Navigability in the Past. The Vouga River as a Case Study in the Roman Period.

Navegabilidade no passado. O rio Vouga como caso de estudo em Época Romana.

Joana Margarida Marques

joanaribeiro.99@outlook.pt

Independent researcher

http://doi.org/10.25267/Riparia.2025.v10.03

[Recibido 25/09/2025; Aceptado 15/01/2026]

ABSTRACT:

This paper examines the feasibility of navigating the Vouga River during the Classical period, from its mouth to the vicinity of the archaeological site of Castro do Banho, in São Pedro do Sul (Viseu, Portugal). The study draws on landscape archaeology, historical sources, and hydrographic analyses conducted in a GIS environment. To complement this approach, the morphology of the drainage basin and rainfall data were analysed, and experimental calculations were carried out to estimate river depth and width for the period under minimum and maximum conditions. The work applies a recently proposed method, enabling a more detailed assessment in this type of case study.

KEYWORDS:

Landscape Archaeology; Navigability; Vouga River; São Pedro do Sul; Geographic Information Systems.

RESUMO:

Este artigo aborda a possibilidade da navegabilidade do rio Vouga em época clássica, desde a sua foz até às proximidades do sítio arqueológico Castro do Banho, em São Pedro do Sul (Viseu, Portugal). Recorreu-se à arqueologia da paisagem, a fontes

ISSN 2442-9761

históricas e a análises hidrográficas através de GIS. De modo a completar essa análise, estudou-se a morfologia da bacia hidrográfica e os dados pluviométricos, aplicando-se ainda, cálculos experimentais para determinar a profundidade e a largura do rio na respectiva época, em condições mínimas e máximas. Este trabalho utiliza um novo método de investigação, que permite uma análise mais detalhada neste tipo de casos de estudo.

PALAVRAS-CHAVE:
Arqueologia da Paisagem, Navegabilidade, Rio Vouga, São Pedro do Sul, Sistemas de Informação Geográfica.

1. Introduction

This article derives from the author's 2023 master's dissertation entitled "Landscape Archaeology: Analysis of Romanised hillforts (castros) in the present municipality of São Pedro do Sul". The development of this sub-topic responds to the scarcity of data and studies on the navigability of the Vouga River, particularly during the Classical period, given that it is the most important watercourse within the present study area.

The information gathered during the research indicates that local populations have long referred to the use of the river as a communication route: it would have been navigable up to the vicinity of Castro do Banho and the former roman thermal baths, and there would also have been a small river landing stage nearby. To date, no archaeological remains of such a landing are known. Nevertheless, several references and lines of evidence concerning navigability can be brought to bear on the problem. Descriptions of the landscape in the Classical period, medieval documentation, local public-works projects and geomorphological studies were among the resources mobilised to assess navigability, alongside discussion of possible climatic shifts that may have influenced meteorological conditions and the state of the inlet at Aveiro during the relevant chronology. Even in the absence of extensive

historical-archaeological studies, the Vouga is a landmark in the landscape and one of the main territorial resources, from the Dão–Lafões uplands to the Atlantic Ocean. Its natural setting is distinctive: it combines maritime and mountainous influences, producing low temperatures and high rainfall in autumn and winter, and relatively mild temperatures and moderate rainfall in spring and summer. To harness water quality and regulate the quantity of water available within the basin, bearing in mind the annual floods in the Middle Vouga, recent decades have seen investment in small hydropower schemes and weirs to supply local communities.

2. The Vouga River Basin

The Vouga River basin rises in the Serra da Lapa at approximately 930 m A.S.L. and extends for roughly 148 km until it reaches the Ria de Aveiro, where it discharges into a lagoon system characterised by multiple channels and marshy haff-delta terrain. With an area of around 3,645 km² and a predominantly east-west orientation, the basin includes several tributaries, notably the Águeda, Cértima, Caster, Antuã and Boco rivers, as well as the Valas de Mira channels[1] (Fig. 1).

[1] J. F. SANTOS, *Estudo da relação entre o caudal e indicadores de qualidade da água no Médio Vouga*, tesis de mestrado, Universidade de Aveiro, 2008, http://hdl.handle.net/10773/584, 15.

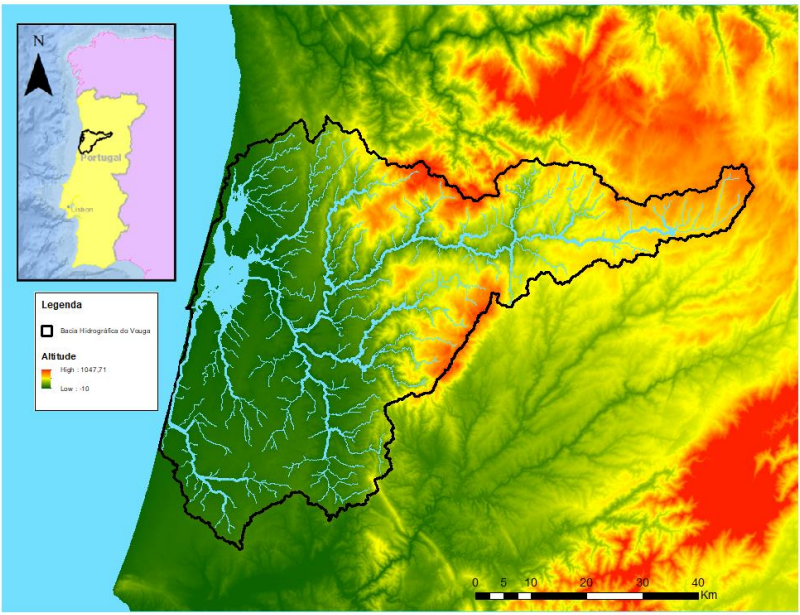

Fig.1. Location of the Vouga River basin. Prepared by the authors based on the altimetric data of the SRTM 30m.

From a morphological and hydrological perspective, the basin can be divided into three major sections: Upper Vouga, Middle Vouga and Lower Vouga, corresponding to distinct relief units (Fig. 2). The Upper Vouga, between the source and São Pedro do Sul, displays an elongated morphology, steep slopes and high drainage capacity, favouring rapid responses to intense precipitation events. The Middle Vouga, between São Pedro do Sul and Albergaria-a-Velha, develops through incised valleys and irregular relief, whereas the Lower Vouga, downstream, is characterised by a broad, low-gradient alluvial plain where runoff is slower and water accumulation is greater during wet periods.

The altimetric distribution shows strong asymmetry, with steep mountainous sectors upstream and an extensive low-altitude area near the mouth, where the topographic gradient decreases progressively (Fig. 2). This configuration constrains

surface runoff velocity, infiltration and the concentration of the drainage network, directly shaping flood dynamics. Functionally, two main sub-basins may be distinguished: an upstream sector of smaller size, rugged relief and rapid hydrological response; and a downstream sector, more extensive and rounded in form, with moderate runoff, culminating in the branching into multiple channels that structure the haff-delta of the Ria de Aveiro[2].

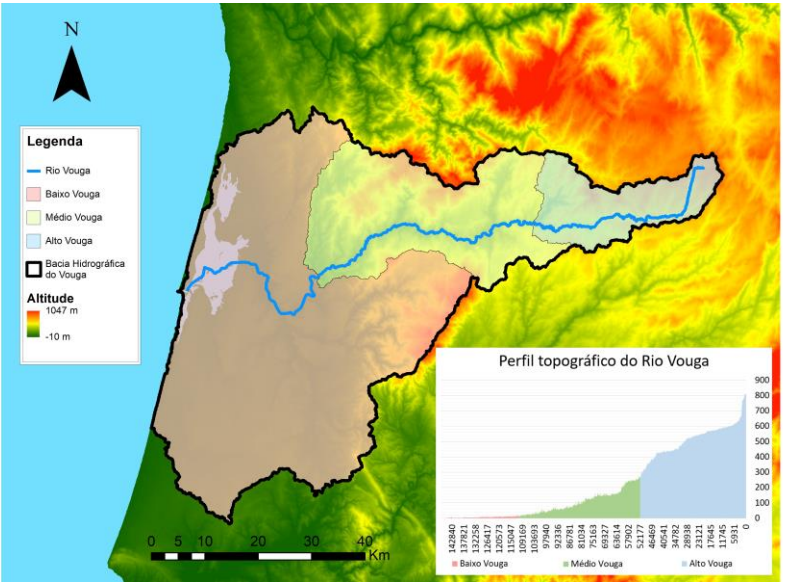

Fig.2. The divisions of the hydrographic basin and the topographic profile of the Vouga River, where the passage from the mountains to the sea is evident. Prepared by the authors based on the altimetric data of the SRTM 30m.

3. Historical-Archaeological Context

Despite gaps in the historical-archaeological record affecting the settlement network and landscape archaeology, the present reading focuses on the period between the late 1st millennium BC

[2] C. M. RODRIGUES; *Risco de Inundação: Área das Termas de S. Pedro do Sul (1960-2001).* Dissertação de Mestrado em Geografia Física, especialidade em Ambiente e Ordenamento do Território; Coimbra; Universidade de Coimbra; 2009; 17.

and the 4th/5th centuries AD, based on the analysis and processing of information undertaken during the master's project.[3]

The territory, now known as São Pedro do Sul, formed part of a larger protohistoric administrative division, still unknown, but potentially related to settlements such as Santa Luzia in Abraveses (Viseu). With altitudes ranging from 60 to 1,100 m and abundant water resources, natural features likely constituted the main delimiters of the territory. It is therefore plausible that subsistence agriculture, livestock raising and pastoralism were predominant, given limited possibilities for expanding arable land. During the Bronze Age, settlements in this area would have been more concentrated. Nevertheless, the hillfort of Nossa Senhora da Guia appears to have been one of the region's main proto-urban centres, with consistent metallurgical and commercial activity. At a subsequent moment, here very briefly framed as the transition to the Iron Age, these spaces were destroyed by fire, whether intentional or not, in favour of other sites (such as Castro do Banho) or a new urban reorganisation (at Santa Luzia). In this new phase, the principal settlements were Cárcoda and Banho, located in markedly different geostrategic settings. Whereas the former presents residential potential, with numerous buildings and an amphitheatre-like relief, the latter seems oriented towards social dynamism, particularly with the arrival of the Romans. The Banho area became increasingly active, both due to the construction of the thermal complex and to investment in road and fluvial communication routes. The sulphurous waters would already have been known and used by local communities, and routes likely already existed in the vicinity of the protohistoric settlement, which functioned as a central point between the

[3] Excerpt from the 'Final considerations and conclusions' of the master's thesis: J. M. MARQUES, (2023b) *Arqueologia da paisagem: Análise dos castros romanizados no atual concelho de São Pedro do Sul* [Master's Dissertation, University of Évora]. http://hdl.handle.net/10174/35798.

interior (the *Civitas* of *Vissaium*) and the coast (*Talabriga*). In any case, the mixing of knowledge, cultures and peoples enabled the transformation and development of the study area.

To date, the purpose of the temporary Roman military camp of Coelheira remains unknown. It is nevertheless noteworthy that it does not visually control any of the hillforts, nor is it visible from them. Given this limited intervisibility, it is possible to propose that the soldiers sought only to rest during an expedition, avoiding suspicion and potential tensions. Moreover, no evidence of violence between romans and local communities is known so far.

4. Complementary Studies

4.1. Climatology

Climate is a determining factor because it directly affects the density and variability of river discharge. Situated within a distinctive landscape setting (between mountain ranges, yet close to the Atlantic Ocean), the region is described as having a "*moderate climate transitioning from maritime to continental, with some local varieties due mainly to relief*"[4]. This regime is characterised by relatively mild and less humid summers, under the influence of westerly maritime winds, and cold, wet winters, marked by easterly winds and high rainfall. Additional microclimates derive from variations in relief, altitude, hydrography and vegetation[5]. Consequently, the Vouga basin displays a seasonal rainfall regime, with precipitation concentrated in the cold season and significantly lower values in summer[6].

[4] J. F. SANTOS, *Estudo da relação entre o caudal e indicadores de qualidade da água no Médio Vouga,* 16-17.
[5] J. F. SANTOS, *Estudo da relação entre o caudal e indicadores de qualidade da água no Médio Vouga*, 16-17.
[6] J. F. SANTOS, *Estudo da relação entre o caudal e indicadores de qualidade da água no Médio Vouga*, 20.

To substantiate this parameter, rainfall data available through the *Sistema Nacional de Informação de Recursos Hídricos* were analysed. These correspond to mean annual precipitation values (in millimetres) between 1931 and 2021, recorded by twenty-three stations across the Vouga basin.[7] The main aim was to establish a reading of the last 90 years and assess whether rainfall indices have changed substantially, identify which regions are wetter or drier, and determine whether there are common years with droughts or particularly intense rainfall. The analysis shows strong interannual variability, with no continuity of similar values across consecutive years, indicating a regime marked by alternating peaks of high and low precipitation. A pronounced contrast is also evident between the coast and the mountainous interior, with lower values in coastal areas and significantly higher values at greater altitudes. Episodes of extreme rainfall appear to occur sporadically, with approximate intervals of three decades, suggesting a long-term cyclicity in the basin's rainfall regime.

4.2. Anthropogenic and Natural Changes

The mouth of the Vouga River has been modified, particularly after the 7th century. Although major geological changes are not observed in the bed of the Upper and Middle Vouga, the north-west Portuguese coastline experienced continuous progradation. This implies that communities had to adapt to the changing environment, abandoning certain zones of salt extraction, fishing, agro-pastoral activity and maritime/maritime-fluvial ports in favour of new ones closer to the Atlantic Ocean. This situation influenced demographic

[7] Data available on March 17, 2023: https://snirh.apambiente.pt/index.php?idMain=2&idItem=1&objCover=920123704&objSite=920685506.

development and the capacity of populations to live from the sea and its resources.[8]

The Aveiro *haff*-delta formed over time as a consequence of systematic morpho-sedimentary changes. Studies by Amorim Girão[9], Alberto Souto[10], João Gonçalves Gaspar[11], Maria Blot[12], and Olegário Pereira and Maria Bastos[13] indicate that the Vouga would have discharged farther inland and ended along a sinuous coastline. Today, an eroded scarp can be observed on the left bank near Aveiro, between Eirol and São João de Loures. Sediment coring at Macinhata identified marine fossils dated to the Quaternary (between 2.6 million and 10 thousand years ago). In summary, the lagoonal zone where the river met the sea would have been located in the present region of Fermentelos, Frossos and Taboeira, since the former coastline would have encompassed Ovar, Estarreja, Salreu, Fermelã, Angeja, Esgueira, Aveiro and Vagos (Fig. 3). At present, conglomerates and recent marine and fluvial sedimentary formations are widespread, as is an ancient marine scarp on the Cojo slopes[14].

[8] Excerpt from the article: J. M. MARQUES; A bacia hidrográfica do rio Vouga: As alterações naturais e antrópicas na faixa noroeste de Portugal. *Cadernos de Cultura: História & Património de Aveiro*, 4, 2023; 92–107. https://rbma.cmaveiro.pt/Catalog/_client/noticias/caderno_cultura_4.pdf.

[9] A. A. GIRÃO, *Bacia do Vouga: estudo geográfico*, tesis doctoral, Faculdade de Letras da Universidade de Coimbra, Coimbra, Imprensa da Universidade, 1922.

[10] A. SOUTO, *Origens da Ria de Aveiro: apontamentos sobre a geografia da Beira Litoral*, vol. I, Aveiro, Tipografia Minerva Central, 1923.

[11] J. G. GASPAR, *Aveiro: notas históricas*, Aveiro, Câmara Municipal de Aveiro, 1983.

[12] M. L. P. BLOT, *Os portos na origem dos centros urbanos: contributo para a arqueologia das cidades marítimas e flúvio-marítimas em Portugal*, Lisboa, Instituto Português de Arqueologia, 2003.

[13] O. A. PEREIRA & M. R. BASTOS, *Poder e representações do litoral de Aveiro (Portugal) na cartografia histórica: séculos XIV-XVII*, *Revista Bibliográfica de Geografía y Ciencias Sociales*, vol. 24, n.º 1282, 2019.

[14] A. A. GIRÃO, *Bacia do Vouga: estudo geográfico*, tesis doctoral, Faculdade de Letras da Universidade de Coimbra, Coimbra, Imprensa da Universidade, 1922, 55-57; A. M. SILVA & G. R. PEREIRA; Povoamento protohistórico na fachada atlântica do Entre Douro e Vouga. Paleoambientes e dinâmica cultural; *Variações paleoambientais e evolução antrópica no Quaternário do Ocidente Peninsular: apresentação de um projeto multidisciplinar*; Braga;

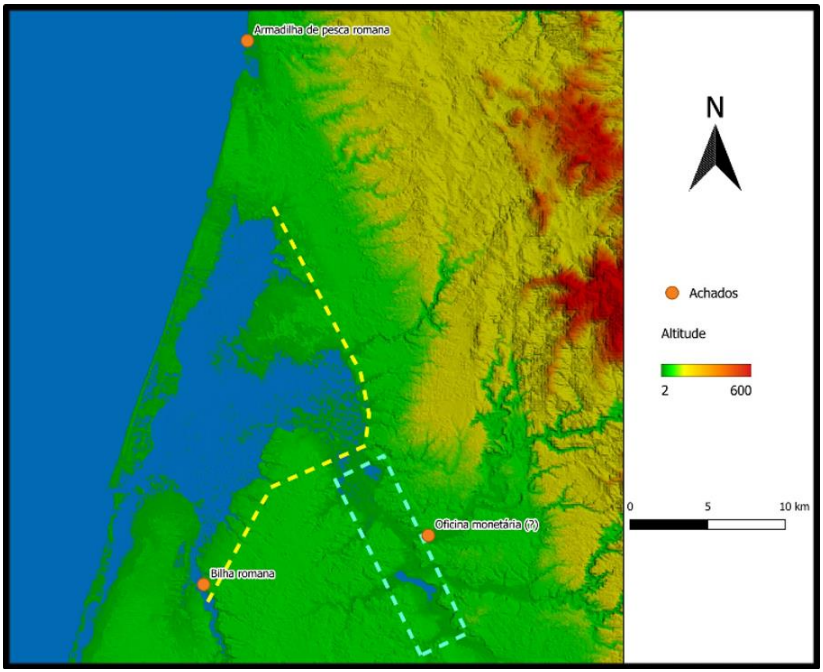

Fig.3. Identification, through lines, of the old lagoon zone and coastline, and location of the respective archaeological remains in the study area. Elaborated by Bruno Gambinhas Leal and Joana Margarida Marques.

Between 2000 BC and the mid-700s AD, the coastline did not show major oscillations, although silting processes were underway within the bay, giving rise to a sandspit to the north and another to the south.

Strabo, in Geography, Book III (Iberia), Chapter III, Section 4, refers to the fertility of the region and the abundance of watercourses running parallel to the Tagus, thus enabling fluvial navigation. He also mentions navigation on the Vouga: "*Of these*

Edição de Ana M. S. Bettencourt, Maria Isabel Caetano Alves, Sérgio Monteiro-Rodrigues; 2021; 189-203.

rivers, the most well-known after the Tagus are the Mondego, which allows some small-scale navigation upstream, as well as the Vouga"[15].

Rufus Festus Avienius, author of Ora Maritima, compiled an ethno-geographical account of seaborne voyages between Hispania and "*the tin islands*"[16]. These descriptions are essential because they corroborate the well-known transformation of the coastal landscape, especially around present-day Aveiro.[17]

Almost two millennia later, Francisco Martins Sarmento analysed Avienius' text and proposed new locations for some territories. For the present discussion, the key issue is the Pelagia ins, an island/peninsula said to have existed between the Vouga and Mondego in Caesar's time. Because it was rich in pastures, *herbarum abundans*, and most likely evolved by accreting sediments, it would have been close to the coast or even within the current channels of the Ria de Aveiro. If it had been in the open Atlantic (the Atlantic Ocean), it would have experienced adverse conditions (winds and tides) that would not have allowed silting, flooding and consequent fertilisation[18].

Cassius Dio refers to the flight of the inhabitants of Mount Herminius during Caesar's campaigns in the 60s BC. The Roman leader ordered the Herminii to abandon their fortified hilltop settlements and resettle in the plain. Resistant to the new political order, they did not accept the instruction. They safeguarded their

[15] J. DESERTO & S. H. M. PEREIRA; Estrabão, Geografia. Livro III. Introdução, tradução do grego e notas; Coimbra; Fundação Calouste Gulbenkian; 2016; 61.
[16] F. M. SARMIENTO, *Ora maritima: estudo d'este poema na parte respectiva à Galliza e Portugal*, Porto, Typographia de Antonio José da Silva Teixeira, 1880, 8.
[17] Avien. *Ora Marit.* 161–168. Academy for Ancient Texts. Available online on 01/04/2023: http://www.ancienttexts.org/library/latinlibrary/avienus.ora.html.
[18] F. M. SARMIENTO, *Ora maritima: estudo d'este poema na parte respectiva à Galliza e Portugal*, Porto, Typographia de Antonio José da Silva Teixeira, 1880, 46-47.

belongings and protected women and children before departing for conflict.[19]

Several archaeological remains have also been found in the study area (Fig. 3). "*A roman jar*"[20], found during repair works on the "*bridge over the Vagos lagoon (…)*"[21]; a fishing trap dated to the 1st/2nd centuries AD found at Silvalde (Espinho), which suggests that the area was not yet silted[22]; and a mint known as "*Vallegia*", located at the former mouth of the Vouga[23].

By the 9th century, a moderate appearance of this sand barrier is confirmed, whereas the following century witnessed its accelerated growth. A foundation and donation charter for religious buildings dated to 897 indicates that there had been a lagoon called Ovil near the town of Esmoriz; it later dried up, enabling salt production at Esgueira and Vagos[24] Another document, dated 26 January 959, records the donation of salt-exploitation lands by Countess Mumadona Dias to the Monastery of Coimbra: "(…) *terras in Alauario et salinas que ibidem comparauimus*

---

[19] Cass. Dio 37.52.3. Penelope, The University of Chicago. Available online on 08/01/2026: https://penelope.uchicago.edu/Thayer/E/Roman/Texts/Cassius_Dio/37*.html.

[20] A. A. GIRÃO, *Bacia do Vouga: estudo geográfico,* 57.

[21] Diário do Governo. (1871, 18 de novembro). *N.º 262*, p. 1512. Lisboa: Imprensa Nacional. Digigov – Digital Government Gazette. Available online on 08/01/2025: https://digigov.cepese.pt/pt/pesquisa/listbyyearmonthday?ano=1871&mes=11&tipo=a-diario&res=.

[22] M. R. BASTOS; *O baixo Vouga em tempos medievos: do preâmbulo da Monarquia aos finais do reinado de D. Dinis*.; Tese de Doutoramento em Ciências Humanas e Sociais, na Especialidade de História; Lisboa; Universidade Aberta; 2006; 35.

[23] M. P. BLOT; Os Portos na origem dos centros urbanos: Contributo para a arqueologia das cidades marítimas e flúvio-marítimas em Portugal.; *Trabalhos de Arqueologia*; Lisboa; en Instituto Português de Arqueologia; 28; ; 2003; 199–200.

[24] *"(...) et in ripa uauga uilla de seueri et mediadate do illa uarcena de caruonario et in ezebrario uilla de bigas quos fuit de froila lopo uilla de ermoriz que est circa lagona de auille (...)*". Portugaliae Monumenta Historica. (1868–1873). *Diplomata et Chartae*, doc. 12: *Charta fundationis et dotis quarundam ecclesiarum inter flumina Durium et Vaugam*. Lisboa: Academia das Ciências de Lisboa. Ex autographo conservado en los Archivos Públicos.

(…)"[25], which points to salt extraction earlier than is otherwise documented.

Between the 13th and 14th centuries, the deterioration of climatic conditions associated with the "Little Ice Age" increased rainfall, wind activity and storm frequency, significantly enhancing sediment transport[26]. These processes led to the formation of an aeolian sand barrier in the area of the present Torreira beach, as well as multiple channels and islands. Remnants of the former inner gulf include Fermentelos, Frossos and Taboeira[27], together with an expansion of salt exploitation[28]

In the 15th century, the Aveiro coast underwent continuous morphodynamic reorganisation, marked by the migration of the natural inlet, the silting of former fluvial accesses, and the redefinition of contact points between the lagoon system and the Atlantic[29]. During the 16th century, this configuration favoured strong marine-water penetration and intense salt production, creating "*salt pans from Ovar to Alquerubim and, along the Boco, to Vagos*"[30] .This contributed to the elevation of Aveiro to the status

[25] J. G. GASPAR, *Aveiro: notas históricas*, 53.

[26] P. VICENTE; O. N. A. PEREIRA & M. R. BASTOS, *Impacto do Pequeno Óptimo Climático na formação e exploração da Laguna de Aveiro (Portugal)*, en *Sociedade, ambiente e tecnologia: Mar afora, costa adentro*, tomo X, Rio de Janeiro, Rede BRASPOR, 2021, http://hdl.handle.net/10400.2/11604, 224.

[27] M. R. BASTOS; *O baixo Vouga em tempos medievos: do preâmbulo da Monarquia aos finais do reinado de D. Dinis*, 48.

[28] P. VICENTE; O. N. A. PEREIRA & M. R. BASTOS, *Impacto do Pequeno Óptimo Climático na formação e exploração da Laguna de Aveiro (Portugal)*, en *Sociedade, ambiente e tecnologia: Mar afora, costa adentro*, tomo X, 224.

[29] A. A. ANDRADE, *A estratégia régia em relação aos portos marítimos no Portugal medieval: o caso da fachada atlântica*, en B. ARÍZAGA BOLUMBURU & J. Á. SOLÓRZANO TELECHEA (eds.), *Nájera – Encuentros Internacionales del Medievo, 2004. Ciudades y villas portuarias del Atlántico en la Edad Media*, Logroño, Instituto de Estudios Riojanos, 2005, 60; M. R. BASTOS; *O baixo Vouga em tempos medievos: do preâmbulo da Monarquia aos finais do reinado de D. Dinis*, 48.

[30] J. G. GASPAR, *Aveiro: notas históricas*, 92-94.

of vila by Philip II of Spain[31]; however, after 1575, the recurrent obstruction of the inlet compromised navigation and the functioning of the fluvio-maritime system[32].

Throughout the 17th and 18th centuries, inlet instability persisted, causing water stagnation, environmental degradation and direct impacts on riverside populations[33]. In the mid-18th century, the southward displacement of the inlet prompted state intervention, materialised in repeated attempts to open and stabilise a new channel[34]. These actions culminated in the construction of the artificial inlet, completed in 1808, closing a long period of morphodynamic transformation of the Aveiro lagoon.

5. Methodology

The methodology is based on the application of hydrographic analysis tools implemented in a GIS programme to calculate the hydrological potential of the river up to a given point. In this case study, the Castro do Banho hillfort was selected because it occupies the most efficient strategic position: it lies within the Middle Vouga section, is the closest site to the river, the vicus and the former Roman thermal baths, and constitutes an excellent place for meetings and exchange.

ArcGIS 10.4.1 was used to analyse the river and its tributaries, estimate water-storage volume and drainage capacity from the source to the location of Castro do Banho. This process is fundamental to assess whether the river was navigable in the

31 M. L. P. BLOT, *Os portos na origem dos centros urbanos: contributo para a arqueologia das cidades marítimas e flúvio-marítimas em Portugal,* 202.
32 J. G. GASPAR, *Aveiro: notas históricas,* 94.
33 F. T. FERREIRA, *Mortalidade infantil em duas freguesias da cidade de Aveiro no século XVIII*, en *Espaços urbanos: dinâmicas demográficas e sociais (séculos XVII-XX)*, Lisboa, Projeto COMPETE / Fundação para a Ciência e a Tecnologia, 2008.
34 J. G. GASPAR, *Aveiro: notas históricas,* 117; A. L. VIDAL, *Reflexões sobre a navegação do rio Vouga, por Dr. Joaquim Baptista (1829)*, 70.

roman period up to Banho. The same Digital Elevation Model (DEM) file was used, complemented by a point layer to identify and locate Castro do Banho. To calculate the capacity of the target basin, an innovative navigability-analysis methodology was adopted, recently published and successfully applied to a similar case study[35]. The modification introduced here concerns the placement of the point where water passage (m^3/s) is simulated. For this purpose, a point was placed downstream of Castro do Banho and of the Beirós stream mouth, with the intention of recording a higher hydrological flow. This procedure yielded the number of pixels comprising the basin: 1,026,559 (Fig. 4).

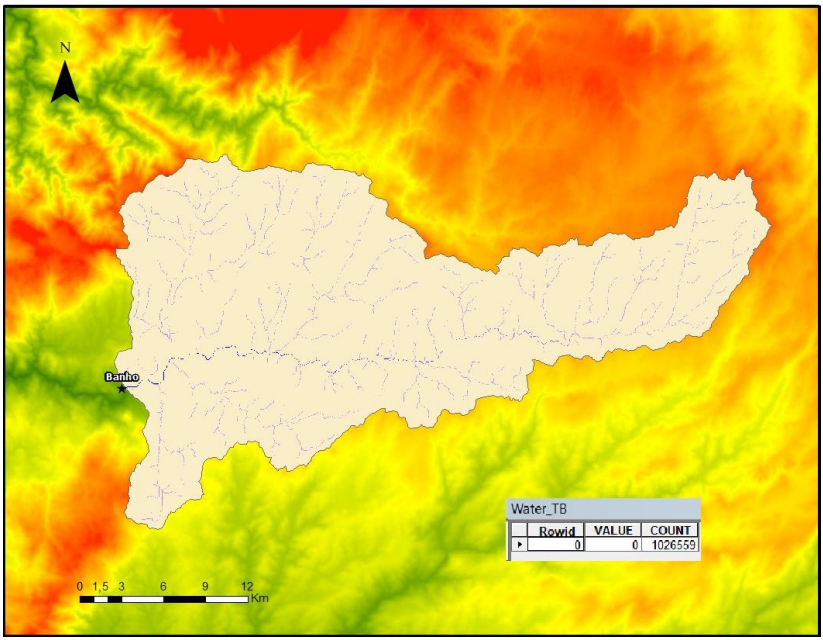

Fig.4. Calculation map of the intended hydrographic basin: from the source of the Vouga river to the Beirós stream, located in the vicinity of the village of Banho and exhibition of the number of pixels

[35] P. TRAPERO FERNÁNDEZ, E. ARAGÓN, A. CARNEIRO, J. CATALÁN, P. FERNÁNDEZ & J. M. MARQUEZ, *Modelling river navigation in the past: General methodology and case studies on Hispanic rivers*, comunicación inédita presentada en el 29th Annual Meeting of the European Association of Archaeologists, Belfast, 2023.

that make up the basin: 1026559. Prepared by the authors based on the altimetric data of the SRTM 30m.

Because each pixel has a size of 25 × 25 m², these values were multiplied (25 × 25 = 625) and then multiplied by the number of pixels (625 × 1,026,559), resulting in 641,599,375 m². The final value corresponds to the number of pixels representing water runoff in a given direction. In short, a file was obtained with a simulated discharge across the landscape. However, factors such as precipitation, evaporation, infiltration and groundwater, which can alter results if not considered, should ideally be accounted for. It is essential to note that, for this procedure, the most appropriate approach is to use values comparable to those of the roman period.

Rainfall data from the *Sistema Nacional de Informação de Recursos Hídricos*, previously used in the climatology study, were employed. The station closest to the basin under analysis was selected: São Pedro do Sul (09I/01C). Because the series includes peaks of particularly wet years, the years with the lowest and highest mean annual precipitation between 1931 and 2021 were used. The driest year was 1944 (591.8 mm) and the wettest was 1978 (1,756.9 mm).

To estimate the amount of water generated in the basin in a drier year, 641,599,375 m² was multiplied by 591.8 mm, yielding 379,698,510,125. Assuming that most water infiltrates (90%), 10% remains, so the previous result is divided by 10, producing 37,969,851,012.5. Because these figures are annual, they must be reduced to 12 months, 30 days, 24 hours and 3,600 seconds: 37,969,851,012.5 / 12 = 3,164,154,251.041667; 3,164,154,251.041667 / 30 = 105,471,808.3680556; 105,471,808.3680556 / 24 = 4,394,658.682002315; 4,394,658.682002315 / 3,600 = 1,220.738522778421. This value represents the litres per second passing the point downstream of Castro do Banho and the Beirós stream. The next step is to convert the value to cubic metres, since it is not possible to

compute area using litres: 1,220.738522778421 / 1,000 = 1.220738522778421 litres per second passing that point. Subsequently, the equation $a \times b = A \times 2\pi$ is solved to determine the value of $a \times b$, corresponding to the major and minor radii, respectively: $1.221 \times 2 / 3.14 \approx 0.778$. In conclusion, if radius a is set to 1 m, river depth would be 0.778 m and river width 2 m (Fig. 5).

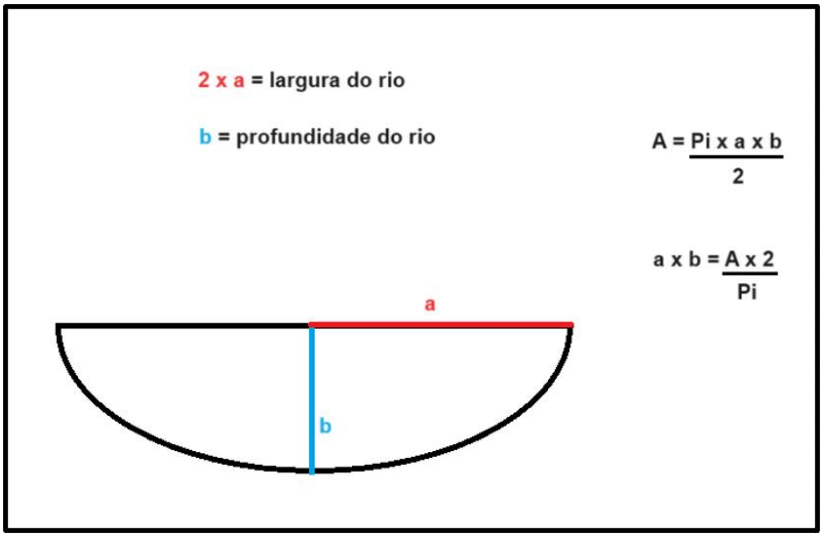

Fig.5. Diagram of the calculations to be performed to determine the minimum hydrogeographical conditions for navigation, where π = 3.14.

To estimate the amount of water generated in the basin in a wetter year, the same procedure is repeated. 641,599,375 m² × 1,756.9 mm = 1,127,225,941,937.5. 1,127,225,941,937.5 / 10 = 112,722,594,193.75. 112,722,594,193.75 / 12 = 9,393,549,516.145833; 9,393,549,516.145833 / 30 = 313,118,317.2048611; 313,118,317.2048611 / 24 = 13,046,596.55020255; 13,046,596.55020255 / 3,600 = 3,624.054597278485 litres passing each m² at the basin point. 3,624.054597278485 / 1,000 = 3.624054597278485 m³/s passing that point per second. Solving the same equation: 3.624 × 2 /

3.14 ≈ 2.308. It can be concluded that 2.3 is the product a × b. If radius a is set to 1 m, river depth would be 2.3 m and river width 4.6 m.

6. Results

It was estimated that, under dry hydrological conditions, the average depth of the Vouga River would have been approximately 0.78 m, with an estimated channel width of around 2 m. Under wetter hydrological conditions, these values increase to approximately 2.3 m in depth and 4.6 m in width. These calculations consider only 10% of total precipitation as effective runoff and therefore represent minimum discharge scenarios.

Regarding navigability, the threshold of 1 m of draught—commonly considered sufficient for small riverine craft—would have been attained only under wetter conditions. In such scenarios, water depth would exceed 1 m during part of the annual cycle, allowing the passage of small vessels. During drier periods, water levels would remain below this threshold, restricting navigation to very shallow-draught craft or to limited stretches of the river. Moreover, the estimated narrow channel width (approximately 2–4.6 m) suggests that navigation would have been constrained to small-sized vessels.

Overall, these results indicate that the Vouga River may have functioned as a seasonal fluvial route for the movement of people and goods between the present-day area of São Pedro do Sul and the coastal zone, but only during periods of sufficient water levels and relatively low flow energy (Fig. 6).

Fig.6. Landscape setting of the Vouga River, the Banho hillfort and the Talabriga-Vissaium Roman road. Aerial photo of the archaeological site kindly provided by Bruno Gambinhas Leal. May 2023.

7. Discussion

The results obtained must be interpreted with caution, as the methodology applied is experimental and based on simplified assumptions. For instance, it was assumed that only 10% of total precipitation is converted into effective runoff, disregarding hydrological variables such as infiltration and evapotranspiration, as well as anthropogenic impacts (e.g. dams, channelization) that may significantly alter discharge regimes. Consequently, the calculated water depths should be regarded as minimum estimates.

Important data gaps also remain. Direct archaeological evidence (such as harbor structures or landing facilities along the Vouga River) is currently lacking, as are local paleoenvironmental studies (e.g. alluvial sediment analyses, radiocarbon dating, or

palynological records) that would allow a more detailed reconstruction of past channel morphology and relative sea-level dynamics. Modern analytical tools could help address some of these limitations: high-resolution remote sensing and bathymetric LiDAR surveys may reveal former channel courses and buried fluvial or fluvio-maritime infrastructures. Furthermore, the application of dynamic hydrological modelling, calibrated using historical precipitation series and paleoclimatic scenarios, would be particularly valuable for testing navigability under different environmental conditions.

In sum, future interdisciplinary research, integrating geoarchaeology, landscape archaeology, geophysics and climatology, will be essential to validate and refine the initial estimates presented here, while addressing both methodological and empirical gaps.

8. Conclusion

The data support the hypothesis that the Vouga River was navigable up to the vicinity of Castro do Banho during the Roman period, particularly under favorable seasonal conditions. This conclusion is consistent with local oral traditions and highlights the strategic importance of the hydrological stretch analyzed in Antiquity.

The results also emphasize the need for an interdisciplinary approach in future research. The integration of geoarchaeology, landscape archaeology, hydrological modelling and climatic studies would allow for a more comprehensive contextualization of Vouga navigability and the development of more robust historical scenarios. Such methodological integration not only strengthens the reliability of the results but also underscores the scientific and heritage potential of this research.

Ultimately, an understanding of the historical navigability of the Vouga River helps to elucidate processes of human adaptation in dynamic coastal environments, offering relevant contributions to contemporary discussions on environmental sustainability and the preservation of cultural heritage.

Bibliography

A. A. ANDRADE, *A estratégia régia em relação aos portos marítimos no Portugal medieval: o caso da fachada atlântica*, en B. ARÍZAGA BOLUMBURU & J.Á. SOLÓRZANO TELECHEA (eds.), *Nájera – Encuentros Internacionales del Medievo, 2004. Ciudades y villas portuarias del Atlántico en la Edad Media*, Logroño, Instituto de Estudios Riojanos, 2005, 57-89.

AVIENUS (Rufus Festus), *Ora Maritima*, vv. 161-168, s. l., s. d., edición digital en Academy for Ancient Texts, http://www.ancienttexts.org/library/latinlibrary/avienus.ora.html

M. R. BASTOS; *O baixo Vouga em tempos medievos: do preâmbulo da Monarquia aos finais do reinado de D. Dinis*.; Tesis doctoral en Ciencias Humanas y Sociales, especialidad en Historia; Lisboa; Universidade Aberta; 2006; 35.

M. L. P. BLOT, *Os portos na origem dos centros urbanos: contributo para a arqueologia das cidades marítimas e flúvio-marítimas em Portugal*, Lisboa, Instituto Português de Arqueologia, 2003.

J. DESERTO & S. H. M. PEREIRA; Estrabão, *Geografia*. Livro III. Introdução, tradução do grego e notas; Coimbra; Fundação Calouste Gulbenkian; 2016.

CASSIUS DIO (Cassius Dio Cocceianus), *Historiae Romanae*, libro XXXVII, cap. LII, 3, s. l., s. d., edición digital en Penelope, The University of Chicago,

https://penelope.uchicago.edu/Thayer/E/Roman/Texts/Cassius_Dio/37*.html

M. CLEMENTE CARRILLO, *Proceso de construcción de la carabela "Niña"*, Trabajo Fin de Grado, Universidad Politécnica de Cartagena, 2015, https://repositorio.upct.es/server/api/core/bitstreams/d8ff9d6f-8e53-4cd8-ac53-80f80cc3c415/content

DIÁRIO DO GOVERNO, n.º 262, 18 de noviembre de 1871, p. 1512, Lisboa, Imprensa Nacional, edición digital Digigov – Digital Government Gazette, https://digigov.cepese.pt/pt/pesquisa/listbyyearmonthday?ano=1871&mes=11&tipo=a-diario&res=

F. T. FERREIRA, *Mortalidade infantil em duas freguesias da cidade de Aveiro no século XVIII*, en *Espaços urbanos: dinâmicas demográficas e sociais (séculos XVII-XX)*, Lisboa, Projeto COMPETE / Fundação para a Ciência e a Tecnologia, 2008.

J. G. GSPAR, *Aveiro: notas históricas*, Aveiro, Câmara Municipal de Aveiro, 1983.

A. A. GIRÃO, *Bacia do Vouga: estudo geográfico*, tesis doctoral, Faculdade de Letras da Universidade de Coimbra, Coimbra, Imprensa da Universidade, 1922.

J. M. MARQUES, *A bacia hidrográfica do rio Vouga: as alterações naturais e antrópicas na faixa noroeste de Portugal*, *Cadernos de Cultura: História & Património de Aveiro*, vol. 4, 2023, 92-107, https://rbma.cmaveiro.pt/Catalog/_client/noticias/caderno_cultura_4.pdf

J. M. MARQUES, *Arqueologia da paisagem: análise dos castros romanizados no atual concelho de São Pedro do Sul*, tesis de mestrado, Universidade de Évora, 2023, http://hdl.handle.net/10174/35798

O. A. PEREIRA & M.R. BASTOS, *Poder e representações do litoral de Aveiro (Portugal) na cartografia histórica: séculos XIV-XVII*, *Revista Bibliográfica de Geografía y Ciencias Sociales*, vol. 24, n.º 1282, 2019.

J. O. PUIG, *Teoría del buque. Flotabilidad y estabilidad*, Barcelona, Edicions UPC, 1994.

C. M. RODRIGUES; *Risco de Inundação: Área das Termas de S. Pedro do Sul (1960-2001)*. Tesis de maestría en Geografía Física, especialización en Medio Ambiente y Ordenación del Territorio; Coimbra; Universidade de Coimbra; 2009.

J. F. SANTOS, *Estudo da relação entre o caudal e indicadores de qualidade da água no Médio Vouga*, tesis de mestrado, Universidade de Aveiro, 2008, http://hdl.handle.net/10773/584

F. M. SARMIENTO, *Ora maritima: estudo d'este poema na parte respectiva à Galliza e Portugal*, Porto, Typographia de Antonio José da Silva Teixeira, 1880.

A. M. SILVA & G. R. PEREIRA; Povoamento protohistórico na fachada atlântica do Entre Douro e Vouga. Paleoambientes e dinâmica cultural; *Variações paleoambientais e evolução antrópica no Quaternário do Ocidente Peninsular: apresentação de um projeto multidisciplinar*; Braga; edición de Ana M. S. Bettencourt, Maria Isabel Caetano Alves y Sérgio Monteiro-Rodrigues; 2021.

A. SOUTO, *Origens da Ria de Aveiro: apontamentos sobre a geografia da Beira Litoral*, vol. I, Aveiro, Tipografia Minerva Central, 1923.

P. TTRAPERO FERNÁNDEZ, F. J. CATALÁN GONZÁLEZ & E.J. RUIZ PILARES, *El río Guadalete en el tránsito de la Edad Media a la Edad Moderna: una propuesta de restitución de su cauce y los condicionantes de navegabilidad a partir de los SIG*, *Vínculos de Historia*, vol. 12, 2023, 261-284.

P. TRAPERO FERNÁNDEZ, E. ARAGÓN, A. CARNEIRO, J. CATALÁN, P. FERNÁNDEZ & J.M. MARQUES, *Modelling river navigation in the past: General methodology and case studies on Hispanic rivers*, comunicación inédita presentada en el 29th Annual Meeting of the European Association of Archaeologists, Belfast, 2023.

P. VICENTE, O. N. A. PEREIRA & M. R. BASTOS, *Impacto do Pequeno Óptimo Climático na formação e exploração da Laguna de Aveiro (Portugal)*, en *Sociedade, ambiente e tecnologia: Mar afora, costa adentro*, tomo X, Rio de Janeiro, Rede BRASPOR, 2021, 215-227, http://hdl.handle.net/10400.2/11604

A. L. VIDAL, *Reflexões sobre a navegação do rio Vouga, por Dr. Joaquim Baptista (1829)*, Lisboa, Estante Editora, 1989.