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From archaeological data to statistical analysis

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ABSTRACT
A doctoral research project, discussed in May 2022, has led to a greater understanding of the settlement dynamics that took place in the Mignone Valley over the long chronological period between the 6th and 11th centuries AD. This understanding has been achieved through the recent topographical investigations conducted in the context of the Mignone Valley. The research employed the ancient land uses, the road system and the exploitation of the rich mineral deposits of the 'Monti della Tolfa' as 'keys' for understanding the change, employing a statistical analysis method for the evaluation of the input data on which the overall assessment of the settlement dynamics in the area was based. The contribution that will be presented here is intended to analyse the type of statistical method that underlies the evaluation of the data collected and the preliminary results that have been arrived at through the realisation of particular spatial analyses calculated in a GIS environment on the data to which the logic-statistical process has attributed the greatest 'weight'.

Section: RESEARCH PAPER

Keywords: landscape archaeology; topography; reliability criteria; measurement; statistical analysis; GIS

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1. INTRODUCTION

The Mignone River Valley stretches 80 km north of the present-day city of Rome along the upper Latium Tyrrhenian coast (Figure 1). It is characterised by a remarkable morphological heterogeneity, with coastal areas and terraces, hill systems and mountainous reliefs all drawn by a dense network of streams, rivers, and ditches [1]. This diversity has always favoured human development since the protohistoric period, generating a highly capillary settlement and economic network that has undergone numerous changes since then, up to the modern age. These changes have involved not only the different forms of population but also the exploitation of the territory. Furthermore, this area has been the setting for a multitude of historical transformations and the actions of numerous political actors. Indeed, following the decline of the Western Roman Empire, there was a gradual transformation of the settlement pattern, which was also influenced by the alternation of different ecclesiastical and secular protagonists who perceived this space as a midway point of their power. In the period between the 6th and 11th centuries AD, a succession of different groups, including Goths, Byzantines, Lombards, the Papacy, ecclesiastical bodies, monasteries and local lordships, occupied the area. These groups followed one another in a dynamic of complementary occupation, with no room for overlap [2]. The heterogeneous nature of the environment and history of the area has prompted extensive study and research activity, which has been conducted since the 18th century [3] with a focus on the analysis of human presence and material remains. However, these studies have concentrated on evidence, such as the road system [4], religious settlements [5] and demic centres. Alternatively, although comprehensive, they have limited the analysis to a specific chronological period [6] or phenomenon [7].

The investigation of the peopling dynamics of a territory as vast and at the same time as poor in known archaeological data for post-classical chronologies as that of the Mignone Valley has from the outset imposed the necessity to consider within the research any type of data known for the context. The investigation has considered a range of sources, including historical, cartographic, and oral sources, archival data, aerial photos, remote sensing, information from local scholars and archaeological data derived from systematic excavation campaigns conducted using the stratigraphic method. However, more often than not, the archaeological data has been derived from clandestine excavations and surface reconnaissance, which have often lacked methodological reliability. This type of heterogeneity immediately posed a problem well known to research in the sector and not yet completely resolved. This is the problem of basing general reconstructions on data that is not totally certain and often scarcely reliable, especially in relation to the chronologies attributed to the single piece of information and

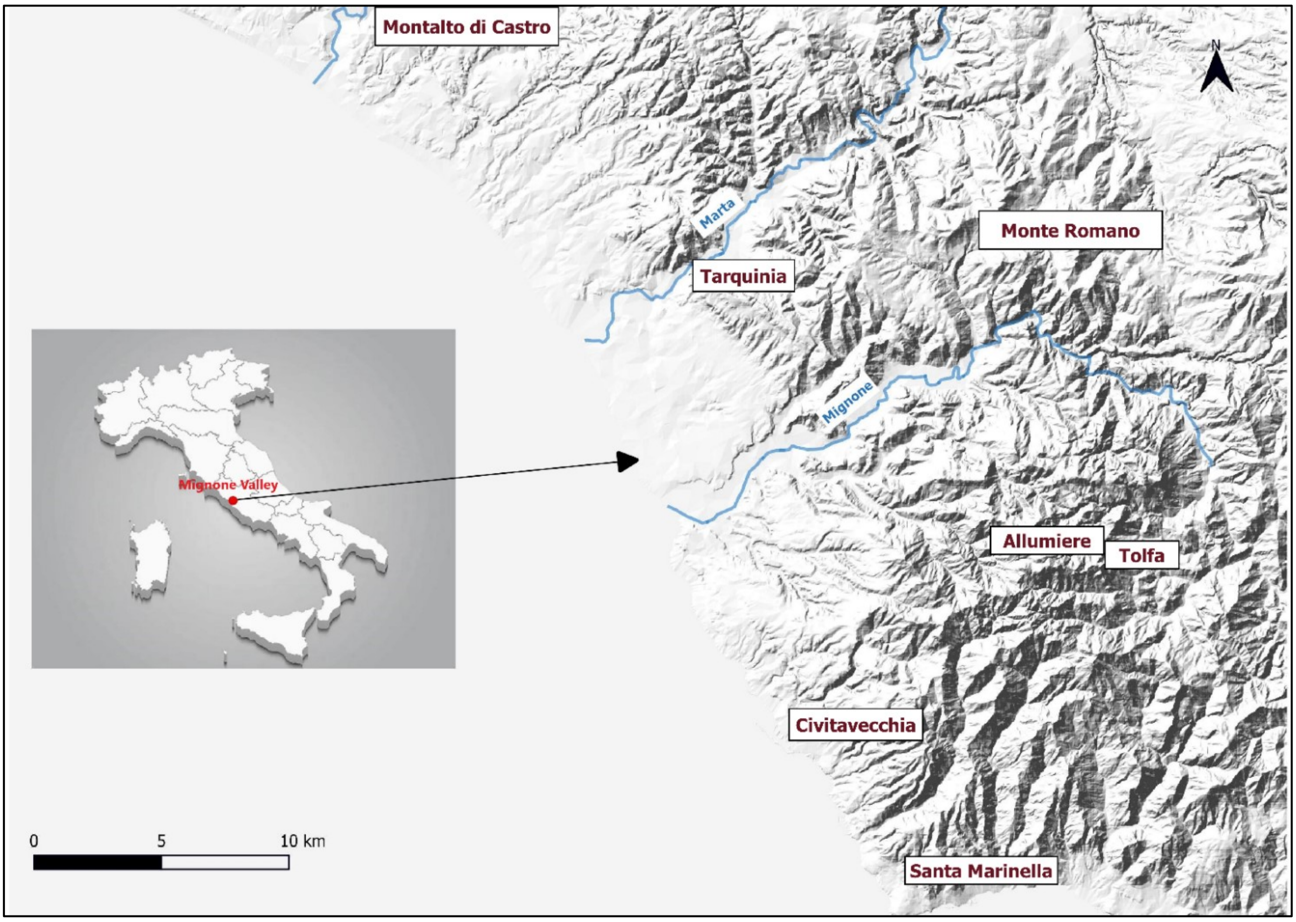

Figure 1. Survey area.

the topographical position transmitted. These often coincide with a buffer area rather than a pair of coordinates, which runs the risk of generating reconstructive hypotheses that are not entirely dependable. The methods used to classify archaeological clusters have been widely used in quantitative archaeological applications for more than 40 years. In the relevant literature there are several examples of data sorting that, by using mathematical methods far removed from the strict computer rules of 'true' and 'false', avoid flattening the indeterminate nature typical of archaeological data, but also the subjectivity factor of the cataloguer [8]. Exemplary in this respect are the solutions adopted in the case of the topographical study of prehistoric settlements in the Great Polish Plain [9], the application of fuzzy logic in the case of the analysis of small finds from the contexts of Festòs and Haghia Triada [10] or the reconstruction of the Via Severiana, through the verification of information from historical sources and its comparison to data from archaeological survey [11]. Nevertheless, none of the methodological solutions already known proved to be fully satisfactory for our type of data, mainly because the statistical solutions adopted cannot be applied universally, as they vary according to context, cluster and research needs. For example, the methods used to classify a pottery sample cannot be the same as those used to classify entire settlements, even though the methods share the same statistical classification logic.

Nevertheless, it is crucial to highlight that despite the inherent vagueness of such information, it cannot be disregarded in a topographical reconstruction that aims to comprehensively investigate the evolution of a territory over an extensive chronological span. Drawing inspiration from the ICCD standards defined for the compilation of some MODI records of the National Geoportal for Archaeology [12], a statistical method was used to calculate the value, expressed in mathematical terms, of each piece of information surveyed. This was done to ascertain the relative importance of each piece of information within the context of the broader framework. The decision to employ a mathematical criterion permitted the enlargement of the cluster, thereby enabling the implementation of spatial analyses conducted within a GIS environment. This approach involved the exclusion of input data that were uncertain or so uncertain as to compromise the final maps with unrealistic results. In the section entitled "Method," the statistical method employed to survey the data in the GIS dataset will be described. The following three sections will describe the GIS analyses conducted for the investigation of the road system, the use of ancient soils, and the exploitation of mineral resources. In this work, aspects that have been identified as useful keys to understanding the social dynamics underlying the settlement transformation of the landscape have been considered. Finally, the results will be interpreted within the context of broader historical frameworks.

2. METHODS

The application of a statistical method for the interpretation of the collected data has enabled us to propose a reconstructive hypothesis regarding the type of settlement pattern present in the investigated area, even during the chronologies considered most 'obscure' from a documentary point of view. This has been achieved by exploiting even topographically and chronologically ambiguous data. It is evident that the archaeological investigation

Table 1. Parameters for attributing topographical and chronological reliability values.

Values	Topographical reliability	Chronological reliability
0	Information about a highly generic positioning.	Information about an attribution to macro-periods (e.g., the medieval age).
1	Documented information indicating toponymic coincidence with a place or building still existing, but of uncertain topographical coincidence.	Information of materials within closer chronological ranges (e.g., early medieval age).
2	Information from archaeological reconnaissance before the use of GPS.	Information from surveys or archaeological investigations dated by means of comparisons.
3	Information from archaeological reconnaissance or investigations carried out with modern topographic tools	Materials from reconnaissance or archaeological investigations dated by radiocarbon analysis or from documentary sources written in a specific year

of a context or an area cannot disregard all the information that is already known, regardless of the provenance and nature of the data itself. Furthermore, the information cannot be pigeonholed into narrow ranges that would distort the original information and create misleading general readings. Analyses of this nature must identify functional alternative solutions for the appropriate consideration of each attestation within the survey, avoiding the imposition of excessive constraints within "watertight compartments" that are unrealistic for the representation of a multifaceted reality such as archaeology. A topographical analysis such as the one conducted in the Mignone Valley was designed to facilitate a realistic territorial reconstruction across a range of historical periods. This approach necessitated the accurate recording of archaeological data within the broader context of ancient and modern sources capable of offering information on the type of archaeological presence found. In this case, the greatest challenge was to make the necessary 'choices', which had to be made independently of personal logic or specific chronological sensitivities. Given the limited quantity of available data for the area under investigation, it was deemed unproductive to discard the least verified data upstream. Instead, an objective criterion based on a scale of mathematical values was identified to allow each piece of data to be considered within the overall assessment for its reliability value. It was deemed crucial that each piece of data could be re-evaluated by readers to demonstrate the elements of deductive reflection and to highlight the inherent criticalities of each piece of information. In a reconstructive analysis, the elements that should be considered when applying the criterion may vary (chronology, topography, origin, geographical context, etc.). However, in a study that sought to delineate the change of a territory and the logics that could have generated it, especially on the basis of the 'where' and 'when' each settlement was born or moved, we considered the date attributed to the find by the source and the reported locality to be the most important elements. Two new columns, designated "Topographical Reliability" and "Chronological Reliability," were added to the attributes table of the "site" *shapefile* within the QGis database. Each site was assigned a different numerical value based on the criteria outlined in the table below (Table 1).

The value resulting from the sum of the chronological and topographical reliability was converted into a numerical series of values between 1 and 6, representing the degree of importance

Table 2. Table of total reliability parameters for input data.

Values	Corresponding data types for each value
1	Near-zero degree of reliability > cannot be considered within the final analysis sample.
2	Low degree of reliability > partially considered within the final analysis sample.
3	Discrete degree of reliability > can be considered within the final analysis sample with large chronological and topographical buffers.
4	Degree of reliability good > can be considered within the final analysis sample with tight chronological and topographical buffers.
5	Degree of reliability very good > can be considered within the final analysis sample with verified dates and placements.
6	Excellent degree of reliability > considered within the analysis sample with chemical dating and topographic positioning deduced with topographic tools.

with which to consider each piece of data within the analysis called "Total Reliability". It should be noted that within this scale, 1 represents the minimum value and 6 the maximum value (Table 2). This criterion, which is also employed for the census of attestations concerning stretches of road, property boundaries and discoveries testifying to quarrying and processing of mineral resources, has enabled the generation of data maps with an overall reliability of between 4 and 6 in the case of the road network (Figure 2) and mining exploitation (Figure 3) and between values of 5 and 6 in the case of the use of ancient soils (Figure 4). Having identified the 'marker' elements of the change, namely those that were most evident in reflecting the change in society, the attestations in the range of values between 4 and 6 were set as input data for more specific territorial analyses that produced circumstantial maps useful for the graphic representation of various scenarios that contributed to the overall reading of the general dynamics of anthropisation of the area.

3. ROADS NETWORK

The topographical analysis conducted on the Mignone Valley district considered the routes, reconstructed, and materially traced, as 'segments of local mobility'. These were functional to the small-scale connection of all the settlements, regardless of their hierarchical position within the investigated territory. Indeed, it is now common in the literature of the sector to posit that in the Middle Ages, it was not only the great arterial roads that created the mobility network of a territory, but above all the individual segments of smaller internal routes that were intended to allow connections with more distant regions according to the logic still underlying the internal mobility of territories not served by modern motorway networks. Based on this assumption, the *Channels Network* analysis was therefore conducted in a GIS environment. In the archaeological context, this analysis starts from the theoretical assumption that the stretches over which watercourses flow can represent the potential connection routes between a centre and its territory in any direction. This is based on a cost surface, i.e. a precise geographical space, represented in *raster* form, within which human movement takes place, taking into account any obstacles and slopes present within the context [13]. This examination identifies potential mobility paths between settlements of the same chronological context based on "attractor" elements indicated to the GIS *post-processing* algorithm in the form of a numerical value. In the context of our investigation, data with a total reliability rating of 4 to 6 were

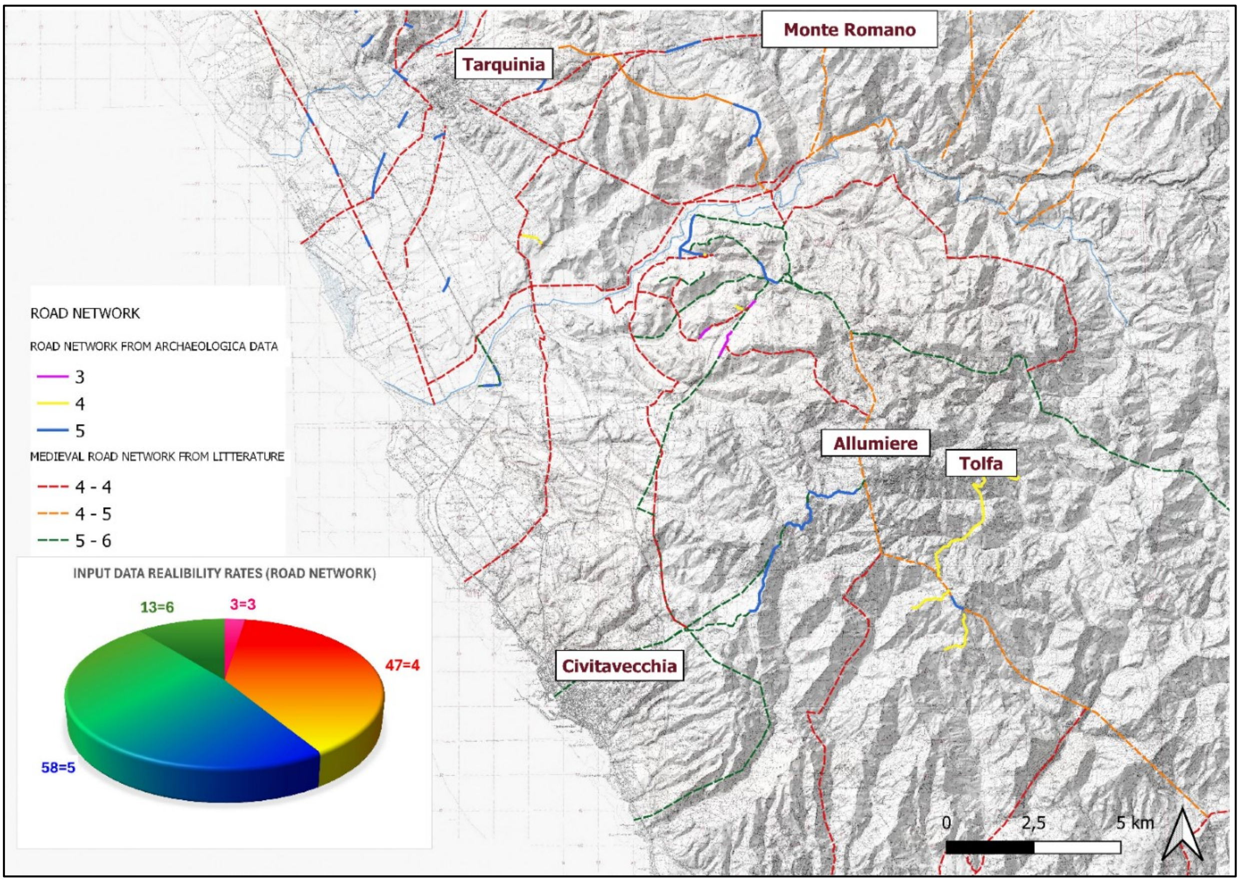

Figure 2. Map showing input data of road network based on the level of reliability obtained.

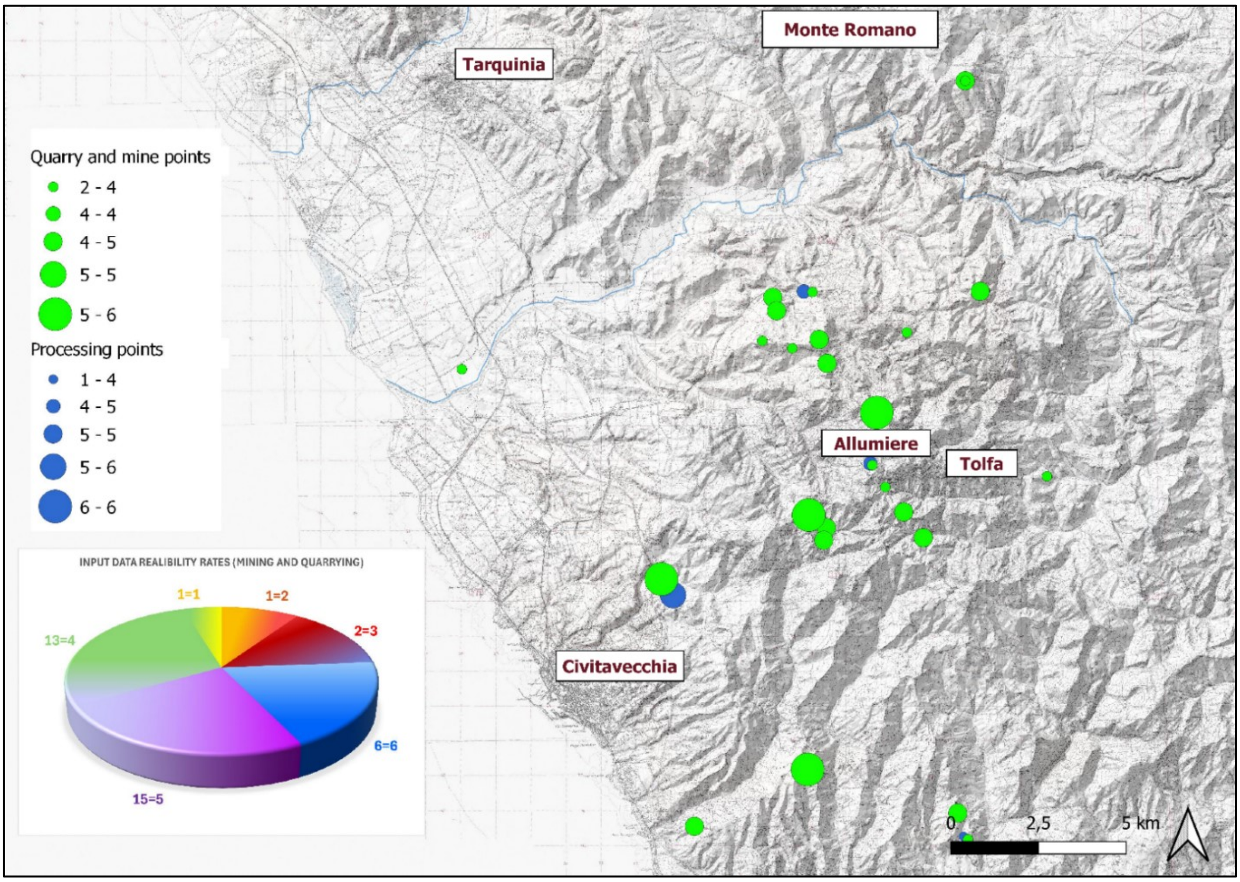

Figure 3. Map showing input data of marks of quarry, mine and processing point based on the level of reliability obtained.

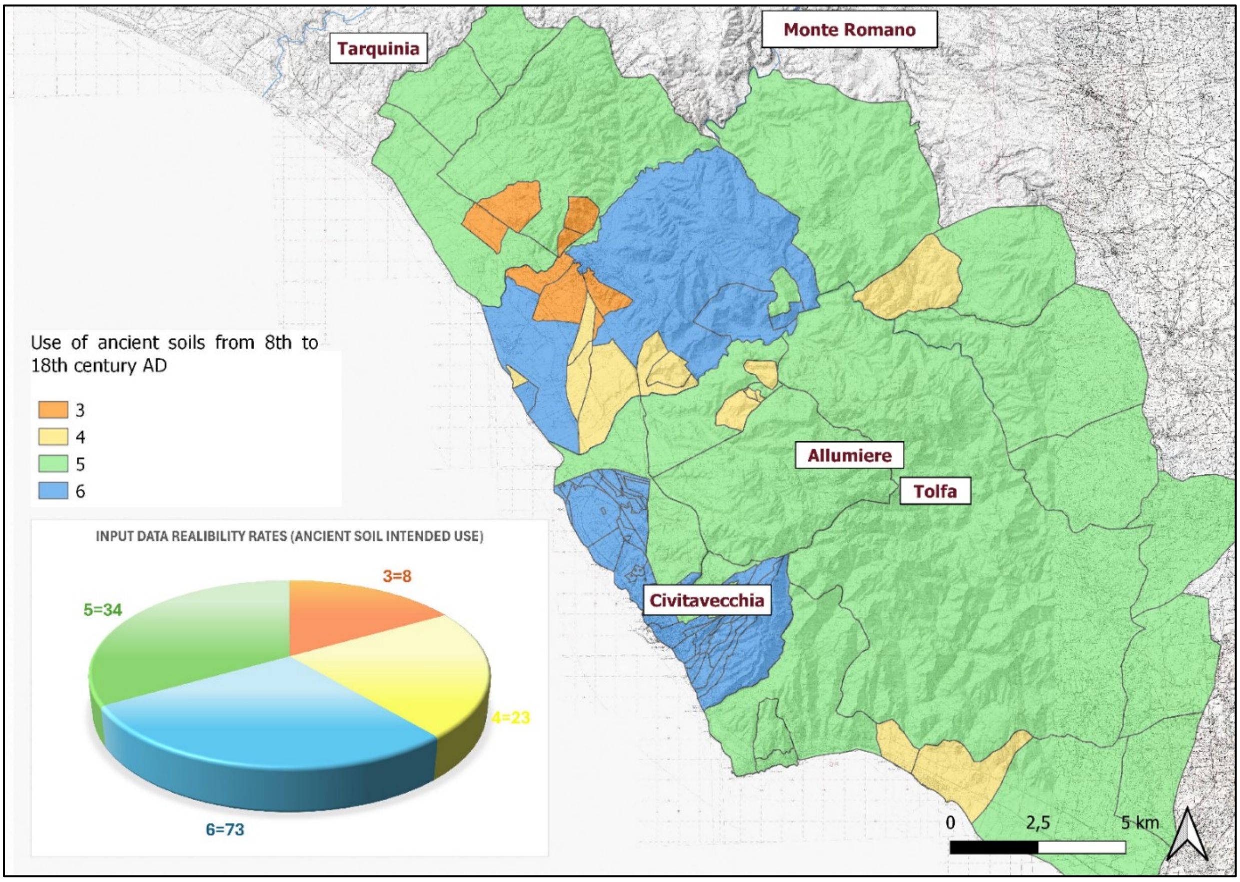

Figure 4. Map showing input data about the use of ancient soil based on the level of reliability obtained

selected as "attractor" elements. The result highlighted a series of segmentations that correspond to the passage points that can be exploited for the 360° movement. It should be noted, however, that the indication provided by the algorithm may not even find correspondence in the archaeological reality. In such a case, it would be necessary to ask why the archaeological traces correspond to a less favourable stretch than the one indicated. In the present case, however, the results of the *Channels Network* and *Drainage Basins* indicated a high degree of correspondence between the hypothesized and, to some extent, archaeologically documented routes, with an estimated 80 % match between the two (Figure 5). In this case, the application of reliability criteria enabled the consideration of fragments of minor routes that had been discovered during sporadic reconnaissance conducted between the end of the 19th and beginning of the 20th century and which, without the implementation of a specific method for assessing the reliability of the data, particularly given the impossibility of verification, would not have been given due consideration within the overall reconstruction. The most noteworthy aspect of the data analysis is the continuity of a huge portion of the routes that were already in use during the imperial era [14]. Some of these routes originated in the pre-Roman period and were crucial for the sub-regional connectivity of the Mignone Valley with neighbouring territories. The routes in question have been maintained through settlements that have yielded traces of a long-standing frequentation, which, although exhibiting a decline, can be dated between the 2nd and 15th centuries AD [15]. In this scenario, quarry exploitation sites, mineral resource processing sites, and agricultural properties, all of which are also attested in the medieval period, have been considered as 'attracting' elements. Consequently, it can be deduced that part of the routes established from the medieval period onwards may have originated precisely in function of this exploitation (Figure 6).

4. LAND MINING EXPLOITATION

The mining vocation of the Monti of Tolfa district is a topic that has been extensively discussed in the literature of the sector, particularly in relation to the exploitation of alum and metal deposits. However, the most certain attestations concerning their use concern the pre-Roman and Roman age, while the medieval age sees the rediscovery of alum deposits from the mid-15th century AD by Giovanni di Castro [16]. Despite this awareness, it is challenging to ascertain the extent to which this type of resource may have influenced settlement dynamics, particularly following the collapse of the Western Roman Empire and the dissolution of its economic system. This is due to the difficulty of chronologically anchoring the 'guiding fossils' of this activity, such as slag, work tools and the quarry marks still visible on the supply fronts. In this context, the waste and processing plants identified in the post-classical stratigraphies of some of the contexts closest to the course of the Mignone River were useful dating elements. Nevertheless, the available data for the area under investigation remain limited, and it is therefore not yet possible to undertake specific GIS analyses that require a larger sample size. To ensure the scientific validity of the reconstruction, the criterion for assessing the reliability of the information in terms of both chronology and topography was also applied to this type of attestation. In addition to the criteria, the set of data to be investigated included toponymic relics, finds of work tools, production waste, processing plants, and traces of

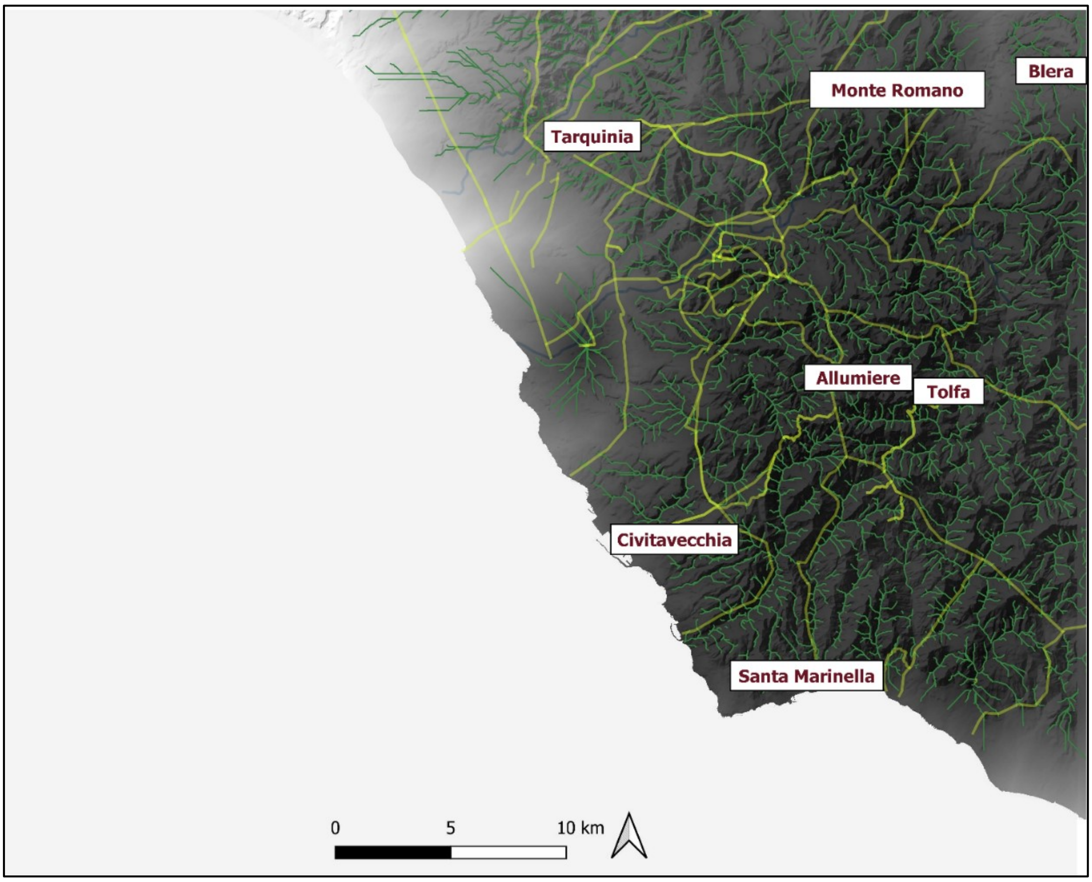

Figure 5. Map of the ‘Channels Network and Drainage Basins’ indicated a high degree of correspondence between the drainage basins (green line) hypothesized and the archaeological data of roads (yellow line).

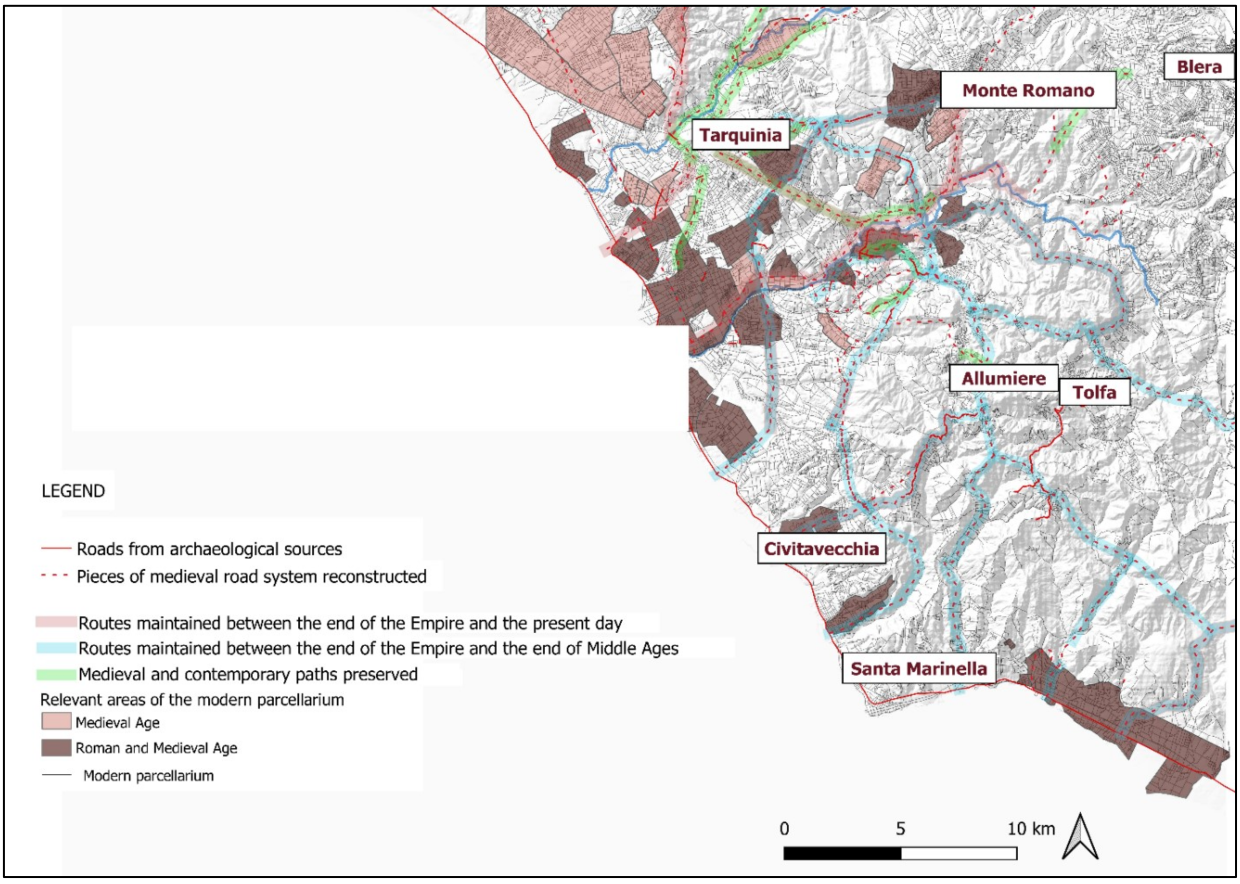

Figure 6. Reconstructive map of the road system in association with surviving areas of Roman and medieval agricultural parcelling.

quarry cuts. These items were considered even if they originated from older, no longer physically verifiable attestations. The sample obtained was utilised as input data for the elaboration of *Kernel Density Estimation* (*Kriging*), an analytical technique that estimates the density of a random variable within a given space [17]. It was postulated that the selection of settlements in the medieval period on the same sites may have been influenced by the potential for mining exploitation. This type of analysis was deemed the most suitable approach to visually represent the topographical recurrence between sites of long-standing occupation and quarries where evidence of activity in the medieval period has been identified. The results demonstrated that this pair is more prevalent in contexts where reliability was deemed to be between 4 and 6, and where longer periods of occupation were documented, in some cases extending as far back as the 15th century AD (Figure 7). In this case, the greater reliability of the input data has enabled the hypothesis to be formulated that the population of the area may also have been conditioned by their proximity to places of extraction, processing, and export of natural resources. This may have been the basis of the regional economy even in the Middle Ages. The analysis, although limited in scope, contributes to the advancement of knowledge about mining exploitation in the Mignone Valley and the Tolfa Mountains by offering new insights and a post-dynastic perspective [18].

5. LAND USE

The forms of agricultural land use that characterised the Mignone Valley over the centuries and that in some way conditioned the settlement choices in the area have only been partially studied. This is due to the fact that the analyses have been limited to specific crops or confined to narrow chronological ranges. This can be explained by the restriction of the studies to certain cultures or to a limited period of time, as well as by the scarce and inaccurate information given by ancient sources, especially for the Late Antiquity and the Early Middle Ages. The aim of this research was also to fill this gap by making an attempt to graphically reconstruct the land used for productive purposes (agro-pastoral and forestry in the hands of monastic bodies and local lordships), taking advantage of the anchoring on topographical data with medium-high reliability values, i.e. between 4 and 6. Among the studies in this field, it is indeed possible to count a number of contributions that dealt with the analysis of the ancient landscape, such as the first studies aimed at understanding the management of farms in Roman times through the mapping of the oil culture in the Mignone Valley [19] or the later ones that focused on the analysis of the distribution of traces of the medieval wine culture in the Tolfa Mountains [20]. There have also been many studies of the agricultural structures of Upper Lazio from a legal-administrative point of view [21] or, in later periods, in connection with other types of land use [22]. It should be noted that in all cases where reconstructions have been attempted, the lack of diachronic reconstructions over the entire territory, albeit in hypothetical form, has been a consistent issue. Even when such reconstructions have been proposed on the basis of source data, they have not been mapped due to the difficulty of defining the boundaries of ancient properties with a reasonable degree of certainty. This approach involved the application of the statistical method initially proposed in an attempt to overcome the

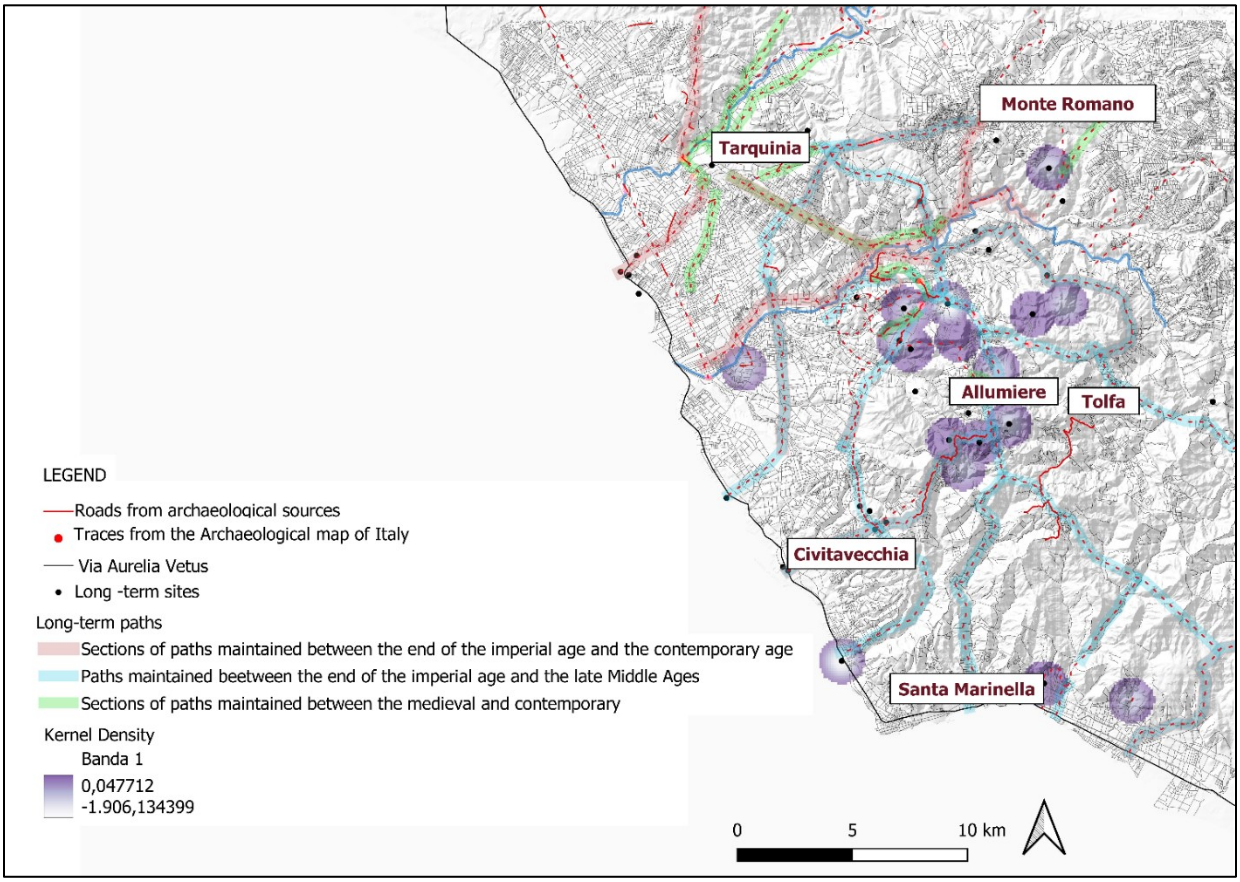

Figure 7. Kernel Density Estimation (Kriging). Shown in purple are the Life Continuity contexts with an overall reliability score between 4 and 6, for which mining had a greater 'weight'.

limitations of previous studies. Here, in fact, the high total reliability value recorded for some attestations made it possible to assign higher values to data of more doubtful provenance. Indeed, numerous properties were documented in written and cartographic sources with a precise indication of land use. However, it was challenging to reposition these topographically, except by means of a more certain toponymic indication for more recent chronologies. This was also the case for older ones, where the lack of certainty was more pronounced. In such cases, the physical proximity with reliable properties for a level 6, on the scale of total reliability values, made it possible to assign a higher numerical value, at least to the topographical reliability range, thus generating an overall sample of data in the range of values between 4 and 6. The evidence collected allows the creation of circumstantial maps of land use over the long chronological period between the 8th and 18th centuries AD. However, these maps will not be included here as they have already been published in other works [23]. The application of the statistical method identified made it possible to show certain changes in the landscape, as evidenced by the locations where wine culture has been observed. The cluster revealed a significant insight into the context, as it encompassed a considerable number of attestations pertaining to the cultivation of vines in the region, with total reliability values ranging between 5 and 6. These values were not considered in previous studies. In this case, it was necessary to conduct a more detailed analysis to ascertain the extent to which the planting of this crop may have altered the landscape during the medieval centuries. The numerous archaeological traces identified in the cluster for this crop were incongruous with the apparent natural suitability of the majority of the territory for viticulture, as suggested by geological evidence. This contradiction emerged mainly from the 'suitability' map created for the area through targeted use of the QGis tool of the *raster calculator*. The input DTM (Digital Terrain Model), specially constructed for the area, was reclassified with the parameters considered discriminating in an area for vine planting (exposure to sunlight, altitude and climatic conditions). Each of these conditions was assigned a numerical value between 0 and 5 where 0 represented the least important parameter and 5 the most important. The final model obtained highlighted with a colour gradient the portions of the analysed territory closest or furthest from this vocation (Figure 8). The results of the analysis were unexpected in that they indicated that the areas most suited to wine-growing were those closest to the coastal strip and almost absent in the interior. This is in contrast to the archaeological data and the numerous documentary sources that show wine-growing exploitation to be homogeneous over a large part of the area under investigation. The numerous *torcular*, as well as the anomalies of the *sulci* recorded by remote sensing and the various plots of land destined for vines listed in the deeds of ownership of private individuals and monasteries, are all elements that, in this scenario, have allowed us to understand the profound human impact on the environment. This impact has been man-made in such a way as to reinforce the cultivation of certain cultures, which have been considered to be relevant and which over the centuries have modelled the agrarian landscape of southern Etruria since the pre-Roman era.

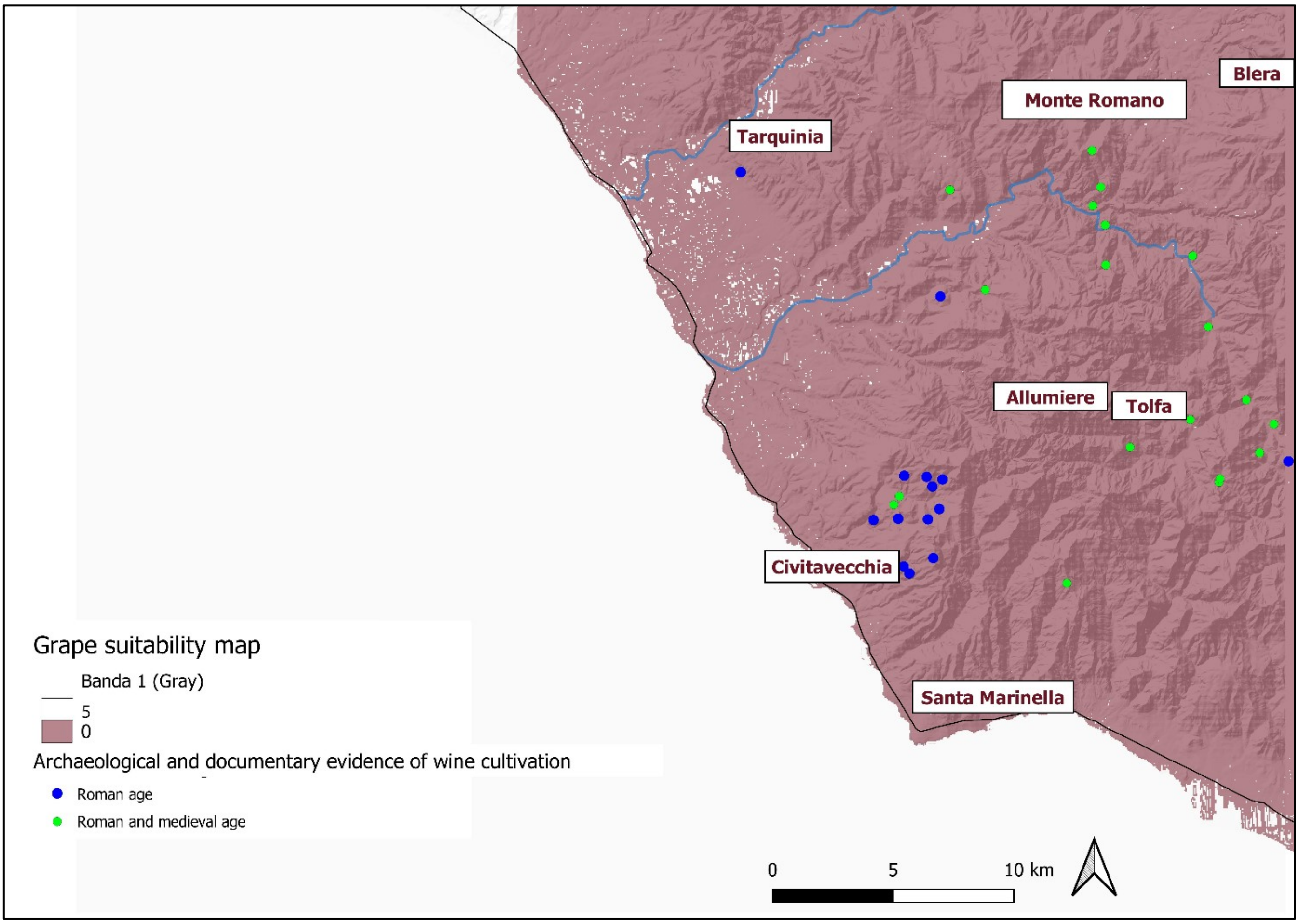

Figure 8. Vine suitability map. The colour scale shows the most suitable areas (in white) and the least suitable areas (in pink).

6. CONCLUSION

The implementation of a statistical method for the interpretation of the collected data enabled the formulation of a reconstructive hypothesis regarding the type of settlement pattern present in the investigated area, even during the chronologies considered more 'obscure' from a documentary point of view. This was achieved by exploiting even topographically fuzzy data, thanks to the adoption of a different data classification strategy that allowed for the consideration of even apparently approximate information that would otherwise not have had the same weight within such a topographical study. Most of the studies that in the past have tried to make a global reading of the Mignone Valley in the medieval period have been able to take into account a very poor sampling, due to the lack of research activity in the area, but also to the inability to georeference the little information known from the sources, based on unstable topography. The search for a statistical method that would allow a more in-depth reading of the landscape and its evolution between the 6th and 15th centuries using a larger cluster led to the identification of reliable information for chronological and topographical anchoring. The innovation of the proposed research is the application in the archaeological field of an 'incremental search' method, now based on machine learning algorithms, which uses the information obtained in the previous step to guide the next step, thus optimising the search process and avoiding the analysis of the entire data set [24]. In archaeological terms, this means starting from a partial network of chronologically and topographically reliable data, i.e. those with an overall reliability value of 6, anchoring on this information between values 4 and 5, and creating a network of progressively implemented data on which to geo-reference the information with the lowest values, i.e. on 4 those with values 3, on 3 those with values 2, and finally on 2 those with values 1. By modifying the cluster on which the reflection is based, it has been possible to propose a different reading of the ancient landscape, settlement dynamics and forms of exploitation, partly confirming what has already been expressed in a series of recent studies [25] and partly highlighting new elements that will be the basis for further in-depth studies in the future.

Upon initial examination of the landscape, which has historically exhibited minimal urbanisation, little to no change had occurred. But closer analysis of the archaeological evidence, which included larger clusters than previously surveyed, showed the entire valley had been significantly altered through time. It became evident that the entire district was affected by a gradual demographic increase as early as the end of the 2nd century AD. However, this phenomenon was recorded with less certainty than in other peninsular contexts. The archaeological data, documentary evidence and the dynamics of territorial exploitation all enabled an understanding of how, between the 3rd and 8th centuries AD, the decrease in traces of frequentation in the spaces of the ancient Roman rustic buildings corresponded with the greater attestation of traces of frequentation, especially in the areas immediately surrounding these buildings. This is in accordance with the dynamics well known from the literature in this sector, which sees the continuous settlement in geographically favourable places from the settlement profile, albeit with the occupation of new spaces. This phenomenon, which occurred between the end of the 8th and the beginning of the 9th century AD, led to the development of the settlement pattern that would characterise the Mignone Valley between the 9th and the 15th century. This period saw further change, with the resumption of alum exploitation resulting in a new topographical definition of the territory. The analyses conducted have demonstrated that the road system has evolved to accommodate the new economic and social centres of gravity in the territory. Rather than eliminating smaller routes, the system has gradually incorporated them into larger, more resilient networks, often respecting the boundaries of property that were established during the medieval period but sometimes preserved since the Roman era. The scenario that can be deduced from this is that of a strongly meta-formal landscape in which respect for different economic, political and subsistence needs led to the occupation of new spaces, but in the same areas that were considered 'attractive' since pre-Roman times. This contributed to the resilience of macro-topographical arrangements.

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