Bronze Age (c. 3300–1200 BCE) stands as a pivotal era in human civilization, marked by the emergence of early state organizations, expansive trade networks, and technological innovations[1–3]. During this era, societies across Eurasia underwent accelerating urbanization and intensifying political centralization—developments that laid the groundwork for the complex polities of the ancient world[4–6]. Within this broad chronological expanse, the Middle and Late Bronze Age (c. 2000–1200 BCE) stand out as periods of particularly profound transformation. These centuries witnessed the rise of complex political entities, an intensification of long-distance exchange networks, and a marked expansion of the textual and archaeological record across the Eastern Mediterranean and Near East. Against this backdrop, Western Anatolia (corresponding to present-day western Türkiye) emerged as a culturally vibrant region of considerable geopolitical significance[7–11], serving as a dynamic cultural and commercial crossroads between the Aegean and the Near East[12–16]. Furthermore, the region was home to a series of Luwian-speaking polities—attested in Hittite texts—that maintained both cooperative and conflictual relations with neighboring powers such as Mycenaean Greece and Hittite Anatolia[17–20]. For example, major centers such as Troy, Beycesultan, and Liman Tepe illustrate Western Anatolia's integration into extensive trade networks and underscore its strategic role in the transfer of metals and goods via both maritime and overland routes[21–24]. These settlements flourished within a broader landscape of fortified sites and interconnected regions, attesting to Western Anatolia's prominence throughout the Middle and Late Bronze Age.

Despite its cultural vitality and strategic role within the Luwian cultural sphere, Western Anatolia has long been underrepresented in syntheses of the Bronze Age. Eurocentric narratives—often casting the region as a cultural void or a marginal buffer zone—have shaped this neglect[15]. The problem has been reinforced by the fragmentation of regional datasets, the absence of standardized metadata, and the limited accessibility of many

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excavation reports published only in Turkish. Together, these factors obscured the region's archaeological richness at the micro-regional level and hindered attempts to discern broader patterns[25].

To address this gap, the Luwian Studies Foundation initiated in 2014 a project that has since evolved into a comprehensive dataset encompassing 483 settlement sites from the Middle and Late Bronze Age (2000–1200 BCE) in western Anatolia—here defined as the region west of an imaginary line running between Eskişehir and Antalya. The dataset is the product of a decade-long meta-analysis that drew on excavation reports, systematic surface surveys, remote sensing imagery, historical sources, and cartographic materials. Each record provides precise geographic coordinates, site names, cultural and chronological attributions, archaeological features (e.g., inscriptions), bibliographic references, and data on associated mineral resources.

By drawing together underutilized sources and weaving them into a region-wide synthesis, the dataset provides a more balanced and spatially comprehensive view of Bronze Age settlement systems in Western Anatolia. What began more than a decade ago as a set of static spreadsheets has since been transformed into structured formats that enhance consistency, searchability, and analytical capacity. The resulting JSON and CSV files preserve these refinements in machine-readable form, ensuring open access, transparency, and long-term usability[25]. The digital catalogue is designed to support interdisciplinary and interregional research across archaeology, history, the digital humanities, and geospatial analysis. At the same time, its semantic design allows interoperability with external digital gazetteers and linked open data resources, opening pathways for collaboration and reuse.

This data descriptor presents the dataset in detail, outlining the procedures of compilation, validation, and digital integration, and situates it within its broader significance: a foundation for studying the Bronze Age of Western Anatolia through a comprehensive, data-driven framework.

Methods

Study area. The study area encompasses roughly 373,000 km² in western Anatolia (26.02–31.82° E, 36.27–41.82° N), a territory comparable in size to modern Germany. Its boundaries were defined through geographic information system (GIS)-based spatial analysis of Bronze Age settlement distribution, combined with a systematic review of archaeological fieldwork projects and relevant historical sources. Settlement locations were further validated by on-site observations, satellite imagery, and topographic mapping, supplemented by published archaeological data. All coordinates are stored in the WGS 84 reference system to ensure consistency and global positional accuracy.

Data limitations and inclusion criteria. Since the early 1980s, when systematic survey methodologies became standard practice, roughly half of western Anatolia has been examined through archaeological surveys (Fig. 1). The intensity of this work varies considerably: some projects involved extensive reconnaissance to identify sites, while others relied on team-based, intensive survey methods. Large parts of the region remain unsurveyed, often because they are mountainous or densely forested and thus less likely to have supported substantial settlements. Even where survey coverage exists, the record is incomplete. Sites may have been eroded, buried beneath alluvial deposits, or misclassified in earlier campaigns, particularly those of the 1980s and 1990s, when identifying prehistoric ceramics posed persistent challenges.

To be included in the catalogue, sites were required to meet two criteria: a minimum diameter of 100 m and the presence of ceramic material attributable to the second millennium BCE. These thresholds restrict the dataset to settlements that likely supported more than 100 inhabitants, setting it apart from catalogues that also register isolated farmsteads or burials. The initial compilation drew on a systematic review of published survey reports, most of them in Turkish. Only sites with explicitly reported Middle or Late Bronze Age ceramics were considered—about 10% of all sites mentioned in the literature. Each entry further had to include both a toponym and published geographic coordinates. Candidate sites were then verified through satellite imagery (Google Earth Pro, Google LLC https://earth.google.com; Sentinel-2, Copernicus Data Space Ecosystem, https://browser.dataspace.copernicus.eu/), with approximately 80% identifiable in this way. The majority of these were subsequently confirmed through on-site inspection. Many correspond to tell mounds (höyük) along the edges of alluvial plains, formed by long-term anthropogenic accumulation while others occupy fortified hilltops.

Data collection. The dataset was developed through the systematic integration of archaeological fieldwork data with comprehensive scholarly research. By combining settlement evidence with historical and literary sources, the project sought to balance methodological rigor with contextual depth in documenting Middle and Late Bronze Age settlements across western Anatolia. Data were compiled from excavation and survey reports, enriched with historical and toponymic records, validated through remote sensing and GIS analyses, supplemented by archaeologically attested mineral resource data, and semantically linked to open knowledge bases to ensure interoperability (Fig. 2).

Archaeological excavations and surveys. Data were drawn from a critical review of 33 archaeological excavations and 33 systematic surface surveys carried out between the late nineteenth century and the present. From a bibliographic corpus of 109 survey reports and 65 excavation reports, 483 settlement sites were identified, together with their stratigraphic, cultural, and chronological attributes[15,26]. Each entry in the dataset is linked to its original publication through a unique identifier.

Historical and scholarly literature. A complementary meta-analysis synthesized information from excavation and survey reports, regional syntheses, historical maps, and records of local toponyms. This process helped detect, validate, and contextualize settlement data, including site locations, material culture, chronological phases, and mineral resources. Place names were standardized to ensure consistency and to facilitate

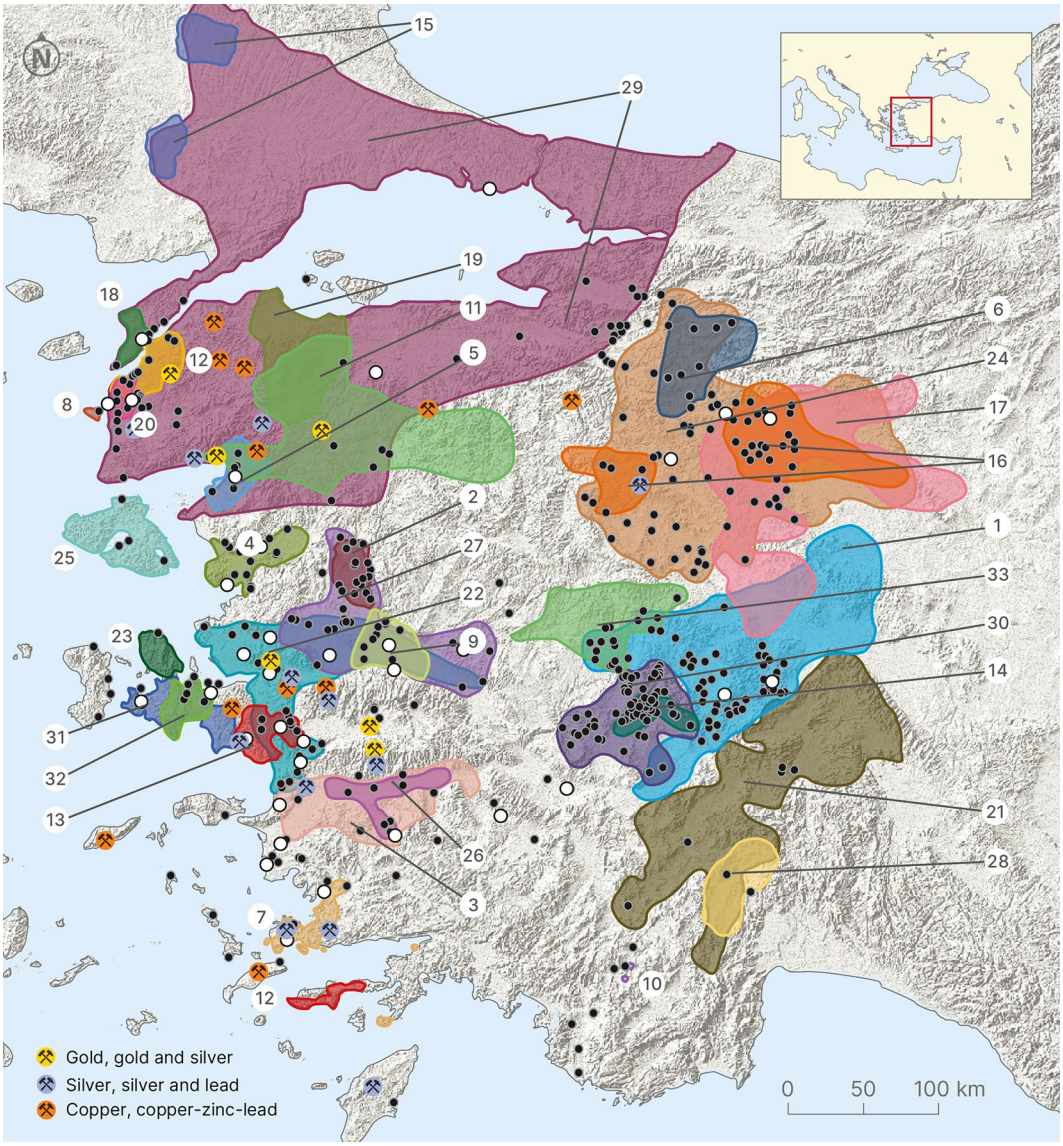

Fig. 1 Relief map of western Türkiye showing archaeological excavations (white dots), settlement sites (black dots), areas covered by archaeological surveys, and archaeologically attested ore deposits (Luwian Studies #0102). A complete list of systematic surveys is provided in Supplementary Table S1, and a complete list of archaeological excavations is provided in Supplementary Table S2.

interoperability with external digital gazetteers. All literature sources used are published works, and their full references are compiled in a dedicated bibliography file accompanying the dataset.

Remote sensing and GIS. Multi-temporal satellite imagery, combined with GIS-based analysis, was used to verify settlement locations and to identify ancient mining activity within the study area. Geospatial analyses were carried out in the open-source platform QGIS 3.34.10 (https://qgis.org/). Each settlement was recorded as a single-point coordinate representing its approximate center and then cross-checked against published maps, satellite imagery, and field observations. This process refined positional accuracy and allowed regional patterns of settlement distribution to be analyzed in greater detail. The dataset ultimately provides precise WGS 84 geographic coordinates (longitude and latitude) for both settlements and ore deposits.

Mineral Resources. Western Asia Minor's diverse geology made the region a major center of mineral resource exploitation from prehistory onward[27]. Rich in gold, silver, copper, and tin, it supported early large-scale mining and metallurgy at sites such as Troy, Limantepe, Beycesultan, and the Kütahya–Eskişehir district[28–34]. Local tin deposits, including those at Kestel[35] and Hisarcık[36,37], suggest that a developed and largely self-sufficient metal industry existed earlier than previously assumed. These resources not only sustained regional production but also fed extensive trade networks spanning Anatolia, Mesopotamia, and the eastern Mediterranean. Metal

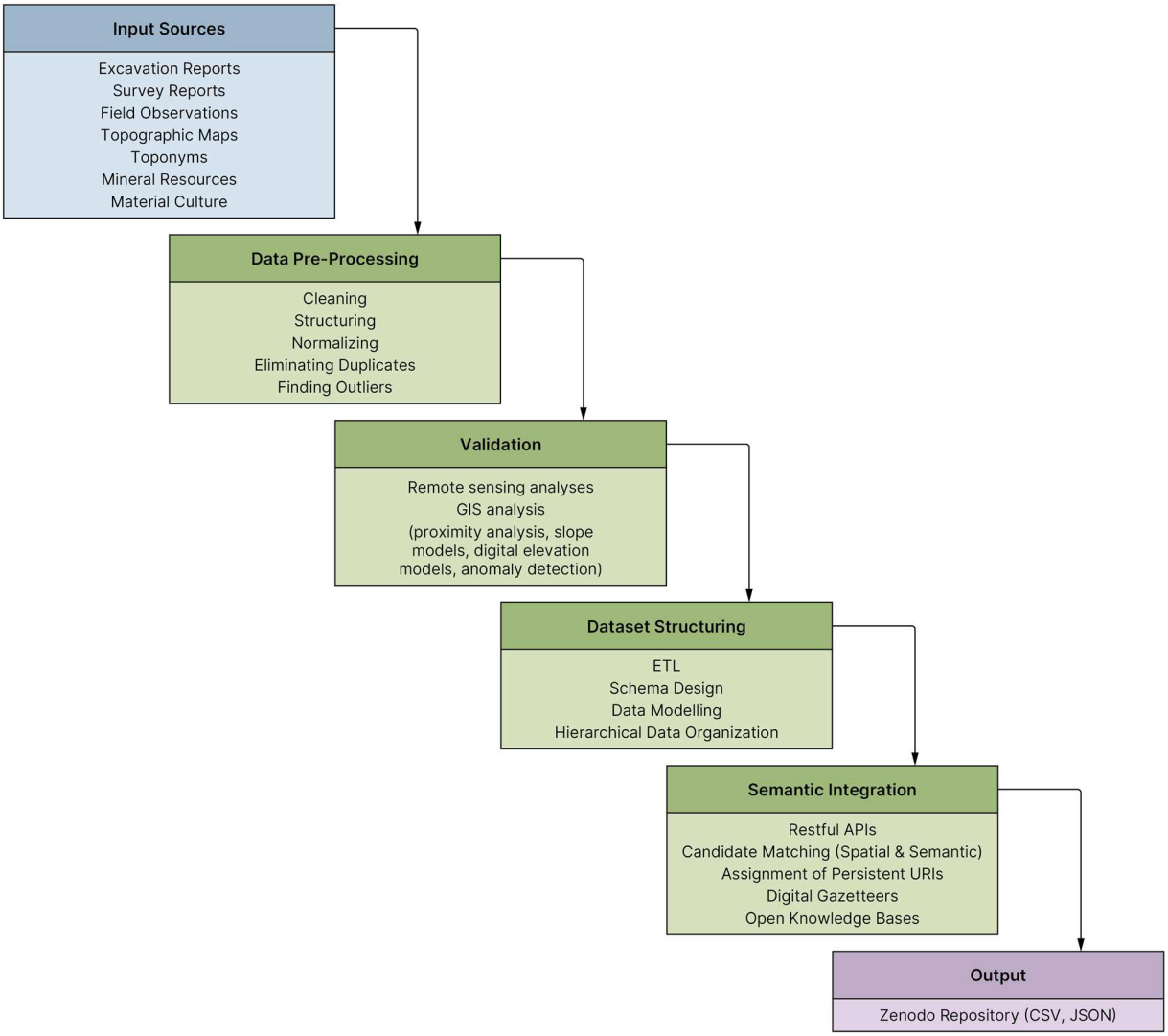

Fig. 2 End-to-end data processing and integration workflow.

objects circulated as symbols of wealth and power, while Hittite texts record a specialized class of metalworkers—underscoring the economic and cultural importance of metallurgy in early complex societies[38].

Ore deposits with archaeologically attested evidence of exploitation were identified through a systematic review of scholarship on ore-bearing zones in the region[27–36]. These findings were corroborated by data from Türkiye's General Directorate of Mineral Research and Exploration (MTA, https://www.mta.gov.tr/v3.0/hizmetler/il-maden-haritalari). In total, 25 ancient mines were documented and integrated into the dataset (Fig. 1), offering key evidence for reconstructing Bronze Age economies and the trade routes they sustained.

Dataset structuring. The dataset was systematically cleaned, normalized, and structured to guarantee consistency, interoperability, and long-term usability. What began as locally maintained spreadsheets was subsequently standardized through an Extract–Transform–Load (ETL) workflow, a process that enhanced transparency, improved internal coherence, and ensured sustainable accessibility for future research.

Schema design and data modeling. A comprehensive analysis of the raw dataset was undertaken to identify its core entities and the relationships among them. From this process emerged a logical schema encompassing settlements, chronological phases, site categories, bibliographic references, and spatial attributes. These elements are interlinked through persistent identifiers (e.g., site_id, period_id, category_id, reference_id), which maintain consistency across the dataset.

Although the dataset is distributed in flat JSON and CSV formats, it preserves an underlying relational architecture. Shared identifiers act as primary keys, linking records across files and allowing users to reconstruct the logical structure of a relational database while working with accessible flat-file formats. This design enables reliable cross-referencing and supports complex analytical queries and comparative studies (Fig. 3).

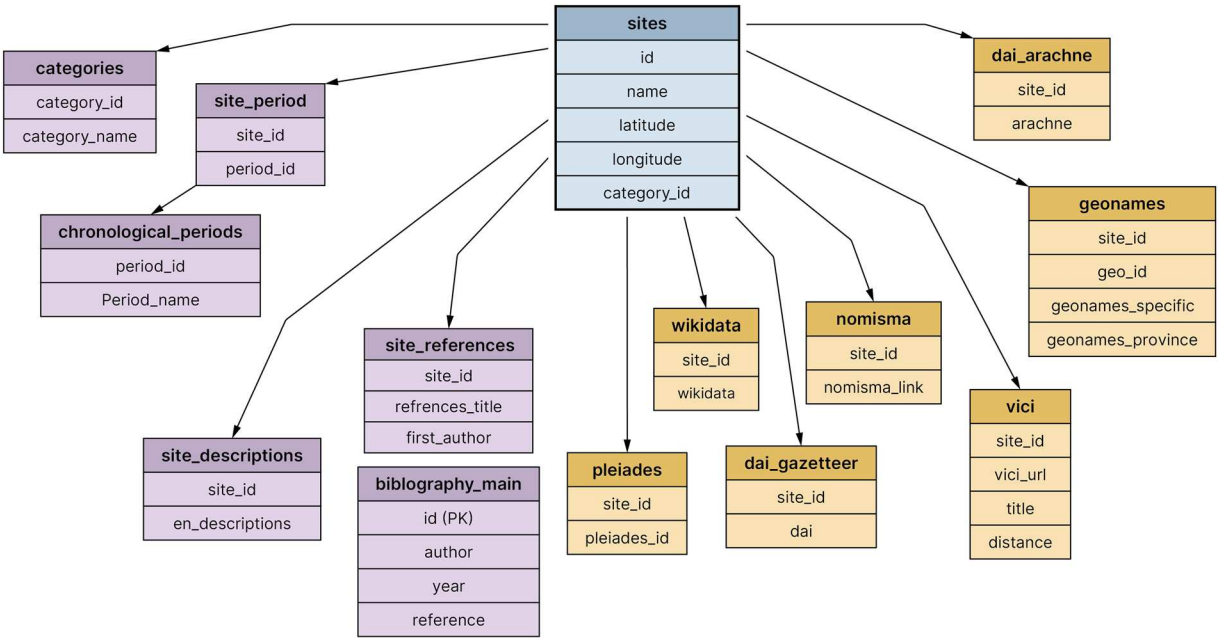

Fig. 3 Logical schema of the structured Bronze Age settlement dataset.

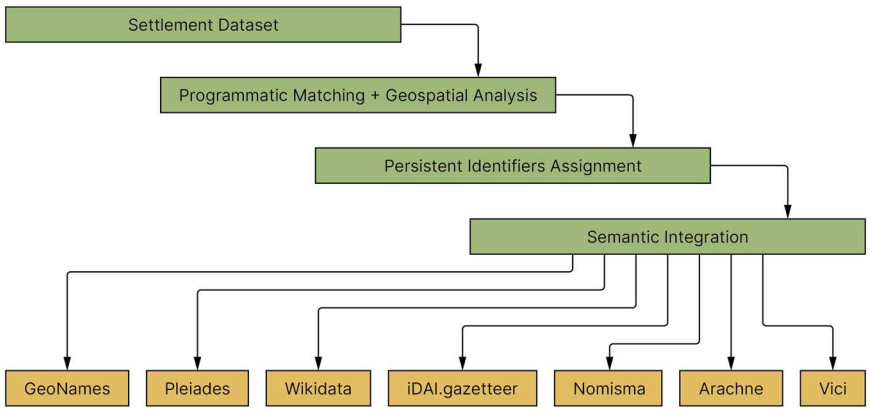

Fig. 4 Semantic enrichment workflow for multi-platform data harmonization.

Hierarchical data organization. Sites were classified according to attributes such as type (e.g., regional center, cemetery), chronological period, archaeological features (e.g., fortifications, inscriptions), and cultural significance. Organized hierarchically, this structure allows multi-criteria filtering and comparative analysis, giving researchers the flexibility to explore settlement patterns from a range of perspectives.

Data cleaning and transformation. The dataset was systematically cleaned to eliminate duplicate entries, harmonize terminology, and resolve null or misformatted records. Controlled vocabularies and standardized attributes were applied throughout, ensuring semantic consistency across the catalogue. These measures not only safeguarded internal integrity but also enhanced interoperability with external linked open data resources.

Semantic integration. To enhance both discoverability and interoperability, settlement metadata were linked to external open knowledge bases through RESTful API queries combined with geospatial and semantic analysis. Candidate matches were evaluated according to their proximity to Bronze Age settlement locations and their semantic alignment with dataset attributes; each confirmed match was then assigned a persistent URI (Fig. 4).

By embedding settlement records within this wider framework, the dataset enables advanced functionalities such as interoperable search, multilingual metadata harmonization, and machine-readable integration. In this way, it operates not only as a self-contained research resource but also as a node within the broader ecosystem of digital heritage and open knowledge dissemination. Connections to external authority records and the assignment of persistent identifiers ensure reliable cross-referencing and long-term semantic interoperability (Fig. 4).

All sources underlying the dataset are published works. Where possible, accession numbers, DOIs, or stable URLs are supplied; in cases where excavation and survey reports lack such identifiers, standard bibliographic

citations are provided instead. Each settlement entry is linked to its original reference through a unique identifier, ensuring both transparency and traceability. All sources are openly available and legally shareable under their respective licenses. The dataset itself does not reproduce copyrighted materials but offers structured metadata derived from these references.

Data Records

The dataset is stored in the Zenodo repository[39], where it comprises 16 interrelated files, each provided in both JSON and CSV formats and uploaded individually without a folder hierarchy. An accompanying data dictionary file provides a comprehensive listing and description of each file, including its contents, format, and key variables. The files record settlement information, site descriptions, chronological periods, categories, bibliographic references, links to external knowledge bases and gazetteers, as well as ancient ore deposits. Together, this structure maintains the logical architecture of a relational database while remaining accessible in flat-file formats.

JSON and CSV were selected for their broad interoperability across programming environments, their capacity to represent hierarchical archaeological data, and their compatibility with geospatial technologies. These formats ensure seamless integration with mapping libraries, GIS platforms, and spatial analysis workflows.

The dataset components include:

Settlements. The core dataset encompasses 483 archaeological sites (Fig. 1), each documented with precise geographic coordinates, classified site types (e.g., regional centers, settlements, cemeteries, inscriptions), associated occupational phases, and contextual notes on historical significance. Together, these records provide a comprehensive spatial and cultural framework for interpreting the settlement landscape of western Anatolia.

Coordinates. Verified spatial data are provided for each site in WGS 84 geographic coordinates (latitude and longitude), making them directly compatible with GIS applications at a global scale.

Descriptions: Narrative summaries bring together archaeological interpretations, historical references, and material evidence for each site. Derived from published literature, excavation reports, and survey data, these entries provide accessible overviews of a settlement's significance, phases of occupation, stratigraphy, urban development, architectural features, and broader cultural context as understood in current scholarship. **Chronology:** Standardized temporal classifications (e.g., Middle Bronze Age, Late Bronze Age) are assigned to each site, enabling consistent filtering and comparison. While the catalogue is restricted to sites occupied during the Middle and Late Bronze Age, additional phases of habitation—from the Paleolithic through the Ottoman period—are retained to capture long-term settlement histories and historical transitions. Absolute radiocarbon dates are not included; chronological attributions instead rely on ceramic typologies and architectural remains as reported in excavation and survey publications. **Bibliographic Sources:** The dataset is accompanied by a dedicated bibliography file comprising 445 publications, including survey reports, excavation reports, dissertations, and scholarly studies on settlements and material culture. Each bibliographic entry is assigned a unique identifier and systematically linked to its corresponding site. Key excavation and survey references are summarized in Supplementary Tables S1–S2, while the complete bibliography is provided in the dataset at Zenodo[39]. **Geographical Toponyms:** This field records both modern and historical place names linked to each archaeological site, including the names of villages, towns, and neighborhoods. Such toponyms offer valuable linguistic and cultural context: they enrich historical reconstruction, facilitate cross-referencing with ancient sources and scholarly literature, and support spatio-temporal analysis. By emphasizing local naming conventions, the dataset also preserves the geographic continuity between past and present landscapes.

Mineral resources. The dataset includes a dedicated file recording 25 archaeologically attested ancient mines in western Anatolia. Each entry carries a unique identifier and provides geographic coordinates (WGS 84), resource type (e.g., gold, silver, copper), and bibliographic references. Cross-linked to the settlements file through shared identifiers, these records can be seamlessly integrated into analyses of settlement patterns and trade networks. **Semantic Links:** The dataset also provides a file of persistent identifiers (URIs) that connect settlement records to external authority data. Each entry links a settlement identifier with one or more URIs, enabling machine-readable connections to open knowledge bases. These links ensure that the dataset can be reliably cross-referenced, integrated with external datasets, and reused in digital research workflows. Designed to complement the settlements, periods, categories, and references files, the semantic links file adds an additional layer of interoperability. Through these connections, users can embed settlement data within broader archaeological and historical infrastructures while maintaining consistent and traceable identifiers across resources.

Technical Validation

Multiple validation procedures were implemented to safeguard the accuracy, consistency, and integrity of the dataset. Site coordinates were cross-checked against excavation and survey reports, field observations, and published scholarship (Fig. 2). GIS analyses were employed to confirm topographic alignment, detect and eliminate spatial outliers, and maintain consistency across datasets. Redundant or duplicate entries were systematically identified and removed during normalization. Remote-sensing anomalies—initially observed in satellite imagery or aerial photography—were assessed against field documentation and verified archaeological sources; features that could not be substantiated were either excluded or reclassified. Mineral resource data underwent additional checks through GIS-based spatial overlays, multi-temporal satellite imagery, and historical geological maps provided by MTA, ensuring both spatial and historical reliability of ore deposit locations.

These validation procedures confirm the dataset's structural integrity and establish its suitability for long-term reuse, interoperability, and integration within broader archaeological and digital research infrastructures.

Usage Notes

The dataset, archived in Zenodo[39], can be readily imported into analytical environments such as Python, R, or SQL and integrated with GIS platforms. These formats ensure long-term usability and support both tabular and spatial analyses.

The resource is released under a Creative Commons Attribution 4.0 International (CC BY 4.0) license. Users are required to cite the dataset via its DOI[39], in addition to citing this Data Descriptor, when reusing the data.

Each record of the dataset is assigned a persistent identifier, ensuring cross-referencing across files and long-term traceability. In addition, semantic links connect settlements to established open knowledge bases and digital gazetteers, thereby enhancing interoperability and facilitating integration within broader research infrastructures.

- GeoNames (https://download.geonames.org/export/dump/) – a global geographical database of place names.
- Pleiades (https://pleiades.stoa.org/downloads) – a scholarly gazetteer of ancient places.
- Wikidata (https://www.wikidata.org) – a collaboratively curated, structured knowledge base.
- iDAI.gazetteer (https://gazetteer.dainst.org) – a spatial authority file maintained by the German Archaeological Institute.
- Arachne (https://arachne.dainst.org) – a database for archaeological objects and architecture maintained by the German Archaeological Institute.
- Nomisma (http://nomisma.org/sparql/) – a repository of stable identifiers for numismatic concepts and related places.
- Vici (https://vici.org) – a community-driven platform mapping ancient and historical sites.

While Zenodo should be regarded as the primary reference for reuse and citation, the dataset can also be interactively explored through the LuwianSiteAtlas web platform (https://luwianstudies.org/siteatlas/advanced-search/) and the interactive web map LuwianSiteMap (https://luwianstudies.org/siteatlas/luwians-itemap/). These resources provide tools for dynamic spatial–temporal queries and visualization of settlement distributions, offering complementary functionality for exploration and analysis.

Users should note several limitations when reusing the dataset. Archaeological survey coverage in western Anatolia remains uneven, with certain areas underexplored due to environmental or logistical constraints. Site identifications and chronological attributions are derived from published reports, which differ in methodological rigor and detail. These limitations should be taken into account when undertaking quantitative modeling or comparative regional analysis.

The dataset also facilitates a shift from high-profile, text-centered narratives—such as the debate over Troy and Ahhiyawa—toward broader, bottom-up spatial perspectives. Scholarship on Ahhiyawa has traditionally emphasized Hittite texts that refer to a Mycenaean-linked polity active in western Anatolia during the Late Bronze Age[19,20,40,41]. The identification of Ahhiyawa with Mycenaean Greece and its role in conflicts over coastal sites like Millawanda (Miletus) has long dominated regional discourse. By contrast, integrating site-based data with geospatial patterns offers a more balanced perspective—one that brings local settlement systems, trade dynamics, and cross-cultural interactions into focus, extending analysis beyond the elite concerns preserved in textual sources[15].

A complete list of archaeological excavations and systematic surface surveys, together with their names and key bibliographic details, is provided in a supplementary file. This information is also included in the dataset archived at Zenodo[39], ensuring transparency, traceability, and long-term accessibility.

Data availability

The dataset[39] is available at Zenodo (https://doi.org/10.5281/zenodo.17128262). The repository includes 16 interrelated files provided in both JSON and CSV formats.

Code availability

The scripts used for data cleaning, geospatial enrichment, and external knowledge base integration are openly available at https://github.com/LuwianStudies/LuwianSiteAtlas. They include modules for spatial querying, administrative region extraction, semantic linking, and proximity matching with ancient place databases. RESTful APIs were employed to programmatically retrieve and match data from Wikidata, GeoNames, and Pleiades. For integration with iDAI entities, the Kgr Finder plugin for QGIS (https://plugins.qgis.org/plugins/kgr_finder/) was used to extract and verify spatial identifiers.

All code is written in Python (v3.10 +) and MySQL, relying on open-source libraries such as Pandas, GeoPandas, GDAL, Requests, RDFlib, and Geopy to ensure reproducibility and extensibility in archaeological data processing.

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Author contributions

Eberhard Zangger initiated the project by recognizing the need for a systematic inventory of second-millennium BCE settlement sites in western Anatolia. Beginning in 2011, he undertook a comprehensive review of published archaeological data in collaboration with Serdal Mutlu, which resulted in a static online database of 340 sites published in 2016. Building on this foundation, Alper Aşınmaz expanded the dataset to 483 sites through an

extensive meta-analysis of excavation reports, surveys, and historical sources. He designed the relational database architecture, implemented data cleaning and normalization protocols, and developed the full digital infrastructure, including semantic integration and the open-access web platform. All authors contributed to the conceptual framework of the project and to the preparation of the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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