

Restituting Roman Aqueduct Hydraulic Systems: A Bibliometric Analysis for Methodological Strategy Applied to the Left-Bank Aqueduct of Tiklat

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ABSTRACT

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Roman aqueducts represent some of the most sophisticated hydraulic infrastructures of antiquity and constitute major components of Mediterranean cultural heritage. Research on Roman aqueducts and hydraulic systems has recently evolved through methodological advances in geophysics, digital modelling, and hydraulic simulation. This study presents a bibliometric analysis of publications indexed in Scopus that focus on the restitution of Roman aqueducts and their hydraulic systems. The corpus was analysed using descriptive statistics, co-authorship mapping, keyword co-occurrence, and co-citation networks. Results show a marked increase in publication output since 2018, reflecting growing interdisciplinarity and methodological innovation. The field remains rooted in Arts and Humanities but increasingly incorporates Earth Sciences, Environmental Sciences, and Engineering. Co-authorship and co-citation analyses reveal collaborative clusters and a stable intellectual core. Despite these advances, geographical coverage is uneven and methodological standardisation remains limited. The study highlights opportunities for enhanced integration of hydraulic modelling, digital reconstruction, and socio-territorial interpretation, providing strategic guidance for future research in archaeology and Roman aqueduct restitution, it also contributes to the development of interdisciplinary protocols applicable to hydraulic archaeological systems. This bibliometric analysis provides a strategic framework for orienting ongoing and future investigations, it also guides the methodological decision-making applied on the case of the Roman aqueduct of Tiklat (Tubusuptu).

Keywords: Roman aqueducts; hydraulic systems; restitution; bibliometric analysis; archaeology; Tiklat.

1. INTRODUCTION

The study of Roman aqueducts has traditionally oscillated between architectural description and historical interpretation. Early syntheses such as Hodge (1992) established a comprehensive technical overview of Roman water supply systems, emphasizing gradient calculation, construction techniques, and maintenance structures. Bruun (1991) complemented this perspective by examining the administrative mechanisms that governed hydraulic distribution in Rome, thus framing aqueducts as instruments of political power and urban management.

However, more recent scholarship has progressively redefined Roman aqueducts as dynamic hydraulic systems rather than static architectural remains. Andrew Wilson (2013) argued that understanding Roman water supply requires quantitative reassessment of flow capacity, sediment management, and distribution networks. In this respect, Wilson highlighted the importance of contextualizing aqueduct performance within broader urban consumption models.

Parallel engineering-based reassessments have further refined this perspective. Moutzouris (2016) demonstrated that Roman hydraulic engineers possessed an empirical understanding of open-channel flow principles, slope optimization, and sediment control mechanisms. His work challenged earlier interpretations that underestimated Roman technical rationality. Similarly, Chanson (2000) emphasized that Roman aqueduct cascades, settling basins, and drop shafts reveal sophisticated turbulence management strategies consistent with modern hydraulic engineering theory.

Beyond Rome itself, Mediterranean case studies have broadened the geographical scope of analysis. Angelakis and Koutsoyiannis (2012) examined urban water systems in antiquity from a comparative engineering standpoint, situating Roman aqueducts within a *longue durée* history of hydraulic innovation. De Feo et al. (2013) further traced the evolution of water conveyance systems, underscoring the technological continuity between ancient and early modern infrastructures.

Recent interdisciplinary research has introduced archaeometric and geomatic approaches to the study of hydraulic heritage. Calzolari et al. (2024) analysed hydraulic mortars to assess durability and material composition, demonstrating the relevance of laboratory-based material characterization for conservation planning. Likewise, Alimonti et al. (2021) employed integrated geomatic surveys and digital modelling to reconstruct structural behaviour and hydraulic performance in partially preserved aqueduct segments.

These contributions collectively indicate a paradigm shift: Roman aqueduct research now occupies a hybrid space at the intersection of archaeology, hydraulic engineering, geomatics, and heritage conservation. Nevertheless, this evolution has not been geographically homogeneous. While European and Near Eastern aqueduct systems have benefited from digital reassessment and performance modelling, North African examples remain comparatively under-studied within international bibliographic databases.

This imbalance is particularly significant in the case of Algeria, where several Roman hydraulic complexes including those associated with ancient Tubusuptu (Tiklat) have received limited integration into global methodological debates. Existing documentation is often descriptive, lacking systematic hydraulic simulation, geophysical exploration, or digital restitution frameworks. Consequently, a methodological gap persists between global research trends and local heritage practices.

The present research addresses this discrepancy by mobilizing bibliometric analysis as an evaluative instrument. Rather than merely mapping publication trends, the study seeks to identify the dominant intellectual trajectories shaping Roman aqueduct research and to determine how these trajectories can inform methodological choices in vulnerable contexts. In doing so, the investigation situates the Tiklat aqueduct within the broader evolution of hydraulic heritage science.

2. METHODOLOGY

The study is designed as a structured bibliometric analysis using data retrieved from the Scopus database. The initial step consists of defining a precise search query that captures the intersection of the three core concepts: restitution, Roman aqueducts, and hydraulic systems. To this end, a Boolean search string is formulated, typically in the form TITLE-ABS-KEY (restitution AND "roman aqueducts" AND "hydraulic system"), with additional variations tested to include relevant synonyms while avoiding excessive noise. The search is restricted to document types indexed as articles, books, book chapters, conference papers, and reviews, ensuring that the corpus encompasses both peer reviewed scientific outputs and substantial scholarly monographs. No chronological restriction is applied initially, allowing the retrieval of the earliest contributions up to the most recent publications.

Once the search results are obtained, the records are exported in a suitable format (e.g., CSV or RIS) containing full bibliographic information, abstracts, author affiliations, keywords, cited references, and source details. The dataset is then cleaned to remove duplicates, correct obvious errors in author names or affiliations, and harmonise keyword variants (for example, "Roman aqueduct" vs. "Roman aqueducts", "hydraulic structure" vs. "hydraulic structures"). This data curation stage is crucial to ensure the reliability of subsequent analyses, particularly for co-authorship and co-occurrence networks, where minor inconsistencies can artificially fragment the structures being observed.

When necessary, manual checks are carried out against full texts or additional catalogues to verify ambiguous records, such as works that refer to aqueducts in a broader context without focusing on hydraulic restitution.

The quantitative analysis is then conducted using a combination of spreadsheet software and specialised bibliometric and network-analysis tools such as VOSviewer. Descriptive statistics are first computed to characterise the temporal evolution of the corpus (documents per year), the distribution by subject area, and the breakdown by document type. These indicators provide an initial overview of how the field has grown, which disciplines dominate it, and what forms of publication are preferred. Next, co-authorship analysis is used to identify principal authors, collaborative clusters, and the intensity of cooperation between institutions and countries. This step highlights the existence of core research groups and reveals whether the field is fragmented or organised around strong, stable networks.

In parallel, co-occurrence analysis of author and indexed keywords is performed to uncover thematic clusters. By visualising the network of terms related to Roman aqueducts, hydraulic systems, geophysical methods, and urban or landscape concepts, the study identifies major methodological and conceptual axes. These include, for example, clusters focused on non-destructive surveys, hydraulic modelling, or heritage and urban-landscape interpretations. Finally, a co-citation analysis of references cited by the corpus is carried out to reveal the intellectual foundations of the field. This involves mapping which earlier works are most frequently cited together, thereby identifying seminal publications and theoretical frameworks that structure current research. Visualisations of these networks, supported by colour coding for average publication year or citation counts, offer an intuitive representation of how the field has developed and which references remain central. Throughout the analysis, quantitative results are interpreted qualitatively and contextualised in light of known developments in Roman archaeology, geophysics, and hydraulic engineering. Attention is paid not only to dominant patterns but also to absences and marginal elements, such as under-represented regions, emerging methods, or poorly connected authors. This mixed-methods approach ensures that the bibliometric findings do not remain purely statistical but are integrated into a broader understanding of the scholarly landscape.

3. RESULTS AND DISCUSSION

3.1. Annual Output of Publications on Restitution of Roman Aqueduct Hydraulic Systems

The time-series curve shows a very low level of productivity in the first decade, with at most one publication in any year between 2006 and 2013 (Wilson, 2009; De Feo et al., 2013; Monteleone et al., 2013).

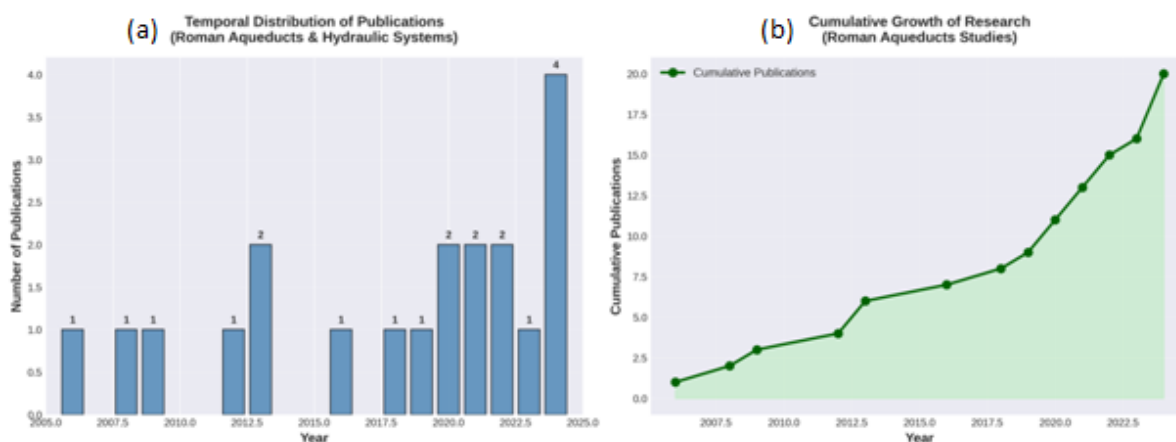


Fig 1 : (a) Temporal distribution of publications, (b) Cumulative growth of research.

In this early period, the topic appears as a niche within broader Roman infrastructure or urbanism studies rather than as a consolidated research line. From around 2018 onward, the curve becomes more dynamic, with publications in almost every year and a gradual increase in counts that coincides with the adoption of advanced digital and geoarchaeological methods. For example, studies integrating geophysical survey and photogrammetric restitution have revealed previously unknown branches of Roman aqueducts, such as the Anio Novus in Rome

through combined ground-penetrating radar and electrical resistivity tomography analysis (Blanco et al., 2021). Similarly, geomatic approaches have been used to estimate flows and reconstruct hydraulic characteristics using precise topographic measurements (Alimonti et al., 2021).

In parallel, broader reviews of hydraulic engineering in ancient water systems document how quantitative engineering analysis has been increasingly applied to Roman and Mediterranean contexts, signalling a methodological shift towards system-oriented studies (Crapper et al., 2021). Moreover, recent research on the material properties of hydraulic mortars in Roman aqueducts underscores the expanding thematic scope of hydraulic system studies beyond architectural description. For example, archaeometric characterisation of mortars from the inner ducts of ancient Roman aqueducts such as **Aqua Virgo** has shed light on the composition and longevity of hydraulic mortars using multi-analytical techniques including optical microscopy and X-ray diffraction (Calzolari et al., 2024).

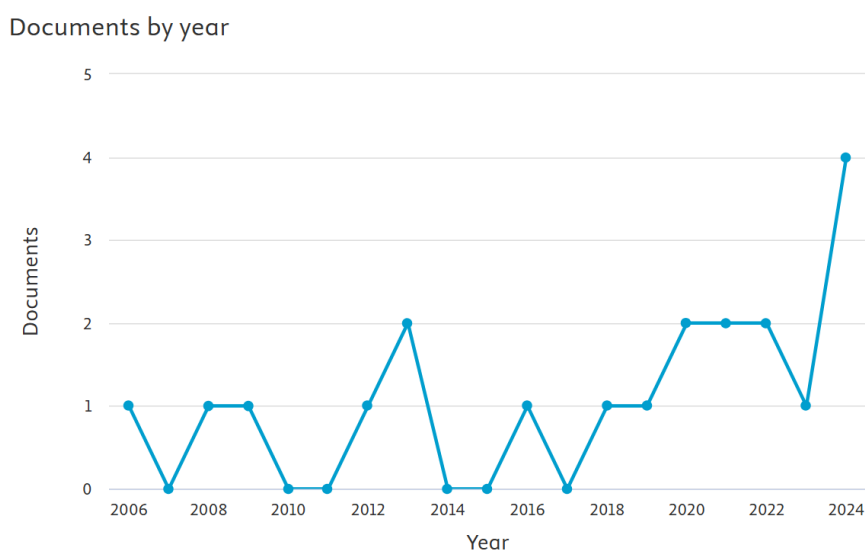


Fig 2 : Evolution of publications per year

3.2. Subject Areas of Publications on Roman Aqueduct Restitution and Hydraulic Systems

The subject-area pie chart indicates that **Arts and Humanities** dominate the corpus with approximately 58.1% of the documents. This confirms that research on Roman aqueduct restitution remains primarily anchored in archaeology, ancient history, and heritage studies. Foundational analyses of Roman hydraulic infrastructure have traditionally emerged from classical scholarship, where aqueducts are examined as key components of Roman urbanism, imperial administration, and socio-technical organisation (Wilson, 2009; Roman Aqueducts & Water Supply; Bruun, 2013). These works situate hydraulic systems within broader political, cultural, and territorial frameworks, emphasizing their role in shaping Roman cities and landscapes rather than focusing solely on technical performance.

The **Social Sciences** category (16.1%) likely reflects growing interest in heritage management, landscape archaeology, and the valorisation of ancient hydraulic infrastructure within contemporary territorial planning. In this perspective, aqueduct restitution is not only a technical reconstruction exercise but also a tool for cultural interpretation, preservation strategies, and sustainable heritage development. Studies addressing the integration of Roman water systems into modern urban and territorial narratives demonstrate this interdisciplinary expansion (Orengo & Miró, 2013).

The presence of **Earth and Planetary Sciences** (9.7%) and **Environmental Science** (6.5%) highlights the increasing contribution of geoarchaeology, geomorphology, and hydrological reconstruction in understanding aqueduct routing, catchment systems, and environmental adaptation. Spatial analysis and terrain modelling have proven essential in reconstructing gradients, flow dynamics, and long-term landscape transformations associated

with Roman hydraulic networks (Orengo & Miró, 2013; Alimonti et al., 2021). These approaches move beyond descriptive archaeology toward quantitative and environmental interpretations of hydraulic performance.

Although representing smaller proportions (around 3.2% each), **Engineering, Physics**, and applied technical disciplines make significant methodological contributions. Hydraulic modelling, structural assessment, and materials characterisation have increasingly informed restitution studies. Quantitative evaluations of flow capacity and channel geometry (Alimonti et al., 2021), engineering analyses of Roman water management systems (Crapper et al., 2021), and archaeometric investigations of hydraulic mortars in Roman aqueduct ducts (Calzolari et al., 2024) demonstrate the progressive integration of scientific diagnostics and performance analysis into the field.

Overall, this disciplinary distribution reveals a research domain historically centred in the humanities but progressively enriched by interdisciplinary collaboration. The restitution of Roman aqueduct hydraulic systems now operates at the intersection of archaeological interpretation, geo-spatial analysis, hydraulic engineering, and materials science, reflecting a shift from purely historical description toward integrated system analysis.

Documents by subject area

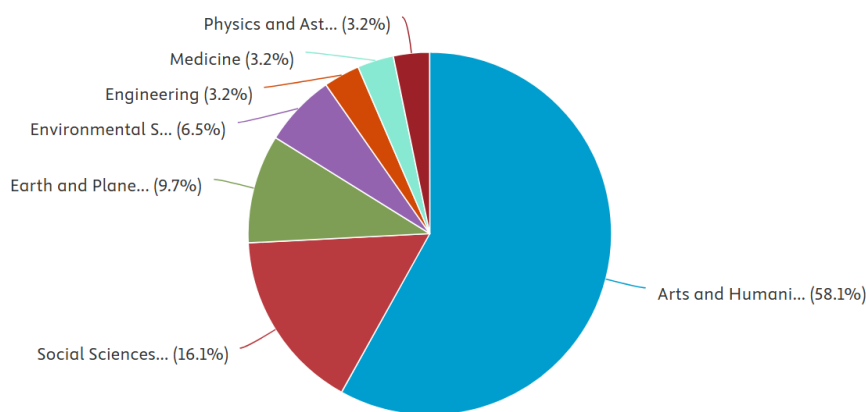


Fig 3 : Documents by subject area

3.3. Document Types in the Scopus Corpus on Roman Aqueduct Restitution

In the document-type donut chart, **books represent 50% of the outputs**, suggesting that comprehensive monographic treatments remain the principal vehicle for presenting detailed restitution studies of Roman aqueducts and their hydraulic systems. Foundational works such as *Roman Aqueducts & Water Supply* and broader syntheses on Roman water management (Wilson, 2009; Bruun, 2013) illustrate how book-length studies provide the necessary space for extensive architectural description, hydraulic interpretation, and territorial contextualisation. The complexity of aqueduct systems including gradient calculation, channel typologies, and distribution networks often requires the depth and structural flexibility offered by monographs.

With **20% each, journal articles and book chapters** indicate that researchers also rely heavily on peer-reviewed periodicals to disseminate methodological advances, case studies, and technical reassessments. Articles focusing on spatial reconstruction and integrated urban water systems, such as Orengo and Miró (2013), demonstrate how journal publications contribute to refining interpretations through geoarchaeological and GIS-based approaches. Likewise, engineering-oriented contributions addressing hydraulic modelling and flow estimation (Alimonti et al., 2021; Crapper et al., 2021) show that journals serve as primary outlets for quantitative and interdisciplinary analyses. Chapters in edited volumes continue to play a key role in situating aqueduct studies within broader discussions of Roman infrastructure, urbanism, and environmental adaptation.

The more modest shares of **conference papers and review articles (approximately 5% each)** suggest relatively limited formal syntheses or bibliographic overviews within indexed databases for this specific topic.

Nevertheless, conference proceedings often function as preliminary platforms for presenting new field data, digital restitution workflows, or geophysical survey results before their expansion into full journal articles. The relatively small proportion of review papers further indicates that the field remains highly case-study driven, with cumulative synthesis emerging gradually rather than through large-scale systematic reviews.

This document-type profile is characteristic of archaeological and historical research traditions, where long-form books and thematic chapters remain essential for presenting excavation results, detailed architectural reconstructions, and complex topographical analyses. At the same time, the increasing presence of technical journal articles reflects the progressive integration of digital modelling, geo-spatial analysis, and hydraulic engineering into the study of Roman aqueduct restitution.

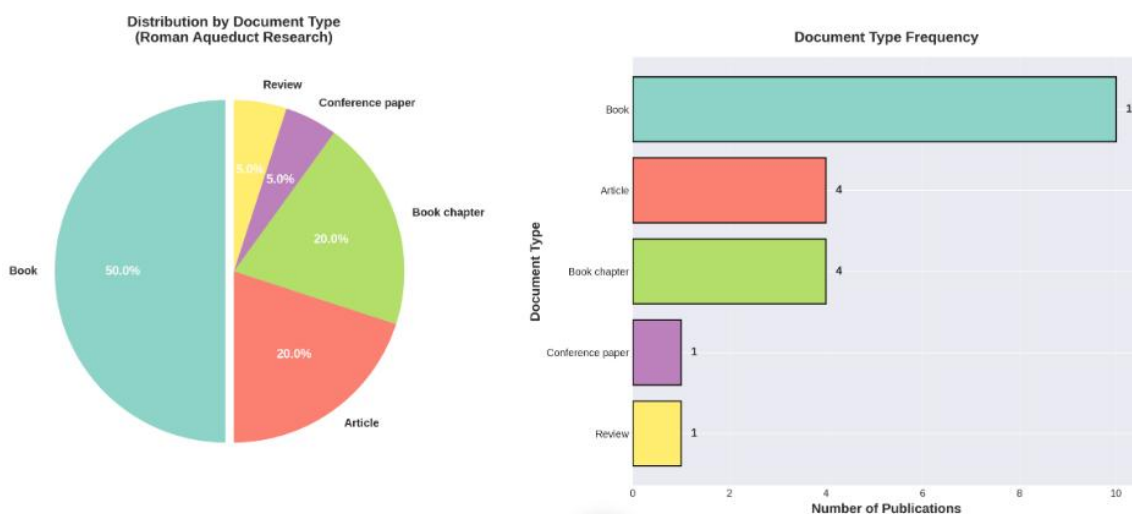


Fig 4 : (a) Distribution by document type, (b) Document type frequency.

3.4. Geographical Distribution and Temporal Evolution of Contributing Countries

The country-level VOSviewer map reveals a limited yet internationally distributed network of contributors, with the **United States** and the **United Kingdom** emerging as major nodes alongside Mediterranean countries such as Italy and Greece. The larger node size for the United States suggests a comparatively high number of documents or citations, reflecting long-standing academic traditions in classical archaeology, ancient engineering, and Roman water management studies within American institutions. Foundational research on Roman hydraulic systems and urban water supply has frequently been produced in U.S.-based scholarship (Wilson, 2009; Bruun, 2013), contributing significantly to the theoretical and historical framing of aqueduct studies.

The United Kingdom node, coloured toward the more recent end of the time spectrum, indicates a noticeable intensification of contributions over the last decade. This trend corresponds with renewed interest in Roman infrastructure within broader debates on imperial landscapes, technological systems, and environmental adaptation. British-based or UK-affiliated research has increasingly addressed Roman water supply within interdisciplinary frameworks linking archaeology, engineering, and landscape studies (Crapper et al., 2021; Mattingly, 2013).

The presence of **Greece** and **Italy** underscores the importance of Mediterranean case studies and proximity to major archaeological remains. Italian scholarship, in particular, has contributed substantially to technical and archaeometric investigations of aqueduct structures, including geomatic analysis and materials characterisation (Alimonti et al., 2021; Calzolari et al., 2024). Greek and broader eastern Mediterranean research contexts have also played a role in documenting provincial hydraulic systems and integrating geoarchaeological methods into restitution processes.

Australia’s smaller yet distinct node suggests contributions from scholars trained in classical and archaeological traditions with strong European research connections. This pattern reflects the broader structure of Roman studies,

where research networks extend beyond Europe but remain closely tied to Mediterranean fieldwork and collaborative frameworks.

Overall, the relatively sparse interconnections among country nodes suggest that, although international collaboration exists, much of the research remains structured within national or regional academic traditions. The field appears internationally distributed but institutionally concentrated, with methodological innovation often emerging from collaborations between Mediterranean field projects and Anglophone research institutions.

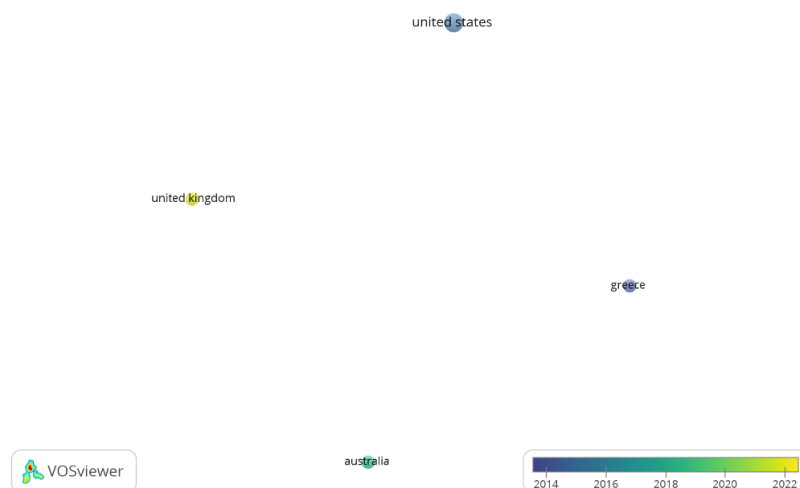


Fig 5 : Geographical Distribution and Temporal Evolution of Contributing Countries.

3.5. Keyword Co-occurrence Network for Studies on Roman Aqueduct Restitution and Hydraulic Systems

The keyword network positions “*Roman aqueducts*” at the centre, linking it to a dense cluster of methodological and thematic terms that reveal the field’s principal research axes.

On the left side, the cluster containing “*geophysical prospecting*,” “*geophysical surveys*,” “*ground-penetrating radar*,” “*electrical resistivity tomography*,” “*photogrammetry*,” and “*structure from motion*” reflects the strong reliance on non-invasive investigation and advanced imaging technologies for detecting, mapping, and reconstructing aqueduct routes and buried hydraulic components. Recent applications of integrated geomatics and topographic modelling have demonstrated how digital survey techniques can refine gradient estimation and channel reconstruction (Alimonti et al., 2021). Similarly, engineering-oriented reassessments of Roman water systems illustrate the growing use of quantitative modelling and diagnostic evaluation in interpreting hydraulic performance (Crapper et al., 2021). These approaches signal a methodological transition from purely descriptive archaeology toward digitally assisted restitution workflows.

Terms such as “*hydraulic structures*,” “*electric conductivity*,” and related geophysical parameters indicate that the physical properties of construction materials and subsurface conditions are essential for understanding both functionality and conservation status. Archaeometric investigations of hydraulic mortars in Roman aqueduct ducts highlight how mineralogical and petrographic analyses contribute to evaluating durability, permeability, and hydraulic resistance (Calzolari et al., 2024). The integration of material science within archaeological research demonstrates the increasing interdisciplinarity of the field.

The presence of broader terms such as “*archaeology*,” “*history*,” and region-specific keywords linked to central Italy reflects the importance of case-study-based research within historically dense hydraulic landscapes. Classical and historical analyses of Roman water supply systems continue to provide the interpretive framework within which technical findings are contextualised (Wilson, 2009; Roman Aqueducts & Water Supply). These works anchor digital and geophysical investigations within long-term historical and urban narratives.

On the right side of the map, terms such as “urban landscape” and site-based keywords connected to major Roman cities underscore the link between aqueduct restitution and urban morphology. Studies integrating spatial reconstruction with urban analysis show how water infrastructure shaped settlement patterns, territorial organisation, and metropolitan development (Orengo & Miró, 2013). In this perspective, aqueduct systems are analysed not merely as hydraulic conduits but as structuring elements of the ancient cityscape.

Overall, the keyword network evidences a dual orientation within the field: on one hand, high-resolution technical and diagnostic investigations of aqueduct remains and their subsurface context; on the other, interpretive research addressing the social, urban, and territorial implications of Roman hydraulic systems. This duality reflects the maturation of aqueduct restitution studies into a hybrid domain combining digital survey technologies, engineering analysis, and historically grounded interpretation.

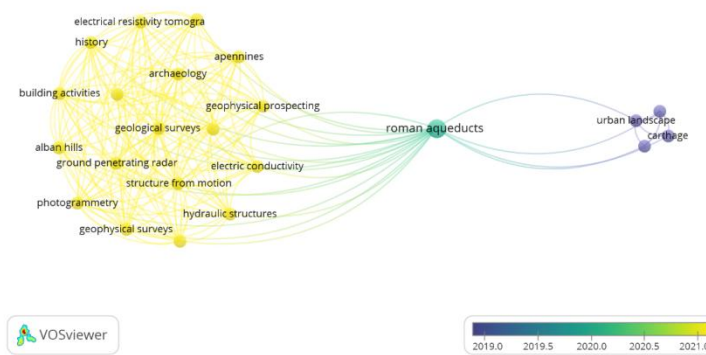


Fig 6 : Keyword Co-occurrence Network for Studies on Roman Aqueduct Restitution and Hydraulic Systems.

3.6. Co-authorship Network of Leading Researchers on Roman Aqueduct Restitution

The co-authorship network reveals a compact and highly interconnected group of researchers, including Valerio Baiocchi, Stefano Urbini, Iacopo Nicolosi, Luca Alessandri, Angelina De Laurenzi, Felicia Monti, Felicia Vatore, and Diego Blanco.

The dense configuration of links among these scholars suggests sustained collaboration within research units specialising in geomatics, geophysical prospection, and digital reconstruction applied to Roman hydraulic infrastructure. Their joint publications demonstrate the integration of topographic survey, hydraulic modelling, and spatial analysis for the restitution of aqueduct alignments and buried segments (Alimonti et al., 2021).

The relatively similar node sizes indicate that productivity is distributed across several contributors rather than dominated by a single highly cited individual. This pattern is typical of interdisciplinary field-based projects, where responsibilities are shared among specialists in geophysics, GIS modelling, hydraulic engineering, materials diagnostics, and classical archaeology. Engineering-focused reassessments of Roman water systems further illustrate how collaborative frameworks combine quantitative analysis with archaeological interpretation (Crapper et al., 2021).

Such a configuration frequently emerges in large-scale mapping and survey campaigns that require coordinated expertise in data acquisition (e.g., ground-based survey, photogrammetry), spatial processing, and historical contextualisation. The integration of archaeometric analysis into aqueduct studies (Calzolari et al., 2024) reinforces this collective research model, as laboratory-based material diagnostics complement field survey and hydraulic evaluation.

The absence of isolated authors within the network suggests that the Scopus corpus is structured around a cohesive collaborative core rather than fragmented individual contributions. This indicates that contemporary research on Roman aqueduct restitution increasingly relies on institutional teams and technically integrated workflows rather

than single-author historiographical studies. The co-authorship pattern thus reflects the broader methodological evolution of the field toward digitally supported, interdisciplinary research consortia.

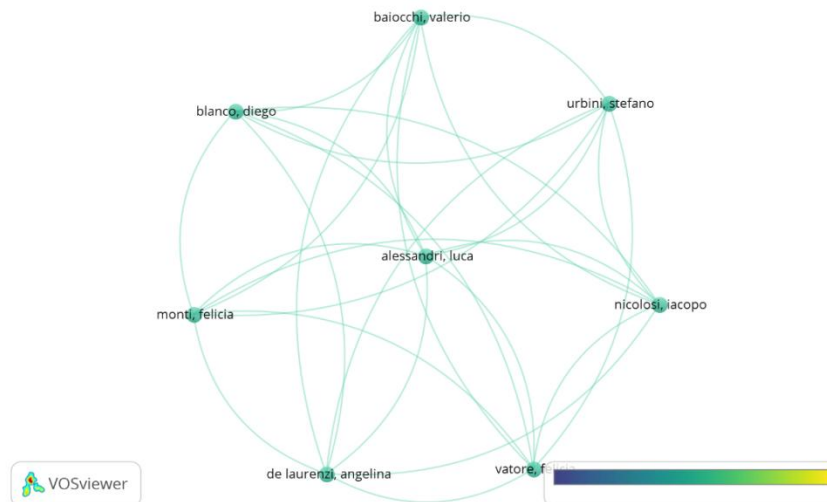


Fig 7 : Co-authorship Network of Leading Researchers on Roman Aqueduct Restitution

3.7. Co-citation Network of Influential References in Roman Aqueduct Restitution Studies

The co-citation map highlights a set of foundational works that constitute the intellectual backbone of research on Roman aqueduct restitution and hydraulic systems. The largest node corresponds to A. Trevor Hodge (1992), whose monograph *Roman Aqueducts & Water Supply* remains one of the most frequently cited syntheses on Roman hydraulic engineering. Its prominence reflects its enduring role as a technical and historical reference framework for understanding construction techniques, hydraulic gradients, maintenance systems, and water distribution mechanisms.

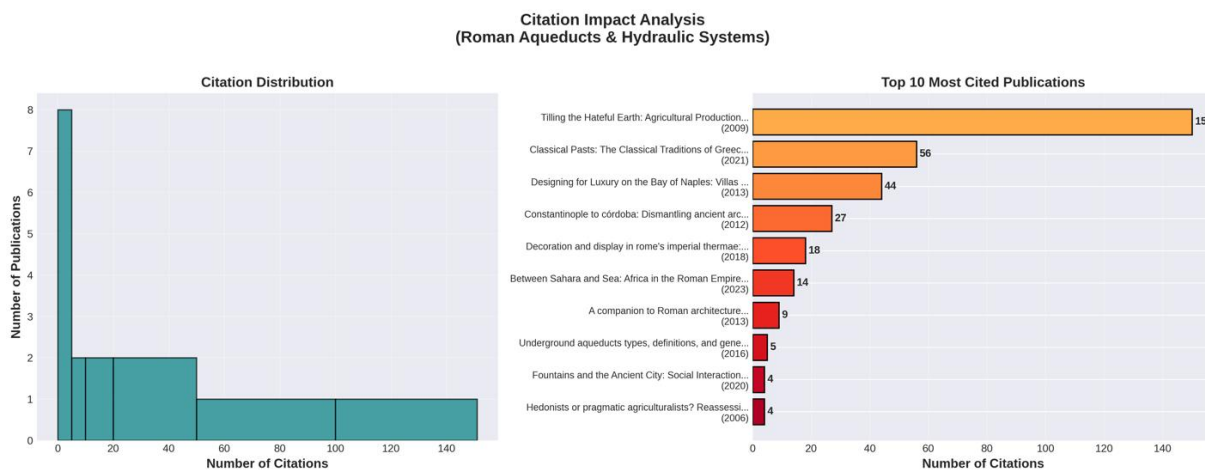


Fig 8 : Citation impact analysis.

Closely connected nodes include Rabun Taylor (2000) and Christer Bruun (1991), whose studies on Roman water management, administration, and distribution networks expanded the field beyond structural description toward institutional and socio-political analysis. These works collectively shaped the methodological and interpretative foundations upon which later restitution and modelling studies are built.

Other prominent references such as Diane Favro (1996) and Adam T. Smith (2003) (in broader urban and landscape studies) contextualised hydraulic infrastructure within urban morphology and imperial spatial strategies, reinforcing the integration of aqueduct research into debates on Roman urbanism and territorial planning.

More recent nodes such as Rabun Taylor (2014), Kostas V. Moutzouris (2016), and Andrew Wilson (2013) indicate the progressive incorporation of engineering reassessments, hydraulic modelling, and archaeometric analysis into the field. These studies demonstrate how empirical data, digital survey techniques, and interdisciplinary collaboration have enriched earlier historiographical syntheses.

The time-gradient visible in the co-citation network shows that while foundational works from the 1990s and early 2000s remain central nodes, the citation structure is progressively updated by recent scholarship integrating geomatics, GIS-based reconstruction, and material science approaches. This pattern mirrors the temporal growth in publication output identified in the documents-per-year analysis and confirms a gradual methodological transition from descriptive architectural studies toward technologically supported, interdisciplinary restitution research.

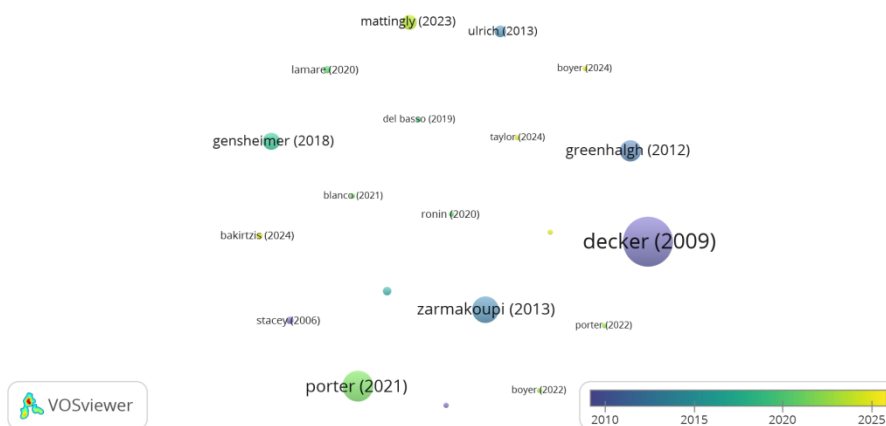


Fig 9 : co-citation network analysis.

3.8. Identified Research Gaps

Bibliometric mapping reveals several structural gaps:

1. Limited representation of North African aqueduct systems within high-impact publications.
2. Insufficient standardization of hydraulic modelling parameters across case studies.
3. Fragmented integration between archaeometric material studies and hydraulic simulation.
4. Scarcity of decision-oriented methodological frameworks tailored to vulnerable heritage contexts.

These gaps justify the application-oriented dimension of the present research.

3.9. From Bibliometric Evidence to Methodological Strategy

The convergence of citation impact analysis, thematic evolution, and journal dispersion confirms that Roman aqueduct research is undergoing a technological consolidation phase.

Highly cited works emphasize:

- Hydraulic functionality
- Sediment management
- Structural optimisation
- Digital documentation

These priorities directly inform methodological selection for vulnerable contexts.

Consequently, the bibliometric findings support the prioritization of:

- Non-invasive geophysical prospection (GPR, ERT)
- High-resolution topographic modelling
- Hydraulic simulation based on reconstructed gradients
- Material analysis for conservation assessment

The next section applies this bibliometrically informed framework to the left-bank aqueduct of Tiklat, demonstrating how global research trajectories can guide local methodological decision-making.

3.10. From Bibliometric Trends to Field Strategy: Application to the Restitution of the Left-Bank Aqueduct of Tiklat (Tubusuptu)

The bibliometric results presented above do not merely describe the evolution of research on Roman aqueduct restitution; they provide a strategic framework for orienting ongoing and future investigations. In this perspective, our case study research focuses on the **archaeological restitution of the Roman aqueduct supplying the ancient city of Tiklat (Tubusuptu), located on the left bank of the Soummam valley in northern Algeria**, is directly informed by the methodological and thematic tendencies identified in the Scopus corpus.

3.10.1. Geographical and Heritage Context of the Case Study

North Africa in general, and Algeria in particular, preserve a dense network of hydraulic infrastructures inherited from the Roman period. The number of aqueducts recorded on Algerian territory is estimated at more than thirty-nine units. However, the two aqueducts supplying the ancient city of Tiklat (Tubusuptu), located west of Béjaïa along the Soummam River, do not systematically appear in national inventories. While the city of Tubusuptu itself was classified as national heritage in 1991, its hydraulic system especially the left-bank aqueduct remains insufficiently protected and only partially documented.

Research on this topic was conducted mainly during the French colonial period, often by engineers of the French military corps, who primarily produced descriptive surveys of visible remains without systematic archaeological excavations. Several scholars contributed to these early studies, including Féraud, Mercier, Carbonnel, Bonvalet, Mélix, Devigneral, and Gsell. After Algeria's independence, however, research activity declined considerably, with only a few notable contributions such as those of Birebent (1964) and later Laoues and Dahli (2014), leaving significant gaps in the study of these hydraulic infrastructures.

The left-bank aqueduct of Tiklat, approximately six kilometres in length, originally supplied the city through a principal channel complemented by secondary branches and large cistern complexes such as the fifteen-compartment reservoirs of El Arouia. Today, only fragmentary segments remain visible. Excavation works, modern infrastructure development, and private construction have led to the destruction of numerous portions of the conduit, including associated hydraulic structures such as jump bridges, sediment traps, and basins. This vulnerability underscores the urgent need for a systematic restitution approach capable of documenting and safeguarding what survives.

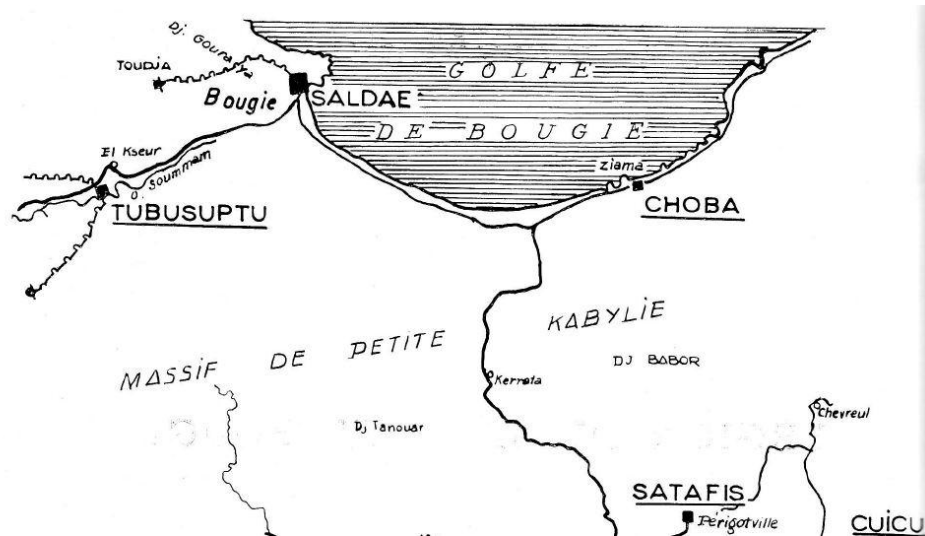


Fig 10 : Geographical Context of the Case Study (**Source:** J. Birebent, 1964, *Aquae Romanae: Roman Hydraulic Research in Eastern Algeria*, Antiquities Service of Algeria, p. 462.)

3.10.2. Linking Bibliometric Insights to Methodological Choices

The bibliometric analysis highlighted three major converging axes in contemporary research: (1) digital and non-invasive survey technologies, (2) hydraulic modelling and engineering reassessment, and (3) interdisciplinary geoarchaeological integration. These axes directly inform the research strategy adopted for the Tiklat case.

First, the strong presence of keywords related to geophysical prospecting ground-penetrating radar, electrical resistivity tomography, photogrammetry, and structure-from-motion confirms a methodological shift from destructive excavation toward non-invasive diagnostics. In the context of the left-bank aqueduct, where large segments are buried and physically endangered, this trend supports the prioritisation of GPS-based geolocation, geophysical prospection, and high-resolution topographic survey. By revisiting the colonial-period tracing conducted by Mélix (1865), and refining it through modern geospatial tools, the project seeks to produce an updated and georeferenced alignment of the aqueduct.

Second, the bibliometric evidence of increasing integration of hydraulic engineering encourages the adoption of analytical frameworks capable of assessing gradients, potential discharge, and hydraulic behaviour. Without presenting results at this stage, the project foresees the implementation of hydraulic simulations and slope analyses to test the functional plausibility of reconstructed segments. This orientation is consistent with the broader disciplinary transition identified in the corpus from descriptive archaeology to system-oriented hydraulic interpretation.

Third, the growing presence of archaeometric and material-science studies within the bibliometric network justifies the intention to undertake material characterisation of selected construction elements. Mortars, channel linings, and sediment deposits may provide crucial information on durability, permeability, and maintenance cycles. Although detailed laboratory results will be presented in subsequent dedicated publications, their integration into the research design reflects the interdisciplinary expansion evidenced in the bibliometric findings.

3.10.3. Restitution as a Tool for Heritage Protection and Scientific Renewal

The bibliometric study also revealed uneven geographical representation, with North African case studies comparatively under-represented in indexed literature. The Tiklat project therefore contributes to reducing this imbalance by situating an Algerian hydraulic system within international methodological debates.

The attempt to reconstitute segments of the left-bank aqueduct is not limited to geometric reconstruction. It encompasses the identification of structural components jump bridges, waterfalls, sedimentation basins, and possible distribution nodes through targeted field surveys and controlled excavations. The ultimate objective is the

preparation of a scientific dossier supporting formal protection measures and raising awareness of the site's vulnerability.

By aligning the case study with the dominant methodological currents identified in the bibliometric analysis digital survey, hydraulic modelling, and interdisciplinary integration the project ensures that local research does not remain isolated but is embedded within global scholarly dynamics. At the same time, it responds to a pressing heritage challenge: the progressive disappearance of semi-buried hydraulic infrastructures that escape visual recognition and legal safeguarding.

4. CONCLUSION

The bibliometric exploration of publications combining restitution, Roman aqueducts, and hydraulic systems demonstrates that this research niche has evolved from sporadic, isolated case studies into a more coherent and vibrant field. The temporal analysis reveals a clear acceleration of output in the last decade, reflecting increased access to advanced survey technologies, greater awareness of water-heritage issues, and the rise of interdisciplinary projects that bring together archaeologists, engineers, geophysicists, and historians. The dominance of Arts and Humanities, complemented by significant contributions from Earth sciences, Environmental science, and Engineering, confirms that the topic is fundamentally rooted in archaeological inquiry but is enriched by technical and environmental perspectives. At the same time, the prevalence of books and book chapters underlines the continued importance of long-form, richly documented studies for presenting comprehensive restitutions of complex aqueduct systems.

The analysis of countries, author networks, and keywords suggests that research is concentrated in a limited number of national contexts and organised around a few highly collaborative teams, many of which specialise in geoarchaeological and geomatic approaches. These teams act as hubs that link diverse methods such as geophysical prospecting, photogrammetry, and hydraulic modelling to specific case studies across the Roman world. The keyword and co-citation networks further reveal a dual orientation: on one side, meticulous technical work on detection, documentation, and modelling of aqueduct structures; on the other, interpretive frameworks that situate these infrastructures within broader urban and landscape histories. Foundational works continue to provide the conceptual and methodological backbone of the field, while recent publications expand its empirical base and introduce new analytical tools.

Taken together, these findings highlight both the strengths and the gaps of the current research landscape. Strong points include the maturation of interdisciplinary collaborations, the integration of cutting-edge survey technologies, and the emergence of detailed case studies that link hydraulic performance to urban and territorial dynamics. However, geographical coverage remains uneven, with some regions and types of aqueducts under-represented, and there is still limited synthesis that compares different systems across the empire using standardised hydraulic and geomatic parameters. Future research could therefore focus on expanding the spatial scope of case studies, developing common methodological protocols for hydraulic and structural restitution, and deepening the dialogue between technical analyses and broader questions about Roman society, governance, and environmental management. By building on the trends identified in this bibliometric study, scholars can better coordinate efforts, avoid duplication, and strategically target under-explored topics, thereby advancing understanding of how Roman aqueducts functioned and how their legacy informs contemporary thinking about water, infrastructure, and heritage.

The bibliometric results function here as a decision-support tool. They clarify which technologies are most frequently and effectively employed in comparable studies, which disciplinary bridges are emerging, and where research gaps persist. Consequently, the Tiklat project adopts a phased strategy:

- precise GPS geolocation and spatial refinement of the historical trace;
- application of non-invasive geophysical methods to detect buried segments;
- digital restitution of selected portions through geomatic modelling;

- hydraulic analysis to evaluate functional coherence;
- targeted material characterisation to understand construction techniques and conservation issues.

The detailed outcomes of these investigations will be presented in forthcoming scientific publications. At this stage, the integration of bibliometric insights into the research design demonstrates how quantitative mapping of scholarship can directly influence methodological pathways in field archaeology.

In conclusion, the restitution of the left-bank aqueduct of Tiklat exemplifies how global research trends identified through bibliometric analysis can be translated into locally grounded, heritage-oriented action. By combining non-invasive technologies, hydraulic engineering approaches, and geoarchaeological interpretation, the project aspires not only to reconstruct a Roman hydraulic structure but also to contribute to its long-term preservation within the Algerian archaeological landscape.

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