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Modelling of Roman-period property surveyor actions in HISPANIA

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ABSTRACT

The literary works produced by the Roman Land Surveyors, also known as agrimensores, provide valuable insight into the management and demarcation of rural properties in the Roman world. Through these sources, we gain an understanding of how farms were partitioned and the elements employed to establish their boundaries. However, due to the general nature of the information, it is often difficult to apply it to modern-day archaeological studies, as we are typically only aware of the primary country house, such as the *pars urbana* in a *villa*. Nowadays, we have tools such as Geographic Information Systems (GIS) that allow us to approximate how could be the territory and its cadastre. In this article, we propose a methodology to combine Roman documentary evidence regarding land surveying, and tools to delimitate *territoria* in ancient sources, with geographic space, establishing a theoretical model on how to delimit estates in order to allow us to know their *fundi*. For this purpose, we use a case study in the Alto Alentejo (Portugal), a unique region where there is a high density of Roman *villae*, but whose settlement structure is not well known, and which could be part of a prefecture of the capital of Lusitania province *Colonia Augusta Emerita*. The proposed model allows us to visually see and relate the criteria applied by surveyors, like delimitation by streams or high elevations. This model translates the ancient knowledge to actual geography to propose boundaries, so we can discuss questions such as the possibility of secondary settlement as settlers or independent landowners or the potential areas of *saltus*.

1. Introduction

The study of ancient settlements is primarily based on archaeological surveys and excavations, which examine the objects and structures that reveal how the ancient landscape and economy functioned. While historical records provide a general overview of what these activities were, they are not sufficiently concrete to be applied to a specific scale of analysis. This is an issue we can observe in the combination in the delimitation of territories in cities in the ancient world. Surveyors were responsible for defining plots and boundaries between cities, and thanks to the *corpus agrimensorium*, (see Appendix A for translations of Latin terms), a significant portion of this literature has been preserved (Dilke, 1971; Chevallier, 1973; Castillo Pascual, 1996; Chouquer and Favory, 2001).

The criteria for delimiting *fundi* and *territoria*, as summarized by the 4th-century Roman surveyor *Siculus Flaccus*, include natural and anthropogenic boundary markers. *From the little hill which is so called, to that river, and through that river, to that stream or that way, and through that way to the foot of that mountain, this place is so called; and thence through the top of that hill to the top of that hill, and through the top of that hill, by the watersheds, to the place which is so called, and thence downwards to that place, and thence to the crossroads of that (place), and thence through the (sepulchral) monument of that place to the place from which it (the boundary) first began to be traced.*[1]

However, one of the challenges in studying the ancient landscape is the inability to comprehend how these boundaries were structured. This issue is relevant to understanding the influence of a particular city, identifying whether a secondary settlement is organized within a larger *villa*, or determining whether an area has no population structures because it was used for other agricultural activities typical of the *saltus*.

This article proposes a method for transferring the fundamental criteria used by surveyors, using Geographic Information Systems (GIS). With these powerful tools, we can transfer historical and geographical information, always in a theoretical way. Our aim is not to reconstruct

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[1] Sic. Fl. *De Cond. Agror.* 128,17. *ex colliculo qui apellatur ille, ad flumen illud, et per flumen illud ad rivvm illum aut viam illam, et per viam illam ad infima montis illius, qui locus appellatur ille, et inde per iugum montis illius in summum et per summum montis per divergía aquae ad locum qui appellatur ille, et inde deorsum versus ad locum illum, et inde ad compitum illius, et inde per monumentum illius ad locum unde primum coepit scriptura esse.*

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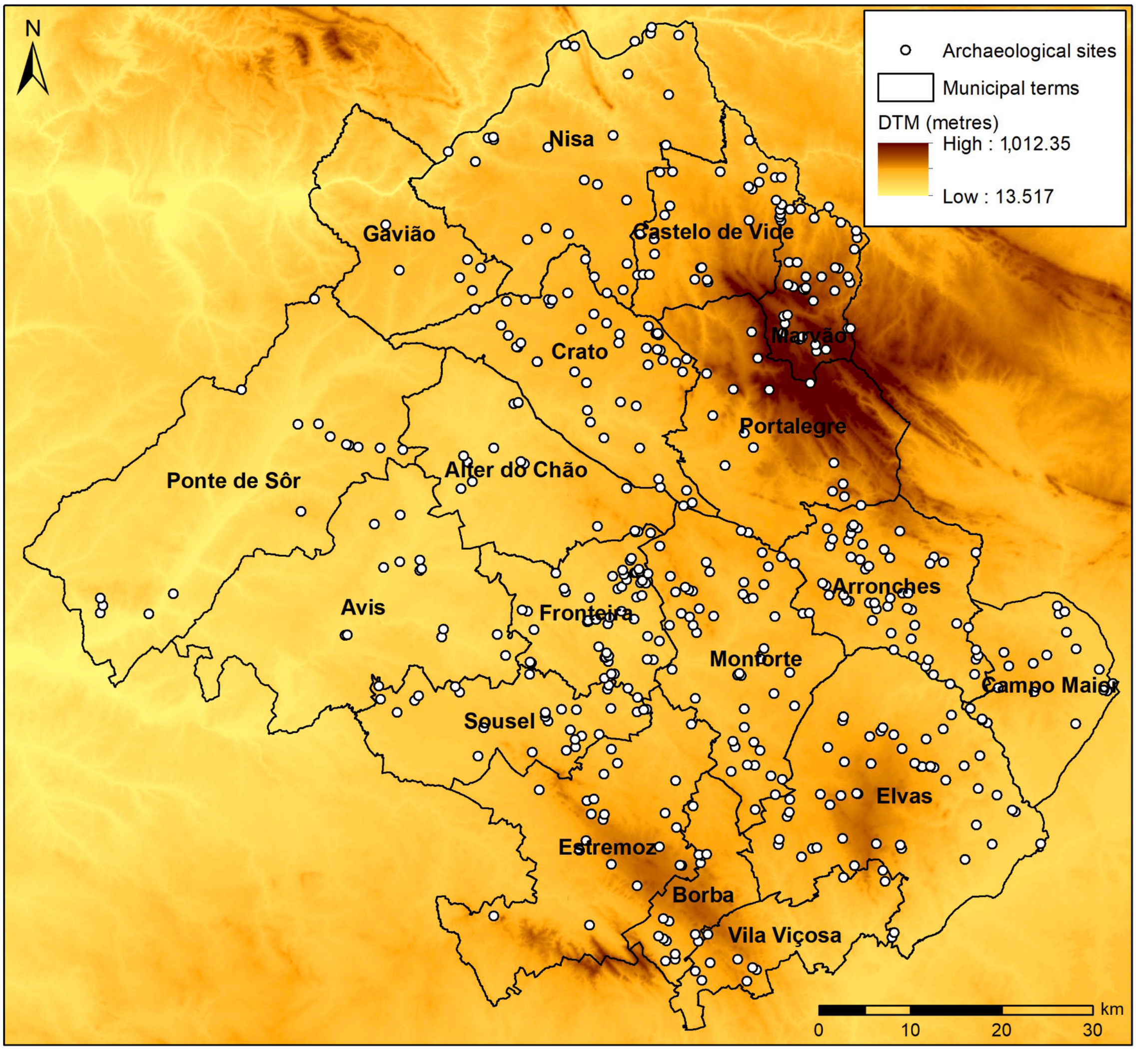

Fig. 1. Study area in Alto Alentejo (Portugal), with the indication of the settlement analysed.

the limits of cities (Fernández Corrales, 1976), but rather to comprehend the existing cadastre (Piganiol, 1962; Compatangelo, 1989), by understanding the production centres, surveyors' advice and geographical boundaries (Chouquer, 2007; 2014).

We can determine the approximate location of streams, rivers, watersheds and other spatial delimiters of natural origin to transfer these criteria to a map and identify logical boundaries for productive areas such as *villae*. Of course, we are missing those delimiters of anthropogenic origin, which have not been preserved. But this theoretical method serves to advance our knowledge of them, as will be seen in the discussion. In a very simple way, it is based on the sum of different layers of accessibility, using, for example, tools of distance cost analysis to calculate the near spaces to one or another settlement centre. This method has been applied in different Roman contexts with successful results (Goodchild, 2007; Viitanen, 2010; Trapero Fernández, 2016; 2021a).

The novelty of this article lies in the utilization of distance cost tools to comprehend the delimitation of archaeological sites based on a Roman pattern. While the use of these tools in understanding human mobility is not new (Haisman and Goldman, 1974), their application in reconstructing ancient road layouts has garnered considerable interest (Verbrugghe et al., 2017; Parcero Oubiña et al., 2019). Over the past decades, numerous researchers have explored this methodology, refining the methodology (Herzog, 2013; White, 2015; Verhagen et al., 2019) and enhancing the involved algorithms (Baek and Choi, 2017). Undoubtedly, the potential for studying communication networks is significant, regardless of scale (De Soto, 2010), and further amplified when incorporating variables such as network analysis (Verhagen et al., 2013). While most applications have focused on estimating travel time and determining historical routes, there are specific cases where other factors have been evaluated, such as mobility in rivers (Trapero Fernández, 2021a, 2021b) or delineating natural features like lakes (Melles et al., 2011). The significant contribution of this study lies in its utilization of historical surveying knowledge to propose boundaries based on topographical features of the terrain, as well as other elements derived from the Roman mentality and translated into geographic terms.

2. The case study, Alto Alentejo region

Regarding its implementation, we have selected a case study in Alto Alentejo (Portugal) (Fig. 1). This territory has a high potential for this type of analysis due to several reasons. Firstly, it is a low-density territory, and above all, it still benefits from a relatively harmonious relationship between human appropriation of space and the natural environment. Despite the intense impact of human action at specific historical moments, such as in 1929–1938 during the so-called "wheat campaigns". It was an initiative launched during the authoritarian system and the Estado Novo o Portugal with the aim of achieving productive self-sufficiency with the replacement of extensive areas of meadows with cereal crops.

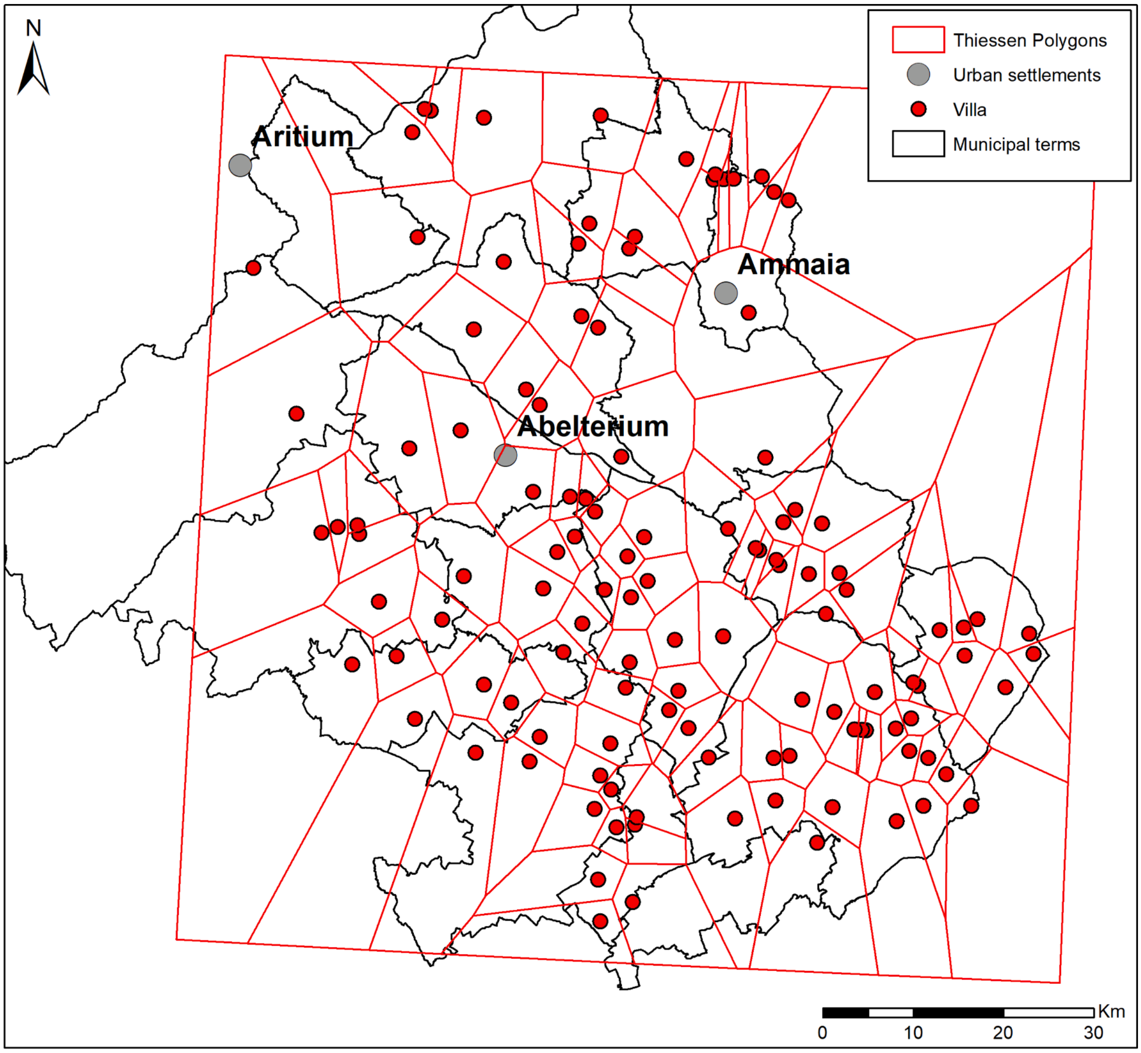

Fig. 2. Example of Thiessen analysis typically used to find average distances between points.

Secondly, Alto Alentejo has not suffered disturbing mechanisms of territorial structuring such as the construction of large urban and suburban areas. Neither have there been large public works involving flooding or razing of extensive areas, nor have there been transformative industrial uses or aggressive exploitation of resources, like intensive and super-intensive cultivation. We can therefore examine the space and still find in it a dynamic of successive contributions that sediment over time. Therefore, it is possible to identify archaeological sites that are still well-preserved and show remaining marks of property organization structures. Thirdly, it should also be considered that the territory of the Alto Alentejo benefits from archaeological research, which although irregular, enables the creation of a package of sites to be compiled into databases, allowing us to analyze the human presence in this territory (Carneiro, 2014). The largest compilation of archaeological sites, based on existing references, identifies over 500 archaeological sites with Roman occupation in the chosen territory, categorizing them by function and chronology. These characteristics allow us to define distinct layers, which, although they require validation because of the different method used in generating these legacy data, still serve as safe thresholds for the understanding of the settlement network. There are also data on other fundamental elements for the modelling of the territory, such as the road network (Carneiro, 2008; 2014: 157-193) and sectoral studies such as, for example, the use of large structures for the containment and conduction of water (Quintela et al., 1987), which allow us to know some relevant data for economic exploitation and the study of property systems.

We need to devote a small paragraph to historically contextualize the area during Roman times. The territory of present-day Alto Alentejo is the closest in Portuguese territory to the ancient provincial capital of Lusitania, the city of Colonia Augusta Emerita. However, historical, epigraphic, or other data do not clarify if this territory was within the orbit of direct administration of the provincial capital or if it was under another type of administration like a praefectura (Carneiro and Trapero Fernández, 2022). The rest of the Alentejo territory has settlement patterns that are better known, such as the colony of Pax Iulia (Lopes, 2003), though with gaps in settlement distribution. The region of central and Alto Alentejo is not well known. In fact, one can only safely point out the presence of urbs with administrative functions in Ammaia (S. Salvador da Aramenha, Marvão), since the status of Abelterium (Alter do Chão) is still difficult to ascertain (Carneiro, 2014).

It is important to note that the information was collected from a variety of sources, forming the base corpus of Carneiro's thesis (2014). It was a work that comes from a variety of sources: excavations by archaeologists, excavations by the curious; archaeological surveys by specialists, study of selectively collected materials, mere casual references without precise metadata, findings mentioned in the regional and local press, monographs by scholars or the merely curious, in which facts are sometimes mixed with legends… The heterogeneous mass of information, including legacy data, has been reviewed in archaeological field surveys and systematized to create settlement models with "points on

Table 1
Definition of settlement classes.

Types	Criteria
Urban Settlements	Referred to in the literature and excavated within urban areas.
Vicus, Mansio and Mutatio	Intermediate sites of enormous dimensions, along communication routes.
Villa	Places with villa indicators, large areas, luxury materials such as mosaics, marbles, productive areas.
Minor archaeological sites	Other smaller sites, low density of materials or lack of luxury materials.

the map." This information, much of it legacy data, has been reviewed in archaeological field surveys and systematized. In this way, we can count on a homogeneous and contracted corpus of data to carry out the study. For this study, sites assigned as villa, with a well-established chronology spanning between the 3rd and 4th centuries, such as São Cucufate in the lower Alentejo (Gorges 1979; Alarcão et al. 1990), were selected for analysis.

3. Materials and methods

3.1. Boundaries with GIS

From the historiographical perspective, there has always been an interest in understanding the limits of different civic communities in the ancient world. Countless works have been dedicated to defining both external and internal boundaries (Leveau, 1993; Orejas Saco del Valle, 2002; López Medina, 2004; Camerieri et al. 2009; Beltrán Llores, 2011). In our specific case, proposals have been put forward for the ager of Colonia Augusta Emerita externally (Sillières, 1982; Cordero Ruiz, 2013). While many of these proposals rely on survey documentation, they frequently lack accompanying GIS studies.

While many of these proposals rely on survey documentation, they often lack accompanying GIS studies (Poirier et al. 2013). However, there are hardly any theoretical methods that have demonstrated the ability to yield significant results, given the very nature of these mathematical algorithms. The clearest example is the use of the Thiessen or Voronoi polygon method, which involves dividing a plane into areas based on a defined distance from a set of predefined points (Fig. 2).

The findings demonstrate an initial division of the territory based on the selected population centres. Visually, this approach offers a straightforward and effective means of understanding spatial organization. However, it does not accurately represent potential actual boundaries due to its heavy reliance on a complete dataset, which is problematic in archaeology since we cannot be certain if all sites have been discovered. Additionally, there is an edge effect that leads to inaccuracies in depicting external entities, and linear distances are employed to separate entities regardless of the variable topography of the terrain. As a quick approximation for visualization purposes, considering the average areas of each location might seem sensible. However, it does not accurately replicate territorial boundaries. For instance, two *villae* could be on the edge of a plot rather than at the

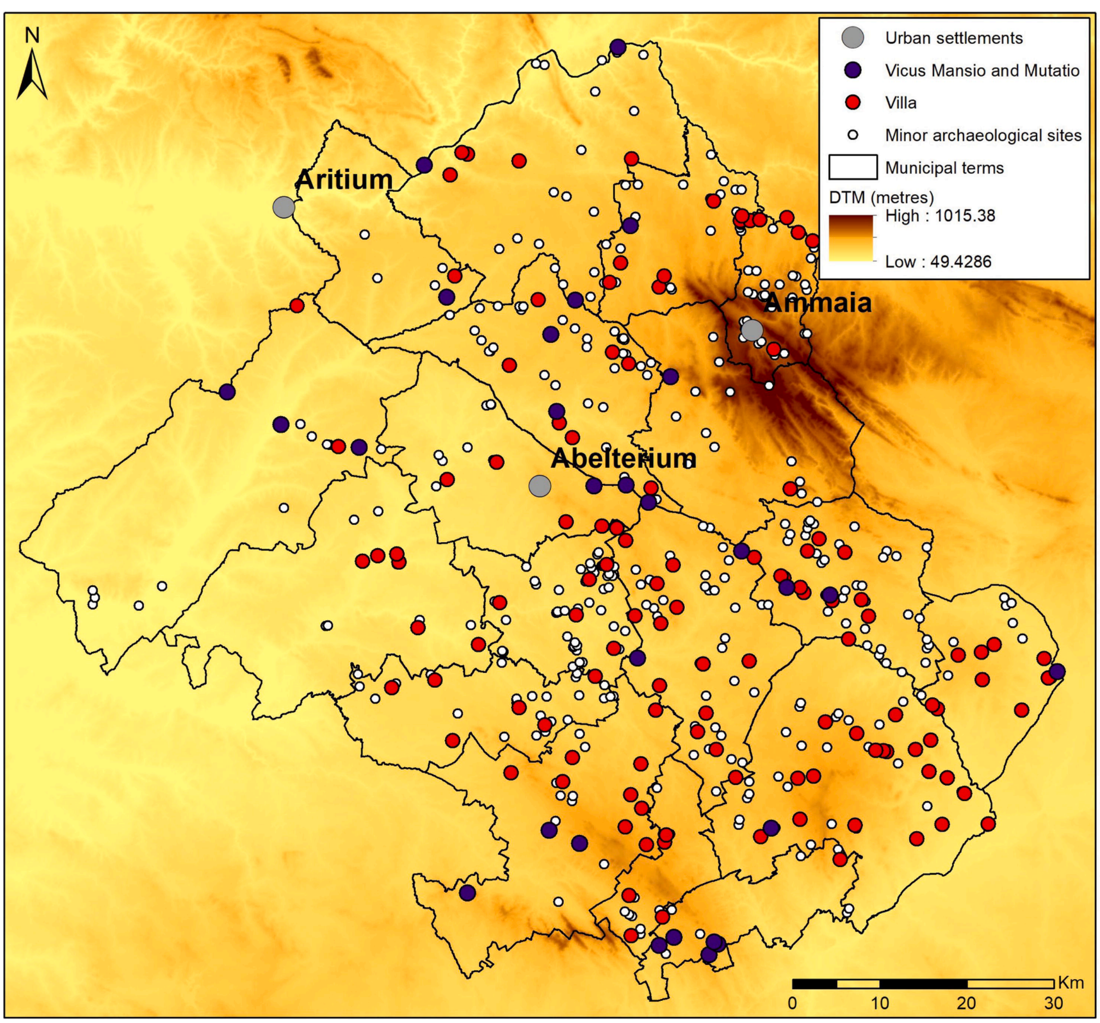

Fig. 3. Classification of settlement into *villa*, production centres and other entities such as *vicus*, *mutatio*, *mansio*, or possible civic entities.

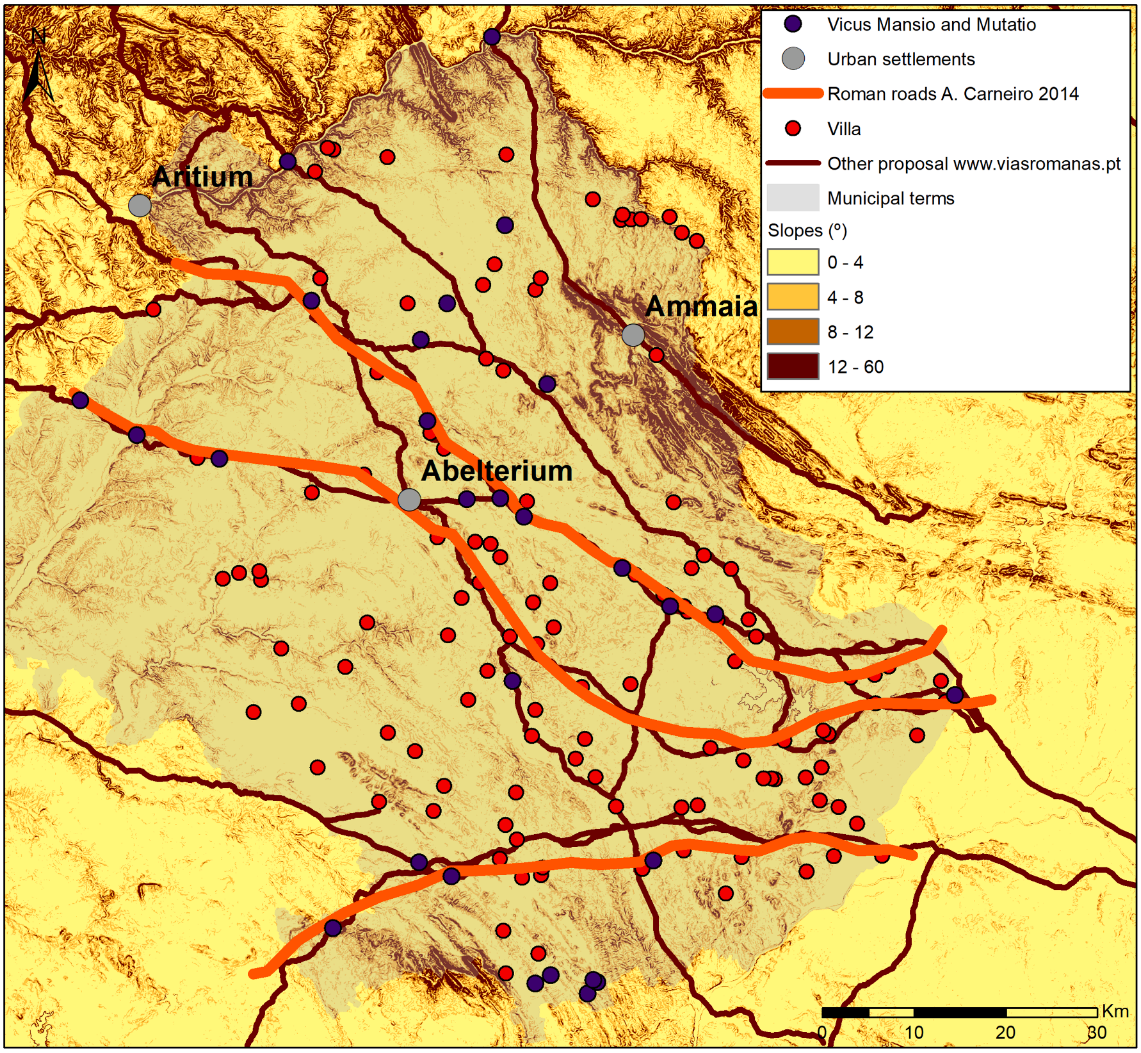

Fig. 4. Roman settlement concerning the Roman itineraries, where we mainly use the option of Carneiro 2014 corrected. In grey the area cover by the municipal terms as the limit of the study area.

centre, which is not accurately depicted by this analysis.

3.2. Archaeological materials

To propose an alternative model, we recommend utilizing the concept of medium distances from Thiessen polygons and the documentation gathered from survey sources. This approach necessitates a solid grasp of the literary survey sources, accurately interpreting each surveyor's terminology with real geographical data, and conducting a thorough examination of the archaeology within the study region. While the significance of the data amassed in Alto Alentejo has been explored, it is not solely about amassing the largest volume of data with the highest possible geographical accuracy. Understanding their typology and chronology is equally vital, a point we will delve into in the discussion (see Table 1).

We categorize the sites based on indicators, building on a prior publication (Carneiro, 2014: I, 43–58). Primarily, there are urban settlements as already mentioned in the introduction. There are also *vicus*, *mansio*, and *mutatio*, which correspond to a medium range of population or strategic locations. *Villae* function as main productive sites, while there are other minor archaeological sites that are challenging to classify. For example, the term "villa," widely employed in archaeological literature, encompasses a broad spectrum of significant attributes, including monumentality and the incorporation of distinctive architectural elements, as well as diversity in material culture patterns. These characteristics facilitate the categorization and differentiation of specific sites that may have served as centres for economic activities and centralized management. This sets them apart from other site categories that lack similar features. Consequently, utilizing these concepts has enabled the creation of dedicated cartographies and the generation of analyses that tend to segregate areas considered central from those deemed peripheral or even more marginal (Carneiro, 2014: I, 275 et seq.). In Fig. 3, we present the classified archaeological data.

3.3. *Geographical* materials

Accompanying this archaeological data, it is imperative to utilize and construct an array of spatial information. Firstly, a 25-meter Digital Terrain Model (DTM) was sourced from the Land Monitoring Service of the Copernicus Satellite Network (EU-DEM, 2022). The DTM raster's cell size should be tailored to the scale of the investigated area, which in this case spans 7,000 square kilometers. Hence, a 25-meter resolution suffices.

We also necessitate an additional set of data, including watersheds, rivers, and streams, as the primary delimiting factors. To procure this information, we employed GIS tools utilizing a 10-meter DTM from the same aforementioned source, employing hydrological analysis packages. In our instance, ArcGIS 10 and Spatial Analysis Tools' Hydrology

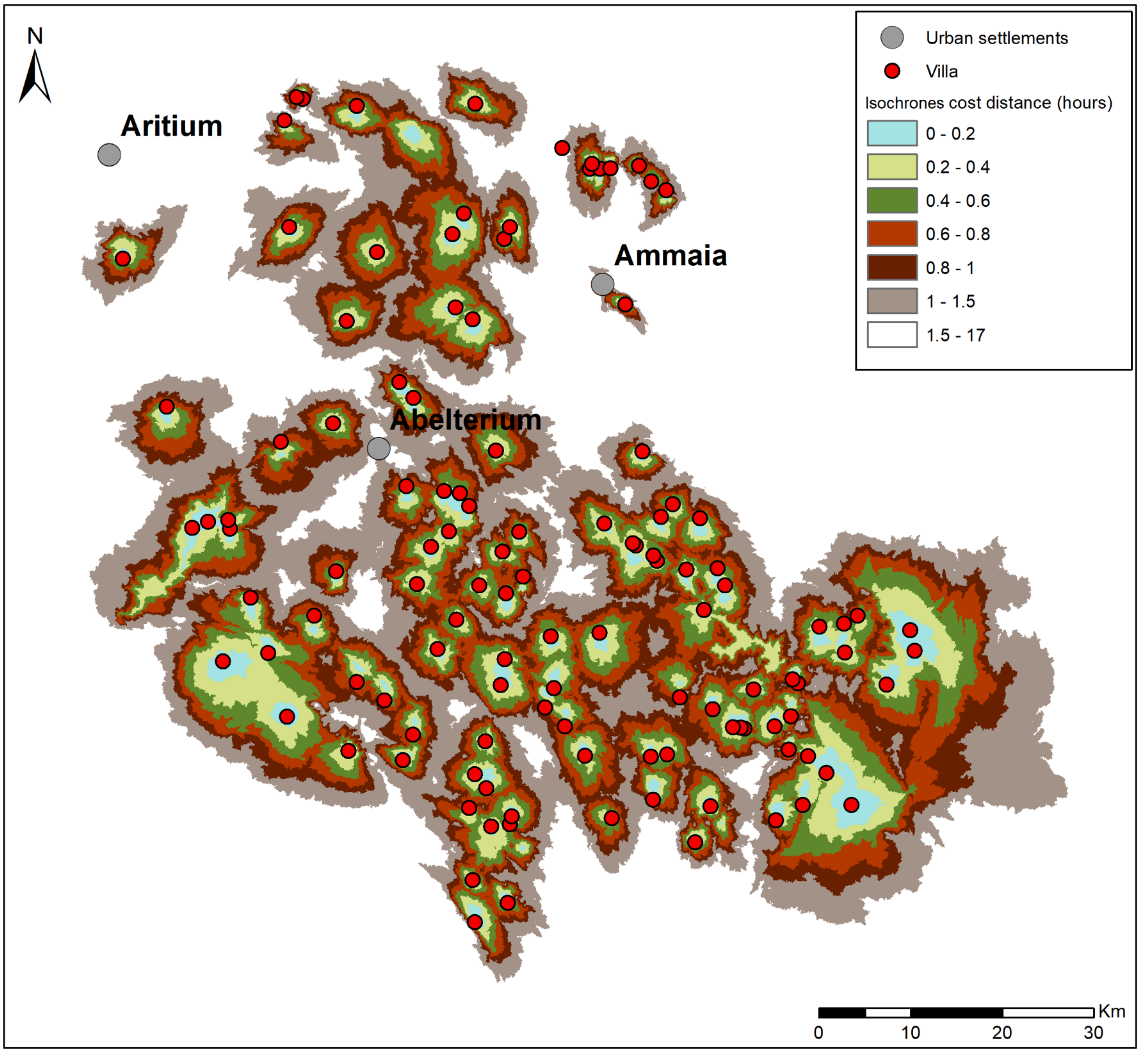

Fig. 5. Isochrones with the cost of distance from the various selected centres.

tools were employed.

Additionally, we require other anthropogenically originated geographic data, such as communication routes. Portugal possesses a repository housing road information, forming the bedrock of our study's "other proposal," allowing for comparison with the roads in Carneiro (2014) (Vias romanas em Portugal, 2022). However, for our study (Fig. 4), we drew from a more recent publication that rectifies and specifies the main routes within the territory, often validated on-site (Carneiro, 2014: I 165–193).

3.4. Cost distance models

To bridge survey data with present geographical constraints, we employ distance cost tools like the Cost Distance function in ArcGIS's Spatial Analysis Tools. In executing such an analysis, we initially create a friction map, encompassing mobility constraints, such as terrain slope, utilizing a mobility algorithm (Tobler, 1993; Llobera, 2000). Moreover, we must confine mobility concerning rivers and streams, as outlined in Trapero Fernández (2021b). This yields a raster wherein each cell designates the cost value of traversing it from an origin point. By selecting all population centres within the territory as origin points and applying a mobility algorithm that denotes, for instance, time, we can generate distance-time isochrones (Herzog, 2010).

This approach provides a closer approximation to reality than the Thiessen polygon method, addressing the aforementioned concerns, as it takes terrain topography into consideration. There exist areas with preferred mobility contingent upon the terrain's topography. This factor significantly affects understanding the potential boundaries of a farm, as it is challenging to envision an agricultural activity necessitating a 3- to 4-hour round-trip travel within a single day. While a specific source does not stipulate this value, Roman agronomy implies that tasks were performed within a radius of the centre, as gleaned from the requirement that workers, except for the supervisor, leave the estate (Varro, *R.R.* 1.16.5). Assuming work spanned from sunrise to sunset, three or four hours could indeed represent a substantial duration for commuting to perform a task. Alonso de Herrera also provides insight, noting that grapes should not be transported more than 4 km for pressing, meaning the vineyard must be within this distance (Alonso de Herrera, 1818: 458). This would result in an estimated travel time of at most 1 to 2 h.

3.5. Fundus methodological proposal

Hence, we can ascertain the cost of movement across the terrain, predominantly influenced by the terrain's slope. By incorporating surveyors' precepts into the friction map, the outcome would visually depict potential property boundaries. In mobility analyses, various spatial elements can function as barriers, including streams and rivers, often outlined due to their algorithm-prone plains nature yet challenging to traverse (Trapero Fernández, 2021b). Our approach adopts this notion while encompassing all spatial constraints we can identify.

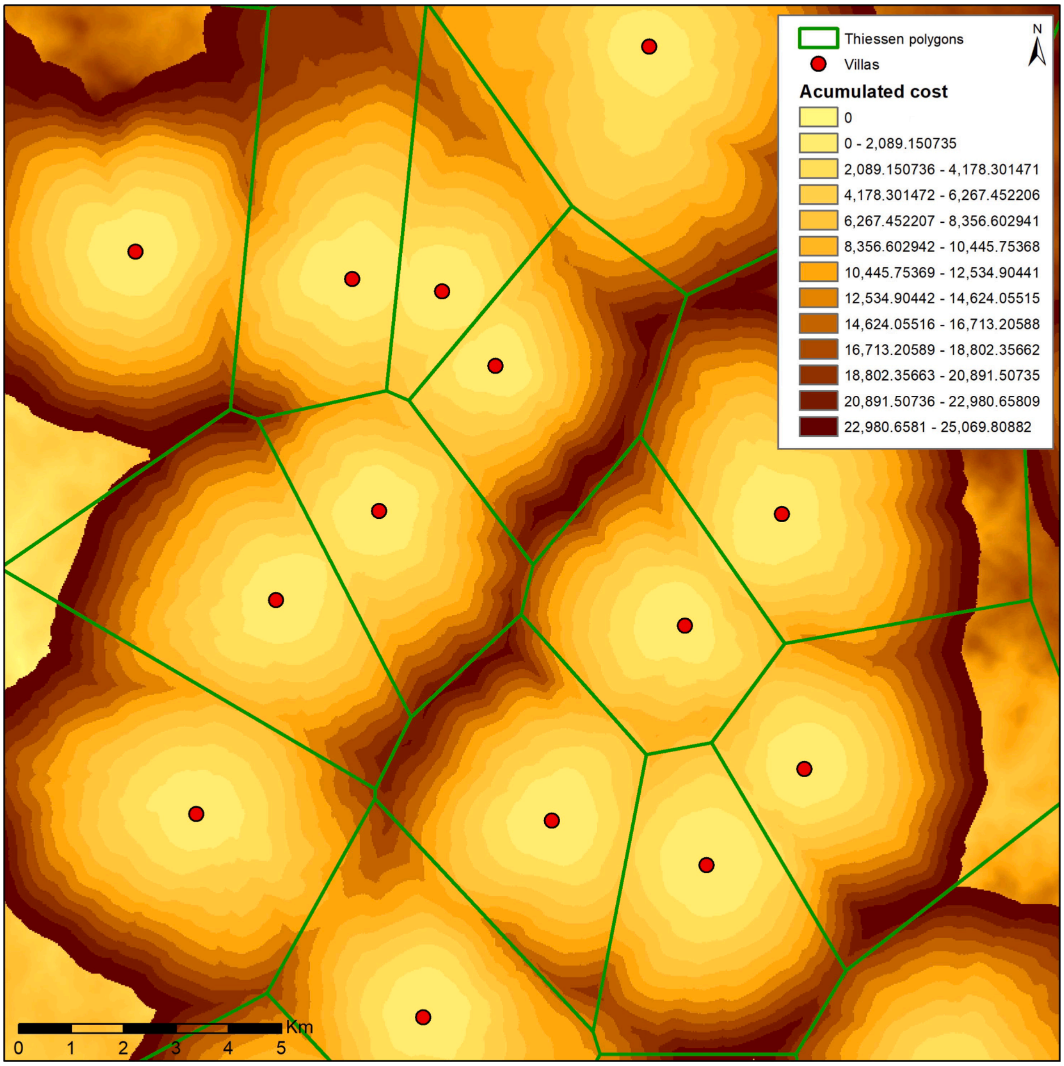

Fig. 6. Detail comparison of the result of the analysis proposed in the article with the Thiessen polygon method.

In addition, for generating the predictive land model, we necessitate a revised population centre layer to compute rivers, streams, and watersheds across the study area as a whole (utilizing ArcGIS's Fill, Flow Accumulation, Flow Direction, and Basin tools of Hydrology), along with the terrain's orography (slope) and the Roman roads (linear layer).

Linear-type entities are transformed into rasters, converting data-less values to 0 while entities in question take on, for instance, a value of 10 (reclassification tools). These layers are combined with a slope raster using the raster calculator, resulting in a new friction raster. In this, delineation occurs at these specific points. This process generates a cost analysis layer where each linear entity (basins, streams, roads) simulates high mountain ranges to cross, directing the algorithm to highlight the most accessible areas within these regions. Calculation emerges from all spatial centres where the maximum cost value aligns on both sides, indicating the optimal spot for a border between the two spaces.

A value of 10 points is applied, signifying a 10-degree slope increase. This value is determined through trial and error, set to be sufficiently high for mobility delineation yet feasible enough to avoid overly steep costs.

4. Results

The result is an isochrone layer that shows a value similar to a distance cost as in Fig. 5, but that is delimiting the geographical features that we have indicated. Fig. 7, is compared with the Thiessen polygon proposal, where it can be seen that it is much more adapted to the reality of space (see Fig. 6).

The application of the analysis to the entire dataset produces a set of maximum isochrones, many of which overlap across different entities. Achieving this can be facilitated through the Cost allocation tool, similar to the Thiessen method but accounting for cost analysis upfront. However, there are pivotal settlement constraints that act as significant barriers to costing, which this model may overlook. Instances include influence areas spanning rivers or roads, logically belonging to another community. It's also essential to juxtapose this information with the generated isochrones, as proximity to the villa is a crucial factor.

Considering these considerations, a substantial cartographic outcome has been attained for comparison with other models. Our methodology can be divided into two distinct facets. Firstly, utilizing the cost allocation tool automatically identifies areas. Secondly, data can be integrated with the previously created isochrones map, allowing layer-to-layer intersection. This blend holds particular significance, encompassing mobility rings that outline the feasible utilization area for the calculated farms. Yet, caution should be exercised in representing data, as the final clipping step could lead to irregular boundaries and illogical peaks. To address this, manual adjustment may be needed to achieve a more visually harmonious representation by eliminating such anomalies. Alternatively, a manual reclassification and extraction process can be employed to minimize the presence of edges and potential imperfections in the final layer.

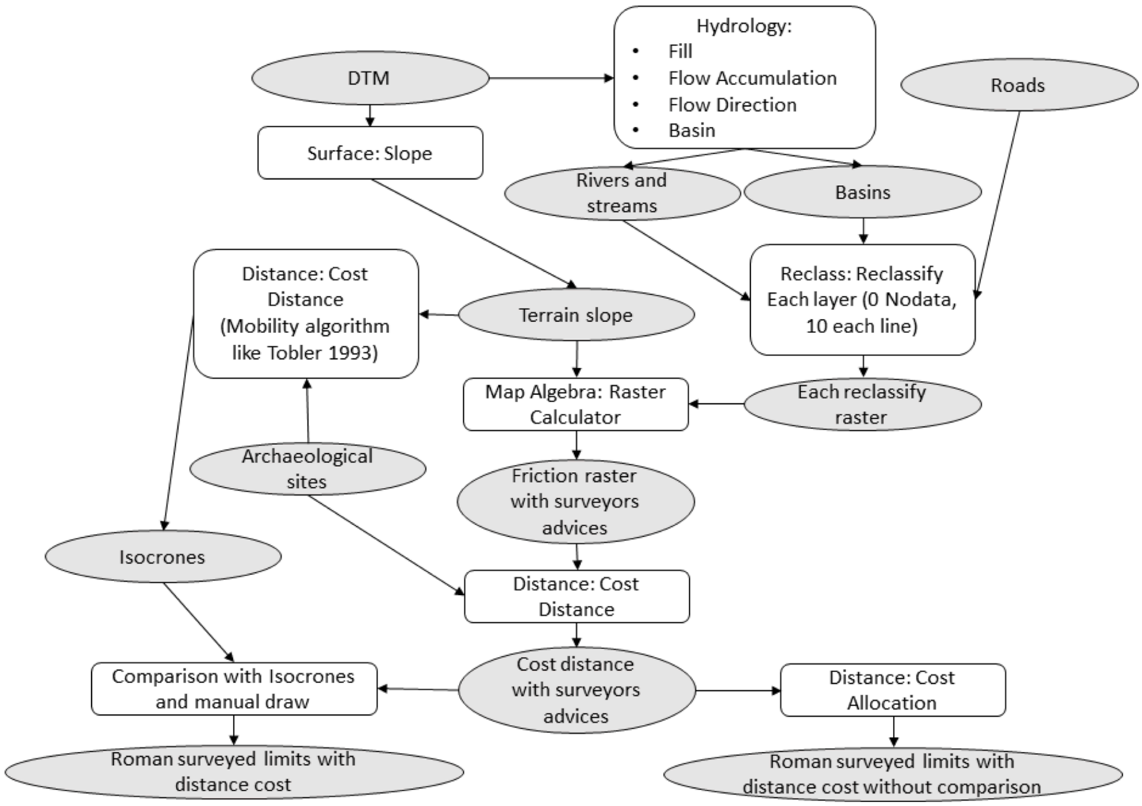

Fig. 7. Diagram of the processes described for conducting analysis.

For this, two criteria have been employed. The first involves selecting the last isochrones that aligns with the subsequent productive centre. However, in cases of high cost or well-defined spatial boundaries (e.g., on both sides of a communication road and traversing a mountain), the last discernible geographical limit is chosen. This yields a semi-automated map proposal for distinct villas.

Fig. 8 displays the outcome of these areas for each location, alongside the vacant spaces, in addition to the comparative Thiessen polygons. Notably, especially in higher mountain regions, the Thiessen polygonization displayed significant inconsistency with historical logic, whereas our model adapts polygons to the geographical reality as defined by surveyors.

5. Discussion and conclusions

The outcome of this analysis generates isochrones that do not represent time or any other interpretable values. Instead, they purely serve to spatially demarcate the selected villae. An interesting facet of this interpretation is that the result aligns with the logical principles of the surveyors. In essence, the isochrones with the highest cost from an adjacent entity marks the most plausible boundary. This border emerges from the crossing of geographical features that can serve as delimiters, such as rivers, streams, watersheds, or roads. Furthermore, this method addresses an issue inherent in using Thiessen polygons by incorporating cost distance. In other words, it does not assume a preference for centrality, as it assumes that the centre of the rural property under examination could be situated on any side. Consequently, this method avoids focusing solely on centrality, as the generated isochrones can expand into more distant areas, as long as no other entity occupies that space and creates a barrier.

Although we are talking about a theoretical approach, we must emphasise that it is very coherent with the ancient logic, thanks to these surveying criteria, but also to be able to advance in analysing the ancient territory and landscape. A good example of this can be seen in Fig. 9, where the secondary settlement of the territory is added to the analysis. As already indicated in the introduction, these are sites not classified as *villae*, but of the same chronology. We indicate secondary settlement, being aware that they can be either farmsteads of small farmers or structures associated with the productive *villae*. Other larger entities such as possible main population centres o secondary like *vicii*. This is made up of smaller sites that are possibly related to secondary buildings of these *villae* or small farms.

With our method, it is possible to understand if these points are within the logical area of exploitation of the same *villa* or if they are outside. That is to say, if from these spaces it is coherent to arrive on foot and have ownership of that space or if it remains in a more residual area. In this case the places out could be primarily understand as small farms or other type of small properties, rather than building associated with the main *villae.*

Furthermore, in a more in-depth discussion, this approach yields a set of empty spaces that can be attributed to various factors, including insufficient research, the absence of *villae* in the vicinity, or alternative land uses. It is important to recognize that these explanations might have distinct causes and could even be a combination of factors. Ideally, we can eliminate the first option through comprehensive historiographical and field studies. Meanwhile, the method allows us to allocate areas to other economic functions such as *saltus* or predict locations where productive site centres might have existed.

In the case of Alto Alentejo, as previously mentioned, significant disparities exist in the intensity of research. Certain municipalities have benefitted from archaeological mappings, with some even having multiple mappings conducted at different times (e.g., Marvão, Portugal). On the contrary, the majority lack such cartography or even a summary survey. This has led to geographical irregularities in the investigation landscape, characterized by extensive areas void of archaeological data due to the absence of documentation efforts, as demonstrated in certain methodological studies (Witcher, 2006).

However, it is crucial to consider the Roman territory's occupation

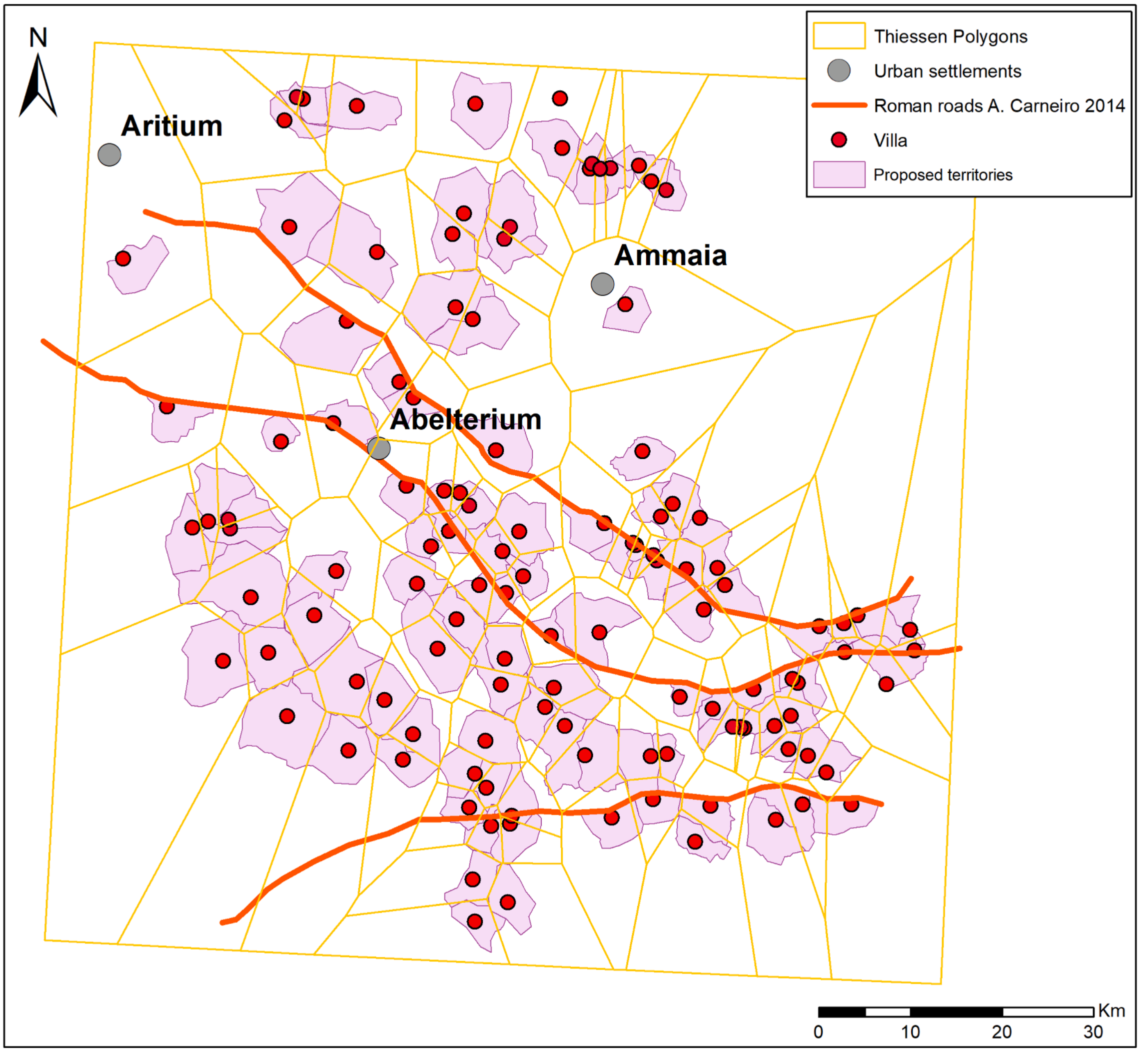

Fig. 8. Adapted polygons using the method with communication routes and Thiessen polygons.

strategy. When we examine the numerical indicators per municipality (Carneiro, 2021: 52), the aforementioned asymmetries in total values across municipal boundaries become evident. We need to consider an analytical filter: generally, *villae* are distinguished by their monumental and lavish remains, making them more likely to capture the attention of scholars or the casually curious. This could explain why we possess more information about these larger *villae*, replete with opulent materials. Yet, even with this indicator, we find that extensive territories lack any documented sites (Carneiro, 2021: 53). It is also possible that these empty or sparse areas are reflective of conditions characteristic of the Roman period. Historical populations tended to concentrate around cities and roads, with a population distribution differing from todays. These areas, known well due to direct landscape familiarity, often had fewer resources for agricultural and livestock exploitation. This includes steep pastures, exposed rocks, and sandy, gravelly lithosols, a prevalent soil composition in territories near the Tagus River.

Consequently, many of these research gaps correspond to the geographical realities of the territory, making agricultural and livestock activities more challenging in these regions. Conversely, we observe a higher concentration around communication routes and resource-rich areas. Notably, the study area's southern region hosts a significant marble production quarry (Trapero Fernández et al., 2023). It is also accurate to note that several factors could contribute to the absence of research, such as the rarity of remains due to inaccessibility or inhospitable landscapes. Such factors make these peripheral spaces less attractive for exploration. This discrepancy is particularly evident in non-systematic research (outside archaeological chart programs) conducted by scholars or enthusiasts who are naturally drawn to more remarkable discoveries. In the absence of these opportunities, they are less inclined to venture into less accessible territories.

In reality, these areas likely remained uncultivated or were repurposed for different uses. In the absence of archaeological sites and research, it is plausible that some of these spaces served as *saltus* areas. Fig. 10 depicts these empty spaces overlaid with a susceptibility layer of forest soils (Epic WebSIG Portugal, 2021). This map provides insight into the natural suitability of land for afforestation. It helps us determine if previously unsettled areas could have been covered by woodland. Low susceptibility indicates a lack of forested environment, while well-forested areas within populated regions suggest that parts of the forest might have been cleared for agriculture.

Interestingly, there are areas within the case study that are unsuitable for forest harvesting (Fig. 10 areas in orange). This indicates the existence of unresolved historical questions. This has implications for further research, particularly when attempting to define city limits or locate Roman cadastres (Chevallier, 1961; Balil, 1964). While conventional approaches often involve drawing lines, we must also consider areas with alternative uses like mountains or forests that might be part of saltus, and thus not serving as recognizable boundaries.

This study aims to present a simple yet potentially valuable method for tracing the plots and territories of different production units during

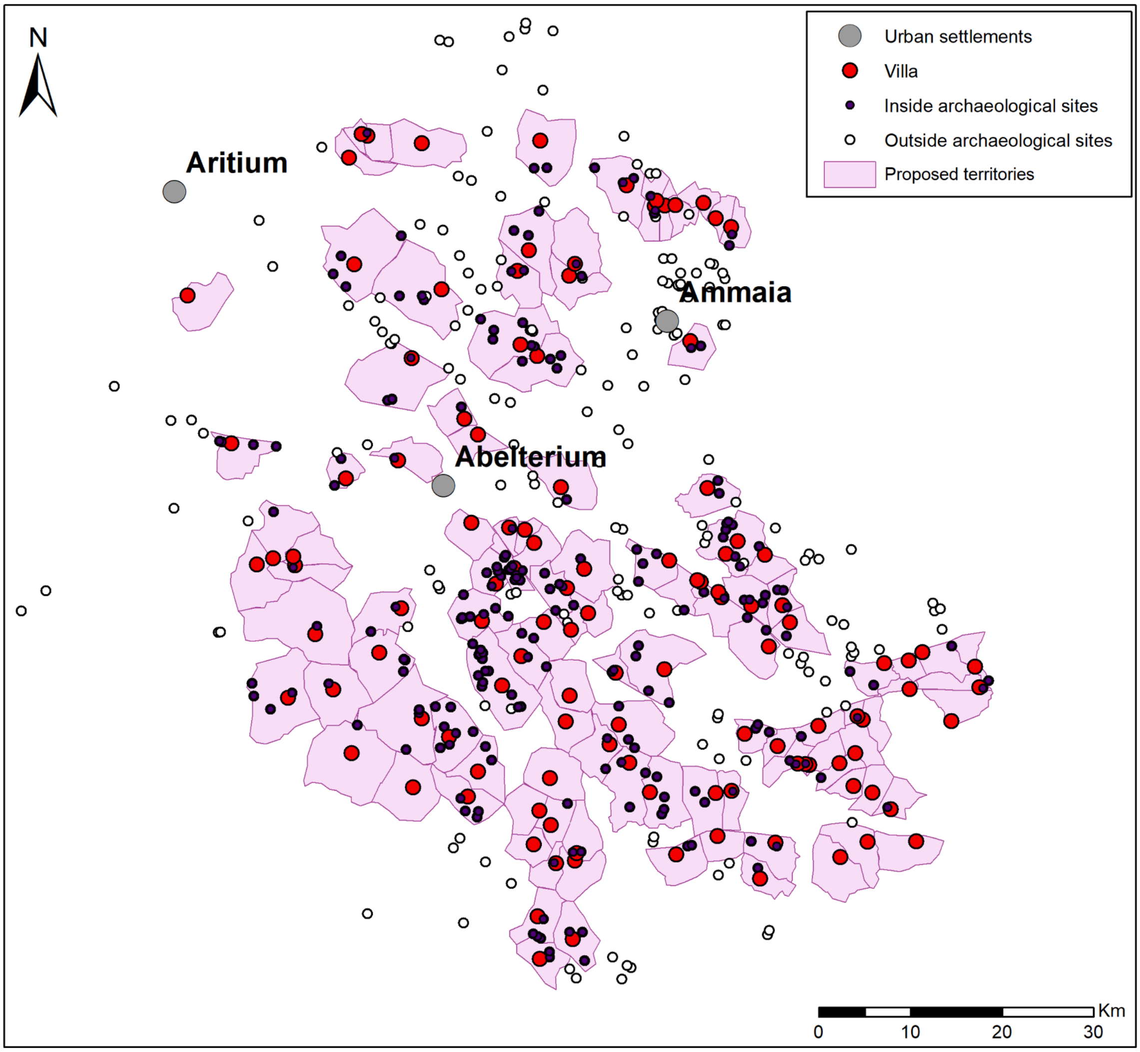

Fig. 9. Results of the study with the rest of the secondary entities, inside and outside the study area.

Roman times. The challenge of bridging literary information with archaeological data demands further experimentation to refine tools and techniques with greater precision. Our objective is to demonstrate the method's application for reproducibility purposes, rather than deeply addressing the primary historical questions about the territory, which we outline briefly.

The potential applications of this method are extensive. For instance, it can be used to analyse the relationship between empty spaces and their potential uses. As previously noted, a correlation exists between empty spaces and the area's geology, which often results in less favourable landscapes for agricultural activities. While this is not the sole focus, as some publications have highlighted (Witcher, 2006), our case study demonstrates a link between these spaces and the landscape. While these gaps may be research-related, numerous discoveries historically were made by amateur archaeologists and through accidental findings, particularly during the "wheat campaigns" in the early twentieth century. Not finding spaces, even if they are unexplored, typically represents a quantitative issue rather than a qualitative one. On the contrary, in regions deviating from this pattern, other primary uses like mining and marble quarries can be identified.

This analysis of empty or occupied spaces can only proceed if we know the settlement or other site locations, enabling comparisons with other territories in future studies. We have briefly showcased two ways to employ this method.

Firstly, it can be used to categorize territory usage. When designating an area, even hypothetically, to the fundus of a villa, the remainder must belong to another entity. This is where the possibility of subdividing the remaining secondary population comes into play, which might consist of small farmers' plots, colonnades, or buildings within the village itself, based on proximity. Employing cost analysis tools for spatial evaluation aids in comprehending a critical variable in this type of research: the distance a person would need to travel to and from agricultural tasks.

Secondly, it helps us comprehend the potential areas of *saltus* in the absence of settlements or any other type of establishment. In such scenarios, these areas might have evolved over time, but through comparison with pedological data as depicted in Figure 11, we can ascertain their potential uses.

Considering the methodological focus of this work and the extensive research required to develop these concepts, we merely suggest their potential. We aim to explore these aspects further in this and other case studies for upcoming publications.

Declaration of Competing Interest

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

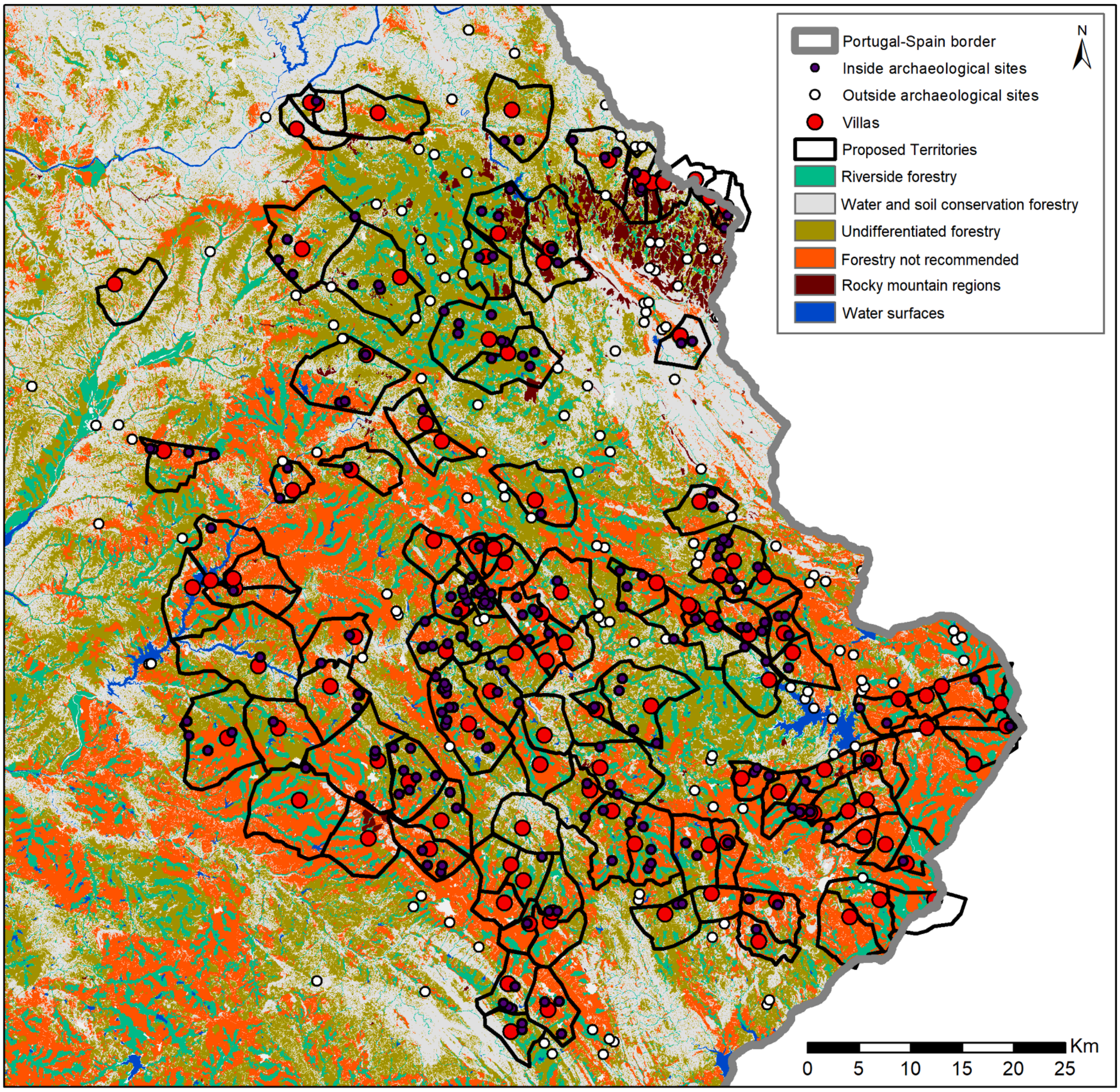

Fig. 10. Comparison of the model with the forest susceptibility of the soil in the region.

Data availability

Data will be made available on request.

Appendix A

Abelterium: Roman city in actual Alter do Chão, Portugal.

Ammaia: Roman city near S. Salvador da Aramenha, Marvão, Portugal.

Colonia Augusta Emerita: Capital of Lusitania province, actual Mérida, Spain.

Corpora agrimensoria: Surveyors' corpus.

Fundus: Territory of a farm or agricultural property.

Mansio: Official primary station as a passageway on a Roman road.

Mutatio: Stop or establishment on a Roman road, to rest and service the animals used for transport. There could have been several mutationes between mansions.

Saltus: Uncultivated land in a city, usually public land.

Urbs: Intramural section of a city.

Vicus: Place of settlement or secondary market integrated within a larger city.

Villa: Agri-livestock production model, similar to modern farmhouses, although it is mistakenly refer to the luxury Roman house, which is the part generally excavated with marble and mosaics.

References

Alarcão, J., Étienne, R., Mayet, F., 1990. Les villas romaines de São Cucufate. Mission archéologique françcaise au Portugal, Coimbra.

Baek, J., Choi, Y., 2017. A new algorithm to find raster-based least-cost paths using cut and fill operations. Int. J. Geogr. Inf. Sci. 31 (11), 2234–2254.

Balil, A., 1964. Centuriatio. Observaciones sobre la parcelación y agrimensuras romanas y su reconocimiento". Revista de Estudios Clásicos 5, 346–359.

Beltrán Llores, F., 2011. El Territorium Caesaraugustanum. In Aguilera Aragón, I., Ona Gónzalez, J.L., (Eds.), Delimitación comarcal de Zaragoza, pp. 93-101.

Camerieri, P., de Santis, A., Mattioli, T., 2009. La *limitatio* dell'*Ager Reatinus.* Paradigma del rapporto tra agrimensura e pastorizia, viabilità e assetto idrogeologico del territorio. In: Dall'Agglio, P.L., Rosada, G. (Coords.), Sistemi centuriali e opere di assetto agrario tra età romana e primo medioevo. Aspetti metodologici, ricostrutivi e interpretatitivi, Ravena, pp. 327-345.

Carneiro, A., 2021. Estruturas e padrões de povoamento rurais em época romana: estratégias e problemas. In: Mayoral, V., Grau, I., Bellón, J.P. (Eds.), Arqueología y sociedad de los espacios agrarios: en busca de la gente invisible a través de la materialidad del paisaje (Anejos de Archivo Español de Arqueología XCI). CSIC, Madrid, pp. 47–60.

Carneiro, A., Trapero Fernández, P., 2022. Patrones de cambio en el poblamiento rural del norte Alentejo (Portugal): propuestas para el análisis de sitios y territorios del siglo I al X, *Cuadernos de arqueología de la Universidad de Navarra*, 30.2, 141-160.

Carneiro, A., 2008. Itinerários romanos do Alentejo. Uma releitura de «As grandes vias da Lusitânia – o Itinerário de Antonino Pio» de Mário Saa, cinquenta anos depois. Lisboa: Edições Colibri/Comissão de Coordenação Regional do Alentejo.

Carneiro, A., 2014. Lugares, tempos e pessoas. Povoamento rural romano no Alto Alentejo. Coimbra: Imprensa da Universidade de Coimbra, colecção *Humanitas Supplementum* 30, 2 volumes.

Castillo Pascual, M.J., 1996. Espacio en orden, el modelo gromático-romano de ordenación del territorio. Universidad de la Rioja, Logroño.

Chevallier, R., 1961. La centuriation et les problèmes de la colonisation romaine. Études Rurales 3, 54–80.

Chevallier, R., 1973. Cité et territoire. Solutions romaines aux problemes de l'organization de l'espace. Problematique 1848–1973. Auftieg und Niedargang der Rominshen Well 2, 762–766.

Chouquer, G., 2014. Les fleuves et la centuriation: l'apport des catégories gromatiques. Jus: Rivista di Scienze Giuridiche 61–2, 379–406.

Chouquer, G., Favory, S., 2001. L'arpentage romain. Histoire des textes, droit, techniques. Editions Errance, París.

Chouquer, G., 2007. Els agrimensors romans, cartògrafs de territoris. Mètode: Revista de difusió de la investigación 53, 2007, pp. 60-67.

Compatangelo, R., 1989. Le cadastre de Pierre de la Péninsule sallentine: polysémie des formes de *limitatio* d'un cadastre Antique. Mefra 101, 365–402.

Cordero Ruiz, T., 2013. El territorio emeritense durante la antigüedad tardía (siglos iv-viii) Genesis y evolución del instituto rural lusitano. Anejos de AEspA LXVI. Archivo español de arqueología, Mérida.

de Soto, P., 2010. Anàlisi de la xarxa de comunicacions I del transport a la Catalunya romana: estudis de distribució I movilitat. Barcelona, Doctoral Thesis, Barcelona University.

Dilke, O.A.W., 1971. The roman land surveyors, an introduction to the Agrimensores. Newton Abbot: David & Charles; New edition.

Epic WebSIG Portugal, 2021. Ecological planning, investigation and cartography. Retrieved September 15, 2021, from http://epic-webgis-portugal.isa.ulisboa.pt.

EU-DEM, 2022. EU-DEM v.1.1. Copernicus Europe's eyes on Earth. Land Monitorin Service. Retrieved May 16, 2022, from https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1.

Fernández Corrales, J.M., 1976. Consideraciones para la distribución y delimitación de las ciudades romanas. Norba: Revista de historia 7, 173–176.

Goodchild, H., 2007. Modelling roman agricultura production in the Middle Tiber valley. University of Birmingham, Central Italy, Birmingham.

Gorges, J.G., 1979. Les villas hispano-romaines, París.

Haisman, M.F., Goldman, R.F., 1974. Effect of terrain on the energy cost of walking with back loads and handcart loads. J. Appl. Physiol. 36, 545–548.

Herzog, I., 2010. Theory and practice of cost functions. In: Contreras, F., Farjas, M., Melero, J.M. (Eds.), Proceedings of the 38th annual conference on computer applications and quantitative methods in archaeology. BAR International Series, Oxford, 2494, 375-382.

Herzog, I., 2013. Theory and practice of cost functions. In: Contreras, F., Farjasand, M., Melero, J.M. (Eds.), Proceedings of the 38th annual conference on computer applications and quantitative methods in archaeology. BAR International Series, Oxford, 375-382.

Leveau, P., 1993. *Territorium urbis*: le territoire de la cité romaine et ses divisions: du vocabulaire aux réalités administratives. Revue des études anciennes 95, 459–471.

Llobera, M., 2000. Understanding movement: A pilot model towards the sociology of movement. In: Lock, G. (Ed.), Beyond the map: archaeology and spatial technologies. IOS Press, Amsterdam, pp. 65–84.

Lopes, M.C., 2003. A cidade romana de Beja. Percursos e debates acerca da 'civitas' de Pax Iulia, vol. 2, Coímbra, 16.

López Medina, M.J., 2004. Ciudad y territorio en el sureste peninsular durante época romana, Madrid.

Melles, S.J., Jones, N.E., Schmidt, B., Rayfield, B., 2011. A least-cost path approach to stream delineation using lakes as patches and a digital elevation model as the cost surface. Procedia Environ. Sci. 7, 240–245.

Orejas Saco del Valle, A., 2002. El territorio de las civitates peregrinas en los tratados de agrimensura. Las civitates del noroeste hispano. Habis 33, 389–406.

Parcero Oubiña, C., Güimil Fariña, A., Fonte, J.E., Costa Garcia, J.M., 2019. Footprints and Cartwheels on a Pixel Road: On the Applicability of GIS for the Modelling of Ancient (Roman) Routes BT. In: Verhagen, P., Joyce, J., Groenhuijzen, M. (Eds.), Finding the Limits of the Limes. Springer, Berlin, pp. 291–311.

Piganiol, A., 1962. Les documents cadastraux de la colonie romaine d'Orange. Gallia 13, Centre national de la recherche scientifique, París.

Poirier, N., Opitz, R., Nuninger, L., Ostir, K., 2013. Lidar in Mediterranean agricultural landscapes: reassessing land use in the Mauguio, *HAL*, Archives-Ouvertes, 1-17.

Quintela, A.C., Cardoso, J.L., Mascarenhas, J.M., 1987. Aproveitamentos Hidráulicos Romanos a Sul do Tejo: contribuição para a sua inventariação e caracterização. Ministério do Plano e da Administração do Território, Lisboa.

Sillières, P., 1982. Centuriation et voie romaine au sud de Mérida: contribution á la délimitation de la Bétique et de la Lusitanie. Mélanges de la Casa de Velázquez 18, 437–448.

Tobler, W., 1993. Three presentations on geographical analysis and modeling: non-isotrophic geographic modeling; speculations on the geometry of geography; and global spatial analysis. University of California. Technical Report, Santa Barbara, pp. 93–191.

Trapero Fernández, P., 2016. Roman viticulture analysis based on Latin agronomists and the applications of a geographic information system in lower Guadalquivir". Virtual Archaeol. Rev. 7 (14), 53–60.

Trapero Fernández, P., Carneiro, A., Moreira, N., 2023. Transport and distribution of heavy loads in ancient times: Estremoz Marbles in the Roman province of Lusitania. J. Archeol. Sci. Rep. 49.

Trapero Fernández, P., 2021a. La viticultura romana en el estuario del Guadalquivir. Las prácticas de cultivo, producción, distribución y modelado SIG en la colonia Hasta Regia. BAR International Series, Oxford, S3022.

Trapero Fernández, P., 2021b. Mobility in Ancient Times: combining land and water costs. Digital Applications in Archaeology and Cultural Heritage, 22.

Verbrugghe, G., De Clercq, W., Van Eetvelde, V., 2017. Routes across the Civitas Menapiorum: Using least cost paths and GIS to locate the Roman roads of Sandy Flanders. J. Hist. Geogr. 57, 76–88.

Verhagen, P., Brughmans, T., Nuninger, L., Bertoncello, F., 2013. The long and winding road: combining least cost paths and network analysis techniques for settlement location analysis and predictive modelling. In: Romanowska, I., Murrieta Flores, P., Papadopoulos, C., Chrysanthi, A. (coords.), Proceedings of the 40th Conference in Computer Applications and Quantitative Methods in Archaeology. CAA International, Southampton, 357-366.

Verhagen, P., Nuninger, L., Groenhuijzen, M.R., 2019. Modelling of Pathways and Movement Networks in Archaeology: An Overview of Current Approaches. In: Verhagen, P., Joyce, J., Mark, R. (Eds.), Finding the Limits of the Limes. Computational Social Sciences. Springer, Nueva York, pp. 217–249.

Vias romanas em Portugal, 2022. Itinerários romanos. Retrieved May 13, 2022, from https://www.viasromanas.pt/.

Viitanen, E.M., 2010. Locus Bonus, the relationship of the roman villa to its environment in the vicinity of Rome. University of Helsinki, Helsinki.

White, D.A., 2015. The Basics of Least Cost Analysis for Archaeological Applications. Adv. Archaeol. Pract. 3 (4), 407–414.

Witcher, R., 2006. Broken Pots and Meaningless Dots? Surveying the Rural Landscapes of Roman Italy. Papers Br. School Rome 74, 39–72.