

Part II

GIS Analysis. The Insight of Modern GIS Analysis of a DEM

Introduction

In this section, the use of GIS and the main methodologies employed throughout this work are introduced. Following a brief history of the use of these methodologies an analytical evaluation of these data will be pursued. Despite the more technical content of this part, it was deemed important not to add it as annex, as in many instances the discussion is mainly archaeological. Further, the scope of this chapter is not to act as a technical manual for this study, but rather to elucidate, and perhaps even act as a point of reference for archaeologists embarking in similar studies.

In one a previous analysis for the Messara region by Déderix focusing on Apesokari, mobility networks in the western and partially central Messara were calculated in which a central role of Koumasa does not show in the hierarchical mobility network produced.⁵⁰¹ In her paper (which was the spark behind the conception of the effort presented here, and hopes to build upon its results concerning the question of connectivity in central Messara, as it concerns the nearby locations to Koumasa) a central role is not necessarily indicated in these environmentally deterministic predictions as they are tasked to answer certain questions. The formulated question there is the relevancy as for the main Messara sites.⁵⁰² To verify these results concerning Koumasa there is a need for a calculation that takes into consideration the entirety of the Messara Asterousia, including the whole of the Messara Valley until Anapodaris stream, which both has Koumasa in the centre of the search area and also encompasses a complete geographic feature which is the main Kophinas peak and the main part of the Asterousia range including the slopes eastern of Kophinas. So a DEM model of this area would include Treis Ekklesies, Rotasi, Charakas and Dhamantri; locations towards which the network of Koumasa (at least partially, within its Macroscale) extends.⁵⁰³ But even in this case, the partially noncentral role is seen to remain, as Koumasa finds itself in a geological niche, in a drop-shaped extension of the Messara to the south, being thus partially

501 Déderix 2017, 17. See also Paliou et al. 2014; Paliou – Bevan 2016. In this analysis, Koumasa’s position at the edge of the map is partially subject to the “edge effect,” as some of the locations that are primary targets of Movement from Koumasa or their paths, as will be presented in the analysis here, are cut off. The analysis, however, is also indicative of this region, as it shows its role as peripheral when movement only in the frame of central and western Messara is concerned.

502 See discussion on 84ff.

503 In the analyses of Déderix and Paliou – Bevan (see above) the DEM used stretch from Kommos to Kophinas at its eastern side.

embedded within a mountainous terrain, that amongst others influences the direct line of sight, as it will be discussed separately in the Chapter 5.4. In the following methodology, the a priori knowledge of the settlement's importance will not be addressed. Only given Koumasa's location, the topographical connectivity potentials will be explored, so that a biased approach would be avoided.

At a second level, during the evaluation, the landscape-driven results are one input, the other being the archaeological situation, as any explanation must exceed the purely topographic criteria, which is the defining characteristic of the GIS methods. Indeed, it is imperative to exercise caution when attributing significance solely based on a series of GIS methods. The efficacy of such methods heavily depends on the precision of the parameters set, thus necessitating a nuanced approach in formulating pertinent inquiries, i.e. one must pose the right questions. Hence the diverse array of approaches delineated below (see also the discussion of the limitations of GIS). As was demonstrated in Chapter 3, the history of the site ranges from centrality to irrelevancy. The results of combining the computed results with the reality of the finds, partially already presented in previous chapters, allows for an interpretation of the location's relevancy per time period, and thus the cultural biography of the site.

Three levels of geographical understanding can be identified concerning mobility networking, each embedded within the other, similar to the popular example of onion layers. The one alluded to above is the macroscale of Koumasa including the Messara-Asterousia region as defined in the introduction. Beside the large-scale focal networking, the results are similar to those obtained by Déderix, so that an interpretation of the importance of the site has to be sought in other parameters, as many other factors can play a role for a site's location beside the vicinity to a main artery of the cumulative cost paths calculated for the extent of the Messara-Asterousia. For example, the strategic route control, which will be explored here. Here, the area identified is the mesoscale of the central Messara-Asterousia region, which includes the locations around the Kophinas peak, and the existing paths between them. These smaller locations, in themselves part of the periphery within the scope of the entire Messara, seem to offer a possibility of a local co-existent and to an extent co-dependent network, that forms an approximate inertial reference frame, to translate this Newtonian term to sociology.⁵⁰⁴ In the analysis done in two parts below in this part, the potential routes to and from Koumasa will be explored looking for the strategic or special features of its locations that will explain the emergence of a regional centre there. Free movement and conditional, i.e. defining locations of interest will be performed, as well as many algorithms, including some problematic ones, as usable results can be obtained when the weakness of the algorithm is taken into consideration, either for comparison or direct use. Another level is the microscale, i.e. the lived experience within the settlement, and the paths leading to, and also crossing the settlement, analysed in Chapter 6.

504 See pages 85ff.; 267ff.

In summary, structurally, this chapter will begin with a history of GIS use and its methodologies from the perspective of the present aims. In Chapter 5, the question is defining movement patterns and connectivity networks in the mesoscale and macroscale of Koumasa, concerning the locations within eye's reach and/or the immediate vicinity from the settlement, so that aspects of the potential role of Koumasa in this network would be presented.

Two fronts are identified. The first, is the relation to the networks traversing the Asterousia ridge. Indeed, on the southern foothills of the Messara, a number of locations have been identified that function – amongst others – as harbours, possibly for the sea route that ended in Kommos. The other front will be in the Messara plain itself and beyond, adding to the above-mentioned insights made by Déderix, but this time focusing on the Messara plain including centres such as Dhamantri and Rotasi to the east. (A macroscale GIS analysis is here performed, partially to evaluate previous results). To adequately cover both sides of the Asterousia region, but also to avoid any phenomenon of edge effect, a DEM will be used having Koumasa central within it, so that the Macro- and Mesoscale in which Koumasa lies may be explored.

In the Chapter 6, a separate DEM, produced by drone flight, will concern the microscale of Koumasa, concerning the direct vicinity of the settlement addressing the movement patterns within it, the intervisibility between various points within and beyond the settlement will be analysed with viewshed analysis and optimal paths.

As the terrain must play a deterministically important role, the paths extrapolated will affect our reading of the map and evaluation of cost distances instead of distances, so that any social networking theories will be evaluated.

4 Modelling Movement Patterns. History of Research

In recent decades, the application of GIS methods in archaeological research has played a crucial role in expanding our understanding of the relationships between space, place, and culture in both regional and transregional behaviours.⁵⁰⁵ GIS applications have been implemented across a range of cultures and time periods, yielding paradigms for interpreting diverse landscapes. Particularly promising is the recent adoption of these methods in Aegean archaeology, a trend that has notably increased since the 2010s.⁵⁰⁶ Indeed, understanding the orographic characteristics of the Cretan terrain based on similar analyses has been helpful in interpreting the choices in the development of populated settlements and the establishment of trade networks and their connectivity patterns. The rise of technology has reached a level where it has allowed an insight into these characteristics and therefore for the cultural biography of a site to be approached with these methods that are often linked with landscape archaeology.⁵⁰⁷ This landscape-driven cultural biography can be used to support or challenge other types of evidence,⁵⁰⁸ but most importantly, and mainly what this chapter will focus on, is used to provide essential complementary insights that allow for an intrinsic understanding of site's place within "its" world, what is referred to in this work as the *locus*. Its understanding is not era-specific *per se*, but it could aid in an explanatory framework of the rise and fall of specific locations, taking into account the historical development.

However, absolute reliance on these techniques risks confining arguments within a purely quantitative framework, lacking the insights derived from walking and experiencing the area, and can be thus subject to critique.⁵⁰⁹

505 Indicatively, see: Chapman 2006; Bevan 2010; White – Surface-Evans 2012; Herzog 2013a; Paliou et al. 2014; Bevan – Lake 2016; Sarris 2024.

506 Which covers a wide geographical area. To name a few examples: Efkleidou 2019 (for Mycenae, Peloponnese), Vouzaxakis 2015 (Thessaly), and for central and southern Crete: Sarris et al. 2011; Bevan – Wilson 2013; Beckmann 2015; Paliou – Bevan 2016; Déderix 2017; 2019; Antoniadis 2024. For a diachronic approach considering the settlement patterns on the island, see Pollard 2023. Although the use of experiences gathered and algorithmic methodologies is not location specific, it is, however, encouraging to have available analyses of a generally similar location and time period that would have been subject to similar weather conditions, climate phenomena or even cultural traditions and other parameters that might not be codified in the landscape.

507 Kluiving – Guttman-Bond 2012.

508 Bintliff 1977.

509 Wheatley 2014, 117–118; Nowicki 2019, 2.

Scepticism toward these methods began to emerge at the end of the 20th century, with some researchers raising concerns not about GIS itself, but rather about its application. The widespread use of GIS, often without critical evaluation, was seen as potentially reintroducing problematic issues, including oversimplification and a lack of contextual sensitivity in archaeological analysis, and reviving “a functionalist approach to archaeological explanation, which had supposedly been discredited by the humanistic critique of processual archaeology”.⁵¹⁰ Therefore the analysis in Part II also aims to demonstrate that the application of these methods is neither uncritical nor limited to a monosemantic explanatory framework. Instead, GIS is employed as an enhancement to traditional practices such as surveying, field walking, and broader archaeological work, enriching rather than replacing these foundational approaches, as will be presented in subsequent Parts.

4.1 History

While the use of GIS has been prevalent in social sciences for some time, its application in archaeology is relatively new and has considerably increased since the end of the 1990s.⁵¹¹ This growth can largely be attributed to the surge in computational power, accessibility to the larger public, availability of geospatial data and the prevalence of user-friendly GIS software that offers tools for the analysis of digital models. A number of experiences have already been available before the 2000s, which since then has been enhanced upon.⁵¹² The GIS methods are particularly applicable in the study of visibility analyses, movement patterns and path systems, as those who used them usually did not leave tangible evidence.⁵¹³

The expansion of GIS methodologies in archaeology has significantly influenced various areas of archaeological practice. However, as Chapman noted, these methodologies have also been shaped by archaeological practice itself, as accumulated insights, nuanced observations, and emerging needs have driven adaptations and refinements in GIS applications. Methods have been developed to overcome various analytical and technical challenges, enabling researchers to bypass potential pitfalls in these applications.⁵¹⁴ This push towards new solutions has posed some issues as the limits of the

510 Bevan – Lake 2016, 23.

511 Herzog (2013a, 179), while addressing primarily the method of least-cost paths (see also Surface-Evans 2012).

512 Fábrega-Álvarez 2006, 7. See also Harris 2000.

513 White – Surface-Evans 2012; Hazell – Brodie 2012. The *Journal of Computer Applications in Archaeology (CAA)* provides a broader scope with a variety of applications.

514 Chapman 2006, as well as Conoly – Lake 2006, reflect an academic interest observed in the decade of 2000s, which saw a rise in publications concerning GIS-based archaeology that not only proposed methodologies but also wrote in a way meant to popularise the subject to non-IT experts, allowing a further boost to these ideas.

algorithms and potential drawbacks began to appear. Standard GIS software offers a wide accessibility to archaeologists without the need for programming IT knowledge, achieving thus the prerequisite expressed by Gaffney – Stančič for a method to be considered successful.⁵¹⁵ One negative aspect is that the underlying methods and procedures are sometimes blindly followed by users with no IT experience, without an assessment before use or in the interpretation of the results. Therefore, it has been argued that these standardised versions lack some features that are important in archaeological optimal use and calculations.⁵¹⁶ Due to the design of these systems, such as Esri's ArcGIS and the open source QGIS used in this work, readily available tools for this purpose can be found. These have led to a much wider interest in the application of these techniques for research. Despite the fact that the workflow in these solutions follows predetermined steps, some manoeuvring is possible.⁵¹⁷ However, the core algorithmic approach is normally not amendable by the user. At least, not without some programming background, so an examination of the back-desk algorithm and methodology is useful. Not doing so can be problematic in the assessment of the results.⁵¹⁸ In a collective work, Kantner offered an overview of the available methods and their shortcomings.⁵¹⁹

Another source of errors is posing the wrong questions or extracting argumentations solely through the GIS analysis.⁵²⁰

The positive development is that these methods continue to improve; however, it is essential to cross-check the results of any model through different iterations and avoid accepting them at face value without critical evaluation. There is a variety of examples and explanations for methods, some of which are clearly constructed guides for archaeologists.⁵²¹ Furthermore, the abundance of examples facilitates the development of an approach that critically builds on previously established methods and trodden paths while employing *ad hoc* parameterisation to better address the specific characteristics of the area under study.

515 Gaffney – Stančič 1991; Herzog 2013a, 198.

516 Herzog 2013a, 198.

517 In ArcGIS, the number of choices in the toolboxes and the parameterisation allows for some freedom. Further, in QGIS one can use independently developed add-on tools through the Extensions tab and even request for, and actively participate in improvements.

518 Herzog 2013b finds an issue with some definitions of anisotropic behaviour.

519 Kantner 2012.

520 Such an example is the refute of an otherwise logical assumption by Bell – Lock (2000), as well as Batten (2007) that suggested the use of least-cost paths for the relative dating of sites, as the location of sites along routes between two others suggest a later dating for them. This, although maybe true in some cases, excludes the natural network development and also seems not to take into account other parameters. For example, in medieval Britain, roads often bypassed villages (Hindle 2002, 16). Similarly, other factors, such as the presence of sanctuaries or obsolete trade networks, will not be represented in this method. See also Wheatley 2014, 117–118.

521 These include Herzog 2010; White – Surface-Evans 2012, Schild 2016.

In summary, GIS used in archaeology, as examined in studies focusing on Bronze Age Crete, is mainly employed for (1) viewshed and visibility patterns,⁵²² (2) watershed analysis, which offers a more nuanced reading of the topographical map of the region, or water drainage around a specific site, and (3) modelling movement; i.e. time or energy to move between (a) set locations (least cost path analysis), analytically presented below; (b) from a specific location across an area (movement without a destination),⁵²³ or focal mobility network analysis, which shows the most practical corridors of movement, in essence being an intrinsic characteristic of the landscape and independent of any areas of interest.⁵²⁴

While all the above methods will be implemented in Chapter 5, given the introductory scope of this chapter, the aspects of cost, slope and used functions will be introduced below.

4.2 Methodology of Modelling Movement

In essence, with the use of GIS analysis of the geospatial data, the problem of seeking the connectivity between regions or places of interest transposes to the study relating to Zipf's assumption regarding the principle of *least effort*. Namely, there is a tendency for human networks to be formed around routes of minimal effort, economising the frequent tendencies.⁵²⁵ Of course, this will be in well-known and often traversed landscapes so that these minimal-cost routes will have been established.⁵²⁶ Possible optimal paths that require a bird's-eye view to recognise might remain unused by a population less familiar with the terrain. These methods have, for example, been used to determine networks of a variety of cultures that show the prevalent role of viewshed and direct visibility in establishing network patterns. This was not always done necessarily based on an in-depth understanding of the terrain or aiming in an optimal use of it, but instead focusing on the temporality of spatial organisation for hunter-gatherer settlements or a grandstand action towards neighbouring regions.⁵²⁷

522 For example, used for visibility networks between peak sanctuaries (Soetens et al. 2002; 2008) and visibility of tholoi (Dédérrix 2016).

523 This is also linked with the isochronous lines. E.g. Pollard 2022, 111–112, Fig. 4.

524 Bevan – Wilson 2013; Dédérrix 2017.

525 Zipf 1949 took the idea out of the philosophical plain, as it had been introduced by Guillaume Ferrero and quantified it, as can be seen by Zipf's law, as an empirical mathematical expression applicable in many aspects of human behaviour, from frequency of words in speech to distances in movement. This allowed the introduction to the economy of geography as a principle of potential movement analysis. This idea was further imbued with insights from realms of evolutionary psychology and sociology.

526 Branting 2012.

527 Kantner – Hobgood 2016 analyse the viewshed of the pre-Columbian Chacoan towers, exploring their potential beyond the pure defensiveness in their visibility potential. A different strategy for land use seems to appear for hunter-gatherer settlements. Kendra – Friedel (2009) shows the effect of seasonality in the choice

Using GIS to identify such routes poses specific challenges, particularly when studying complex societies for which we have limited knowledge of social dynamics. These latent factors could influence choices that cannot be ascertained based purely on geographic data and the study of geomorphology.

The parameters defining more complex behaviour such as trade is less straight-forward than needs of hunter-gatherer routines. In a more complex network, optimal routes can be avoided or preferred based on the relative importance of some of the nodes, which is not always tangible in the terrain. Further parameters for path choice can be taxation, the presence of robbers or even taboos relating to religious traditions, that would render a central position less frequented or vice-versa.

In the context of the issue at hand, the rise of Koumasa during the Minoan period, despite its apparent topographic limitations, was discussed above.⁵²⁸ The role of Kophinas sanctuary and the harbours in the Asterousia can be one of the latent factors that allow for a node to emerge in the area of Koumasa. Of course, harbour use during the Minoan and Post-Minoan periods might have varied significantly. They might have functioned as pit stops for ships on their route towards destinations like Kommos or, later, Matalon. Alternatively, they could have served as end stations, or perhaps their role might have comprised both possibilities. The parameters to be explored include aspects of the political landscape that could exert pressure on controlling trade routes. During the Palatial period, would eventual shortcuts through the Asterousia be seen as a potential loss of revenue for a centralised power in the Phaistos area, or would this possibility offer advantages in connecting the far inland locations with their coast, thereby enhancing the trade networks within the Messara, thus fitting in a narrative of decentralisation? Similarly, the chronology of the Kophinas sanctuary is known. But to what extent would a settlement like Koumasa profit from its strategic location along the access route to the peak sanctuary from the west? What GIS can contribute – and will be explored in this chapter – is the analysis of possible linking routes, followed by a quantitative comparison to provide an evaluation. Additionally, comparing the paths from the small harbour areas to Koumasa with the route toward Kommos would be of particular interest. Evaluating these results may offer insights into such a network's potential existence and functionality. The qualitative analysis, taking into account the archaeological finds, will be discussed in Chapter 10.

of settlements and a network pattern for each site is extrapolated with a preferred daily travelled distance of 10 km. This idea is further explored with cost catchment models in Surface-Evans 2012. Similar efforts include Byrd et al. 2016 which examines the results of modelling foraging ranges for late Pleistocene locations in the southern Levant.

528 See discussion on pages 84ff.

4.3 Costs

A fundamental challenge of the method lies in quantifying the difficulty of paths, which is crucial for establishing a reliable framework for assessment and comparison. A central concept in the development of these algorithms is the “currency cost”: In summary, it is used as an indicator of either time or energy required for traversing a sloped terrain. The popular Tobler’s equation discussed below assumes time as a currency.

The main parameter used in archaeology over which cost is defined is slope, which was favoured since the dawn of the GIS usage, as it was argued that slope can reasonably predict actual human movement costs.⁵²⁹ It is, however, the method that diverges most when compared with other methods, and has some intrinsic problems, (as will be explained below further, in Chapter 4.4). Therefore, careful implementation is required.⁵³⁰

Isotropic-Anisotropic

Generally, the costs can be divided in two types, isotropic and anisotropic, referring to those independent and those dependent on the directionality of movement. The isotropic calculation is frequently employed in cost accumulation techniques, wherein the cost of a path between two points is treated as equal, regardless of the direction or the starting point.⁵³¹ Vegetation, land cover, an approximately flat surface and the calm sea can be considered isotropic, and the algorithm assigns the same level of costs independently of the content of the neighbouring cells. Meaning that movement from a cell to each of the neighbouring eight cells will add the same cost as movement to it. Whereas this does not occur in anisotropic movements, such as up and down a river, or – more relevant to the task at hand – steep slopes.⁵³²

Ancient forestation or presence of thieves or other social barriers cannot be easily represented. Also, after a certain degree of the slope (discussed analytically below) will force shortcuts or zigzagging. Another element for choosing a path is the readiness of the walkers and the nature of the path, with an established path being of course much easier than a similar one in virgin terrains.⁵³³

Time – Energy Currencies

Various GIS approaches stress the element of time, following Bintliff who underlined the importance of walking time rather than map distances in the evaluation of the actu-

529 A fact often mentioned (see Herzog 2010, Kantner 2012, 226) that becomes obvious when one looks at the archaeological case studies.

530 Kantner 2012, 234. As he adds, one solution to verify the results is beyond GIS, namely to empirically test the algorithms with contemporary examples of human movement.

531 Llobera – Sluckin 2007; Kantner 2012; Déderix 2017.

532 Conolly – Lake 2006; Herzog 2013a, 18.

533 Llobera – Sluckin 2007, 216.

al feeling of a distance between to places.⁵³⁴ Regardless if it was known to him, he put forth the same argument that was used in the beginning of the 20th century by Pendlebury of walking time rather than map distances. As he pointed out, “only those who have actually walked the mountains can tell how misleading a map may be”.⁵³⁵

An algorithmic model will rely on coding a mathematical expression, and there have been mathematical expressions correlating speed, or time directly to slope. Most algorithms are based on the most popular of these. These include the Naismith and Langmuir rules of walking time, which was used by the `r.walk` function in GRASS, and Tobler’s hiking function.⁵³⁶ The latter is extracted from data of the Swiss military on walking time, and is frequently used by a number of developers.⁵³⁷

Downhill movement is easier for humans up to a certain degree than uphill movement.⁵³⁸ This is demonstrated in the Tobler-function, which will yield different results for movement between two points, based on the direction of movement.⁵³⁹ The $T(x)$ function used in Chapter 4.5 represents the isotropic version of the Tobler function, taking the mean of the two anisotropic functions. Various versions of this equation have been produced, taking time as the crucial factor to be determined.⁵⁴⁰

Other approaches focus on the weight and load of the walker,⁵⁴¹ and others on visibility.⁵⁴² The load of the walker pertains to energy spent. This term, in essence, corresponds to metabolic rate. Pandolf’s team analysed the correlation of load carrying and slope in laboratory conditions, the data of which were used to produce an equation of energy consumed as per slope. It was found that this has a significant impact on how people could move through the landscape and particularly the time required for movement.⁵⁴³

534 Bintliff 1977, 112–113.

535 Pendlebury 1939, 7. It is noteworthy that there is an effort to correlate Pendlebury walking times with those computed in GIS (Bevan 2010, 31–32, Fig. 2)

536 For an introduction and comparison of these rules, as well as their adaptation to algorithms used by GIS applications, see Herzog 2010, 377, Fig. 2; Wood et al. 2023, 2–4, Fig. 1.

537 Kantner 2012, 227 (see Tobler’s function below).

538 See Footnotes 547 and 566 below.

539 Tobler 1993. Moving away, often understood from a higher area to one further below. The equation representing speed is given by the equation: $f(s) = 1/(6 - 3,5 * \text{abs}(s + 0,05))$; whereas the different direction of movement is expressed by: $f(s) = 1/(6 - 3,5 * \text{abs}(s - 0,05))$; where s represents the slope degree.

540 Kantner 2012, 227. On the issue of choosing suitable functions for a problem at hand, see Antoniadis 2024, 118–119.

541 Duggan – Haisman 1992.

542 Verhagen – Jeneson 2012.

543 Pandolf et al. 1976; Pandolf et al. 1977; for developing the equation, see Duggan – Haisman 1992; for a critique of the results and suggestions for optimising, see Drain et al. 2017; for an application of the principle in extracting a velocity function, see Groenhuijzen – Verhagen 2015, 29–30.

4.4 Slope Issues

The debate about whether slope inherently represents a cost surface or if it requires additional weighting is complex and depends on factors such as the topography of the area in question. Kantner's differentiation based on whether the area is relatively level or not is relevant, as it influences amongst others the isotropy or the anisotropy of the slope.⁵⁴⁴ The region of Koumasa combines both possibilities in all of the three scales under study. The area to the north of Koumasa tends to be closer to a level terrain, while to the south, it is more rugged. This mixture of conditions necessitates careful consideration of the isotropy or anisotropy of the slope in the analytical process but also of the model used.

The consideration of how humans, animals carrying load, or wagons navigate slope inclines is crucial in understanding real-world movement patterns. The tendency for individuals is to adopt a zigzag – or switchback – approach on steeper slopes, deviating from the direct path, and favouring a less steep sideways path with sharp turns. The angle of slope, above which a Z-shaped path is favoured, is dubbed as “critical angle”. This behaviour is a practical adaptation to reduce the overall steepness of the ascent and make the climb more manageable, albeit longer in total distance. It introduces a level of complexity that goes beyond a simplistic linear path, and capturing such nuances is important for a more accurate representation of movement in the landscape.

The choice of establishing such paths is highly connected with the difficulty to a walker per unit distance. In the analysis of this phenomenon is dubbed “metabolic cost”, and is defined as a function of the gradient in the direction that the walker is travelling and of the total distance. Plotting the calculated function the metabolic curve is received, as seen in Chapter 4.5.

Most approaches try to identify a critical angle, or slope, above which either a zigzag pattern is sought or the path would avoid. It was seen, a fact that for terrains with a gradient less than the critical angle, or slope, zigzagging is adding no benefit to the walker. The generally accepted limits are around 15 degrees for carts or heavy load and 25 degrees for paths.⁵⁴⁵ For antiquity, it was observed that Roman roads almost never exceed 15 degrees.⁵⁴⁶ Using more advanced approaches to the issue, critical slope was calculated by Llobera – Sluckin at around 16 degrees upwards and 12,4 degrees in downward movement.⁵⁴⁷ This critical gradient is steeper for uphill walking than downhill, which directly renders slope as an anisotropic criterion.

544 Kantner 2012, 227.

545 This limit stems back to Langmuir 1984; in Llobera – Sluckin (2007, 216), the notion is made that modern roads are often based on paths, pulling thus the limit towards their result (see next footnote). This was noted also in Tobler 1993, 2. Often, a value of 20 degrees is given.

546 Verhagen – Jeneson 2012, 125; Antoniadis 2024, 110.

547 Llobera – Sluckin 2007, 215. The authors note that their results fit with the empirical knowledge. This is visually best represented in Llobera – Sluckin 2007, Fig. 5, following the analysis in: Llobera – Sluckin 2007, 208–12.

It is noteworthy that the upper limit for the Roman road is fitting with the Llobera-Sluckin results. Furthermore, it allows for higher degrees in the less demanding conditions (both in distance as well as in transfer means and requirements) of the interest area in this work. Efkleidou offers a summary of the approached on critical slopes.⁵⁴⁸

In the relatively narrow central Asterousia, the number of paths is limited, as will be shown in the chapters below. Therefore, a two-direction road can be assumed. This understanding opts for isotropic application. Coming back to the question of energy and time as cost currencies, most of the above mentioned ideal-slopes for roads pre-assume a macrocosm in which options for avoiding mountain areas are possible. Movement within Asterousia however, including the transportation of goods, requires a different approach. On the issue of the critical slope, the area lacks paved roads or smooth paths, that large scale transport requirements of later periods would presuppose, such as the Roman road networks, which is the subject of many of the GIS-based movement analyses.⁵⁴⁹ Therefore the critical slope will be revisited with *ad hoc* approaches, in Chapter 5.2, Study 3. As per the movement itself, humans carried load could be considered as well as the use of equines.

The parallels from various cultures of using equids for transport in mountainous terrain are numerous, as the donkey (*equus asinus*) is better adapted and surer footed in hilly and mountainous terrain.⁵⁵⁰ Furthermore, in longer distances the use of animals is more economic for transporting goods, as the crew needed per kilogram transported is minimum.⁵⁵¹ The equids are used to carry 75–80 kg. of load when divided on the two sides, a practice recorded for modern and ancient Near East alike,⁵⁵² while on the extreme side of modern use, more than 100 kg. on smooth surface have been recorded.⁵⁵³ Regarding mountainous terrain, measuring the oxygen consumption, donkeys running at full speed on 10% slope performed excellently, although causing more fatigue.⁵⁵⁴ Furthermore for short distances up to 8 km., even in uneven terrains, a donkey can carry more than half its weight.⁵⁵⁵ These data indicate why donkey and mule is a preferable way of transport in mountainous areas, with studies being done worldwide, from South Africa, to the Andes. These studies indicate a 100 kg. weight limit is a practical consideration, taking into account both the capability of the animals and the challenging terrain

548 Efkleidou 2019, 491–92.

549 E.g. Verhagen – Jeneson 2012; Groenhuijzen – Verhagen 2015; Abou Diwan – Doumit 2017.

550 Brodie 2008, 301.

551 Brodie 2008, 301.

552 There is old Assyrian textual evidence for a standard load weight of 75 kg recorded for the ass (Larsen 1967, 141–155), which, as Shai observes, is very near the modern practice recorded in Egypt, which is 80 kg (Shai 2016, 4).

553 Bukhari et al. 2021; 2022.

554 Mueller et al. 1994, 1433–1438.

555 In a study for equine use in Pakistan, donkeys and mules travelling over 8 km. per day were more than 90% likely to carry loads of more than 50% of their body weight (Bukhari et al. 2022, Table 3; Fig. 3).

they may encounter. Overloading can lead to difficulties in transportation, especially in areas with steep slopes, and can cause fatigue in the animals due to the complexities of mountain topography.⁵⁵⁶

Modern use of donkey use in the Asterousia is known.⁵⁵⁷ To what extent can such a usage be assumed for the Minoan times? While no direct finds in the southern Messara support this idea, the equine's presence and use on Minoan Crete is considered secure. A sub-species of the African wild ass is recorded for Egypt of the 4th millennium and in western Asia in the 3rd millennium at the latest, perhaps since the Chalcolithic.⁵⁵⁸ Its integration into the rural culture around the Mediterranean is manifested in the animal's representation in art and literary references, as it was able to carry a huge weight for very long distances.⁵⁵⁹ Its earliest presence in the Aegean is from a zoomorphic terracotta in Sitagri III (early 4th millennium) and physically attested through bone fragments in Lerna since the EH II.⁵⁶⁰ On Crete, the earliest evidence for equids is through assumed representation on seals as early as MM IA and one with a MM IB–II or EM chronology from central-east Crete, on an engraving of a three-sided prism bead representing an equid: an ass according to Evans or a horse according to Kenna.⁵⁶¹ The donkey's head appears as a sign in the MM hieroglyphic syllabary⁵⁶², that could denote a significance for the newly arrived animal. Modern bone analyses suggests neolithic dates for the first equites on Crete with a greater presence beginning in the MM I period.⁵⁶³ A main

556 See a study conducted on the mules used today in rural villages on the Andes (Pineda – Florio-Luis 2016, 77).

557 In the earliest mention of walking on the Asterousia by Fynes Moryson in the 16th century, the essential role of equines is made clear (see Footnote 1104). On modern use in the area of central Asterousia, see discussion on page 1138.

558 Shai 2016, 1–2.

559 For Minoan representation, see below. As for other Bronze Age references for the use of the equid, the Middle Kingdom story of the “Eloquent peasant” from Egypt is enlightening, as donkey caravans are mentioned carrying load from his home to central Egypt: “Then this peasant left for Egypt, after he had loaded his donkeys with vine, purple nutsedge, natron, salt, sticks from [...], pieces of wood from Farafra, hides of panthers, skins of golden jackals, pondweed, anw-stone, tnm-plants, wild carrot, serpentine, s3kswt, mjswt-plants, ochre, wild mint, hedge plants, pigeons, narw-birds, gutted fish and plucked fowl, wbn-plants, tbsw-shrubs, gngnt-beans, fenugreek and anise. Abound with all good products of the Wadi Natrun This peasant then went south.”; lines 1.7–6.2 (Translation after Parkinson 1991). See also mentions of their use in the Assyrian textile trade in Anatolia in the 19th century BCE (Michel 2014, 113–114) and the standard load weight mentioned above (Footnote 552).

560 Brodie 2008, 299.

561 *Knossos IV*, 520; Kenna 1960, 94, Fig. 50.

562 Crouwel 1981, 36; the reading is, however, rather uncertain. For the sign in question, see Montecchi et al. 2021, Fig. 1, sign 014.

563 Only two bones have been dated to the Neolithic period, originating from Knossos and Kavousi. The subsequent period of presence commences from MM I, after which there is a consistent increase in data across all periods (Klontza-Jaklova 2024). The absence of evidence from the Early Minoan period and the initially low representation in the Neolithic may indicate that the presence of donkeys during the Neolithic was not sustained.

reason for their expansion is that donkeys are adept at navigating steep and rugged terrain, making them suitable for transportation in mountainous areas.⁵⁶⁴

The assumption of the hypothetical use of donkeys in the Asterousia area remains speculative. However, considering their arrival in Crete during the Protopalatial period, as suggested by evidence, it is likely that their use had an impact on trade, potentially expanding its usage to various regions.

The examples above illustrate that, regardless of how the mountain communities were connected, the methodology for identifying routes will differ from the most prolific methods used for more level plains. Hence, the study of the routes in the mountain will differ from parallel studies done for the Messara plain, with one difference being identifying time as the cost currency for walking in the valley and energy for movement on the mountain. Koumasa, namely, presents a challenge of being on the verge between the mountain and the valley, with a stark difference in the geomorphology. Besides the least-cost-path analyses, which could be divided into mountainous and level ones, the differentiation in the topography will pose an issue in choosing the functions for flow accumulation and the reclassification used, in which either the paths of the mountainous region or those of the more level Messara region show more realism, but not both at the same time, as it will be presented below (Chapter 5.3.2).

4.5 Functions

One of the most known equations taking time as its currency is given by Tobler's hiking function, as presented above, which was estimated from empirical data given by the Swiss military.⁵⁶⁵ In this function, the critical slope can differ in anisotropic algorithms, e.g. 11 degrees for ascending and 23 for descending.⁵⁶⁶ Function $T(x)$, as presented in Figure 19, represents one of the isotropic versions of Tobler's function. The pace is the element shown, which is the reciprocal to speed.⁵⁶⁷

The critical slope is a parameter representing the limit where the transition to zig-zagging (or switchbacks) becomes more effective than direct uphill or downhill paths. For a small downward slope of 5% until a 1-degree upward slope, the speed maximises (the -0.05 in the exponential causes an offset to -2.8 degrees of slope). It is noted that off-path travel increases the difficulty by a factor of 0.6.⁵⁶⁸

There are many variations of the Tobler function, with the Kondo and Seino Function resulting in a much steeper drop-off in speed with increasing slope compared to

564 Crouwel 1981, 43.

565 Imhof 1950, 217–220; See Footnote 539.

566 Kantner 2012, 227–228.

567 Based on the formula $1/6 \times \exp(-3.5 \times |\tan(x) + 0.05|) = 0.6 \times \exp(3.5 \times |\tan(x) + 0.05|)$.

568 Tobler 1993, 2.

4 Modelling Movement Patterns

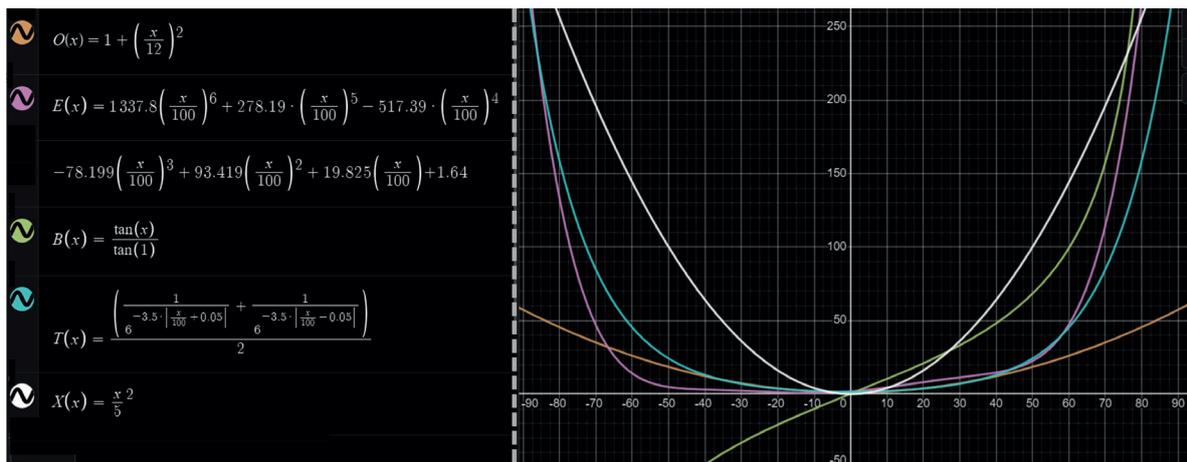


Figure 19: Overview and plotting of the functions under discussion.

Tobler’s function, meaning it models higher movement costs on steeper slopes.⁵⁶⁹ A further example, $E(x)$ function in Figure 19, is a fifth-degree polynomial curve that was proposed as an energy consumption function, based on physiological data, which has nevertheless been criticised for the downhill slope values.⁵⁷⁰ These modifications did not yield different results than the Tobler in the region of interest, possibly due to the relatively small area of the mountainous region of the central Asterousia, and thus will not be discussed further, although their applicability in larger areas should be taken into consideration.

An effort to improve these algorithms is undertaken based on empirical data of walking from all around the world.⁵⁷¹ Other approaches, however, take human metabolism as a factor, as discussed in Chapter 4.3. It is clear that the reality is more complicated if carts or load-animals are taken into consideration.⁵⁷² As for carts or animal-powered movement, the “Ox cart” function is one proposal to codify this type of movement, which could also be considered for moving with the load on animals.⁵⁷³ The function was used considering a critical slope of 12 degrees.⁵⁷⁴

569 $KS(x) = 5.1 \times \exp - 2.25 \times \text{abs}(\tan(x) + 0.07)$, while the energy spent is given by a modification of the inverse for the speed, $0.315/5.1 \times \exp - 2.25 \times \text{abs}(\tan(x) + 0.07)$. See Kondo – Seino 2010, 162–163.

570 Herzog 2013a, 184.

571 Kantner 2012, 234.

572 For the question of donkeys, see above. As per carts and their use in the Aegean Bronze Age, see Crouwel 1981.

573 Llobera – Sluckin 2007; Herzog 2010, 378.

574 $1 + (x/12)^2$.

Two other easily implemented functions include one based on the tangent of the slope ($B(x)$ in Figure 19).⁵⁷⁵ This equation states that the relative cost of moving either up or down the slope is equal to the tangent of the slope (s , in degrees) divided by the tangent of 1° .⁵⁷⁶ The final function approximates a second-degree polynomial, where the raster is reclassified with steps of 5 degrees, and the cost assigned to each step increases analogous to the x^2 function ($X(x)$ in Figure 19). This is often referred to as an exponential function, a name which is adopted here, although the name is not precise.

Figure 19 offers a summary of the main functions discussed and used in this work. This graph is used as a representation and not as a classification of the cost units chosen, be it energy or time-based. Their currency (y-axis) is portrayed here in a nominalised way in order to allow for a visual representation and is plotted against slope degree (x-axis).⁵⁷⁷

The Ox-cart function $O(x)$ does not increase at the rate of the others, walked by humans carrying the same load, which is a logical conclusion. It assumes zigzagging for higher slopes, however. $E(x)$ is anisotropic, as the cost (energy required, i.e. difficulty) rises more rapidly for uphill movement. However, its results in the high slopes downhill have been criticised as mentioned above. Its results do not differ rapidly from the mean Tobler function $T(x)$ for a slope less than 60 degrees, which includes the range of walkable slope. For this reason, within the scope of this work are considered similar. Bell-Lock's tangent function $B(x)$ is isotropic if the absolute value is taken, but here it is plotted to include all integers to showcase the relation of the function to the tangent. Its characteristic is that it mathematically never crosses 90° which fits the theory of the slope. In relation to other functions, it is closer to the exponential function, and could be used for the scope of studying movement in the Messara. It is somewhat closer to the linear function for degrees up to 40° . If $\tan(2)$ is used instead of $\tan(1)$ in the denominator, the function comes closer to Tobler's function in the high-degree slope, but it yields less natural results overall, especially in the small degrees where the function is very close to the linear function $f(x) = 2x/3$ for degrees up to 50. Finally, the exponential function ($X(x)$), although it varies from the empirical data, nevertheless could be argued that it can be used as a crude approximation of them, which has the positive aspect that it is easy to implement. Especially in more theoretical approaches, such as those in this work, no great differences or crucial errors were observed using this function when comparing it with the results of the others.

Discussion

Another point related to the nature of Zipf's principle applied in computers is the monosemantic result pattern. The optimisation component will push less-than-optimal

575 This model relies on the friction surface: $C = \tan s / \tan 1$. Bell – Lock 2000, 88–89. This function was used by Déderix (2017, 15–16).

576 Bell – Lock 2000, 88–89.

577 Plotting the equations was done with the help of the site: <https://www.desmos.com/calculator>.

solutions to irrelevancy, leading to one clear result. This will offer “one” good solution, but as we know from experience, the most optimal route is not always the one chosen. Also, choosing between the determining factor of time and energy (i.e. metabolic cost) is not always easy. Small variations from the major path are expected between two points when terrain and other parameters allow it. Furthermore, weighing other parameters not known to us plays a significant role in the presence of optimal paths.⁵⁷⁸

All accumulation cost and least-cost-path algorithms, beginning at the starting point, take the centre of each cell as a node and begin to form links with the nearby cells, exploring all possible directions. At its core, the spreading algorithm performs a raster-to-vector calculation. The produced links to the starting point will be weighed against each other as per the cost, extracting the most beneficial one. During this process, essentially, a conversion of the input raster into a weighted graph with positive weights proportional to the travel cost is extrapolated. Although different algorithms are available, most rely on Dijkstra’s algorithm, a brute-force algorithm that has not been free of criticism.⁵⁷⁹

Due to its user-friendliness and compact design, Esri’s ArcGIS is one of the most popular solutions, and due to its widespread use in archaeological research, it is used here as a parallel control of the results.⁵⁸⁰ The main source of the presented results in this work is based on the platform of QGIS, which has the benefit of being open-source, with its algorithms being more transparent and amendable.⁵⁸¹ A negative is the lack of the holistic approach offered in ArcGIS.⁵⁸²

An augmentation of these methods is experiencing the suggested paths by walking the mountains. This empirical verification was done both as an effort to verify the suggested paths, as, in the end, the algorithm is based on simplifications, starting from the raster form of the DEM itself, which is, after all, an approximation of reality. Evaluating the suggested paths offers tangible information not subject to algorithmic methods but based on the human element. Further, it offers an experience no map can provide; an empirical understanding of the surroundings, be it the terrain characteristics, the wind, perception of the surroundings along the way, and even the fatigue felt after a long mountainous walk. Pendlebury had already touched upon this within his effort to experience walking the island as opposed to merely studying it on a map.⁵⁸³

578 Variations on the parameters have been suggested as a method to confront this issue, and is the reason for the approach undertaken here (Saerens et al. 2009; Herzog 2013a, 199).

579 White – Surface-Evans 2012; Schild 2016, 19.

580 Abou Diwan – Doumit 2017, 229.

581 Versions used are 3.16 Hannover and 3.28 Firenze.

582 For a practical comparison of the methodologies, see Seifried – Gardner 2019, Chapter 4.

583 See above Footnote 535.

It is crucial to physically traverse paths to empirically test algorithms, rather than just calculating them, using contemporary examples of human movement before applying them to prehistoric scenarios.⁵⁸⁴

Walking is part of the sensory experience involving all senses, for which it can be argued that is subject to investigation of the archaeology of the senses.⁵⁸⁵ It renders the activity of path walking to the overall experience of living in that place and puts the researchers (literally) in the footsteps of ancient inhabitants' everyday lives (see Chapter 11 for further elaboration).

584 Kantner 2012, 234.

585 Hamilakis 2011, 209, 216–217.

5 Insight of GIS for the Mobility Networks around Koumasa to Messara

Using geodata as the primary analysis tool prerequisites a consensus on the unchangeability of the region for the subject time period. The Messara-Asterousia region has not experienced a significant change as it appears in other locations (such as the presence of man-made lakes, major modern constructions, etc.). The coastline of the eastern part of the island is considered fairly stable, as discussed above,⁵⁸⁶ a fact verified, amongst others, by the presence of ancient harbours at the modern coastline. As for the mountain range, the natural corrosion and landslides might have affected certain locations on the microscale, especially given the earthquake history of the island as an area, i.e. certain rock collapses that block or free certain paths and thus minimally affecting human walking behaviour, but in the macroscale, a terrain stability can be assumed.⁵⁸⁷ A large-scale change in the region is climate-based, caused by deforestation and fires; however, a fully forested Asterousia that would block the ways is hardly conceivable. It is to be added that there are not enough sources on this matter.⁵⁸⁸ Literary notions such as the large-scale fire in the Asterousia upon the first Ottoman period can be considered exaggerated. Still, a core of truth in this narration could be considered valid.⁵⁸⁹

In Chapter 5.1, the setting up of the GIS project is presented; in Chapter 5.2, the implementation of the concepts elucidated in the preceding chapter is presented in the case of least-cost-path analysis, offering a more detailed exposition rather than merely presenting the raw results.⁵⁹⁰

586 For changes in the geology of Crete, see Chapter 2.4.1.

587 Stiros – Jones 1996; Jusseret – Sintubin 2017. See also Discussion in Chapter 2.4.1.

588 For our knowledge of forestation on Crete, see Chapter 2.4.2.

589 See Vrentzou 2017, 32.

590 The wide and ever-growing available literature on the subject, ranging from the fields of computer science, geography to archaeology, the main bibliography for the steps in this chapter includes Déderix 2016; 2017; Schild 2016; Seifried – Gardner 2019.

5.1 Setting up the DEM Modell in GIS

The first step for the analysis is deciding on a DEM, its resolution and its range. It has been presented that a finer resolution than 30 m. for a large area does not affect the results of least-cost-path analyses, even by going down to 5 meters: In a 2012 study, a 5 m. resolution Airsar DEM produced very similar results to that of a 30 m. Aster DEM. Those, in turn, were seen as very accurate compared to a 90 m. DEM.⁵⁹¹ It should be noted that vertical accuracy is, for some developers, a much more relevant criterium than that of spatial resolution and should not be overlooked.⁵⁹²

For the purpose of this work, a DEM for the Messara-Asterousia region was requested from Mr. A. Sarris and provided, courtesy of the Laboratory of Geophysical-Satellite Remote Sensing and Archaeo-environment IMS-FORTH.⁵⁹³ The region chosen ranges between 0 and 1470 m. above sea level and has an accuracy of 20m. It is bordered by the Libyan Sea to the south and southwest, and includes the large Messara plain, the southern slopes of the Psiloritis, and the Asterousia Mountains (see Figure 20). This DEM will henceforth be referred to as the 20m.-DEM

Another raster (SRTM DEM) extending to the whole central Crete from with 30 m. accuracy was used.⁵⁹⁴ This raster will be referred to as the 30m.-DEM.

After receiving the DEMs, functions and cost attributions could be made to export useful results. The DEMs were imported in Esri ArcGIS and QGIS for quality control, but the results from the two programmes were identical. ArcGIS will mainly provide the following images in this chapter, while the QGIS images were mainly used in the other chapters.⁵⁹⁵ The illustrations created with ArcGIS will primarily use the “terrain” base map, while in QGIS, the “hillside” base map will be mainly utilised. Other options, such as topographic and satellite imagery, will also be included, as each base map provides a unique perspective on the area being analysed.

After experimenting with a variety of coordinate systems, the two main projects were set to the Greek Hellenic Geodetic Reference System GGRS87, EPSG: 2100 and UTM 35N, EPSG: 32635.⁵⁹⁶

A next step to be taken is the extraction of the zero value from the DEM, thus removing the possibility of sea route. Then, from the sea-free DEM a slope raster can be produced that will not allow the sea route in the search for optimal paths.

591 Doyle et al. 2012.

592 Racoviteanu et al. 2007.

593 I would like to express gratitude to Mr Sarris and IMS-FORTH for allowing the acquisition of this raster.

594 NASA Shuttle Radar Topography Mission (SRTM GL1) Global 30m Ellipsoidal, acquired from <https://opentopography.org/> (Data exported in a WGS84 [EPSG: 4326] coordinate system).

595 This choice should not reflect a preference for one of the two solutions, except in some respects to be presented separately.

596 A third parallel project was run using the raster coordination system EGSA87_Transverse_Mercator, with no influence on the results.

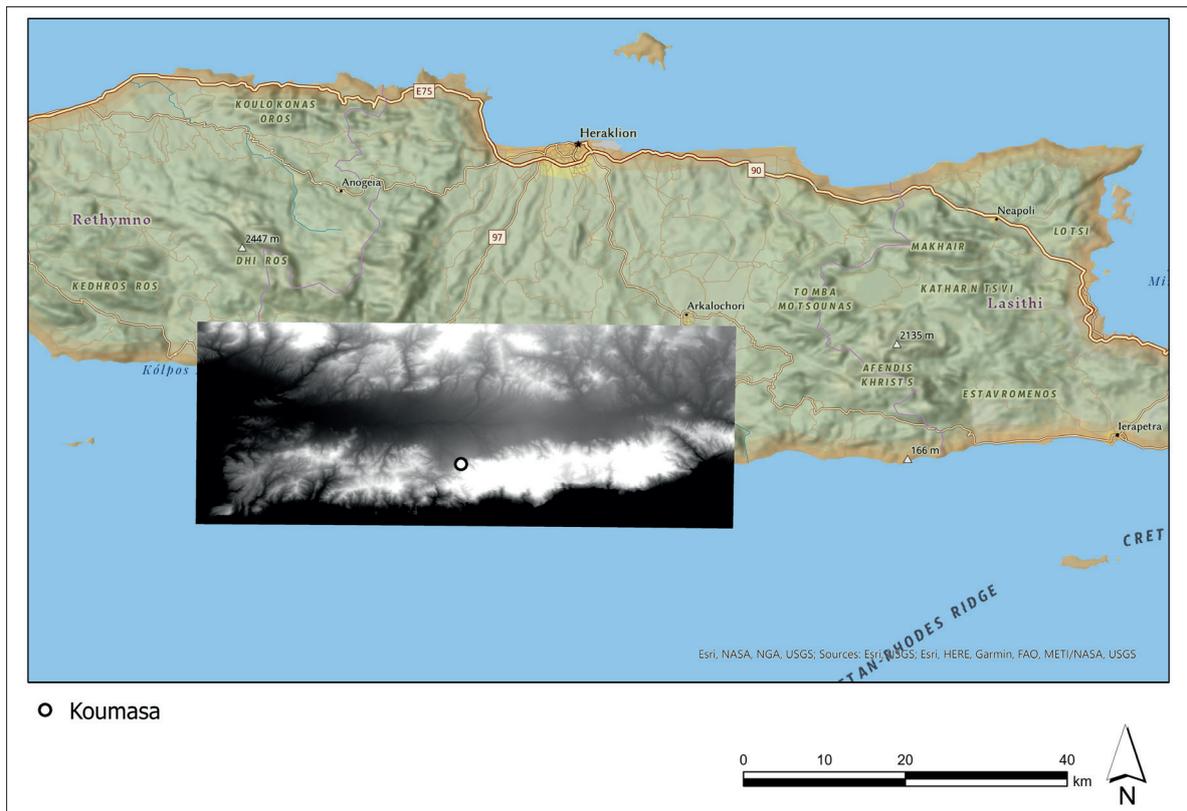


Figure 20: The extent of the acquired 20m.-DEM model. The SRTM 30m Model extends to the whole of central Crete, from Ierapetra to Prasies by Rethymno.

The zero value is useful to remove since calculations of walking on land would otherwise tend to use the zero value, which, in the examples of this work, are either the sea or the area outside the DEM. This step can be taken on the slope raster if the region under study does not contain level areas.⁵⁹⁷ This is a common procedure in regions proximate to the sea, especially when determining the viability and efficacy of land routes is of concern.⁵⁹⁸ However, in some of the iterations, the DEM, including the zero value, will be presented, as the nature of the sought network around the Asterousia cannot exclude the zero-value connection, as the sea shortcuts are vital.

A slope raster was extracted, both in degrees and in percentages. The mean slope value in the case of the 20m.-DEM is calculated at 13,5 degrees while the maximum slope (located near the Kophinas peak) reaches 79 degrees. As is to be expected from a mostly even surface, the mean deviation around the mean is 10,74. The 30m.-DEM produces slope that reaches a maximum of only 72 degrees, which is an effect of the higher

⁵⁹⁷ In ArcGIS the zero value can be replaced with *nodata* from the reclassification toolbox set. In QGIS there is no tool to make the transformation automatically, so the zero value can be removed by utilising the Raster calculator and applying the following transformation: $(\text{"DEM_Slope_re@1"})/(\text{"DEM_Slope_re@1"}>0)$.

⁵⁹⁸ E.g. Schild 2016, 24.



Figure 21: Calculated slope on the 20m.-DEM after removal of zero value (sea level). Locations of interest around Koumasa are 1: Apesokari, 2: Trypiti, 3: Salamias bay, 4: Ayios Ioannis, 5: Dhamantri.

degree of rasterification (or pixelation) of the second case. Figures 21 and 22 show the slope from the DEM without the zero value for the two DEMs.

The slope in degrees will be used in the next steps as it is the most commonly utilised cost surface for further cost-path analyses. Given its long-standing success in GIS archaeology, as mentioned earlier, and the wealth of parallel case studies, this approach will be favoured in this work. However, it is important to note that other methods are available where using percentages may be more practical.

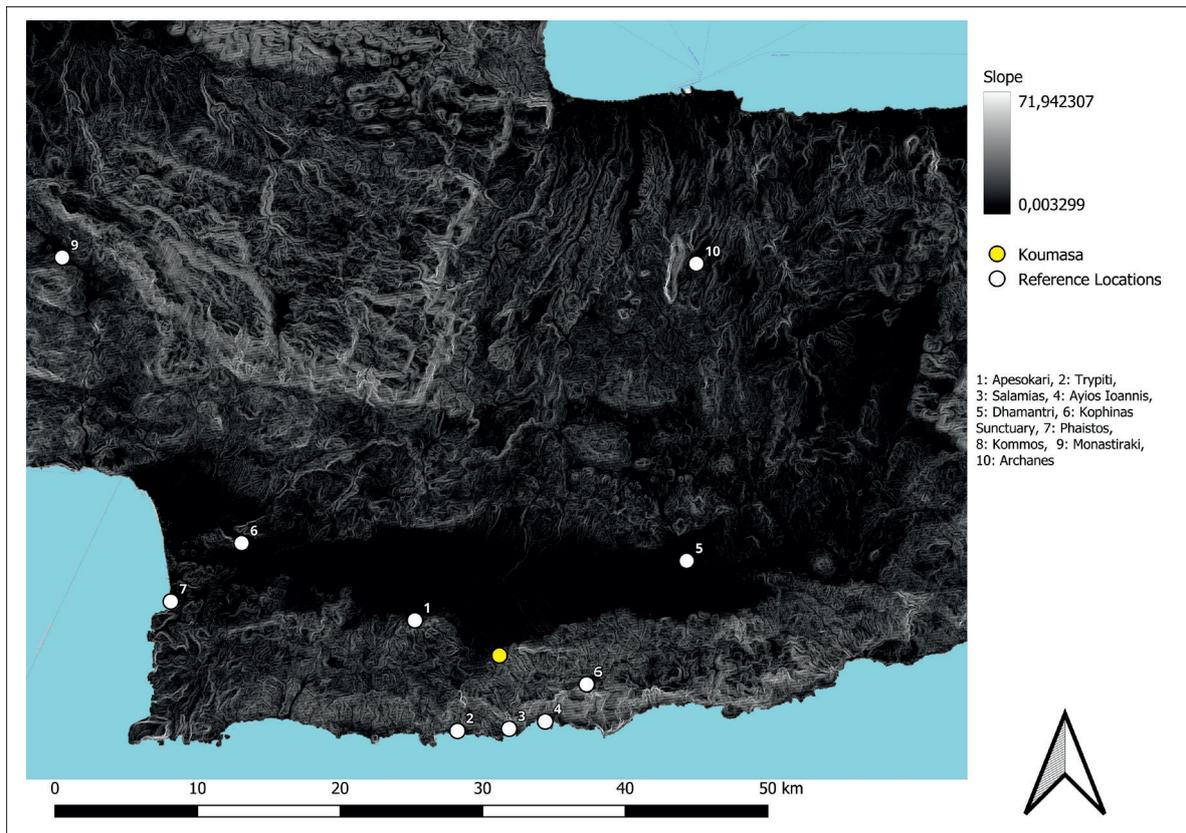


Figure 22: Calculated slope of the 30m.-DEM, after removal of zero value.

5.2 Least-Cost Paths Between Defined Locations

Least-cost-path analysis building on its implementation thus far in the Aegean Archaeology⁵⁹⁹ is used here to study mesoscale and macroscale of Koumasa and paths around the central Messara and central Asterousia. In Chapter 6, the same methods presented here are used for the microscale of Koumasa. For the primary investigations of paths through the Asterousia the method of least-cost path is first presented. Separate iterations were conducted and presented analytically below, with the results of each contained therein. At the end of the chapter, under the conclusions, a summary of all the results of the least-cost-path analyses will be presented together with an evaluation of this method, which, although not sufficient on its own, nevertheless yields useful insights.

In this first application, the direct method was used, where the locations of interest are preassigned by the author so that the programme will enforce a search based on the preloaded places. The optimal paths are calculated using the cost distance tool from the

⁵⁹⁹ See Siart – Eitel 2008, Fig. 1 for paths in central Crete; Efkleidou 2019 for paths around Mycenae; Antoniadis 2024 for paths from Knossos.

spatial analyst toolbox, the slope from the DEM as an input parameter, and the vector layer of the chosen locations as the network nodes.

This approach clearly has the limitation of assuming direct connections of the assigned locations, so any unknown nodes that had been places of interest but are unknown to us will not appear. The question of finding paths through a mountain range for archaeological purposes is fruitful when these connections are proven, such as in the work done by Schild regarding the mountain range of Amanus to calculate the paths across the western and eastern side of the Amanus Mountains regarding investigations for the Bronze Age and Iron Age communication networks in modern southeast Turkey. There, the points chosen were on the foothills of the two sides of the mountain range, and the optimal paths were searched.⁶⁰⁰ A second issue is that the method is sensitive to parameterisation since only the optimal path will be presented based on the criteria, which encourages the user to run multiple iterations.

Study 1

Based on the 20m.-DEM, the Tobler function of moving towards a location, the Ox-cart function, the Bell-Lock function, and the exponential (second-degree polynomial) function were used to produce optimal paths from Koumasa towards a chosen set of reference locations. Figure 23 visualises the paths, and Table 1 analyses their costs.

The routes in the Messara are, to a great extent, similar for all functions. The most obvious deviation is the preference for a more northern route towards Apesokari, Phaistos and Kommos by Bell-Lock and the exponential function (both pass through Vayionia, whereas the rest prefer the route near Vasilika Anoyia). The reason for this is illustrated in the plotting of the functions in Figure 19 above, as $B(x)$ and $X(x)$ have higher costs for medium slope than the others, thus the algorithm is pushed in preferring the lowest slope possible for walking in the valley, even though this does not reflect the reality of walking.

As for the mountainous Asterousia, there are more deviations between the functions. The direct way to Trypiti is recognised by all functions except the exponential, which favours a way passing through Krotos and north of Trachoulas. The other noteworthy deviation is towards Kophinas, for which a route through Panayia is proposed by $B(x)$ and $X(x)$. Both reflect the tendency of slope minimisation discussed above. The other functions have a greater degree of correspondence, with the Bell-Lock function being the one deviating the most, proposing a point west of Panayia to ascend to Kophinas, and proposing a route to Salamias and Ayios Ioannis through Trypiti via the coastline. As in the case discussed above, this function limits crossing high terrain, i.e. the Asterousia, as much as possible.

The Ox-cart and Tobler functions propose a route to Kophinas and to the coastal destination points that correspond most to the empirical data of walking (Chapter 11). The Ox-cart function is the only one recognising the route to Ayios Ioannis through

600 Schild 2016, 23.

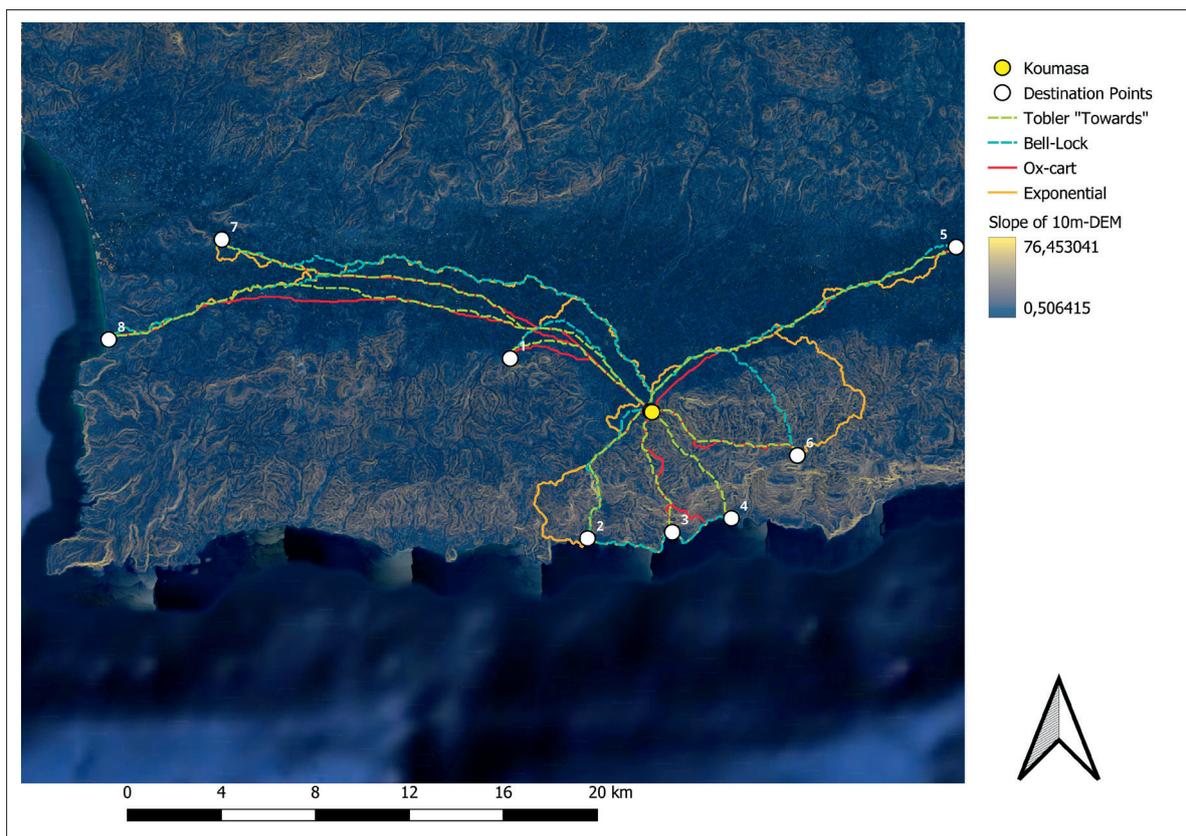


Figure 23: Least-cost paths from Koumasa to chosen locations; interpolation of 4 functions. Based on 20m.-DEM.

Seferis, which is a possible route but a difficult one.⁶⁰¹ Similarly, both functions propose a direct route to Salamias through the Salamias Gorge, which is rather misleading due to sudden drops of elevation in this gorge that are not captured in the 20m.-pixel DEM.⁶⁰²

In summary, the Ox-cart and Tobler functions appear to be closer to the reality of walking. The table compares the costs for walking from Koumasa to the reference locations, with the numerical sequence of the difficulty of each path per function shown in brackets. Normalised costs, based on the shortest distance for each function, are also presented for a visual representation of the results. The locations are arranged based on their nominal distance from Koumasa, as the crow flies, which serves to prove the relative irrelevancy of this metric, a fact known empirically and also highlighted with the comparison to the actual difficulty of travelling to each location, calculated on the basis of the analysis per the functions.

⁶⁰¹ See discussion at the end of Chapter 11.1.3.

⁶⁰² See discussion on page 284f.

Table 1: Comparison of the costs for moving towards the reference locations per used functions.

Analysis Locations	Distance from Koumasa (km)	Tobler	Normalisation	Ox-cart	Normalisation	Bell-Lock	Normalisation	Exponential	Normalisation
Salamias	5.3	25914 (3)	1.5	737,256 (3)	1.72	40,393 (7)	3	1120,092 (6)	6.78
Ayios Ioannis	5.7	31572 (6)	1.82	883,319 (6)	2.06	43,112 (8)	3.2	1151,087 (7)	6.97
Trypiti	6.1	25623 (2)	1.48	626,696 (2)	1.47	32,707 (5)	2.4	918,588 (5)	5.55
Apesokari	6.3	17326 (1)	1	427,335 (1)	1	13,479 (1)	1	176,460 (2)	1.06
Kophinas	6.5	30437 (5)	1.76	764,054 (4)	1.78	39,391 (6)	2.9	1338,886 (8)	8.1
Dhamantri	14.8	30325 (4)	1.75	852,652 (5)	1.99	17,245 (2)	1.3	165,216 (1)	1
Phaistos	19.6	41028 (7)	2.3	1143,952 (7)	2.6	24,242 (3)	1.8	240,431 (3)	1.4
Kommos	23.2	50728 (8)	2.9	1389,952 (8)	3.2	29,766 (4)	2.2	259,080 (4)	1.57

As for their costs, as the table above shows, Tobler's function considers Apesokari the quickest to reach, with Phaistos and Kommos the furthest. Normalisation was performed on all elements of the table based on the path with the least-cost for each function to facilitate a comparative analysis. In the case of the Tobler model, the least-cost path is the one to Apesokari, which was assigned a value of 1. When normalising according to this quickest route, Kommos has a cost distance that is 2.9 times greater than that of Apesokari, while Phasitos is 2.3 times greater. (i.e. Apesokari is 2.9 times faster to reach than Kommos). Both Trypiti and Salamias have a time cost of 1.5 times the distance to Apesokari.⁶⁰³ This pairing is interesting as it showcases the effect of the mountain. Although Salamias is closer in cartographic distance, the walker would lose time due to the greater difficulty of this path. This is even better demonstrated for the next two locations, Kophinas and Dhamantri, where both have a similar relation close to 1.8 as per the normalised cost.⁶⁰⁴ Ayios Ioannis shows greater cost behind Kommos and Phaistos, at 1.82 normalised cost units. This is to be explained by the very mountainous path identified by this function, which is, to a great extent, unnatural (climbing to the top of Gerakias gorge, which is a significant effort). The longest distance is less than 3 times that of the shortest. The longest two are the furthest, which corresponds with this function's main optimisation being for time.

The correlation of the Ox-cart function with the Tobler is also seen in the costs, as the Ox-cart shows a similar sequence and normalised values with the Tobler. An

⁶⁰³ 1.48 for Trypiti and 1.5 for Salamias.

⁶⁰⁴ 1.75 for Dhamantri and 1.76 for Kophinas.

inversion is seen in the sequence of Kophinas and Dhamantri. The normalised ratios also change slightly, with the difference between Dhamantri and Ayios Ioannis being minimal. Again, the route to Ayios Ioannis shown by the Ox-cart is not the one chosen when walking, but the path shown exists. The one indicated by Tobler to Ayios Ioannis, however, cannot be walked without climbing.

In Bell-Lock function, the smallest cost is again for Apesokari, with the cost, beginning from this iteration being the metabolic factor. Dhamantri is 1.3 times more fatiguing to reach. Phaistos and Kommos follow with 1.8 and 2.2 times the normalised value, respectively, with the mountainous path to Trypiti (at 2.4) and Kophinas (at 2.9) following. The last two places are occupied by Salamias and Ayios Ioannis, which are shown accessed through Trypiti, leading to a less accurate path cost. The most difficult distance is due to these last two locations, more than 3 times that of the easiest.

The Exponential function vary the most also in its costs, as can be seen in the table. As in the Bell-Lock, Salamias and Ayios Ioannis are accessed through the coastline from Trypiti, with the algorithm failing to find the mountainous ways (as discussed above, and as seen in Figure 19, the exponential function would stress the minimisation of slope more than the others). This contributes to the distribution of the costs to be similar to the Bell-Lock. Dhamantri and not Apesokari is the lowest cost destination, although barely. A great variance is observed in the case of Kophinas, as the destination with the most cost is ca. 8 times more than the cost to Dhamantri.

This analytical presentation of the results of these functions should demonstrate the inadequacy of choosing only one method and further shows (or rather verifies) that Tobler and the Ox-cart yield good results when mountainous terrain is under investigation.

Study 2

Applying the same steps to the 30m.-SRTM-DEM with the addition of Monastiraki as a target (see Figure 24), the results for the other locations vary slightly but not greatly for those destinations discussed in study 1, which is in correlation with the notion that a 30m.-DEM is not crucially worse than a 20m.-DEM.

One of the most notable discrepancies is that the Bell-Lock and Ox-cart functions now show identical paths for Salamias and Ayios Ioannis, which is considered an improvement. The Bell-Lock function now provides a different route to Trypiti, avoiding the Trypiti Gorge. However, this new route is deemed impractical based on empirical criteria. A further simplification introduced by the wider pixels is noticeable in the level area of the Messara, where the Ox-cart function presents non-naturalistic segments of straight lines. This pertains to the lesser applicability of the Ox-cart function on level terrain, as it will be presented below.⁶⁰⁵

605 See an evaluation of these functions on page 639.

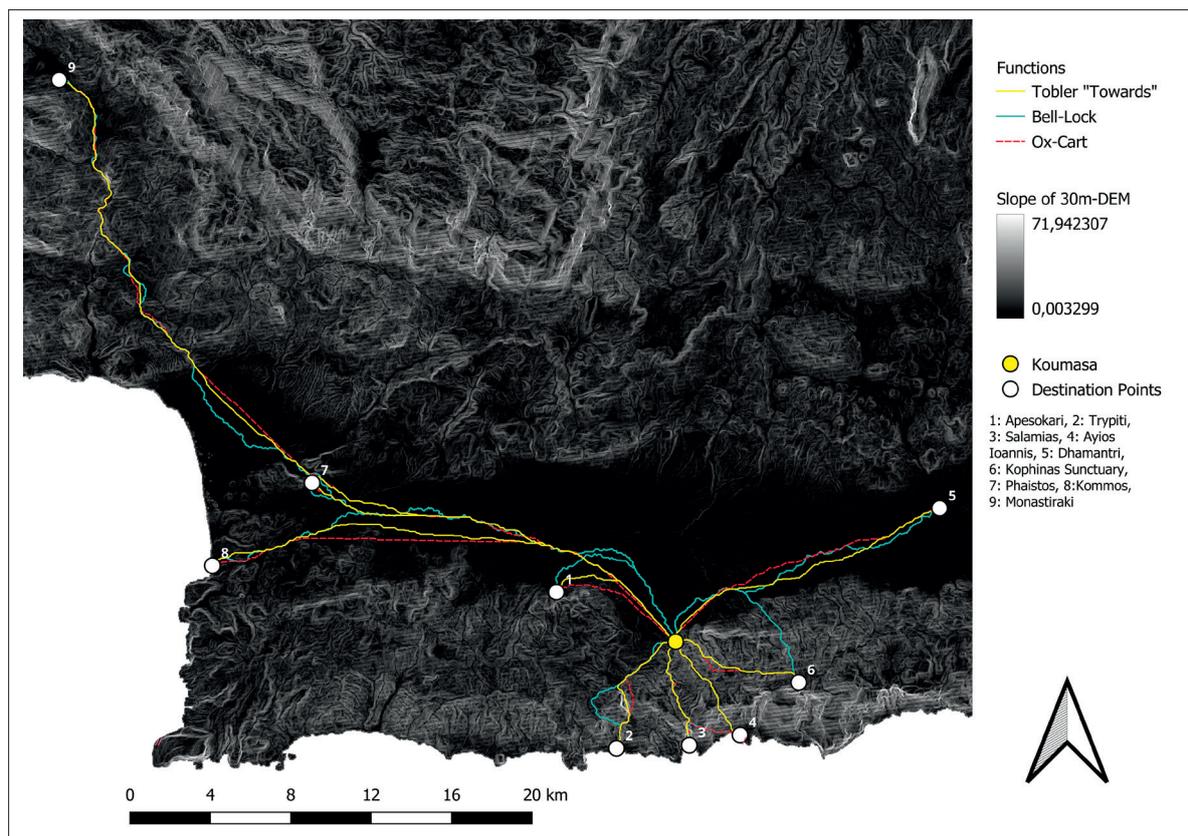


Figure 24: Least-cost paths from Koumasa to chosen locations on 30m.-DEM; interpolation of 3 functions.

Implementing Tobler and Oxcart, the least-cost paths were estimated, this time originating from Phaistos (Figure 25).

An interesting result, seen in the costs of Tobler, is that the path from Phaistos to Monastiraki is the second most costly after the path to Ayios Ioannis. The destination of Monastiraki is calculated to be 1.8 times more time costly than the path from Phaistos to Koumasa. In the case of the Ox-cart function, the path is 1.4 times more costly, approximating the distance ratio, which is 32 km. from Phaistos to Monastiraki and 23 to Koumasa.

Study 3

After studying the effects of various functions above, study 3 will follow a smaller scope of step-by-step implementation, aiming to take a closer look at the region of the Koumasa mesoscale and act as a guide for similar implementations.

As one of the interests of this work is showing the routes traversing the mountain range, only locations on either side of the Asterousia will be taken into consideration, thus excluding Kophinas in this study. Two Messara locations are included as a reference, which will also help the discussion.

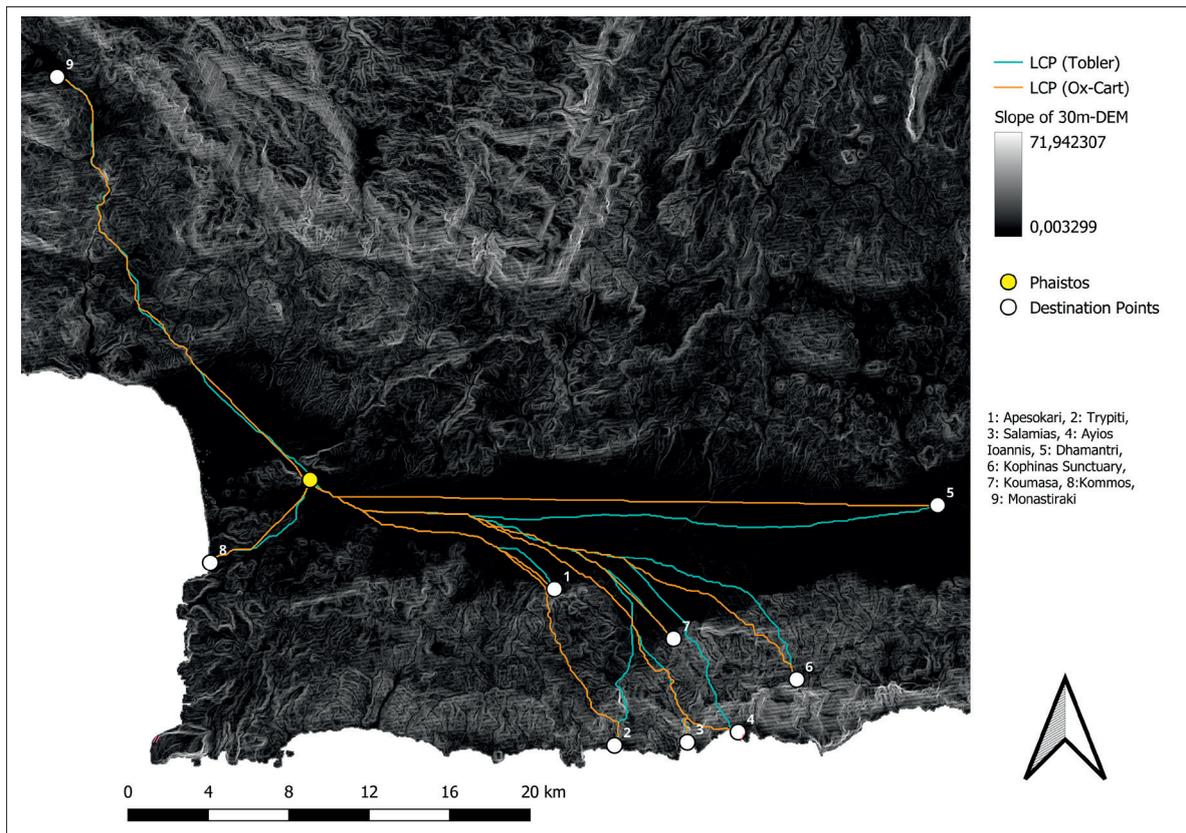


Figure 25: Least-cost paths from Phaistos to chosen locations on 30m.-DEM; interpolation of 2 functions.

The slope is used here with no reclassification, meaning the default classification of the GIS programme will be accepted, as to avoid discussion of the functions discussed above and focus on other parameters. The reclassification is close to the second-degree polynomial (the Exponential, as discussed above), which, although problematic, serves as adequate here. It is recommended, however, to avoid using the automatic reclassification. As in the previous studies both origin and destination points are allocated, which in itself might not be the most holistic approach. The downside of this method and the proposals to overcome it will be discussed in Chapter 5.3. The points chosen, despite being few, indicate nodes critical in understanding mobility through Asterousia in the central Messara-Asterousia region. The points include some of the harbour areas at the southern side of the range that are relevant in this work, beneath the highest points of Kophinas. Further, some exit points to the north are defined. As a quality control, other known nodes were expected to appear.

Iteration 1: Least-cost-path between the two sides of the centre of Asterousia

In this iteration, the zero values are not removed from the DEM, allowing for the sea route. The resulted paths are seen in Figure 26.

The fact that the zero value is not removed is clear from the mobility presented along the coastline. To further study the results, the field of length is added in the attribute table of the created path layer so that a cost and a length value are available for each path. This length does not correspond with the distance of these two locations in general but only expresses the length of the path. The cost/distance values for the various route locations are analysed in Table 2.

Cost accumulation and pathfinding techniques

Even when the points included in the input layer for the function of cost distance analysis only included Koumasa, Apesokari and Dhamantri to the north of Asterousia, and Ayios Ioannis and Trypiti on the coastal side, without adding Salamias or Tris Ekklesies, path passing through them are obtained, meaning the paths through Salamias bay and Tris Ekklesies were deemed the most natural connections, thus highlighting their importance as nodes for the connection to the coastal region (in the case of Salamias) and between the two sides of the mountain range (in the case of Tris Ekklesies).⁶⁰⁶

In total, four distinct paths traverse the Asterousia in this iteration. This clear-cut result is, of course, influenced by the intrinsic characteristics of the algorithm. The lack of alternatives or forks, for example, is due to the nature of the least-cost-path approach, in which secondary and tertiary results are being neglected. The resulting four paths do, however, remain indicative of the movement possibilities. Two of them lead from Salamias bay and Trypiti to Koumasa. Another leads from Trypiti to Apesokari through the area of Krotos.⁶⁰⁷ The last one, bypassed the mountain peak from Tris Ekklesies, representing the way from the eastern end of the central Asterousia⁶⁰⁸ and through the Anapodaris valley towards the Messara, towards the region of Dhoraki, Rotasi, and ultimately reaching Dhamantri.

For all paths, the length and the total cost are presented in the table above, except the last one, which, since it follows the 0 value for half its course, is less relevant. The parameter of cost takes into account the accumulation of the slope factor. This is clear in the comparison of the paths from Koumasa towards Apesokari and from Koumasa to Ayios Ioannis, with similar path lengths of 9.73 and 10.56 km. respectively: The accumulated cost of the path to Apesokari, which traverses mostly a relatively even plain is calculated at 34 units of cost, while the one through the Asterousia to Ayios Ioannis has

606 In Figure 26, Salamias is indicated as a target location, but even when it is not, the path calculated towards Ayios Ioannis passes through it. Similar behaviour of some functions was discussed in Study 1.

607 As already mentioned, this automatic reclassification resembles the Exponential of Study 1. This is mostly evident in the path through Trachoulas, and Krotos mentioned here, which is similar to the paths of the exponential and the Bell-Lock presented in Study 1 above.

608 On the proposed regions of the Asterousia, Chapter 9.1.

5.2 Least-Cost Paths Between Defined Locations

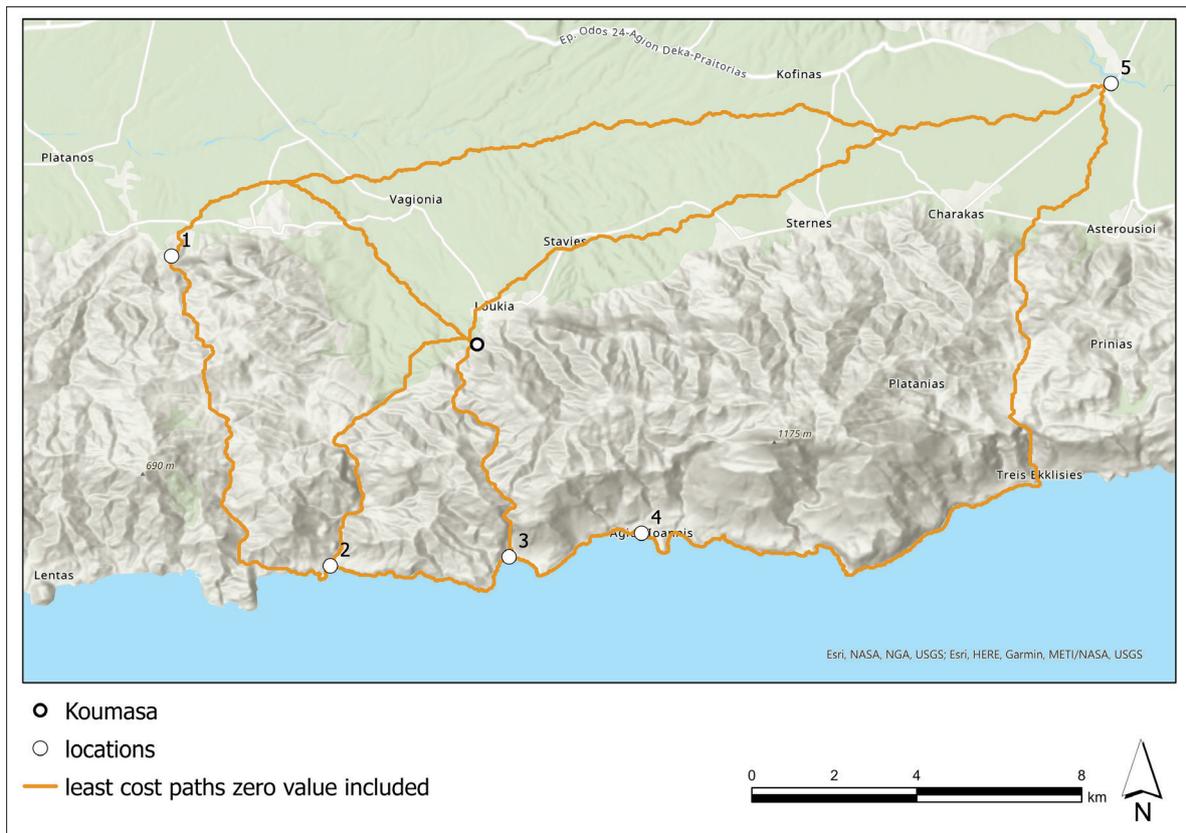


Figure 26: Least-cost paths between Koumasa and the locations of 1: Apesokari, 2: Trypiti, 3: Salamias bay, 4: Ayios Ioannis, 5: Dhamantri. The calculation was based on the 20m.-DEM including the sea level (zero value).

Table 2: Cost and distance of Routes calculated in iteration 1.

Route	Cost (in thousands)	Distance (km)
Koumasa–Apesokari	34,057	9.736
Koumasa–Ayios Ioannis	84,599	10.56
Koumasa–Trypiti	68,971	8.36
Koumasa–Salamias	78,125	6.831
Koumasa–Dhamantri	35,481	17.67
Salamias–Ayios Ioannis	5,474	3.73
Salamias–Trypiti	16,202	5.05
Trypiti–Apesokari	84,111	11.72
Apesokari–Dhamantri	45,327	23.65

more than double the cost, namely 85, despite having approximately the same length. Most of this cost is due to the path from Koumasa to Salamias, with 78 units of cost for 6.8 km. through the steep slopes of Asterousia, with the rest 3.76 km. from Salamias to Ayios Ioannis being covered by the coastline. Yet another example to illustrate the point of the inadequacy of the length alone to estimate difficulties of travel, the Koumasa–Trypiti path measuring 8.36 km. is shorter than the Koumasa–Apesokari path of 9.73 km., but its cost of 69 units is almost exactly double of the above-mentioned cost of the Koumasa–Apesokari path.

Discussion

The analysis alludes to dependencies of the harbour regions on the few mountainous paths to reach the centres of Messara on the northern side of the Asterousia. The Kophinas peak and the surrounding range act as a clear obstacle, allowing only a few paths to traverse it. Around the exit points from the mountain, such as the area of Koumasa or the Rotasi area, have the potential to assert a degree of control over these routes. Trypiti is connected with both Koumasa and Apesokari, with the cost and path distance to Koumasa being somewhat smaller than that to Apesokari.⁶⁰⁹ Salamias, where a Minoan port has been alluded to,⁶¹⁰ connects to Koumasa through a path, that is also used by the path to Ayios Ioannis, continuing 4 km. east of Salamias along the coastline. The reason is that the land route between Salamias and Ayios Ioannis is deemed more costly than the zero-cost alternative of the sea route in this iteration. Koumasa is then in potential contact with three ports in total, of which exclusive contact with two. It is also at the end point of two paths through Asterousia, being located at the exit point of them towards the Messara.

Further to the east, the fourth path of the central Asterousia is to be seen on the eastern side of Kophinas. The path begins at Tris Ekklisies and ends in the Messara not far from Dhamantri or Rotasi. Evidence of settlement activity at the output of Anapodaris further to the east has been known,⁶¹¹ and this access illustrates the importance around Rotasi, which remained in the Post-Minoan times.⁶¹²

Iteration 2: Removal of the zero value

As could be verified from the attribute table of the DEM raster, the point count stretches from 0 to 1208, which corresponds to the height of Kophinas according to the projection followed by this DEM. The “count” field for the value of zero (which can be obtained from the preferences of the raster) has the highest count number, as to be expected from

609 On the existence of tholoi on two of those paths at Krotos and Christos, see below and discussion in Chapter 9.3.

610 See Chapter 11.3.2.

611 See Footnote 381.

612 See Footnote 288 and discussion in Chapter 2.5.

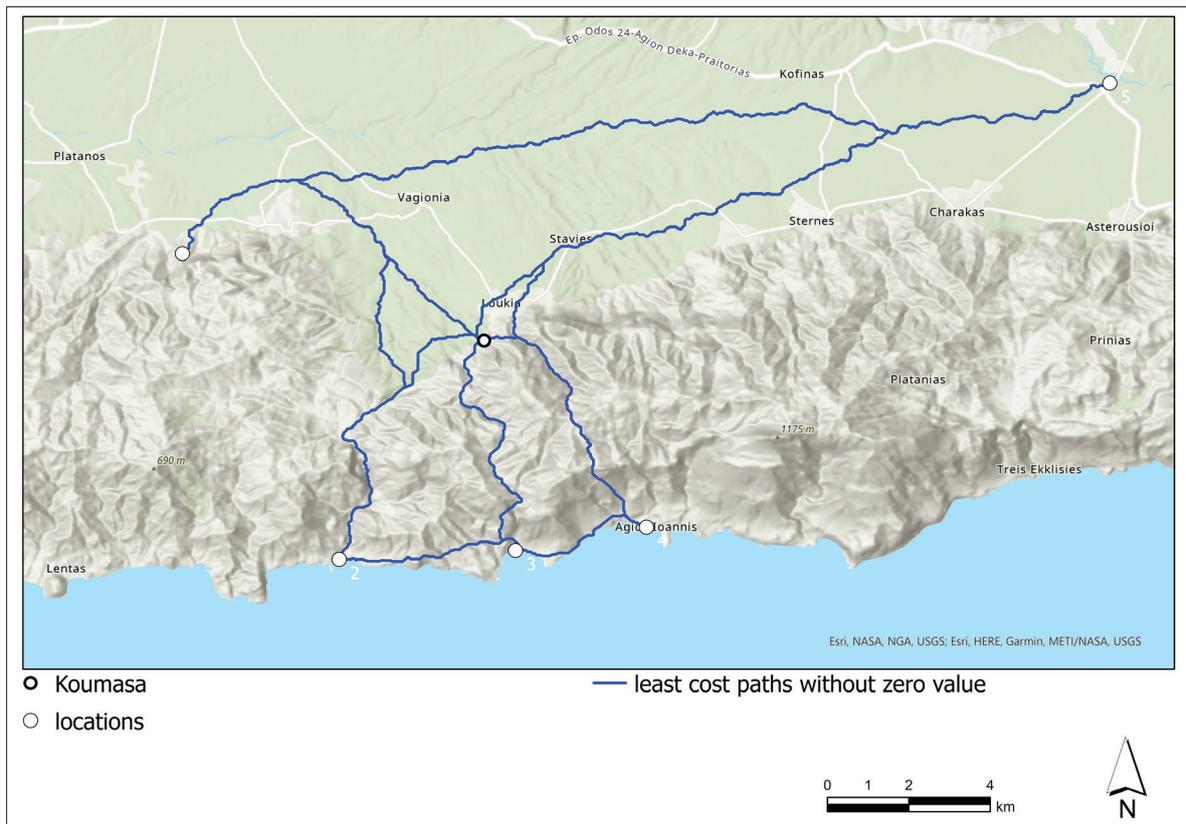


Figure 27: Cost Distance without the value 0.

the sea level. A new raster was obtained using the tool of “Extract by attributes” with the clause of all greater than zero.⁶¹³ Then, the slope in degrees is extracted, after which the steps for cost connectivity are repeated for the same six locations as before (see Figure 27). Again, the default classification was used.

The new network has some differences from the one produced in iteration 1, offering a new insight but also acting as a good demonstration of the algorithmic procedure. Those differences are explained through the removal of the zero value from the DEM, no longer offering the low-cost sea route as an option. Hence the route through Tris Ekklisies, which again was not used as a node, is absent. The details of the paths are given in Table 3.

The new Koumasa–Ayios Ioannis path is ca. 15 thousand more in cost units, which explains why it was discarded in the first iteration despite being 3.5 km. shorter. This new path branches before exiting the mountains to direct towards Dhamantri to the east and Koumasa to the west. Another new route is the one between Trypiti–Ape-sokari, which was suggested due to the absence of the sea connection west of Try-

⁶¹³ This was done in ArcGIS. The same result can be obtained in QGIS through Raster Calculation tab, and applying (“DEM@1”)/ (“DEM@1”>0).

Table 3: Cost and distance of Routes calculated in iteration 2.

Route	Cost (in thousands)	Distance (km)	Comparisson with iteration 1
Koumasa–Apesokari	34,057	9,736	Same as in the first iteration
Koumasa–Ayios Ioannis	99,354	6,931	New. 15,0 more cost
Koumasa–Trypiti	68,971	8,36	Same as in the first iteration
Koumasa–Salamias	78,125	6,831	Same as in the first iteration
Koumasa–Dhamantri	35,481	17,67	Same as in the first iteration
Salamias–Ayios Ioannis	43,674	3,35	New
Salamias–Trypiti	50,582	4,24	New
Trypiti–Apesokari	86,533	16,1	Partially new
Apesokari–Dhamantri	45,327	23,65	Same as in the first iteration
Ayios Ioannis–Dhamantri	125,190	23,274	New

piti, bypassing the Trachoulas promontory. The route is slightly more costly, mainly through distance rather than slope.

The new land routes for the neighbouring Salamias and Ayios Ioannis are also of interest. While being of similar distance, even 400 meters less, the difficulty is 43.7 in comparison to the ca. 5.0 of the first iteration, showing the difficulty of the terrain caused in that area. The land connection of Salamias to Trypiti is represented with 15% more cost than the path to Ayios Ioannis.

Discussion

The first two iterations present a straightforward choice regarding the use of the sea. However, as discussed in Chapter 11, the second iteration aligns more closely with the actual experience of walking (with the exception of the path to Ayios Ioannis). The reality is seen to be a hybrid combination of both approaches.

The two most obvious differences are the appearance of a direct path between Ayios Ioannis and Koumasa, and the other is the disappearance of the route through Tris Ekklisies. Now the sea route to Dhamantri through Tris Ekklisies is no longer available from Ayios Ioannis, preferring a route through a path close to Koumasa. Also, since travel from Salamias to Ayios Ioannis is no longer possible through the sea level, another path was found by the algorithm, which in the first run was discarded, partially due to the high cost of the path segment between Ayios Ioannis and Salamias. However, this path is actually very close to the actual path connecting the two locations that was walked by the author (path 4, in Figure 92).

The path between Ayios Ioannis and Koumasa, however, traverses a significantly steep mountainside, passing not very far from the village of Kapetaniana. As will be

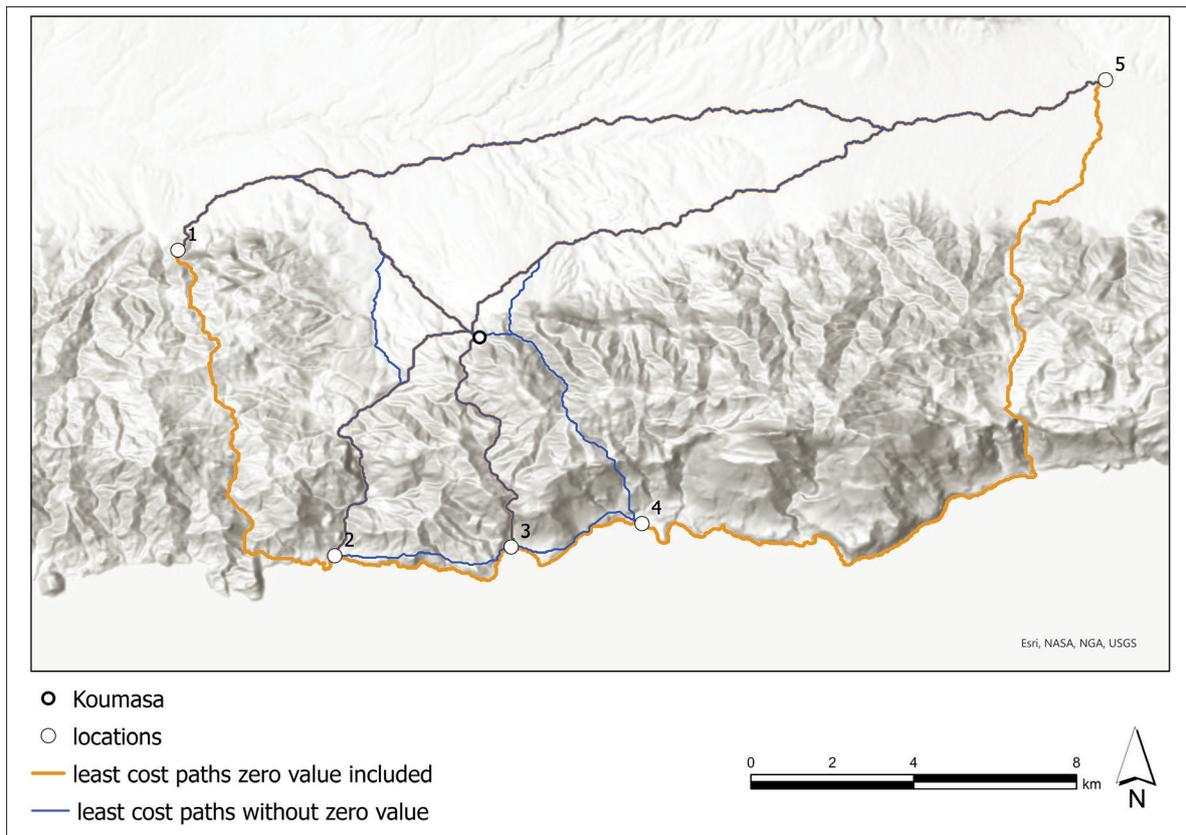


Figure 28: Overlapping two calculated least-cost paths showing the different paths from the two iterations.

discussed in Chapter 11.1.3, it is not practical for walking. However, it is close to the path proposed by the Ox-cart function (see Figure 22), which represents a difficult but walkable path.

When the two resulting datasets are compared (see Figure 28), it becomes obvious how the parameters influence the results. Both have merits, but they can be used only as indicators and not as proof.⁶¹⁴

Iteration 3: Cut-off slope

This iteration presents a cumulative analysis of two approaches that involve setting upper slope limits of 35 and 40 degrees, in contrast to the no cut-off method used in iteration 2, with removal of the sea level for all variations. Here, the focus is distinguishing movement patterns from those observed on relatively even terrain.

⁶¹⁴ As discussed at the beginning of this chapter, the function used here is not the optimal one; used here as a case-study of the steps for evaluation of the results. Even this function, is seen to provide some useful information when the results are approached critically.

As presented above, the accepted slope for trade routes is around 20 degrees.⁶¹⁵ Indicatively, for the network in Messara, Déderix applied a cut-off angle of 30 degrees. This approach follows established patterns indicating that movement along steeper slopes is considered impractical for trade routes and human walkers from a metabolic perspective.⁶¹⁶ However, trade and pastoral movement are prerequisites for any connections within the Asterousia. The feasibility of moving trade in mountainous terrain is studied in other parallels such as the Andes or South Africa, where the use of carrying animals was used, primarily the donkey (*Equus asinus*) discussed above or by parallels in modern Crete.⁶¹⁷ More crucially, however, the elements of raster imagery must be carefully examined, and as proven by the author's movement, single or a few pixels of slope value of 40 degrees or slightly more do not pose a hindrance in the movement through the terrain. For example, in the movement from the Trypiti shore towards the Trypiti EM settlement, which lies atop a hill, or walking on the Korakies hill of Koumasa, one passes through many pixels of elevation between 30 and 40 degrees (see e.g. Figure 64 in Chapter 6).⁶¹⁸ For example, using the 35-degree cut-off would render the Trypiti settlement or the 'sanctuary' at Koumasa less accessible, which is naturally not the case. Of course, assigning more cost to those pixels is in accordance with the reality of the movement, but as seen in Figure 29, cutting off all pixels with a value higher than 30 degrees removes pathways that could be assumed to be realistic, and after walking the terrain, were proven to be good indications of actual paths. So, for example, the Salamias–Koumasa route passes through 20 pixels with slope more than 20 degrees, with them not being consecutive but scattered through the whole path. Many of these points can be easily bypassed though, a fact that least-cost-path analysis has problems identifying. Thus, implementing various degrees of cut-off the resulting interpolation of paths can be used as an indication for the area. Having this caveat, the analysis below renders some insight and is therefore deemed useful.

Inserting the cut-off, the algorithm is forced to find different paths. Two different levels are presented, with a cut-off at 35 and 40 degrees, where the slope was used with the default values of manual intervals and 11 classes, based on the distribution of the degree values. A repetition of the steps with the use of the reclassification option did not produce any different results.⁶¹⁹ The easiest method for this step is by deleting the rows upon the wished threshold and applying the option of changing missing information

615 See Discussion on page 110.

616 Déderix (2016, 558) applied a virtual cut-off, by applying a very high cost to cells above 30 degrees, so as to force the software to bypass those areas, following Proffitt et al. 1995.

617 See discussion on pages 111ff.

618 The paths through these areas were walked by the author, noting that moving around the pixels with high degrees results in a more fatiguing climb. Of course, elements of zigzagging can be assumed, foremost for the movement within the settlement, but the result remains that cutting off these individual pixels leads to less realist movement overall.

619 Under spatial analyst tools in ArcGIS. The reassigned classes were experimented upon with steps of 1-, 3- and 5-degree steps, with no change in the outcome, as was expected.

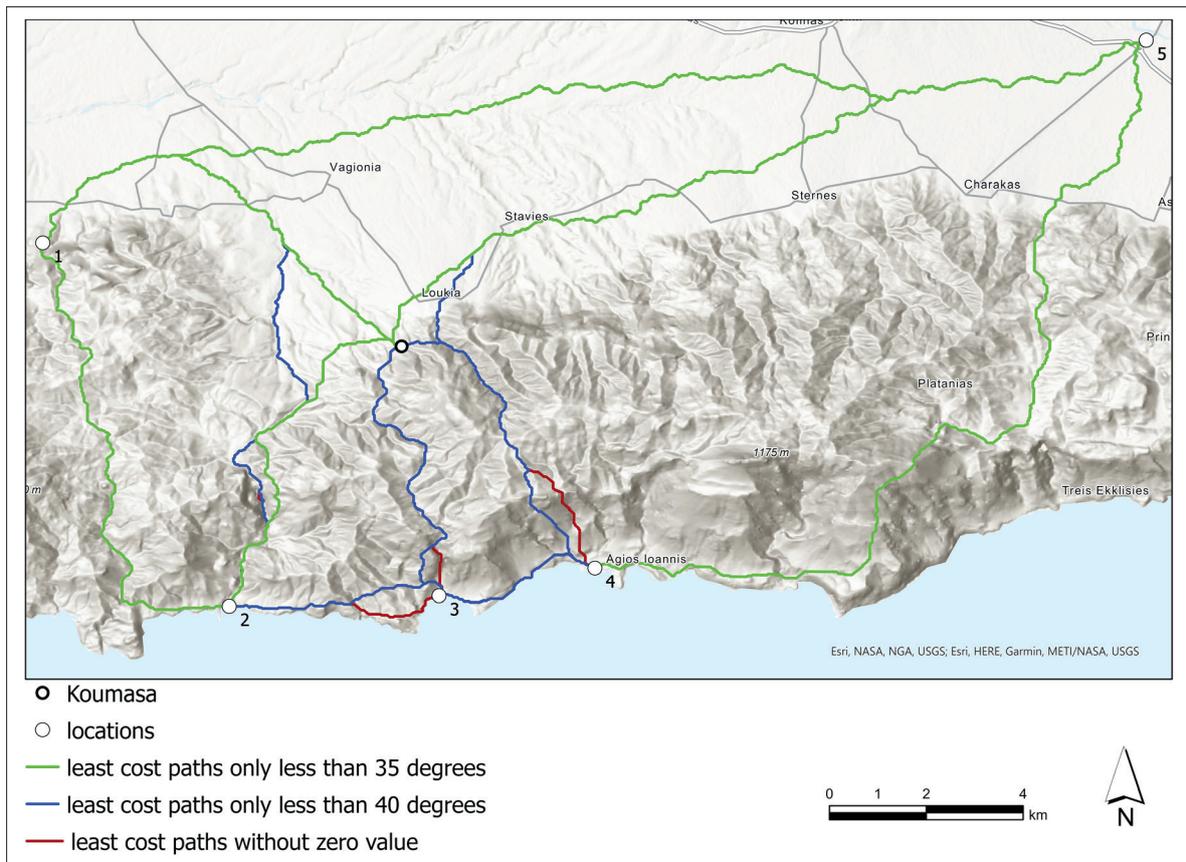


Figure 29: Implementing the cutting off of cells from the slope raster at different values.

to “Nodata”, since when just assigning a very high value (virtual cut-off) the algorithm will force the same connections as in iteration 2, when no other route is possible.⁶²⁰ Those paths are overlapped with the results of iteration 2 (i.e. without a cut-off) in red.

When the 35 and 40-degree cut-off are identical, only the green line appears, as it overlaps it. The overlapped result of iteration 2 is shown only where it differs from both cut-off implementations.

Discussion

From this iteration, it is noteworthy that in the 35-degree cut-off, the only three connections from the southern harbours are that of Trypiti to Koumasa, of Trypiti towards Apesokari, through Trachoulas towards Apesokari and the long connection from Ayios Ioannis towards Dhamantri, passing near the Treis Ekklesies point, thus bypassing the Kophinas peak through the extreme east and west of the study area. The other paths are rendered not accessible with this cut-off.

For movement allowed beneath the 40-degree limit, the same paths towards Koumasa and also between the southern points as in iteration 2 appear, including from

⁶²⁰ This refers to the virtual cut-off, as implemented elsewhere (see Footnote 616) is not practical here.

Salamias and Ayios Ioannis, with slight variations to their south in the areas where pixels with slope degree values between 35 and 40 appear. In the case of Salamias, the way through the Salamias gorge is, in actuality, bypassed, favouring a way to the west of the gorge.⁶²¹

The way from Koumasa to Trypiti remains as it was in iteration 2 when applying the 35-degree cut-off since the route does not showcase any pixels with a slope degree higher than 35. However, the routes to Salamias and Ayios Ioannis vanish completely at the 35-degree cut-off, where, as mentioned above, around 20 pixels have a value of more than 40. As discussed, this does not render this path unwalkable, but the *desideratum* of an on-site inquiry was made apparent. Evaluating these paths after walking to these locations will be discussed in Chapter 11.

Iteration 4: Scattered destinations around interest area

For this iteration, the goal was to observe the least-cost paths from Koumasa towards all directions by specifying 35 points around the area of interest surrounding the central Asterousia (Figures 30, 31). This method has been used to specify the main corridors leading to a specific area, such as by Efkleidou for Mycenae.⁶²² Another parallel example was performed for the Amanus mountains, where Schild used Tobler's hiking function.⁶²³

The resulting outcome illustrates groups of paths originating from Koumasa as the origin point in a *quasi-omnidirectional* least-cost-path module. While this approach may appear similar to the flow accumulation in Chapter 5.3.2, it remains distinct. Nevertheless, it serves as an approximation for it, with the evenly distributed points along the desired periphery emulating natural paths or free walking, akin to what flow accumulation represents (as seen in Chapter 5.3). Since the endpoints are semi-arbitrarily fixed, the resulting paths indicate the main arteries of communication, as opposed to the flow accumulation method, which indicates possible directions of movement based on the terrain. As expected, the paths crossing the mountain resemble those generated in iteration 2 for the non-reclassified slope (Figure 30). Paths based on the Ox-cart function are illustrated in Figure 31, chosen as this function was seen to emulate the natural walking on the mountains at a satisfying degree. In the latter case, which, as expected, yielded more natural results with a higher degree of branching, the five main path groups, or axes, are numbered and discussed below.

This summation illustrates the barrier that the central Asterousia poses. Further, for the coastal area until before Tris Ekklises, the paths favoured are through Ayios Ioannis, Salamias and Trypiti, while from Tris Ekklises and eastwards the paths are bypassing the mountain peak of Kophinas from the east, exiting the mountain in the area around

621 To be noted, that this path is not practical when walking with load, a fact that is missed by the algorithm due to the pixelation effect, discussed on page 291. However, it acts as an indication of possible paths, which proved to be true.

622 Such an example is Efkleidou 2019, Fig. 5.

623 Schild 2016.

5.2 Least-Cost Paths Between Defined Locations

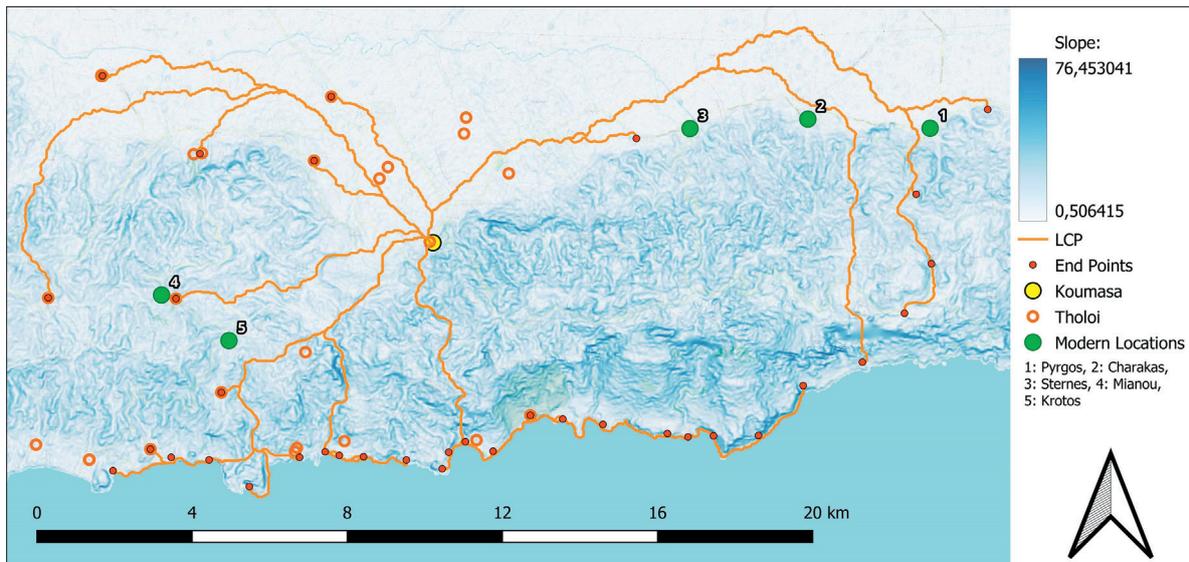


Figure 30: Least-cost paths from Koumasa to peripheral points, based on the slope raster.

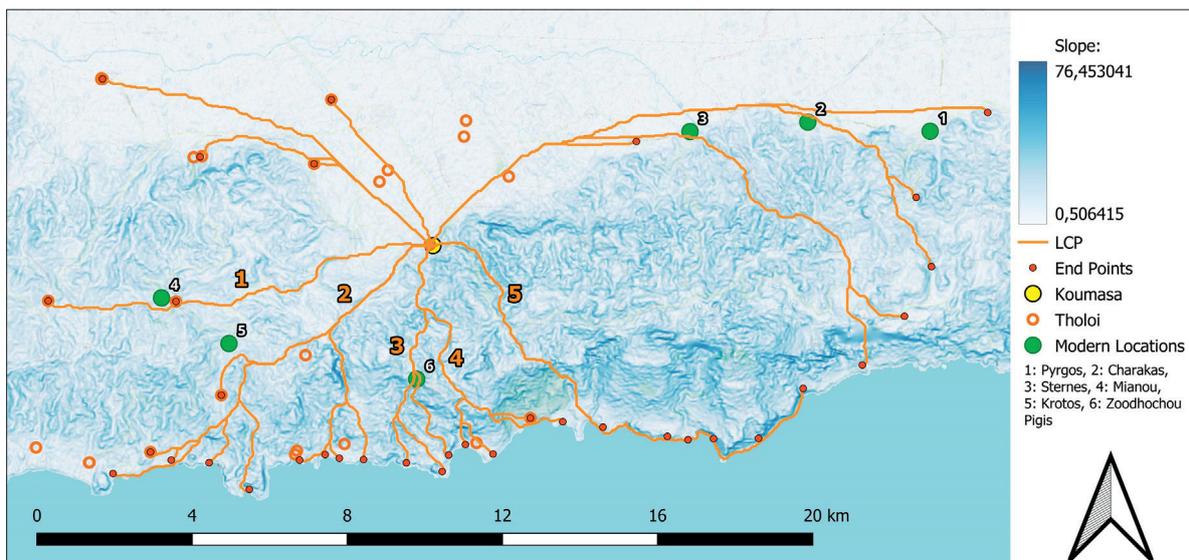


Figure 31: Least-cost paths from Koumasa to peripheral points, based on the Ox-cart function.

Pyrgos, Charakas and Sternes, adding to the reasons this area is seen as distinct, dubbed as eastern-central Asterousia.⁶²⁴ This would hint at the location of Koumasa as the access node from the Messara to the coastal areas up to Tris Ekklisies, in the area dubbed as central Asterousia. It is noteworthy that one of the two modern roads accessing the Kophinas peak sanctuary begins from Panayia/Sternes (the other being from Loukia passing through Kapetaniana). When the endpoints further to the east are assumed as targets, the areas of Rotasi and then those along the Anapodaris for the eastern Asterousia become clear as access points, as anticipated (no figure was included for this case).

Some of the endpoints were chosen near tholoi concentrations, such as Lebena and Trypiti, while some were directly on tholoi, such as Krotos, Ayios Kyrillos and Korakies, near Miamou. In the case of the second Figure (following the Ox-cart's parameterisation), the same direct path (path-group 1 in Figure 31) leads from Koumasa to the latter two tholoi, which are located in the western-central Asterousia; while in Figure 30 only Korakies is directly connected and Ayios Kyrillos is accessed through the valley from a path bypassing Apesokari and modern Plora before ascending, approximating thus the modern road. Again, the tendency of the exponential function (as also the Bell-Lock) to always favour the valley is demonstrated here. The connection to Koumasa could be seen in connection with observation, discussed in Chapter 5.4, that the Korakies tholos seems to have a direct eye-of-sight contact with Koumasa.

The next axis paths (path-group 2) lead to the area of the Christos tholos, where (as discussed by Pendlebury) the paths branch into one leading to Trypiti and another leading to Miamou and Krotos (Krotos being one of the target locations on the path group 2).⁶²⁵ This second branch eventually leads to Lebena. Most of the branches represent possible paths, as walked by the author.

Path-group 3 leads to the church of Zoodhochou Pigis, from whence they branch southward, under the effect of a rough gorge beginning directly south of Zoodhochou Pigis. The easternmost of these paths leading to Vourlidia is very close to the walked path.⁶²⁶

Path-group 4 leads to Ayios Ioannis and Salamias, alluding to the actual possibilities but disregarding some obstacles in the path towards Salamias through the Salamias gorge.

For the locations further east up to Tris Ekklisies, instead of passing through Ayios Ioannis, a direct path (path 5) passing to the north of Ayios Ioannis is proposed, that, although possible and partially walked by the author, this is not be considered as a valid option for a path considering load carrying.⁶²⁷ A qualitative discussion of the limitations of the GIS-produced paths in relation to the reality of walking will be further discussed in Chapter 11.1.

624 On the proposed regions of the Asterousia, see discussion on page 237 in Chapter 9.1, and Figure 78.

625 Pendlebury et al. 1935, 87. See also the discussion in Chapter 11.1.1.

626 See path 3 in Figure 92 and Chapter 11.1.2.

627 See path 5 in Figure 92 and Chapter 11.1.3.

5.3 Network Connectivity

5.3.1 Accumulation Cost Surface

In the studies of the examples above, optimal routes between a given set of places were produced. For the purpose of analysis of a location's potentiality, in terms of terrain accessibility, this method lacks some information; as, for example, not all possible destinations from a starting point are known. Without this *a priori* knowledge the methods described above will not provide a clear view of the role of a certain location within its landscape and focus on conditioned optimal routes.⁶²⁸ Therefore, the concept of moving without a destination was developed, where given one starting point, all optimal routes are calculated and guide the movement.⁶²⁹ Instead of channelling movement to specific locations, the most accessible natural parts of the terrain are made visible in an accumulated cost surface. Building on this, the most natural paths are obtained.

A method from the field of hydrology is used to accomplish this. The logical step behind this is that the flow of water in a region towards a basin is similar to the paths leading to a selected source, both following the slope, which can be parameterised or reclassified. In this way, the point of choice serves as the equivalent of the lowest point of a catchment, and the paths will be “pouring” into it branching out the further one goes from the starting point. The cost surface was used as an input raster for the calculation of the flow direction, so the flow from the locations of high-cost values, such as slopes, will flow downwards towards positions of lower cost value. This will not be only downwards, ie towards lower slopes, but also nearer to the starting point, because with these cost maps after this parameterisation, as the movement-direction-layer shows, the programme renders the map not as per their actual height, but relating to their distance/cost towards the point of origin, as distance or effort are the main cost factors for the cost map utilised.⁶³⁰

Utilising the 20m.-DEM, the following accumulated cost surface can be produced, indicating travel effort from Koumasa (Figures 32, 33).

Various modalities can be applied to extract valuable information from the DEM, such as the use of different bands.⁶³¹ Notably, however, the extraction of vector layers, such as paths (as discussed in the next chapter) or isochronous lines, is of significant importance for evaluations. Isochronous lines are algorithmically akin to contour lines on an elevation raster. The key distinction lies in applying this algorithm on the accumulation cost, illustrating equal cost-distance from the source (Figures 34, 35).

628 Iteration 4 of Study 3 was an effort to address this issue, but the downside of predetermining locations as well as the monosemantic solution of the least-cost-path method remains.

629 Fábrega-Álvarez 2006, 7.

630 Fábrega-Álvarez 2006, 8. In other words, the point of origin is artificially rendered as the basin where all paths gather.

631 Bevan 2010, Figs. 3–6; Casarotto 2018, 53–55.

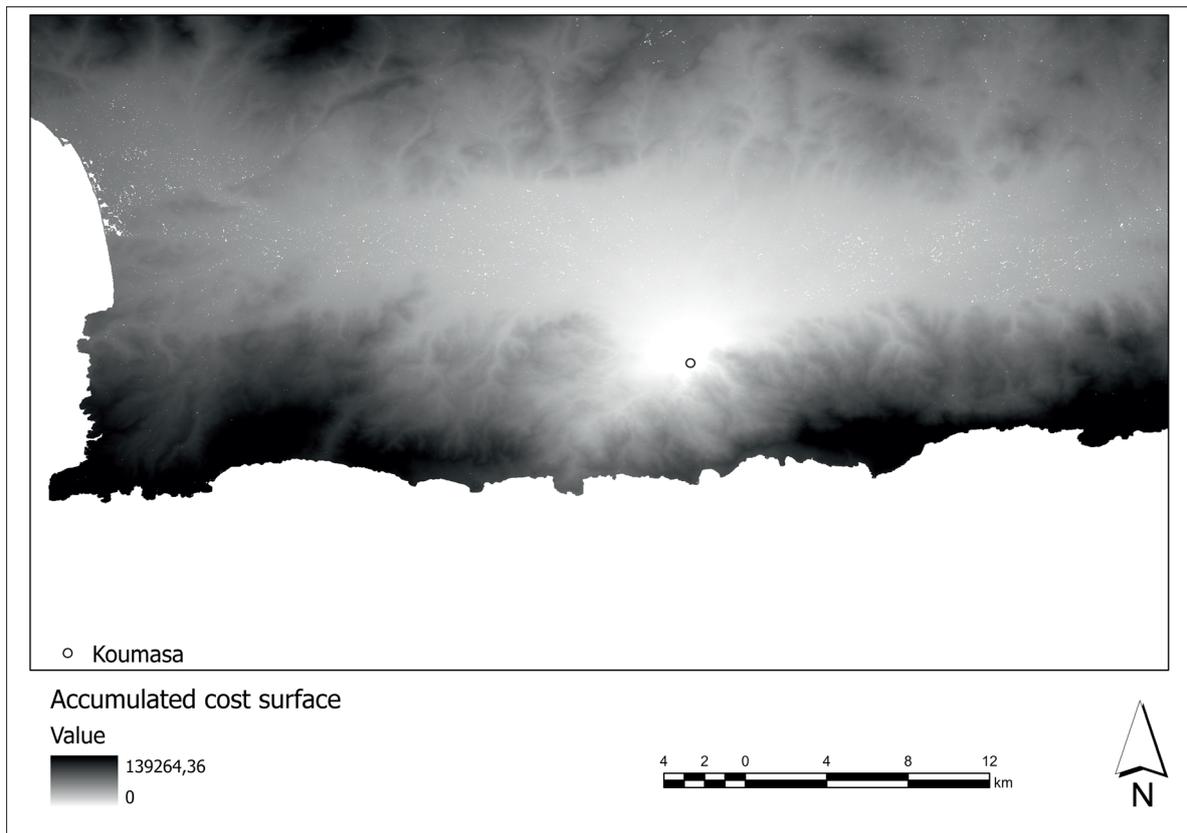


Figure 32: Accumulated cost surface for the Messara-Asterousia region of Koumasa on the 20m.-DEM. The dark and bright areas represent a scale for representing each cell, corresponding to the cost of traveling from each cell to Koumasa.

In the instance of a time currency for cost, as depicted in the first Figure 34, Tobler's function is implemented on the 20m.-DEM. Meanwhile, Figure 35 represents the outcome of the accumulation cost calculation of the not-reclassified 30m.-DEM, providing insights into metabolic effort considerations.⁶³² The isochronous lines in the second example are double the interval of those in the first, a choice made for better visualisation purposes.

A first observation concerns the difference in the portrayal of mountainous terrain compared to the valley due to the difference in the cost allocation and is irrelevant to the difference in the DEMs.⁶³³ In the time-dependent cost representation of Figure 34, Apesokari lies on the 4th time contour line, whereas locations in the Asterousia region are around the 6th time contour line, indicating a 1.5 times longer travel time to reach

⁶³² The r.walk Function of QGIS was utilised.

⁶³³ Both methods were implemented in both DEMs showing little dependance on the DEM used.

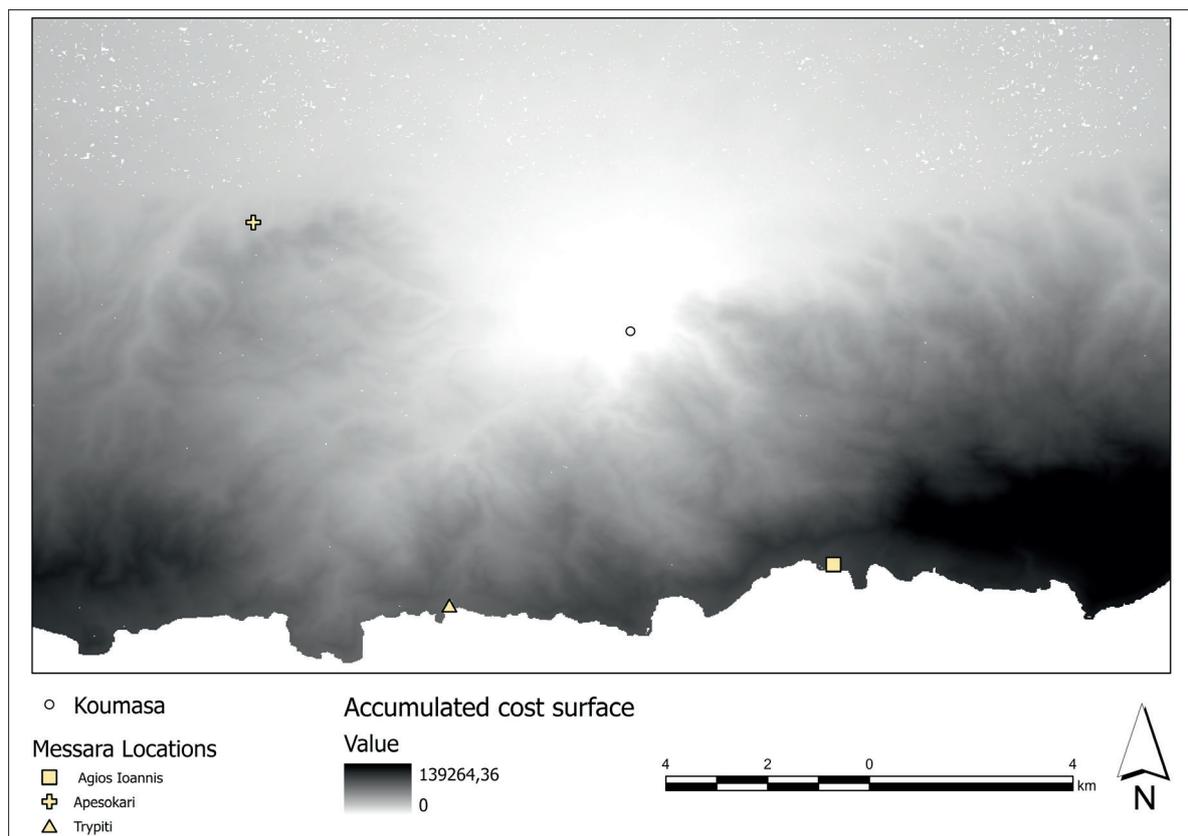


Figure 33: Accumulated cost surface for the region around Koumasa on the 20m.-DEM. The dark and bright areas represent a scale for representing each cell, corresponding to the cost of traveling from each cell to Koumasa.

these areas, in comparison with the time needed for Apesokari.⁶³⁴ Phaistos is more than twice the time required for Apesokari, falling between the 8th and 9th time contour line. In Figure 35 (where each isochronous line corresponds to two in Figure 34), Phaistos is 1.5 times farther than Apesokari (in terms of time), while reaching the Asterousia locations requires 2 to 3 times more time than reaching Apesokari. This results in a reversal of the finds from the first case.⁶³⁵

In the first scenario, the actual distance plays a more crucial role in the cost currency, whereas in the second scenario, the impact of mountainous slopes becomes more significant. Consequently, level areas appear closer in the second case, in contrast to the first, while mountainous locations seem farther due to the increased time and effort required to traverse the paths to them. Another notable observation is that in both cases, Dhamantri is situated nearly on the same isochronous line as that of Phaistos.

⁶³⁴ The reference to the time-distance to Apesokari serves as a normalisation factor in this discussion, facilitating the analysis without implying any particular significance of Apesokari in this context.

⁶³⁵ Refer to Study 1 in Chapter 5.2 and the discussion of the differences in the functions there.

5 Insight of GIS for the Mobility Networks around Koumasa to Messara

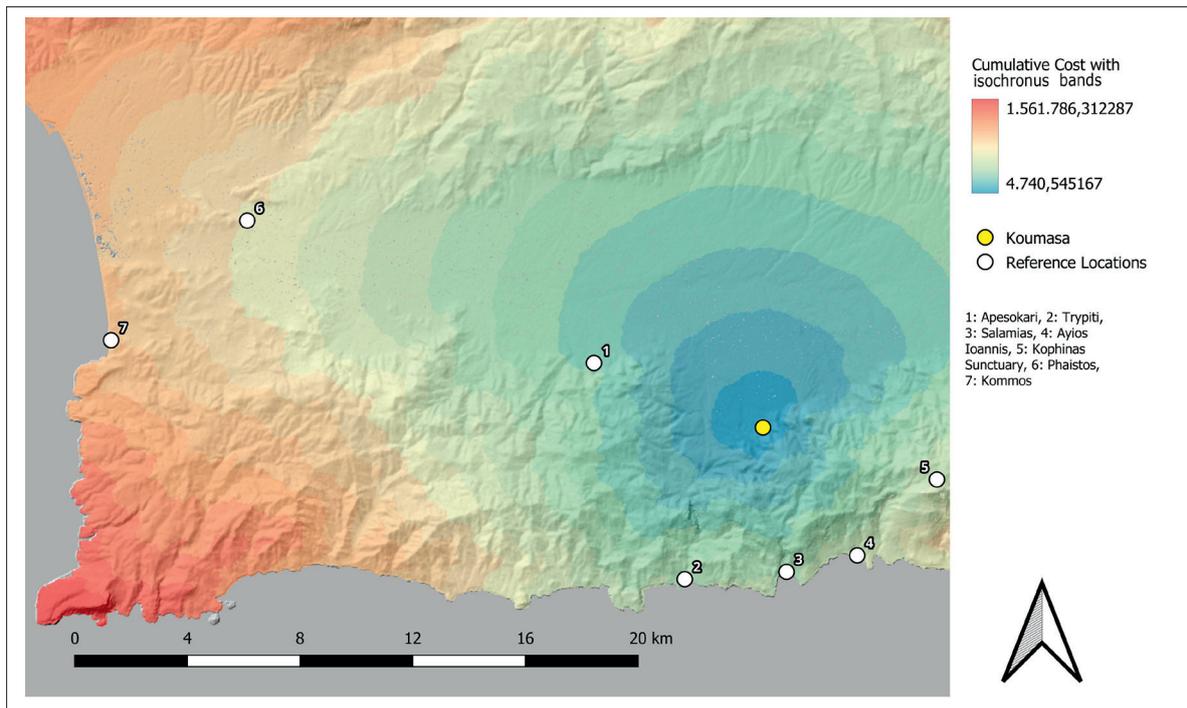


Figure 34: Isochronous bands on the accumulated cost surface of the 20m.-DEM.

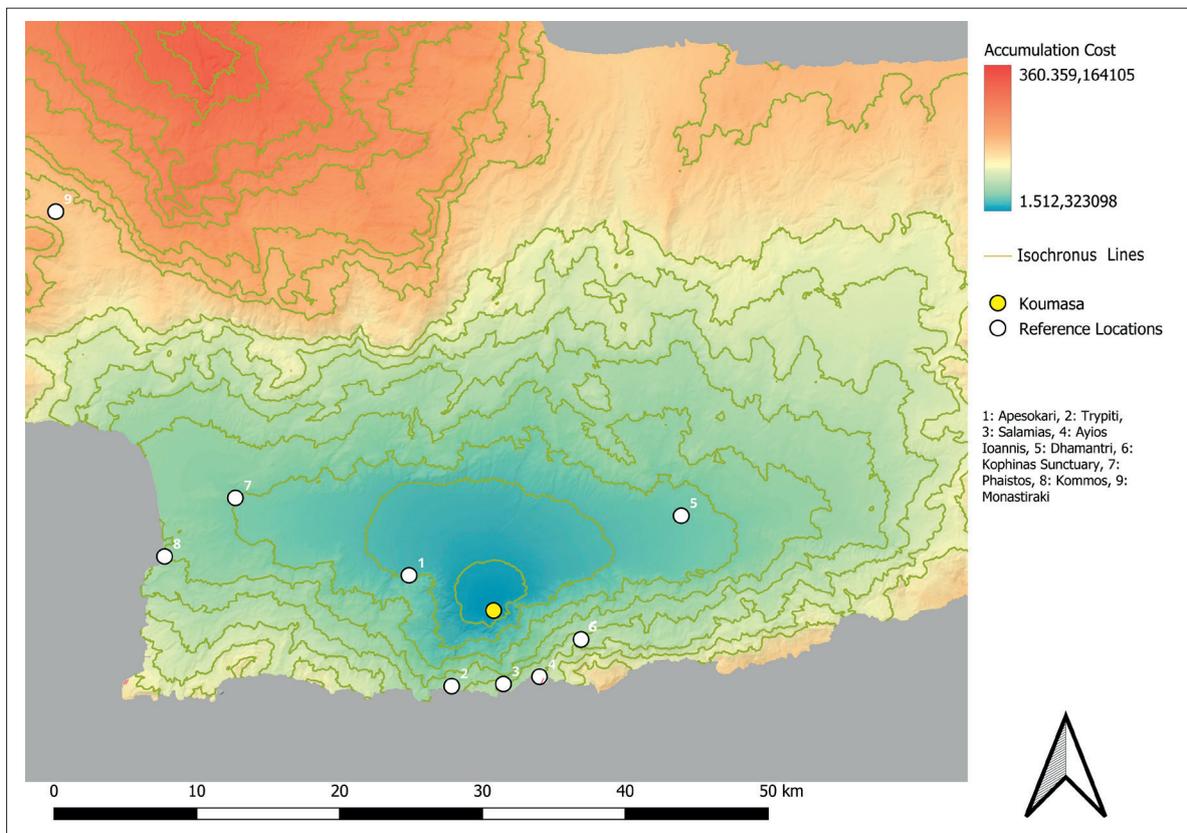


Figure 35: Isochronous lines on the accumulated cost surface of the 30m.-DEM.

This contrast should serve as yet another example that underscores the caution required when extracting information based on a single iteration or function.

5.3.2 Flow Accumulation

The cost raster is used as an input to the flow direction tool for the second step of extracting a vector layer of paths. It represents the direction of water flow by a slope raster, but since the reclassification enforces the programme to assume the origin of movement as the basin level (a fact that can be seen in the *Movement Direction Layer*), the paths originate from the origin point, adding to one another resulting in paths that split following the inverse of the Strahler principle as to form main paths and their tributaries.⁶³⁶ The main paths receive flow from various branches; the further one gets, the dimmer is the accumulation value. In the iteration below, the various paths were divided using different criteria, which essentially represent a visualisation choice. Mainly the Strahler classification is kept, indicating which Strahler values are excluded. These can be reclassified into groups, as was done in Figure 36, where paths were reclassified into nine distinct types based on the calculated accumulation. Similar paths were produced by Déderix in her study of Apesokari, which was an inspiration for this task performed in this work.⁶³⁷

The process is dubbed flow accumulation in ArcGIS's vocabulary; it can be retrieved from the Channel Network and Drainage Basins tool in QGIS. The two programmes yield identical results but with different initial parameterisations, which the user can influence.

Using the accumulation surface of the 30m.-DEM, the following paths are extracted:

Two paths are represented as class 9, one leading through Phaistos to Monastiraki and the other towards Pediada. The northern coast is accessed through paths with grade 8, passing near Dhamantri and west of Yuchtas. Dhamantri, Archanes and Knossos are directly accessed with paths of grades 5–7. Asterousia appears accessible beginning with grade 5, and the reference locations appear on the paths from grade 4. Lower grades are not represented, as they expand exponentially, making the map visually less helpful. It is noted that the locations were not inserted as targets, and their appearance on the various paths is only a result of their topographical location. Thus, the connection to Phaistos and Monastiraki is indicative of the positioning of these locations on optimal paths through the Messara, which express natural paths beginning from Koumasa.⁶³⁸

636 See Footnote 663.

637 Déderix 2016, Fig. 1; 2017, Figs. 3, 4. Here, as a gesture of gratitude to her kind advice, Déderix's explanation of these paths is cited: "Such a map records the accumulated flow to each cell and emphasizes areas of greater accumulation, which correspond to streams in the case of hydrological modelling and to optimal paths leading to the destination in focal mobility network." (Déderix 2016, 556).

638 It is to be noted that the grade as per Strahler is not indicative of difficulty of access. It merely represents the centrality of routes.

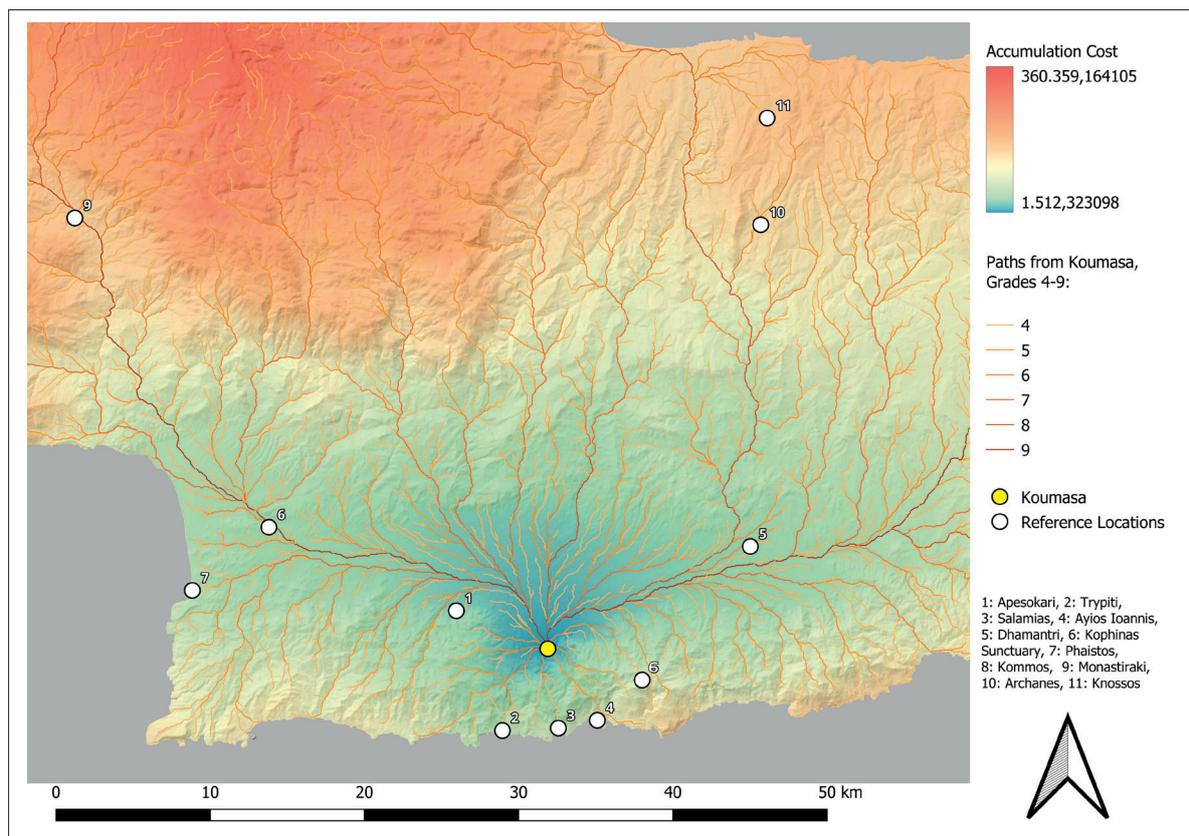


Figure 36: Flow accumulation from Koumasa, on cost raster based on 30m.-DEM.

A comparison with the paths in the Messara, computed as least-cost paths between defined locations by Siart – Eitel, shows compatibility with the paths in the direction of Galatas and further to Archanes and Knossos.⁶³⁹

The cost raster of Figure 36 is the same used in Figure 35 above. Despite the algorithm’s intrinsic difficulty regarding the mountainous paths, the Asterousia locations appear directly on the natural paths as relatively easy to access, albeit with values in the middle of the range 1–9.

Based on the 20m.-DEM, several iterations were executed to generate natural paths using accumulated cost rasters derived from the discussed functions. For the purpose of discussion, two of the results pertaining to the region closer to Koumasa region are initially considered (Figure 37, 38).

The primary distinction between the two lies in the fact that, in the iteration based on the Bell-Lock function, the treks within the valley exhibit *less natural* curvatures, tending to follow noticeably straighter lines compared to the more naturally shaped paths generated with the Tobler function. Conversely, in the mountainous regions, although there is a general similarity in the identification of movement channels, it is the

639 Siart – Eitel 2008, Fig. 1.

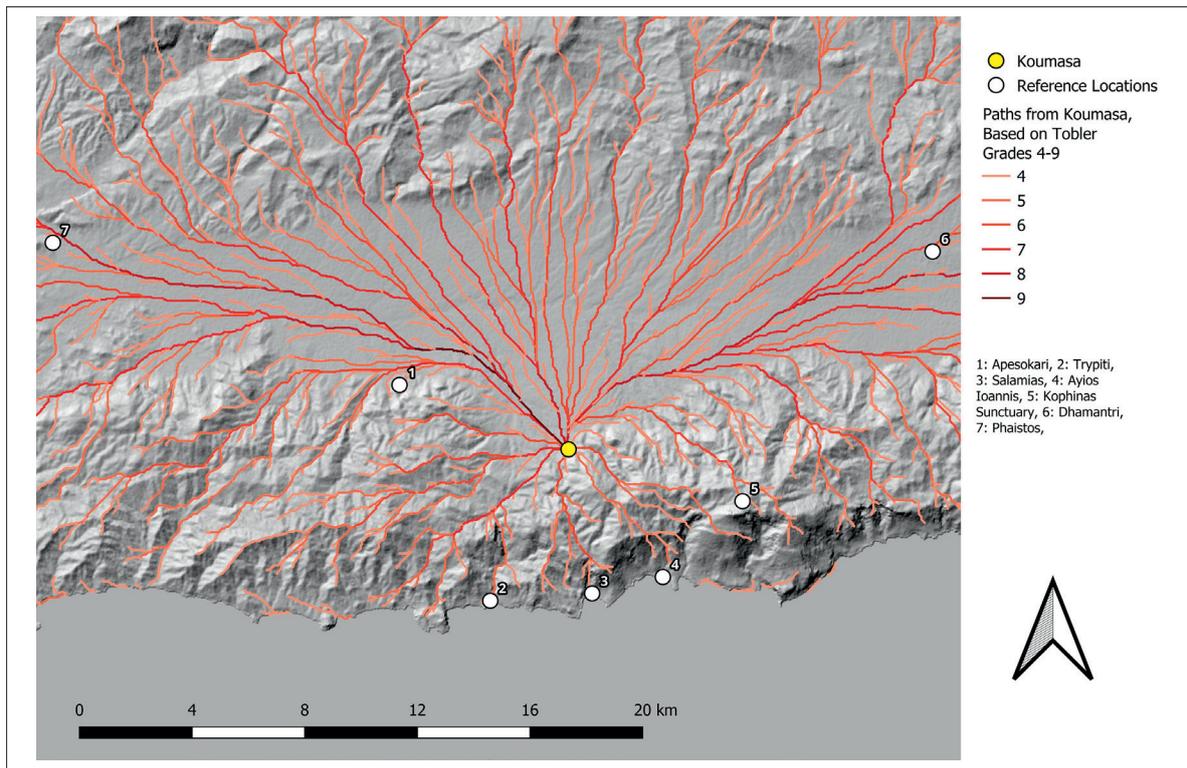


Figure 37: Flow zpaths, based on a cost raster defined with Tobler’s function.

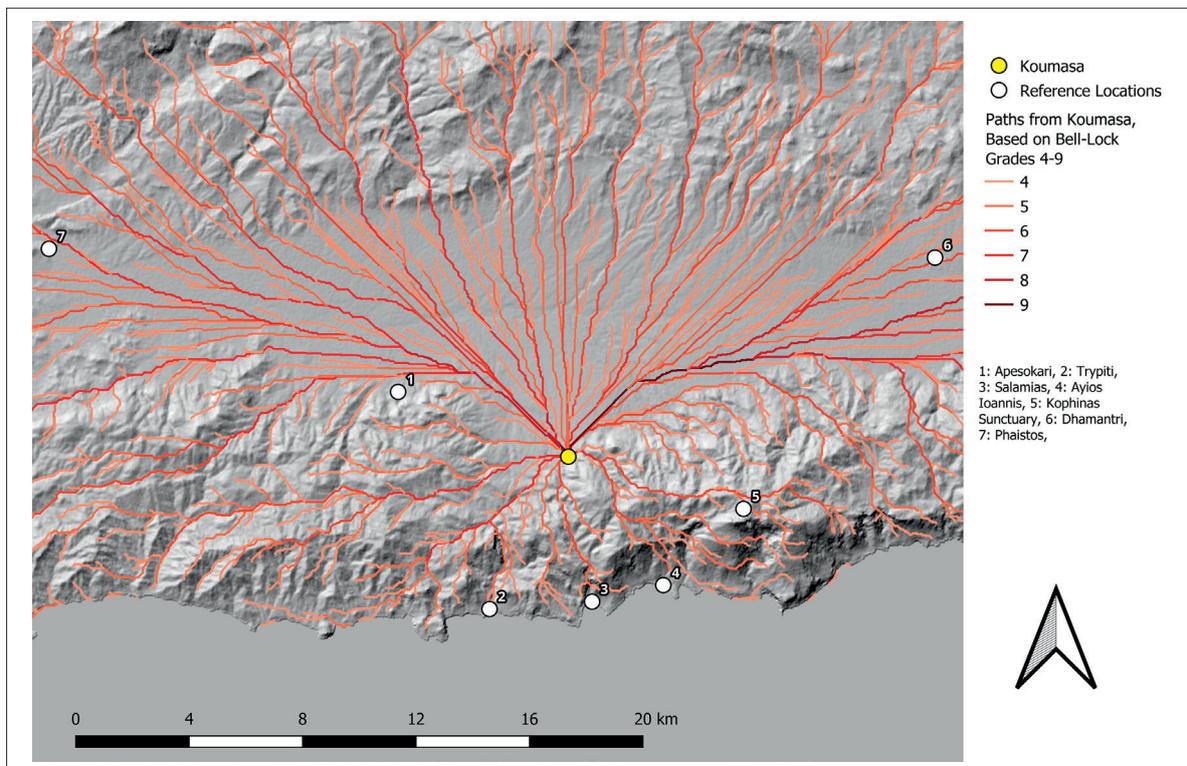


Figure 38: Flow accumulation paths, based on a cost raster defined with Bell-Lock’s function.

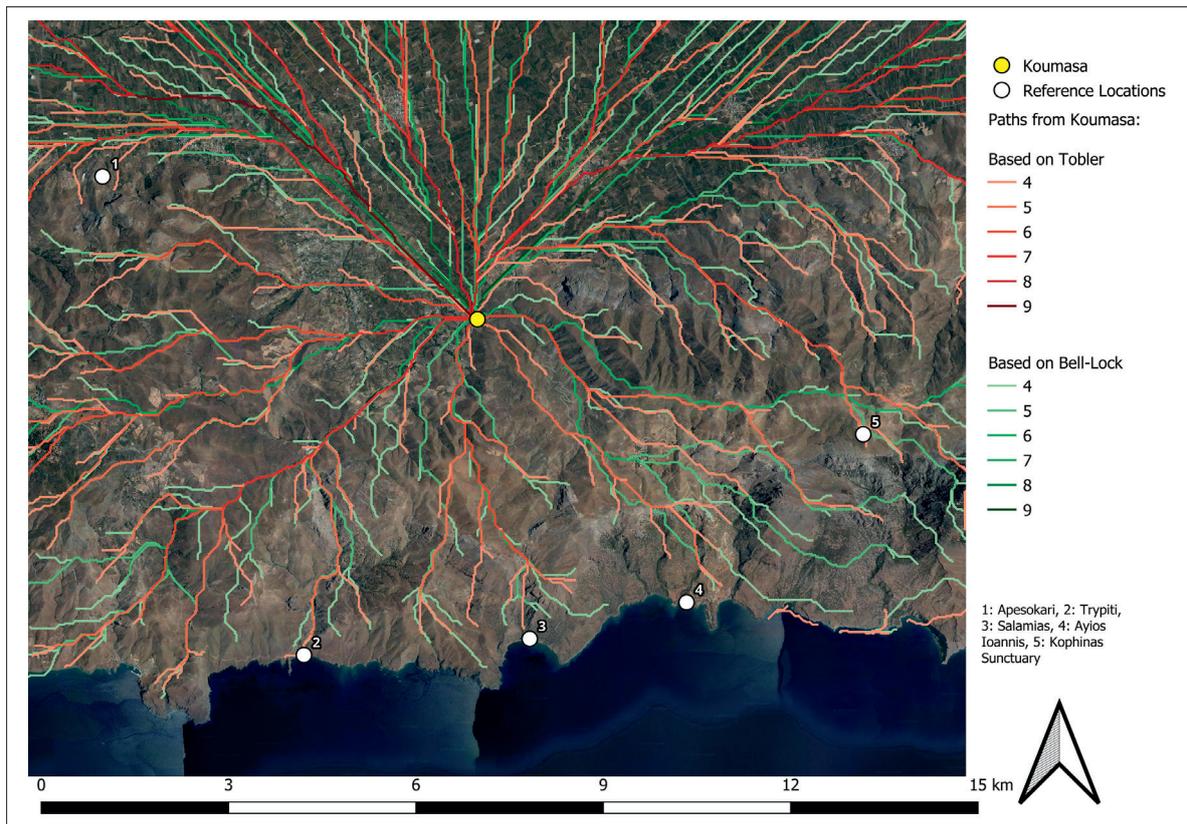


Figure 39: Interpolation of the two former iterations for the immediate vicinity of Koumasa.

Tobler function that yields paths appearing *less natural* with more straight lines. Simultaneously, the Bell-Lock function produces slightly more flexible path routes and exhibits more tributaries, providing a better depiction of possible movement on mountainous terrain. This distinction becomes more evident when interpolating the two results on a scale that focuses on the central Asterousia (Figure 39).

An additional iteration on the same area using the exponential function is illustrated in Figure 40 (not included in Figure 39 for visual clarity). Once again, based on the cost surface accumulation – this time approximating the second-degree polynomial – a flow accumulation was calculated. This depiction highlights how movement is channelled primarily along far-reaching solitary paths, excluding the tributary paths, and classified into three grades. These grades aggregate the flow of the furthest, least central paths.⁶⁴⁰

⁶⁴⁰ A separate iteration using the Ox-Cart function was performed which is not represented here, as the method yielded results comparable with those seen in the extended least-cost-path analysis seen in iteration 4 of Study 3 in Chapter 5.2 (Figure 30). Although not identical, it shows the potential and applicability of the method shown in iteration 4.

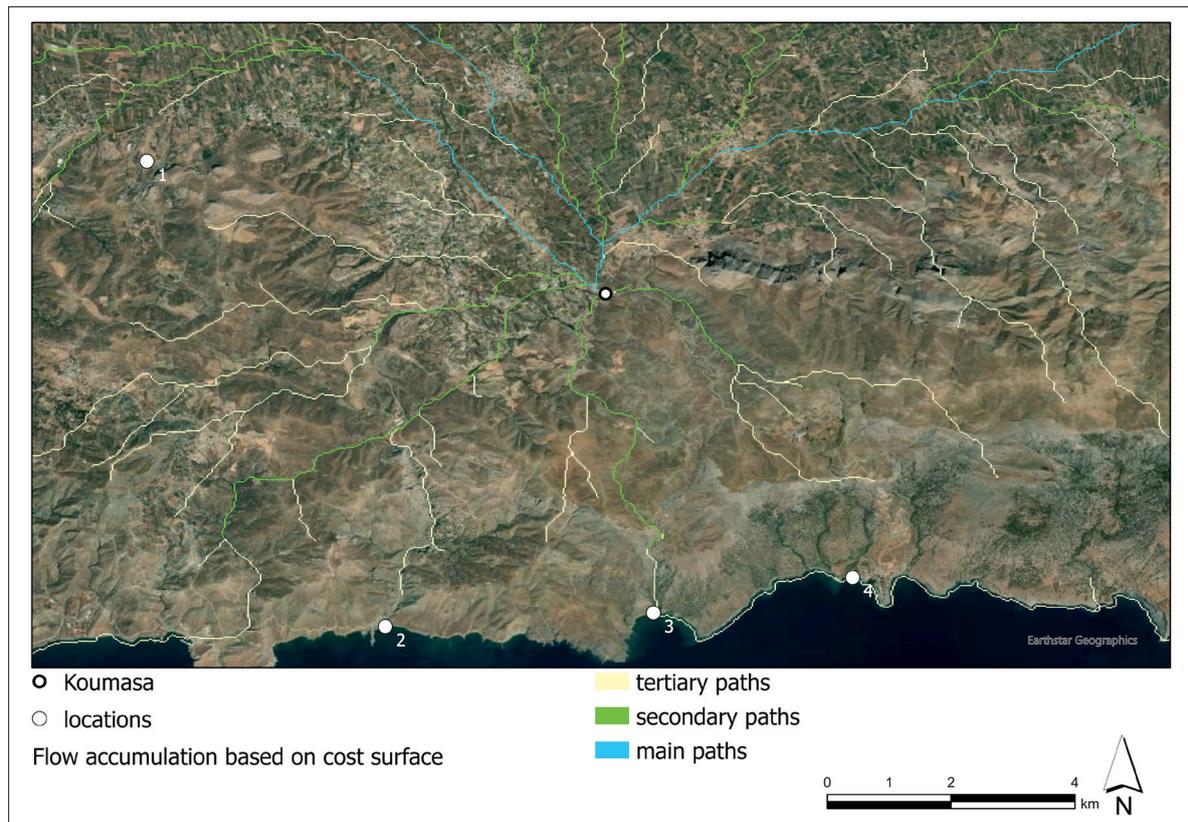


Figure 40: Flow accumulation paths based on the cost raster defined with the Exponential function.

When considering the locations of interest, it is notable that almost all are situated directly on natural paths, including Trypiti, Salamias, and Kophinas. Only Ayios Ioannis remains partially *shadowed*, a phenomenon attributed to the height of the mountain directly above it. Chapter 11 will discuss the evaluation of these paths in comparison to actual walking to these locations.

This methodology represents the initial step towards developing the focal mobility network.

5.3.3 Focal Mobility Network

In Chapter 5.2, both starting and ending points were defined. In Chapter 5.3.2, movement was explored without specifying target points, examining natural paths from a given starting point. Following the same logic, the third step is a further level of abstraction that illustrates the natural paths in a given area without considering starting or endpoints. This type of iteration provides the natural corridors of an area, thus being unrestrained from our perceived importance of locations. In the case of Minoan times, this methodology can levy the factor of unknown places or other latent factors. The

method acts as an impartial evaluation of the terrain, albeit with limitations imposed by the available DEM and the functions used for obtaining the results.⁶⁴¹

One major methodological issue in the two methods described above can be summarised in the inherent assumption of a direct route between individual points, which may not reflect reality. This concern was touched upon when discussing the implications of different routes imposed by our restrictions on the algorithm. The reality of roads often involves a system of paths and arteries of communication rather than a direct link between locations. These weaknesses have been recognised in the early stages of GIS methodology development.⁶⁴²

One way to approach the reality of paths is to investigate patterns of movements rather than individual cost paths. Then, the set of locations of interest is evaluated concerning their relation to the optimal paths.⁶⁴³ One of the most known algorithms was introduced by Llobera, which is an exhaustive methodology that forces a calculation of least-cost paths between all pixels of the study area and then combines the results.⁶⁴⁴ This methodology has been implemented to study the accessibility of ancient sites from various cultures⁶⁴⁵ and, more recently, in the Messara.⁶⁴⁶

The method, as initially proposed by Llobera, faces the issue of the computational intensity required and the redundancy in the calculation. Many pixels would exhibit similar behaviour, leading to redundant computations as the extrapolated flow of movement would stem from very small areas.⁶⁴⁷ Consolidating the two extreme methods – the monosemantic least-cost path analysis and the exhaustive point-to-point least-cost calculation – a proposed solution is using a grid of points.⁶⁴⁸ The denser the grid, the closer it aligns with the Llobera solution. Unlike the solutions above, where points are selected based on points of interest in the area of investigation, the origin points are randomly placed following the grid, approximating the physical characteristics of the terrain.⁶⁴⁹

The grid solution is preferable over one where chosen locations are inserted (say, all known sites in the Messara) as sites unknown to us are inherently not represented,

641 Fábrega-Álvarez 2006, 7.

642 Wheatley – Gillings 2002, 151–159.

643 Déderix 2016, 555. See also Vouzaxakis 2015.

644 Llobera 2000.

645 Llobera et al. 2011.

646 Déderix 2017.

647 Nevertheless, this approach is sometimes applied. Such as case is Verhagen 2013. Although it is to be noted that this example is applied on a plain surface with three types of friction movement, which reduces the overall computation needs (Verhagen 2013, 384–385). Such an implementation is not relevant for the mountainous Crete.

648 Déderix 2017, 13.

649 Other solutions implementing an intensive calculation of multiple least-cost paths include the use of natural entry points (Fáiren-Jimenez 2007, 290–2) and the use of points alongside the border (See also Whitley and Burns 2008). Iteration 4 in Study 3 above was an approximation of this method.

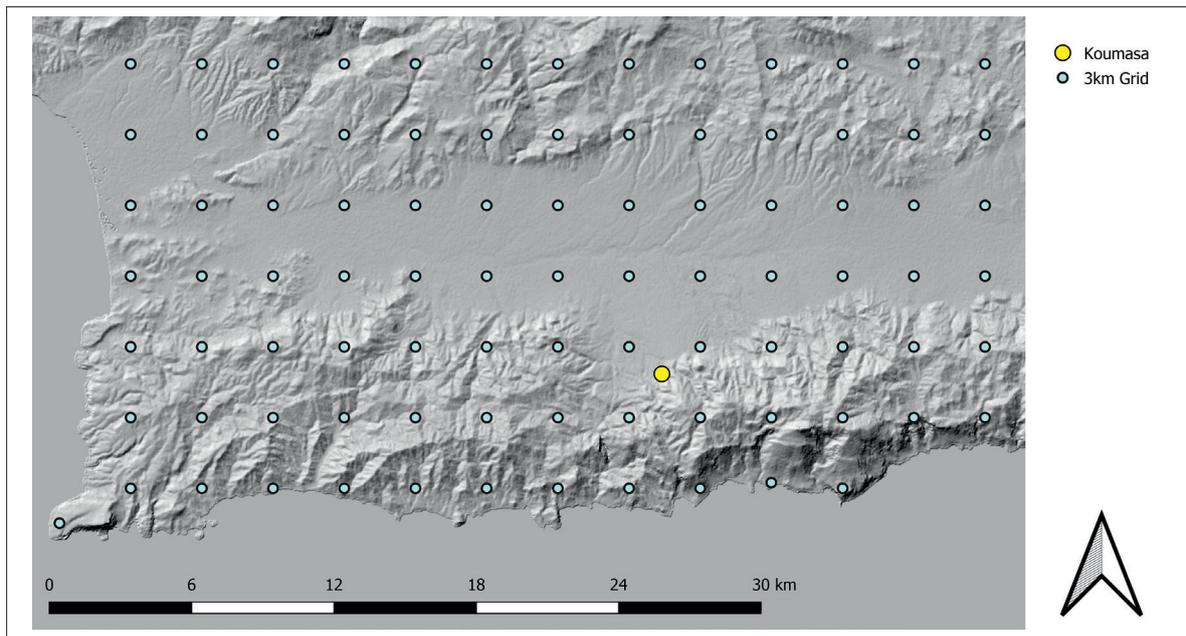


Figure 41: Grid points around the Messara.

and furthermore, the results will not represent the free movement of the focal mobility network proposed here.⁶⁵⁰

For the 20 m.-DEM, two iterations were made, one with a grid of 100 points spaced 2 km. apart and a smaller one concentrated around the Kophinas Peak and the slopes around them. The results are compatible with the focal mobility network that was performed for the western Messara by Déderix to produce a focal mobility network.⁶⁵¹ It is demonstrated that the presence of Koumasa at the edge of the DEM used by Déderix did not influence the overall result.⁶⁵² Rather, as also indicated in the main paths of the Messara in Chapter 5.3.2, Koumasa lies indeed peripheral to the main communication arteries through the Messara. It is this peripheral location, however, that requires an explanation for the development of this area, especially in the LM I period, as discussed above.⁶⁵³ In relation to the paths around the central Asterousia however, Koumasa has a rather central location.

For enhancing the approach, the steps were repeated on a cost raster based on Tobler's function, performed over a 3 km. grid (Figure 41). Again, as before, the main paths of the Messara do not pass near Koumasa, as around the central Asterousia, no

⁶⁵⁰ This approach was used by Déderix, assuming the tholoi as origin points (Déderix 2017, 17).

⁶⁵¹ Déderix 2016, 558–560; 2017, Fig. 7.

⁶⁵² In other words, the method is less prone to edge effects. Further, using tholoi instead of a grid (Déderix 2017, 17–18, Fig. 6) is seen as yielding similar results for the western Messara, with its dense coverage of tholoi, since the available tholoi locations are high.

⁶⁵³ See discussion on page 85ff.

5 Insight of GIS for the Mobility Networks around Koumasa to Messara

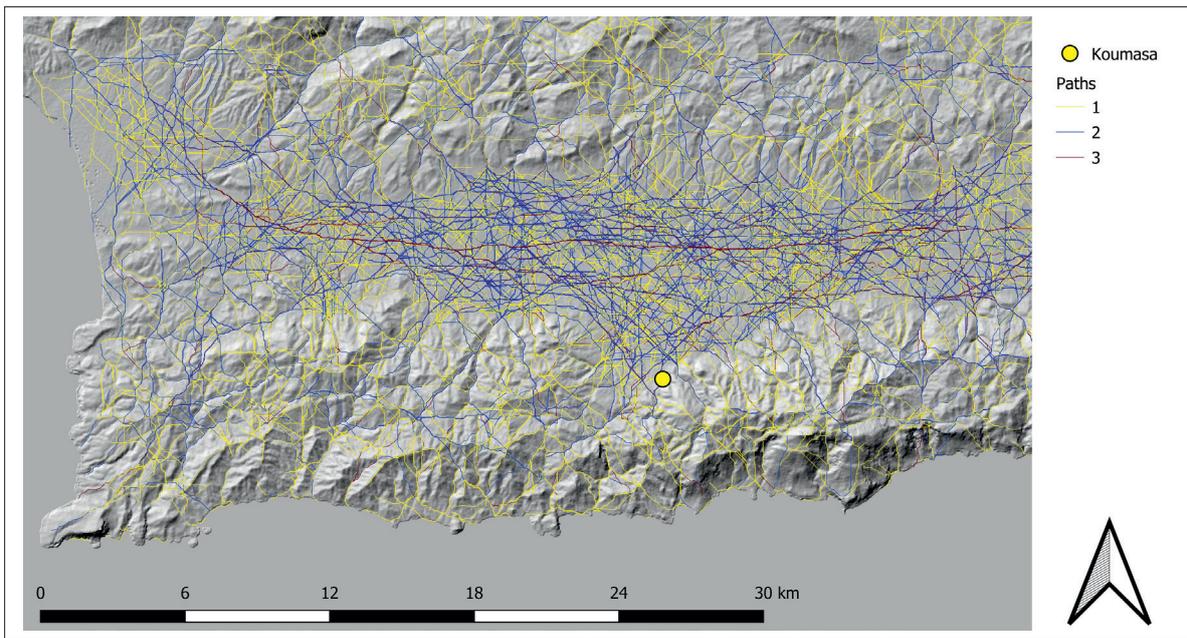


Figure 42: Network connectivity for the Messara area.

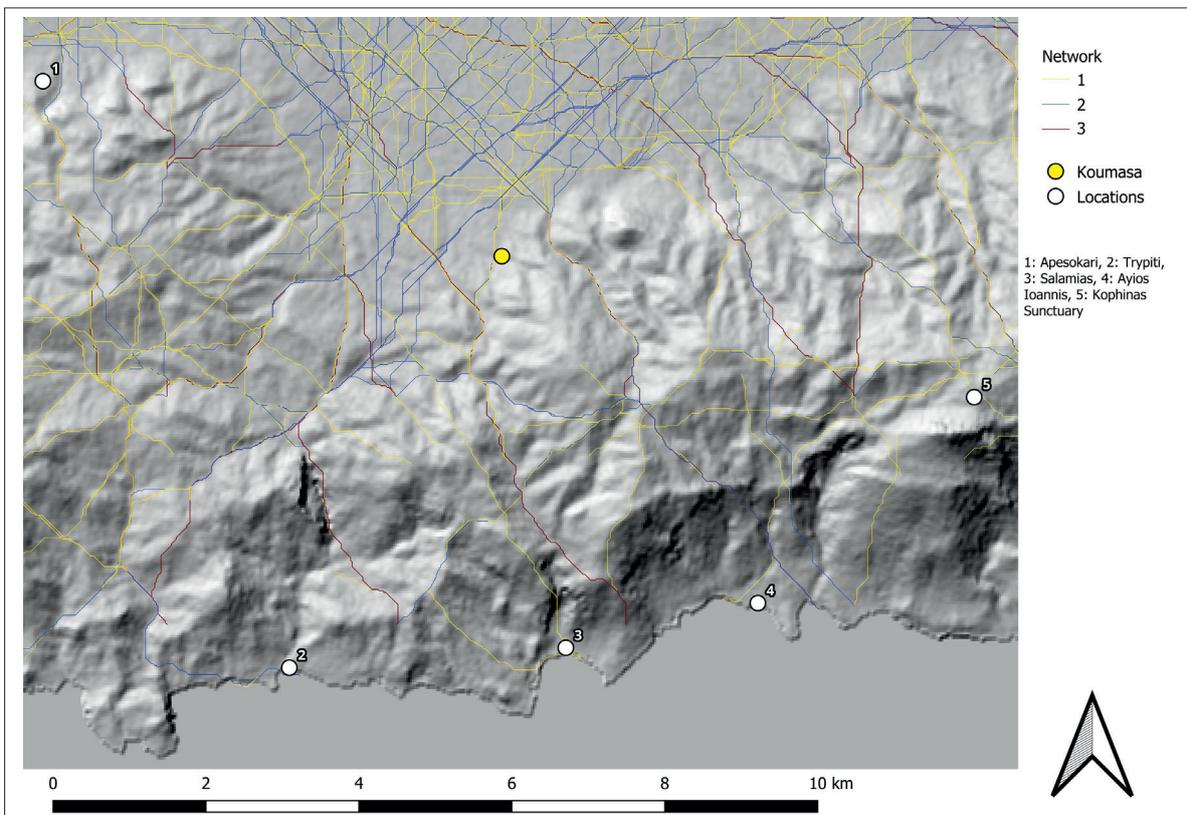


Figure 43: Network connectivity for the Koumasa area.

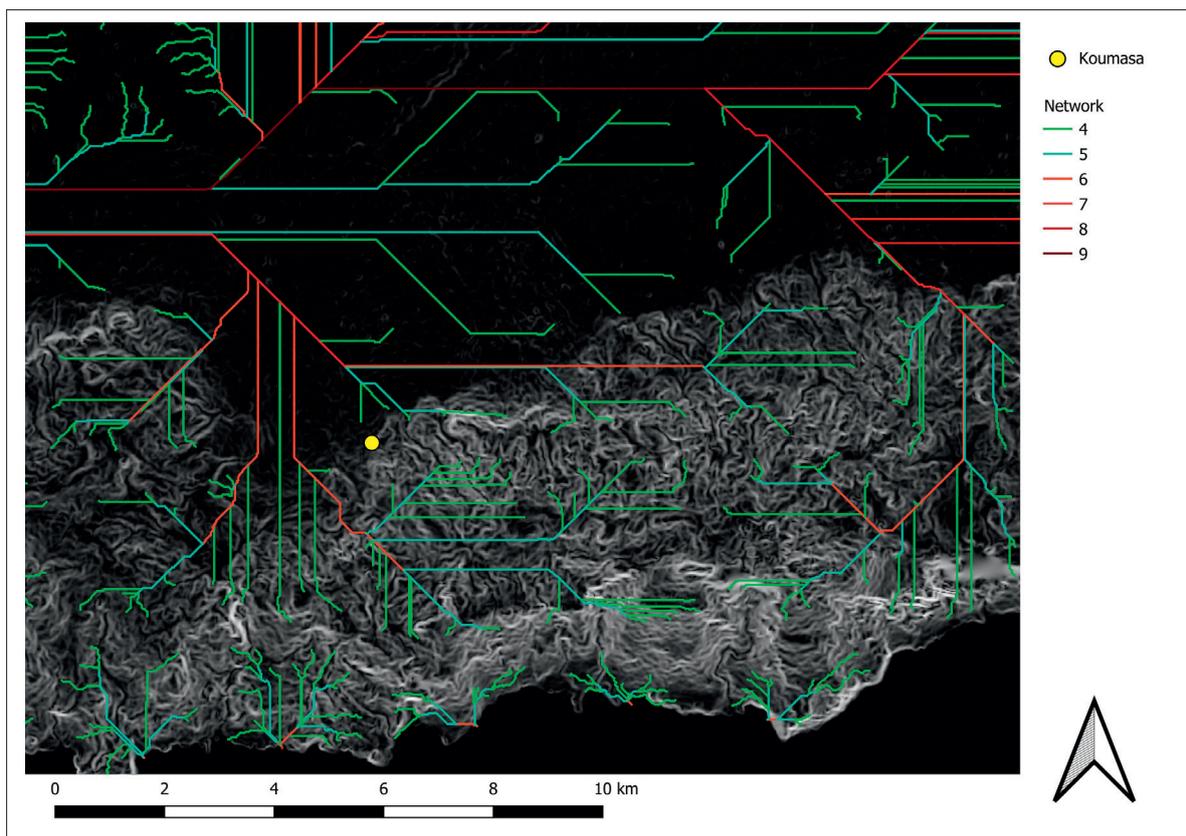


Figure 44: Schematic rendering of paths around central Asterousia.

paths of the Strahler order 8 and 9 appear, which correspond with the prime paths of type 3 in Figure 42. What distinguishes the region is the fair concentration of secondary paths near Koumasa, in comparison with the other locations around central Asterousia (Figure 43). Hence, no centrality is suggested in the Messara, but rather one in the central Asterousia becomes evident. Specifically, a strategic position near path networks crossing the mountain is apparent.

An artificial illustration of this result is seen in Figure 44, where the paths are quantified based on a cumulative accumulation map using the grid points, based on the Bell-Lock Function.⁶⁵⁴ Filling, flow direction and channel identification were performed, resulting in a pixellated path network bound by the grid points. This iteration serves as an easily readable alternative to the results of Figures 42 and 43. This image again shows the symmetry of paths as per the Kophinas peak, with an accumulation of main paths from the area of Koumasa and the semi-circled extension of the Messara of the region which ends at modern Vassiliki. The other access point to the central Asterousia is from the area of Charakas, to the right of the image; it approaches the area of Kophinas from the northeast and branches towards Tris Ekklesies. The access point to

⁶⁵⁴ Based on the *r.walk* function. Other functions not depicted here yield comparable results.

the coastline up to the point west of Tris Ekklisies is mainly facilitated from the area of Koumasa and modern Vassiliki.

As mentioned above, the topography around Koumasa is characterised by the dual nature of ragged mountainous terrain to its south and the smoother Messara plain to its north. This duality influences the efforts to establish models for the movement behaviour, as each of these two regions reacts differently to different parameterisation. So, some reclassifications, such as the Tobler, appear more nuanced in the flat terrain, while others, such as Bell-Lock or Ox-cart, yield more nuanced results for the mountainous region.⁶⁵⁵

The area of Koumasa is seen, as in the case of the least-cost-path analyses in Chapter 5.2, to be central as per its local environment, offering exclusivity to the central Asterousia and the shoreline south of it.

5.4 Viewsheds

Another important application of DEM analysis is the determination of viewsheds. This analytical tool helps establish the line of sight between observation points on the DEM, illustrating the extent of visibility. This technique has been used to determine the viewing coverage of towers and, concerning Crete, the sight coverage of peak sanctuaries and tholoi.⁶⁵⁶ Also innovative ideas could be explored such as the possibility for communication networks based on viewing posts in the Pediada region.⁶⁵⁷

For the application of the viewshed GIS methodology in this work, the observer's heights at both ends of the line of sight are set at 1.6 m. to closely simulate the lines of sight between standing individuals. This height was assumed as an acceptable median height of people of the Asterousia in the Bronze Age, with the mean height from Tholos B at Moni Odigitria being 160.79 cm, with a height distribution that is similar to that of other skeletal remains on Crete.⁶⁵⁸ This height also corresponds well with the assumed average height of Bronze-Age Europe and Egypt.⁶⁵⁹ So an assumed height of

655 The Bell-Lock function has the characteristic of being almost linear up to the level of 40 degrees, thus intrinsically favouring level areas, as discussed above.

656 Soetens et al. 2002; Soetens et al. 2008; and Déderix 2016 respectively.

657 Sarris et al. 2011, 507–509; Panagiotakis et al. 2013, Figs. 4, 7.

658 For the EM Tholos B of Moni Odigitria, the mean stature of the individuals is 165.4 cm. for men and 156.6 cm. for women, while the funeral sites of EM Ayios Charalampos and LM III Armeni, Mochlos and Khania yield comparable results (Triantafyllou 2010, 243, Table 140, Fig. 117).

659 In Egypt, based on femur and tibia lengths of 150 skeletons from across Egypt, the stature of the individuals was computed. From the Neolithic until the Middle Kingdom the average height was calculated at 167.9 cm. for males and 157.5 cm. for females. The period with maximum height was observed by the Early Dynastic period, where the height was calculated at 169.6 cm. for males and 159.5 cm. for females (Zakrzewski 2003, Table 3). Explanatory frameworks for the changes between the periods concentrate on social structures (Zakrzewski 2003, 228). In the European Neolithic of the Linear Band Pottery Culture onwards the average

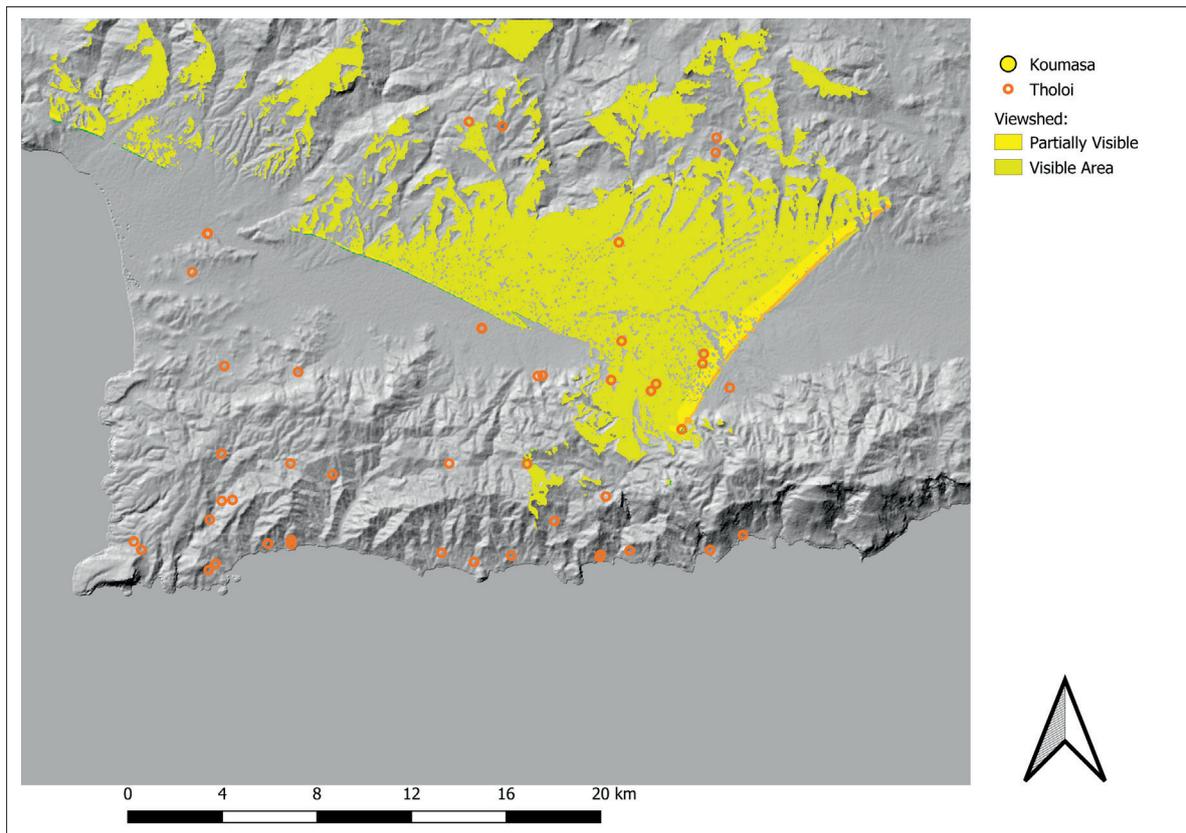


Figure 45: Viewshed of Koumasa, calculated on the 20m.-DEM.

160 cm. for applying the viewshed can be considered well within the anticipated individual heights.

Two iterations were performed on the 20m.-DEM, one from Koumasa and another from Apesokari (Figures 45, 46). For the first study, which is the determination of the viewshed from Koumasa, five points were defined on the settlement and the ‘sanctuary’, particularly around the peaks. The resulting viewsheds offer valuable insights into the visual coverage of the landscape from these vantage points.

The total area seen from Koumasa is 163.6 km², of which 99.9 km² in the Messara valley. The implications of this viewshed will be discussed in Chapter 9.2.

The total area of the Viewshed from Apesokari is 129.8 km², of which 93.9 km² on the Messara valley. It covers thus less area both in total as well in the valley, but the viewshed extends more to the west and east, compared with Koumasa, as seen in Figure 46.

An additional point of interest, emphasising the efficacy of visibility analysis, pertains to the viewshed from the summit of Kophinas. Illustrated in Figure 47, the view-

height for males was calculated to have been around 165 cm. for males to 150 cm. for females (Hermanussen 2003, 175).

5 Insight of GIS for the Mobility Networks around Koumasa to Messara

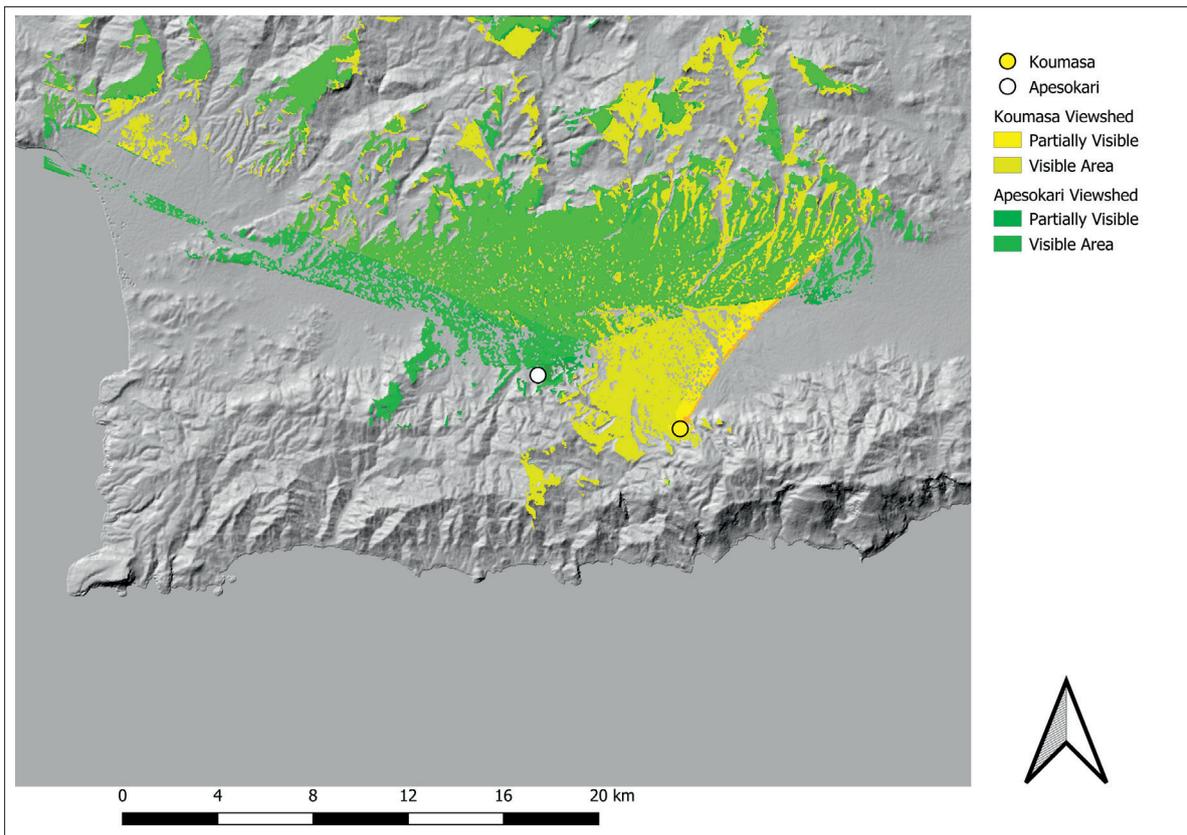


Figure 46: Viewsheds of Koumasa and Apesokari, calculated on the 20m.-DEM.

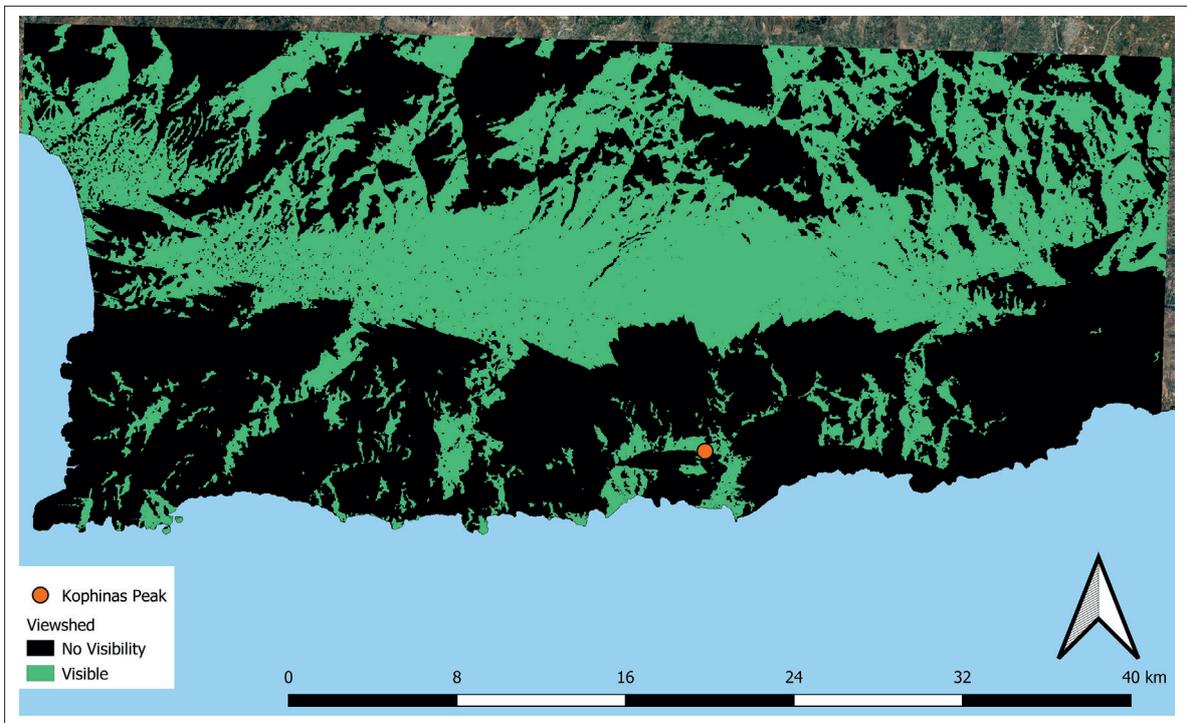


Figure 47: Viewshed from Kophinas, based on the 20m.-DEM.

shed from Kophinas encompasses a broad perspective of the Messara and the northern mountainous regions, which from experience extends from Psiloritis to Dikti. Notably, the distinctive silhouette of Kophinas is discernible on the southern skyline from locations in the Messara with significant or partial visibility, which is verified when walking in the Messara. This feature establishes Kophinas as a prominent reference point for the region's inhabitants. The significant meaning that this line of sight held is further underscored by the deliberate alignment of the entrance of the Tomb of Korakies with the peak of Kophinas.

Consequently, when positioned within the tholos, the peak becomes centrally visible through the tomb's entrance.⁶⁶⁰ The assumption may be posited that the constructors of the Korakies tholos deliberately incorporated a topographical feature, using it as a statement of the quasi-unique local skyline, which is integrated into the architectural design. Alternatively, it is plausible that the peak held inherent significance that the builders sought to honour. It is noted that none of the other tholoi located on the central and western-central Asterousia or at the coastline have this possibility, with the exception of the tholos at Ayios Ioannis, where a possible orientation of its entrance to the peak can also be seen. For the Korakies tholos, situated on the mountain, the peak transcends being a mere distant feature on the horizon, as is the case with other tholoi in the Messara that have a line of sight connection with Kophinas, such as Kamilari or Platanos, where the Kophinas peak is a distant point; for the dweller or walker of the mountain, the peak exerts a tangible influence and dominance over the surroundings.⁶⁶¹

From the Asterousia, numerous locations in close proximity lack a line of sight to the peak, including Koumasa, as seen in Figure 47. However, the visibility range extends extensively to the direct west of the peak, encompassing Kapetaniana and extending 4 km. along the path leading to the peak from the direction of Kapetaniana and Koumasa. Further westwards, another area with substantial visibility coverage is that which includes the Korakies tholos.

When observing from Kophinas towards the south, all promontories are visible up to Cape Lithino. Figure 48 illustrates the reciprocity of this visibility.⁶⁶² Not only is the view commanding, but those turning on a boat from Cape Lithino face a skyline dominated (or, alliteratively, blocked) by the Kophinas peak.

660 Goodisson 2018, 280, Fig. 1a.

661 On the influence of the peak, see Chapter 11.4.

662 The photograph from the sea was taken by Stylianos Perrakis from a boat. The photograph from the Kophinas peak is taken by Olympia Makri. The small promontory of Akra Trachili at Gerokampos between Leben and Megalonisi is not denoted in the Figure 48.

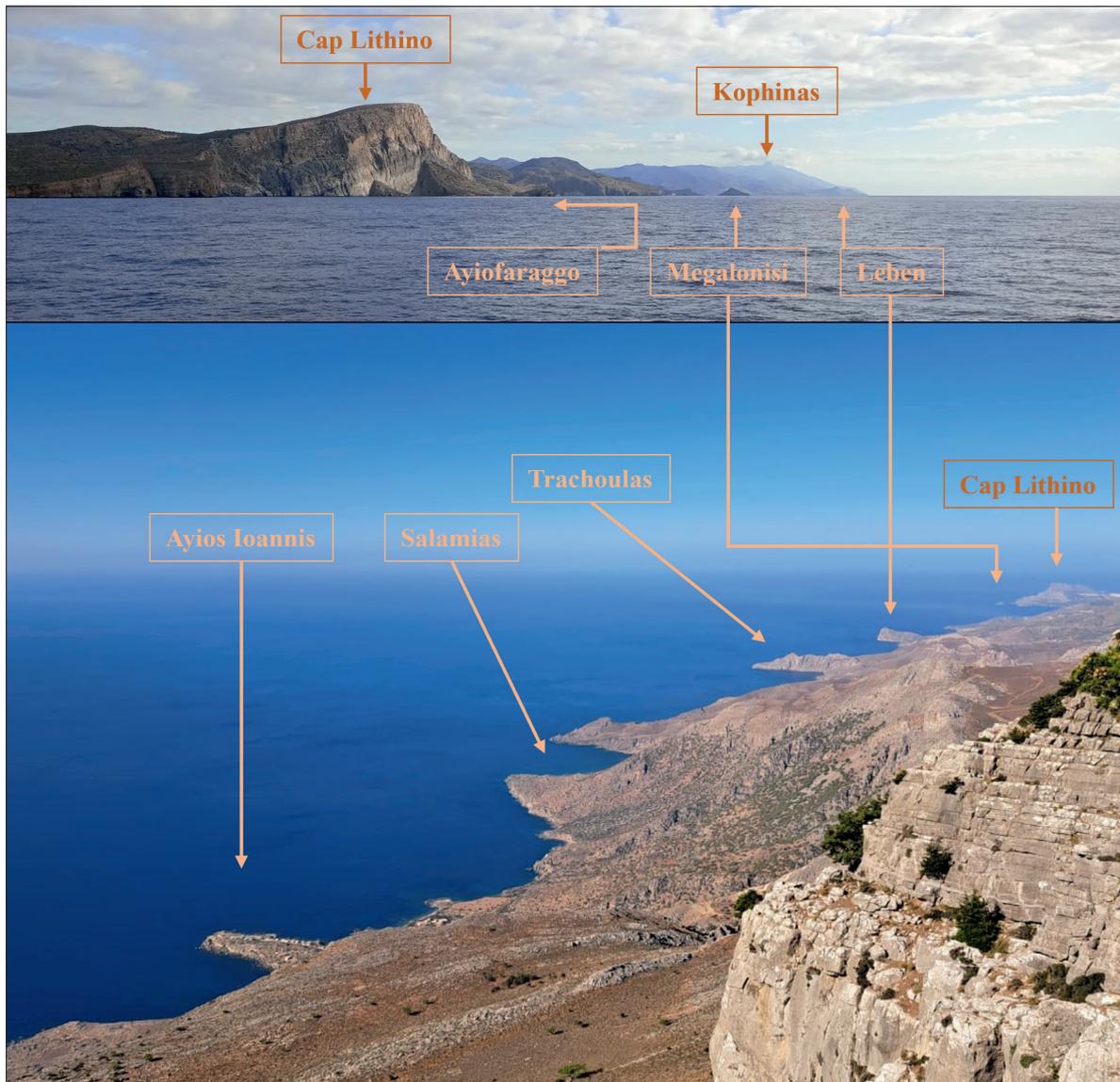


Figure 48: Reciprocity of the visibility between Kophinas and the sea level at Cape Lithino.

5.5 Watershed

On the 30m.-DEM, the process of filling sinks was executed, which calculates the flow of water downwards, enabling the representation of catchments. It's important to note that this method is susceptible to the edge effect, meaning that more sink catchments will be represented at the edges of the DEM due to the cut-off of the DEM's edge. This accurately reflects reality only when the cutoff occurs at the seashore. The drainage basins and channels were then calculated on the filled DEM, resulting in streams ordered according to Strahler and the fill basins functionality in GIS.

The stream order indicates the level of branching, following a top-down approach. If two streams of the same order merge, the resulting stream is given a number that is

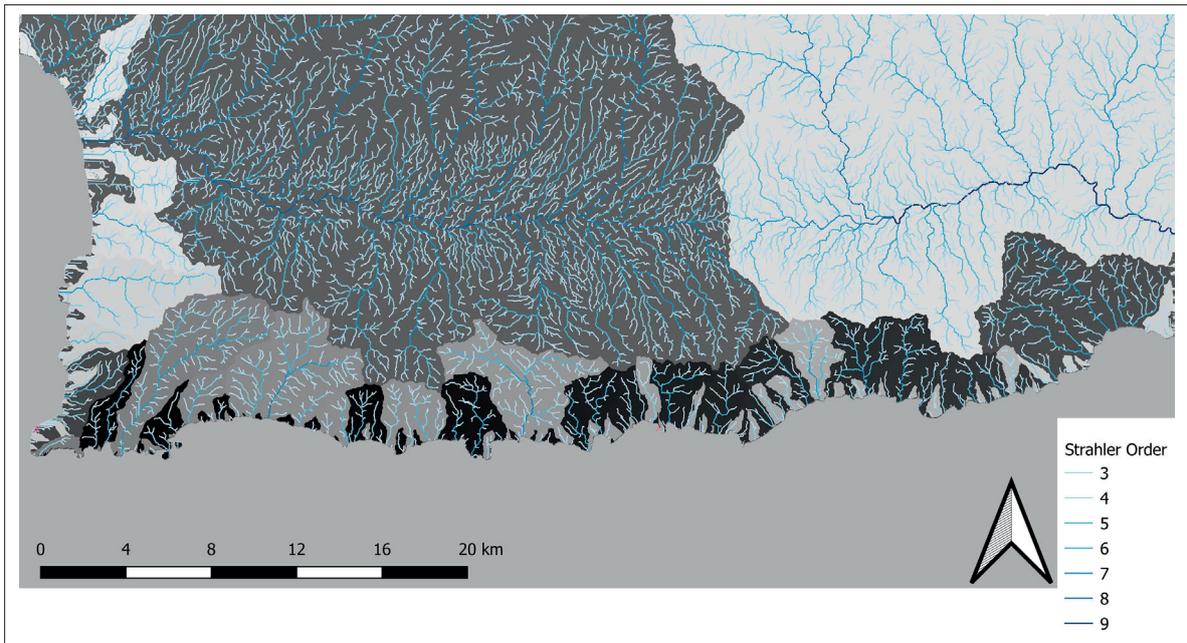


Figure 49: Water drainage basins of the Messara, with Strahler Order 3 and above. Computed on the 30m.-DEM.

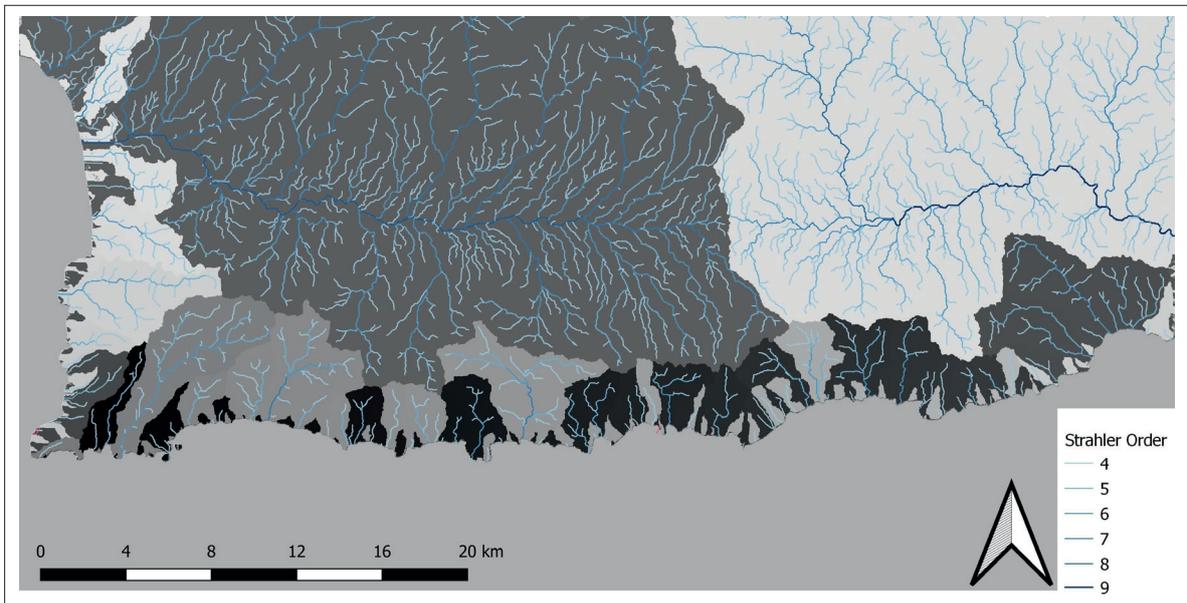


Figure 50: Water drainage basins of the Messara, with Strahler Order 4 and above. Computed on the 30m.-DEM.

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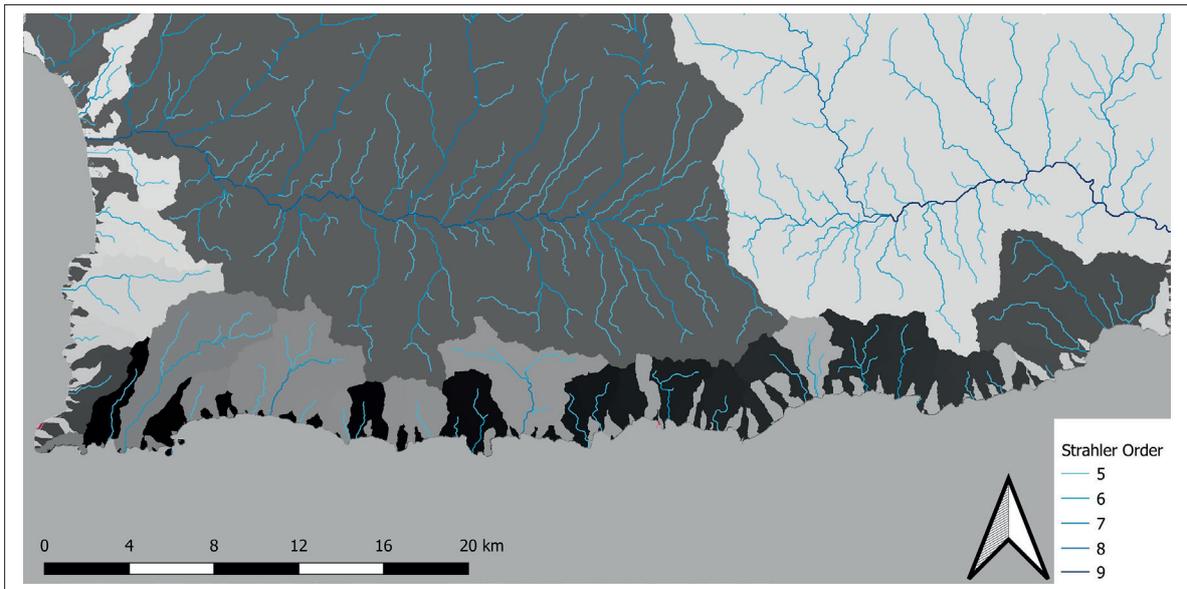


Figure 51: Water drainage basins of the Messara, with Strahler Order 5 and above. Computed on the 30m.-DEM.

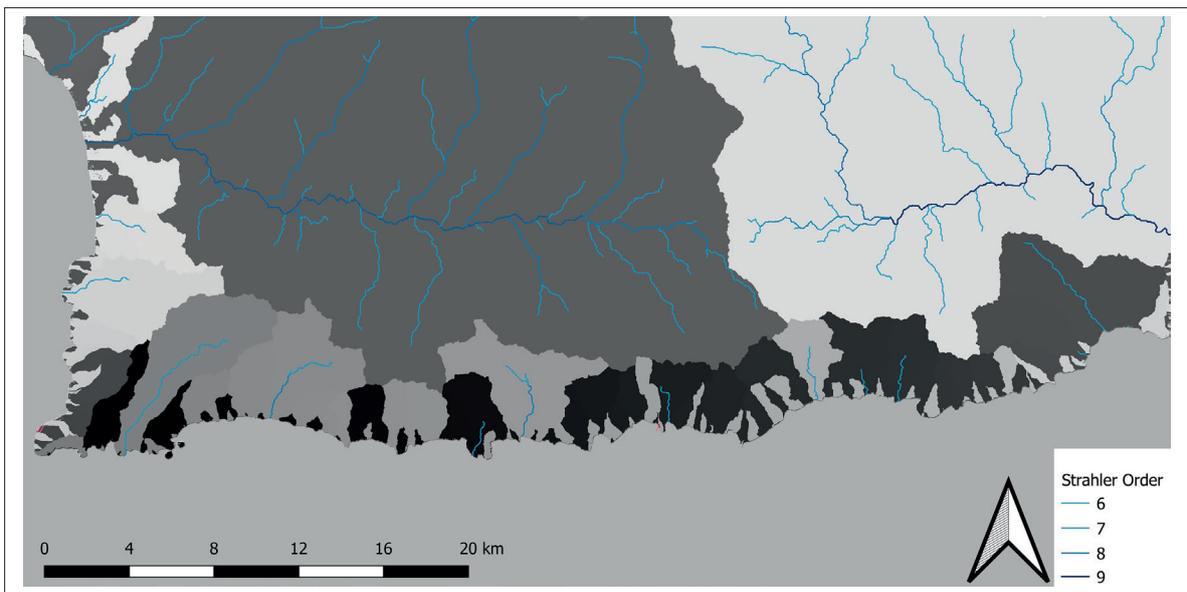


Figure 52: Water drainage basins of the Messara, with Strahler Order 6 and above. Computed on the 30m.-DEM.

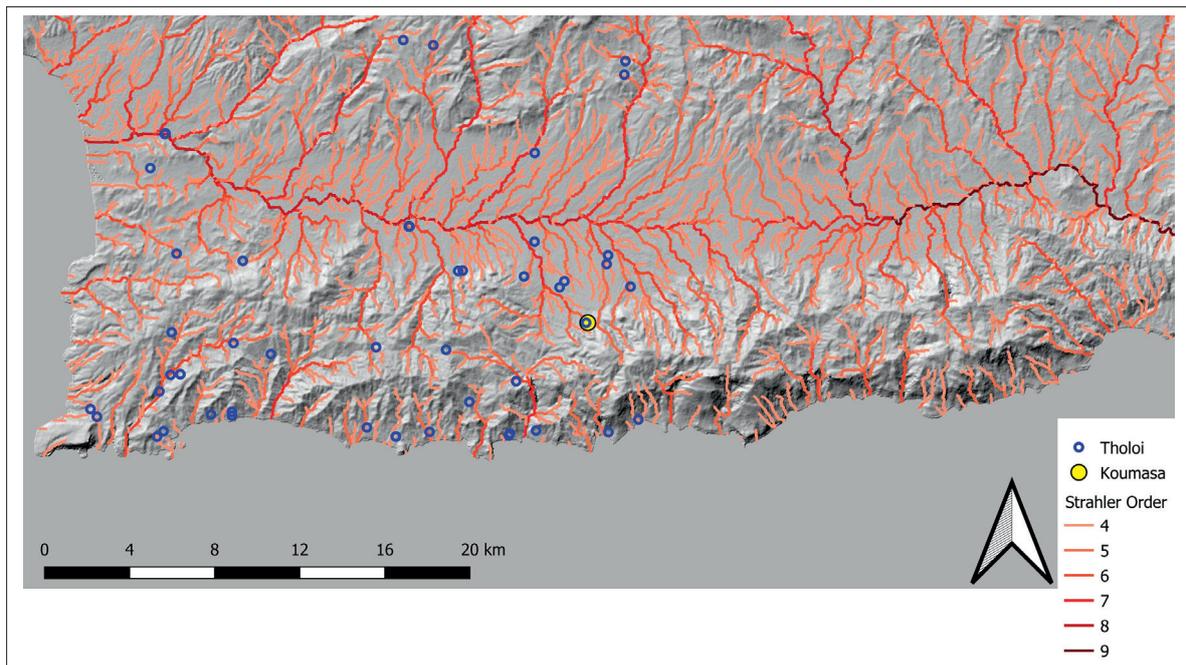


Figure 53: Water drainage basins of the Messara as in Figure 50, including locations of tholoi.

one higher. Streams with no tributaries have the Strahler order 1, those with one tributary the number 2 etc.⁶⁶³ For visualisation purposes, Figures 49, 50, 51 and 52 show the catchment area of the Messara and Asterousia, with four different visualisations of the streams, beginning with Strahler Order above 3 and extending to Strahler Order 6 and above. The lower the Strahler order shown, the more complicated the resulting image is, as the number of tributaries tends to grow exponentially. The basins have also been calculated elsewhere, showing results that are compatible with those calculated here.⁶⁶⁴

Choosing the visualisation of Strahler order 4 and above (Figure 53) and then 5 and above (Figures 54, 55, 56), the tholoi and the location of Koumasa were interpolated with the waterways, showing these locations in correlation with water paths. In Figure 56, the reference locations were also included. It is immediately noticed, that all of the tholoi in the valley are located on these waterways or very close to them.

Or otherwise formulated: the distribution of the tholoi is highly dependent on the main waterways crossing the Messara.

It is noted that this also applies to tholoi in the coastal area in the southern part of Asterousia. To substantiate the non-random nature of the proximity of tholoi to the water channels, a two-dimensional normal distribution analysis was conducted for the tholoi locations. This analysis was then compared with the distances of randomly se-

⁶⁶³ See Strahler 1964.

⁶⁶⁴ Daliakopoulos – Tsanis 2014, Figs. 1–5; Malagò et al. 2016, Fig. 4.

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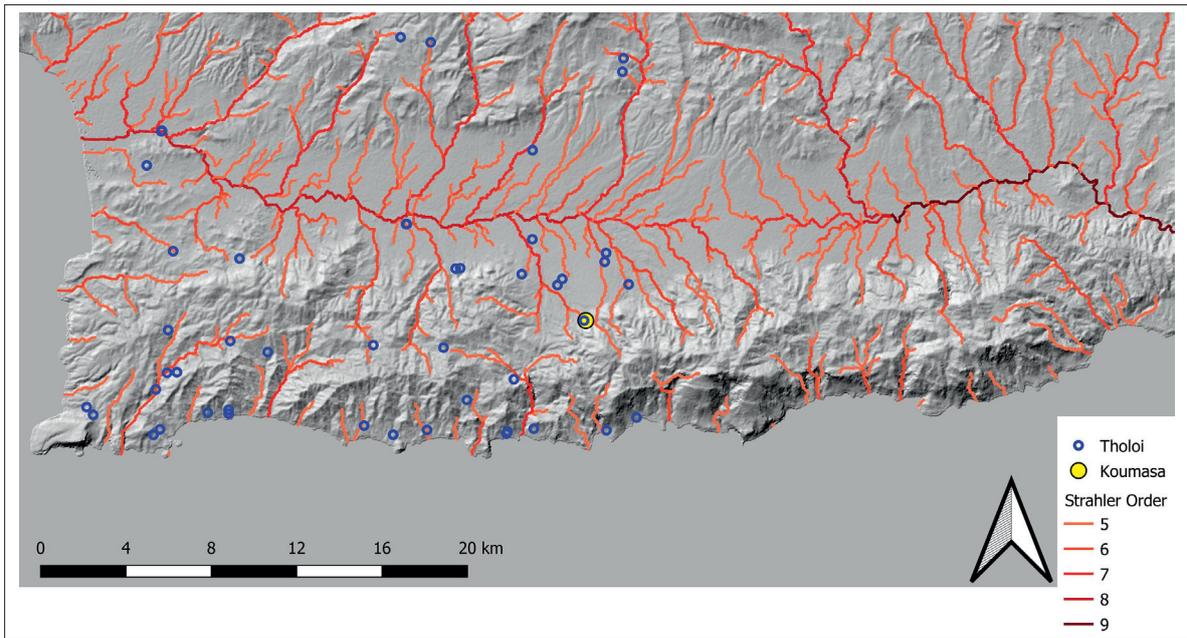


Figure 54: Water drainage basins of the Messara as in Figure 51, including locations of tholoi.

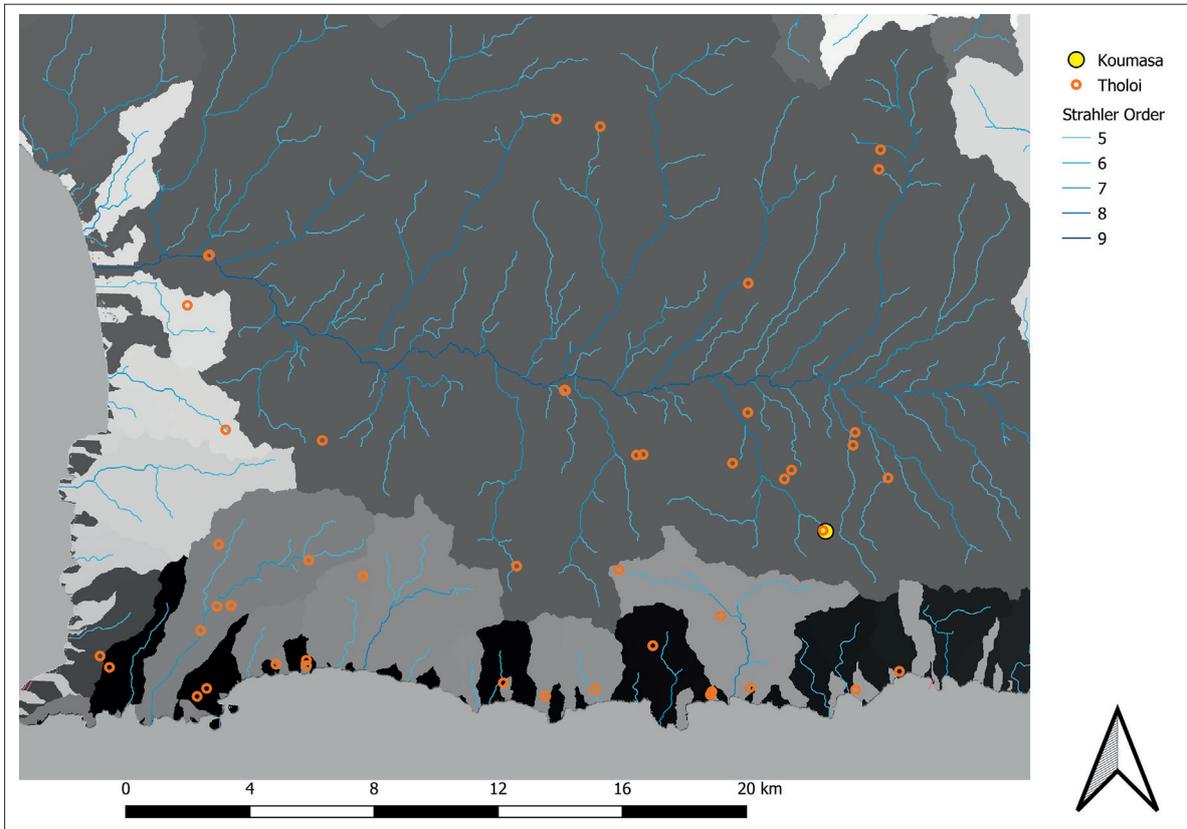


Figure 55: Water drainage basins of the Messara as in Figure 54, concentrating on the Geropotamos catchment.

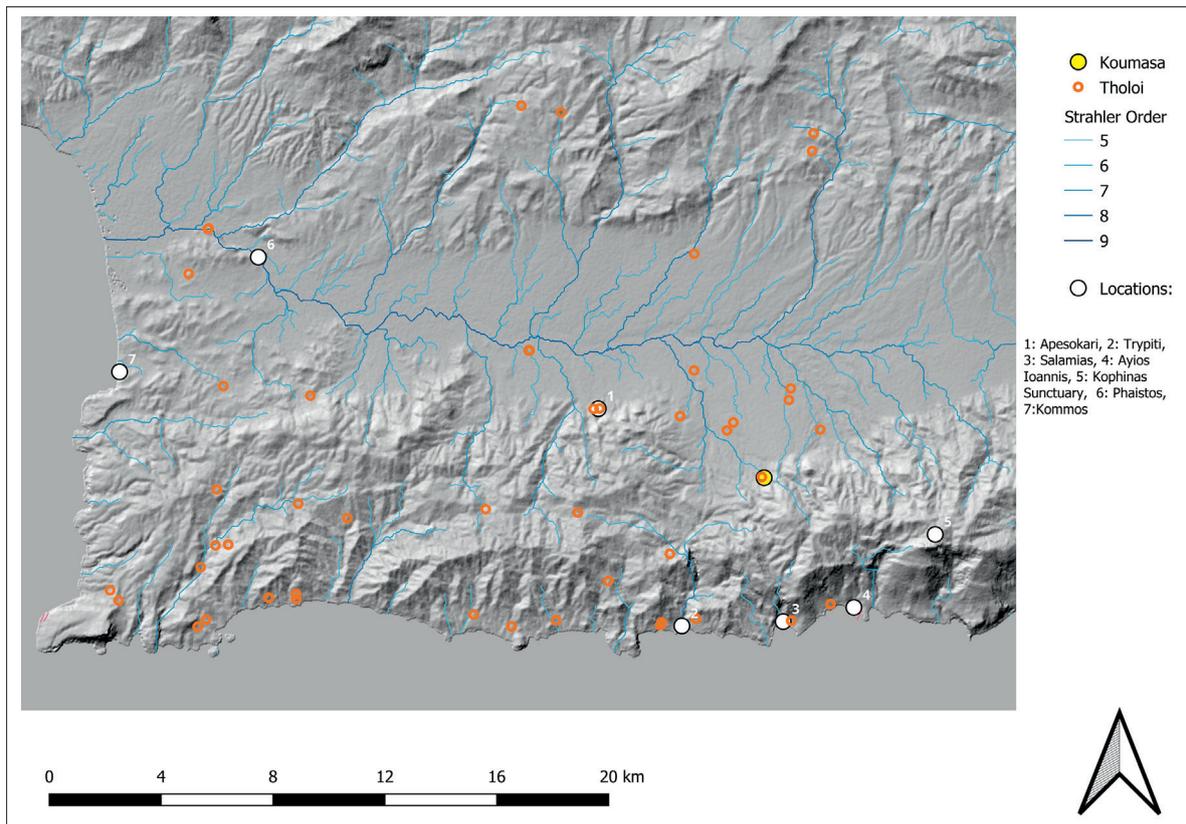


Figure 56: Water drainage basins of the Messara, as in Figure 54, including reference locations.

lected points to the nearest channel. The outcomes of this examination confirm the statistically significant correlation between tholoi distribution and water channels of both Order 4 and Order 5, as indicated by the results of the normal distribution analysis.⁶⁶⁵

Examining the streams categorised with Strahler Order 5 (depicted in Figures 54, 55, and 56), it becomes evident that several tholoi are situated at the inception of this category of streams, including Vorou A, Vorou B, Marathokephalo, Kalathiana, Korakies, Ayios Kyrillos, and Koumasa. These streams receive additional tributaries as they flow towards their respective basins, specifically the Geropotamos in this context. They exhibit a relative weakness in terms of water volume at their initial stages. However, the mentioned tholoi were established at these locations that would have water access above the average of the region, although not in the maximum possible amounts. This suggests that while access to water is essential, an excessive abundance may not be a determining factor in tholoi placement.⁶⁶⁶

⁶⁶⁵ See analysis on pages 256ff. For a more in-depth evaluation of the Strahler order and watershed analysis on the valley basin versus the steeper southern side of the Asterousia, see Ayash 2025.

⁶⁶⁶ Ayash 2025.

This outcome serves as a foundational point for further investigation into the rationale behind the chosen locations for tholoi, a subject revisited in Chapter 9.3.⁶⁶⁷

5.6 Conclusion

The main objective of the analysis in this Chapter was to investigate the geographical context of Koumasa within the broader topographical landscape of the Messara-Asterousia region. The analysis primarily involved examining the relationships between key landmarks in the region, considering factors such as terrain influence on walking routes, visibility, and the impact of water streams. The study also aimed to discern general topographic characteristics that offer insights into understanding the area unrelated to any given location (focal mobility network, watershed). The focus on analysing different methodologies and functions, aimed at a broader understanding of the methods used and gaining the most from them.

The approach in Chapter 5.2 encompassed utilising least-cost-path methods, incorporating slope data and predefined locations to identify feasible paths. Subsequently (in Chapter 5.3.2), the flow direction methodology was employed to reveal *natural paths* originating from specific locations. Finally, a network connectivity perspective was adopted to explore free movement influenced by the landscape, utilising a surface accumulation approach (Chapter 5.3.3).

Various iterations were conducted, with experimentation involving different threshold values for slope cut-offs and the utilisation of diverse functions, as detailed in Chapter 4. These iterations ensured the accuracy of the results, offered a framework for evaluating said methods and functions, and extracted the maximum amount of information, given an understanding of the used functions. The analyses contribute to a comprehensive understanding of the methods' limitations and facilitate a critical evaluation of their effectiveness to optimise their utilisation.

It is important to stress that the aforementioned GIS-based procedures were executed with an awareness of the method's limitations. It was acknowledged that these tools serve to contribute to the prediction of areas where movement patterns may have concentrated or where they could have concentrated during the Minoan era, as well as evaluating areas on the basis of lines of sight and water availability. Importantly, however, it was also seen that the results should not be regarded as monosemantic, but rather as a part of a broader analytical framework.⁶⁶⁸ GIS can be a very useful tool, but completely replacing the actual pathfinding could prove misleading. After all, even if belonging to different cultures, aspects of pathfinding and navigating the terrain remain an intrinsic characteristic of human behaviour, encoded in the genes of our species, so

⁶⁶⁷ A tentative proposition is that the branches of these waterways, especially those currently lacking identified tholoi, might serve as potential areas for discovering yet-unidentified tholoi.

⁶⁶⁸ Verhagen 2013, 383.

that the modern walker may share more with the ancient counterpart than one would assume.⁶⁶⁹

Despite their inherent distinctions, these methodologies exhibit a convergence in highlighting natural movement patterns. While the route toward Trypiti was anticipated to be validated by the flow accumulation, the emergence of a direct connection to Salamias and Ayios Ioannis through the flow accumulation was somewhat unexpected yet promising. This result served as an inspiration for the subsequent on-site exploration. Although the identified paths do not perfectly align with the nuances of actual walking (refer to Chapter 11.1), they provided a valuable estimation and served as an initial qualitative assessment of the terrain under investigation. Their usefulness is therefore assessed as positive both before embarking on the walking expedition and also afterwards for furthering the understanding of the terrain.

To this effect, aspects of the viewshed (Chapter 5.4) and watershed (Chapter 5.5) aided in quantifying further aspects of the terrain.

The position of Koumasa is verified to be peripheral in the macroscale of movement channels in the Messara and beyond, but at the same time nodal in the connections within the area of its mesoscale, presiding over pathways around the central and western-central Asterousia to the south and the valley to the north. Otherwise formulated, the cumulative results affirm the presence of an attractive force for natural pathways around the Asterousia converging toward the site of Koumasa. This phenomenon can be likened to that of a “gravitational pull”.⁶⁷⁰ This renders some locations central, which, as per the definition provided by Mills et al. ascribes to some nodes within a structured system with a certain prominence.⁶⁷¹

Koumasa therefore is seen to play a pivotal role as a local node, facilitating movement from the valley to the mountainous central Asterousia, exhibiting a considerable degree of exclusivity towards some locations, particularly concerning the harbours of Ayios Ioannis, Salamias, and, to a lesser extent, Trypiti and Kophinas. This exclusivity in the latter two is shared with Apesokari and the broader region of Rotasi, respectively.

Additionally, Koumasa boasts extensive visibility and, in respect to the watershed, aligns with other locations featuring tholoi in access to important water sources.

The techniques implemented here in the large-scale 20m.-DEM and 30.-DEM are also applied in the case of a local DEM for Koumasa in Part III, Chapter 6, so that the effects of the topography’s influence over the microscale can be examined, followed by the analysis of the architectural implementation on the ‘sanctuary’, in Chapters 7 and 8.

669 David – Thomas 2008, 113–115. For aspects of evolutionary psychology, see also Chapter 12.

670 Rivers et al. 2013, 136; see also Renfrew’s discussion of gravity in determining the directionality of distribution patterns (Renfrew 1977, 87).

671 Mills et al. 2013, 186–187.