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ORIGINAL PAPER

A geospatial analysis of the influence of landscape and climate on the location of Greek vernacular settlements using GIS

Aristotelis Vartholomaios[1]

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Abstract

A core argument of several studies that focus on Greek vernacular settlements is that climate and landscape had a significant impact on their spatial distribution and growth. For the majority of these studies, this argument is primarily underpinned by qualitative observations at the geographical scale or by detailed microscale analyses of specific case studies. A nationwide analysis of the relation of vernacular settlement locations with key environmental factors has not yet been conducted in Greece. The present study seeks to cover this research gap by adopting a geospatial analysis approach. It utilises Geographic Information Systems (GIS) to relate the location of Greek vernacular settlements with the sea, the sun, the wind and the local geomorphology. The results of the study provide valuable insight on these relations and ultimately support the argument of the environmental responsiveness of vernacular settlements with quantitative data.

Keywords GIS · Geomorphology · Vernacular settlements · Environmental analysis · Climate · Landscape · Greece

Introduction

Vernacular settlements in Greece constitute an essential component of the Greek tradition, cultural heritage and the rural landscape. Lifestyles, techniques, aesthetic preferences and social relations, as well as the wealth and diversity of Greek anonymous architecture of the post-Byzantine era, are imprinted in vernacular settlements networks and their surrounding landscape (Phillipidis and Lavvas 1995; Moutsopoulos 2004; Doukellis et al. 2005; Dimitsantou-Kremezi 1995). Their spatial distribution and growth were largely unplanned, since it was guided by the historic, social and economic circumstances and folk wisdom amassed throughout the centuries. The adaptation of settlement and building form and function to the local climate and landscape constituted a central aspect of this wisdom.

Thermal comfort, safety, surveillance and the utilisation of available natural resources were key human needs of that era that rendered this adaptation a necessity (Mpouras 1992a, 1998; Phillipidis and Lavvas 1995). The documentation and analysis of the environmental responsiveness of vernacular settlements are not only a matter of preservation and regeneration of the old, but also a matter of learning from the past to adapt the modern cities and societies to contemporary challenges. While the ideas of 'bioclimatic regionalism' (Olgyay and Olgyay 1963; Fathy 1986) and 'learning from the past' (Butina and Bentley 2007; Lanier 2009) are not new, there is a globally ever-growing need for enhancing the resilience of contemporary settlements against climate change and the depletion of non-renewable natural resources. Thus, the systematic analysis of the folk wisdom on architecture and settlement form and function can provide valuable lessons for the structuring of more resilient urban landscapes.

There is now a wide body of literature that focuses on the relation of vernacular architecture and settlement growth patterns with the natural environment (see the "Background" section). However, the vast majority of these studies are largely qualitative in nature. Consequently, the argument of environmental responsiveness of pre-industrial settlements is open to debate (Vellinga 2013). The present study steers away from notions of 'ideological romanticism' or 'ecological valorisation' of the vernacular (Vellinga 2013) by employing a quantitative and technical approach to the study of traditional settlements. The aim of the study is to conduct a nationwide geospatial analysis of vernacular settlement locations in Greece with respect to basic environmental parameters, such as winter insolation, wind exposure and ventilation, sea view,

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✉ Aristotelis Vartholomaios
avarth@arch.auth.gr; avarthol@teemail.gr

[1] Department of Architecture, Aristotle University of Thessaloniki, University Campus, 54 124 Thessaloniki, Greece

terrain defensibility and access to fresh water and forest resources. The quantitative nature of the results will eventually underpin or challenge—depending on the findings—the qualitative observations made by previous studies.

Background

A brief historic overview of Greek vernacular settlements and their statutory definition and protection

The majority of Greek settlements now considered vernacular were developed between fifteenth and nineteenth century (Phillipidis and Lavvas 1995). Historically, this time period starts with the fall of Constantinople in 1453 and ends with the Greek revolution and the establishment of the Modern Greek State in 1828. During that period the Greek geographical space was under Ottoman and partially Venetian rule with the Greek population residing chiefly in mountainous and semi-mountainous areas, often under restricted forms of self-governance. The populations of continental Greece were largely preoccupied with agricultural activities, while crafting industries and trade would grow in only a handful of places where local circumstances enabled them (Papageorgiou and Pouzoukidou 2014). From the eighteenth century and onwards, the introduction of neoclassical and eclectic architecture by a new upper class of Greek merchants and later industrialists altered the authentic vernacular character of some settlements such as Ermoupolis in Syros Island (Institute of Modern Greek Studies 2008). The demise of several vernacular settlements was eventually brought by the intense military conflicts of the twentieth century and post-war urbanisation which left the Greek countryside in a state of abandonment and decay (Karanikolas et al. 2003).

The idea of protecting vernacular settlements gradually evolved from preserving individual buildings to regenerating and managing sustainably whole landscapes of exceptional aesthetic and cultural value. The concept of 'vernacular settlements' first appears in Act 622/1977 and the subsequent Presidential Decree (P.D.) 594/1978 which listed 420 settlements considered worthy of protection. However, a concrete definition of vernacular settlements was provided a decade later, initially through the adoption of the Granada Convention in 1992 (Act 2039/1992) and finally by the Greek Council of State (Decisions 2526/2003, 3244/2004) according to which such settlements retain their traditional urban tissue, individual structures and architectural elements either as a whole or in parts (Papageorgiou and Pouzoukidou 2014; Katapidi 2014). More recently, Act 3937/2011 introduced the concept of 'protected landscapes/seascapes' which include both man-made and natural environments that are sustainably managed as a whole. Until today, over 920 settlements have been characterised as 'vernacular' by the relevant legislation, which according to the latest census (ELSTAT 2013) constitute approximately 7% of the total number of settlements.

The Greek climate

The local climate and the influence of landscape features on it have a central role in this study. The climate of Greece is Mediterranean (predominant Köppen classes CSa and CSb) (Kottek et al. 2006) which is characterised by hot-dry summers and mild-humid winters. Locally, the interaction between the continental mountainous relief and the extended coastline generates colder (CFb, DFb, DFc) or more humid (CFa) climatic variations even over relatively short geographical distances (Mariolopoulos 1982; Yalamas 2010). Greece is divided by the Pindus mountain range between a more humid west and a drier east. In addition, the surrounding seas create marine variations of the Mediterranean climate and contribute to the formation of the periodic regional wind patterns known as Etesians (Mariolopoulos 1982). Regarding air temperature, Greece can be divided in four climate zones (Fig. 1), according to the Greek Building Energy Code (KEnAK) (TEE 2012). In zones A and B, winters are generally milder and summers are hotter, while in zones C and D, winters are cooler and summers may vary between warm and hot. These variations have a considerable impact in both building energy requirements (Fig. 1) and human thermal comfort (Fig. 2).

Observations on the environmental responsiveness of Greek vernacular settlements by previous studies

To date, there have been two government-led multi-participant studies of vernacular settlements, the first in the 1970s and the second between 1982 and 1984. While the former contributed to the drafting of the list of the first 420 legally protected settlements (Mpouras 1975; TEE 1977), the second was criticised for the lack of a clear and standardised methodological framework (Papageorgiou and Pouzoukidou 2014). The voluminous collection of monographs published under the title 'Greek Vernacular Architecture' during the period 1982–1995 (Phillipidis and Lavvas 1995), stands out as the first in-depth documentation of built heritage in Greece.

Since then, several researchers from different academic backgrounds (e.g. architects, engineers, sociologists, planners, geographers, historians and archaeologists) have studied different aspects of the Greek vernacular settlements. These studies generally fall in two broad categories:

(i) Those that examine the environment along with historic, cultural and sociodemographic factors that influenced their growth and modern conservation policies (Vasileiadis 1969, 1979; Kalogirou et al. 1990;

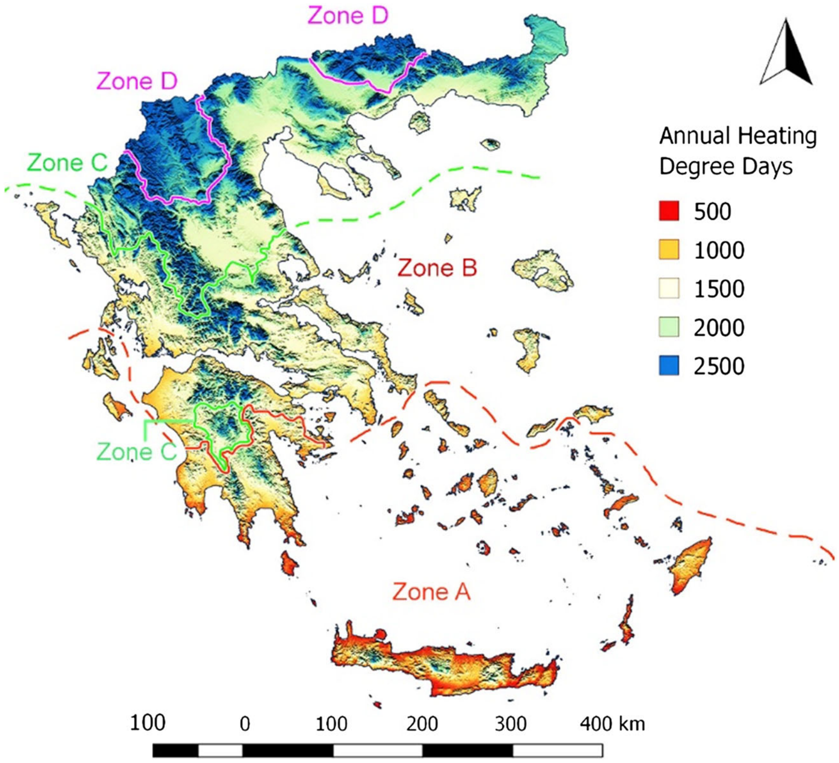


Fig. 1 Geographical distribution of annual HDDs and the four KEnAK climate zones

Belavilas 1993; Lafazani 1993; Mpouras 1998; Spanos 2000; Andriotis 2002; Panagiotopoulos et al. 2003; Karanikolas et al. 2003; Noussia 2003; Moutsopoulos 2004; Kalogirou and Paka 2007; Lafazani et al. 2010; Papageorgiou and Pouzoukidou 2014; Keppa 2014; Gavala-Manioudi 2015; Giannakopoulou and Kaliampakos 2016)

(ii) Those that document and analyse elements of bioclimatic architecture, aesthetics and clean construction technologies (Andreou 2014; Desyllas 2008; Kalogirou 2002;

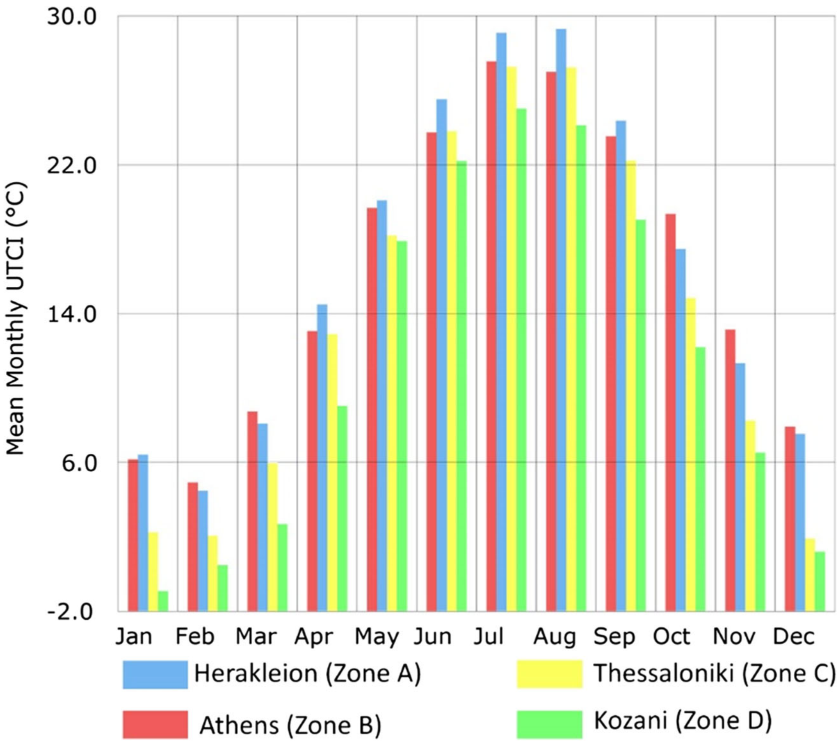


Fig. 2 Mean monthly Universal Thermal Comfort Index (UTCI) values in four representative cities in each KEnAK climate zone. The calculation of UTCI was done using Ladybug Tools (Roudsari et al. 2013) and IWEC climatic data (ASHRAE 2001) assuming a fully unobstructed view to the sky

Kalogirou et al. 1990; Kostoula 2001; Marmaras 2008; Moutsopoulos 1967, 1982, 2002, 2005, 2012, Mpouras 1975, 1992a, b; Oikonomou & Bougatioti 2011; Stasinopoulos 2006; Theocharopoulou 2010; Theodoraki-Patsi 2009; Tompazis & Pelekanos 1986; Tzelepis 1997; Vissilia 2009)

The review of these studies reveals that apart from immaterial factors, such as the economic, social and historic circumstances, the spatial distribution and growth of these pre-industrial settlements was influenced by their immediate environment. The environmental responsiveness of these 'non-designed' settlements was largely the product of folk wisdom on the relation of man, architecture and the environment, amassed over the centuries (Mpouras 1992b). According to the reviewed literature, thermal comfort, safety and proximity to key natural resources were three key human objectives that dictated the relationship of vernacular settlements with their environment. The major findings from the review are summarised below and in Table 1 which also relates them with the quantitative indicators employed in this study.

In areas with cold winters, such as the mountainous parts of northern Greece, warmer southern slopes were generally preferred over colder northern slopes, wind-exposed ridges or depressions where cool air masses accumulate. In these areas, there are plenty of examples of passive solar architecture that employ strategies such as building compactness, southern orientation, narrow openings, sunspaces, high thermal mass and insulation (Kostoula 2001; Moutsopoulos 2005; Bougiatioti et al. 2015). In areas with strong winds and hot summers, such as the Aegean Sea, a compact building configuration and narrow street networks would provide shelter from sun and wind. Wind-exposed areas were generally avoided while earth-sheltering techniques were employed in steep slopes to reduce unwanted heat exchanges with the environment (Mpouras 1992a; Marmaras 2008; Theodoraki-Patsi 2009). On the contrary, in regions with high humidity, such as the Ionian Sea, wind-exposed areas and less compact configurations were generally preferred for their higher ventilation potential (Zivas 1974). The dominant use of high thermal mass materials such as stone or clay would take advantage of the large diurnal temperature differences in the summer to regulate the indoor environment through night ventilation (Phillipidis and Lavvas 1995).

Settlement safety was directly linked to the defensive potential and visual control of the landscape; particularly the sea. The fear of war, pirate raids and internal conflicts, such as uprisings or vendettas would drive Greek populations away from the coast and the flatlands and towards more rugged and easily defendable locations (Mpouras 1992a; Belavilas 1993). Sociocultural and religious differences between ethnic groups and the desire to retain some form of identity and self-governance would also contribute to this trend (Papageorgiou and Pouzoukidou 2014). Direct surveillance of the sea from a defensive position would often be preferred for both aesthetic and security reasons (Belavilas 1993). The settling of less accessible locations would eventually lead to the organic growth of street networks that adapt to terrain contours to minimise slope (Moutsopoulos 2005). The central square that is characteristic of Greek vernacular settlements

Table 1 The relation of human needs with environmental parameters that influence the location of settlements and the proposed indicators that enable the study of these relations

Human needs	Qualitative observations	Environmental parameters	Indicators
Defence and accessibility	Rugged terrain offered more defensive potential at the cost of accessibility. Coastal areas provided trade and fishing opportunities yet were often avoided due to pirate raids.	Terrain morphology	Terrain Ruggedness Index (TRI) (m) Mean slope (°) Geomorphon class Euclidian shortest distance to coast (m)
Visual coastline control	Locations that would offer direct sea view were considered advantageous for both aesthetic and security reasons.	Sea view Settlement orientation	Sea view (Boolean true/false) Mean settlement aspect (°) Coastline vector (°)
Access to basic natural resources	Forested lands and water features would provide basic resources to nearby settlements.	Proximity to fresh water and forests	Features within an 1 km buffer zone (Boolean true/false)
Unobstructed winter sunlight	Southern, warmer slopes were generally preferred over northern ones in areas with harsh winters such as Epirus.	Settlement orientation Winter terrain insolation	Mean settlement aspect (°) Winter solstice insolation (kWh/m^2) Heating Degree Days (HDDs)
Ventilation and protection from strong winds	In areas with high humidity, such as the Ionian Sea wind-exposed areas were generally preferred. Sheltered areas were sought in regions with strong winds like the Aegean Sea.	Wind speed	Mean roughness length z_0 (m) Mean annual wind velocity (m/s)

and constitutes the core of social life would often be located on a relatively even terrain, while houses would form compact clusters around them (Keppa 2014). Compact settlement forms required fewer construction materials, had less heating requirements and provided an additional measure of defence and microclimate regulation as open spaces were sheltered by surrounding building volumes.

Additionally, the need for fresh water and natural resources had a considerable impact on settlement location. While in continental Greece the fresh water issue was resolved by being close to a river or a lake, the water scarcity of the islands led to an adaptation of architectural form which maximised water collection and retention using a network of connected flat roofs and cisterns (Theodoraki-Patsi 2009). Another advantage of being close to a river was the potential use of water power by pre-industrial water mills (TIMS Greece 2017). Similarly, while the forests of continental Greece provided timber and other resources to nearby villages, settlements of the Aegean Sea relied more on trade and to import resources. As a result, the rarity of timber in the Aegean islands is reflected on the local architecture (Marmaras 2008).

The need for a more quantitative approach to the study of the environmental responsiveness of Greek vernacular settlements

The previous section demonstrated that the impact of the local climate and landscape on the spatial distribution of vernacular settlements in Greece is generally acknowledged by the reviewed studies and often constitutes one of their central arguments. However, for the majority of these studies, the argument of environmental responsiveness of vernacular settlements is largely underpinned by qualitative empirical observations or basic quantitative information such as site elevation and proximity to the sea (e.g. Keppa 2014; Papageorgiou & Pouzoukidou 2014).

Studies that emphasise a quantitative approach are relatively few and often focus on particular ‘case study’ buildings or settlements (Kostoula 2001; Oikonomou and Bougatioti 2011). At the microscale, building physics and microclimate simulations are often employed to analyse the environmental performance of preserved buildings and settlements. For example, Andreou (2014) conducted a comparative microclimate analysis of the vernacular and contemporary urban tissues at the island of Tinos using simulations and in-situ measurements. Vissilia (2009) performed a typological analysis of the bioclimatic characteristics of buildings in the vernacular settlement of Sernikaki, relating the local climate and the landscape features with the prevailing outdoors and indoors microclimatic conditions. Bougiatioti et al. (2015) conducted a similar microclimatic and daylighting study at the traditional settlement of Psarades, focusing on both the neighbourhood and building scales.

Studies that consider the macroscale environmental characteristics of vernacular settlements follow a different approach and often employ Geographic Information Systems (GIS). Internationally, GIS have been used in several historic landscape and archaeological studies, with the main focus areas being spatiotemporal analysis, documentation of antiquities, support of decision-making processes and site geovisualisation (Scianna and Villa 2011). GIS have also been incorporated in the management, conservation and documentation of cultural heritage including vernacular landscapes, settlements and buildings (Baker 2013; Spiridon et al. 2016; Ma Li 2017; Statuto and Picuno 2017). However, very few studies (Fabbri et al. 2012; Danaci Mutlu and Atik 2014; Sousa and Gomes 2014) have utilised GIS to relate the location of vernacular settlements with local climatological and geomorphological parameters.

The same observation can be made for studies that focus on Greece. For example, Sevenant and Antrop (2007) analysed the land use distribution and viewsheds of two vernacular settlements in different geographical contexts in Greece using GIS to relate development patterns with the visual control of the surrounding landscape. Ntassiou et al. (2015) explored the historic seasonal migration (transhumance) routes with respect to settlement and encampment locations and the local geomorphology in Southwest Macedonia using GIS. Vlami et al. (2017) assessed the notion of ‘culturalness’ in the ‘Natura 2000’ preserved landscapes of Greece by analysing 12 cultural attributes linked to heritage values, landscape aesthetics and traditional land uses using GIS. Oikonomopoulou et al. (2017) proposed a methodology of allocating tourism activities and routes using GIS in order to minimise impact on the natural and cultural landscapes and local resources.

The review of both qualitative and quantitative studies demonstrates that a nationwide geospatial analysis of vernacular settlement locations in relation to environmental and climatic factors has not yet been conducted in Greece. Even internationally, few studies incorporate GIS in the analysis of the environmental responsiveness of traditional settlements or architecture. Hence, the present research can be considered as a necessary step towards the documentation and better understanding of the relation of the vernacular with the local climate and landscape. The study proposes a methodological framework that best adapts to the Greek geographical space. However, its structure and methodological steps can be used as a blueprint for similar studies in world other locations as well.

Methodology

The study employs QGIS 2.18 (QGIS Development Team 2018) as the primary platform of geospatial analysis. QGIS is a free and open-source software (FOSS) that integrates several native geoprocessing algorithms with SAGA GIS, GDAL and GRASS geoprocessing libraries under a unified user interface. The use of these geoprocessing algorithms is explained in more detail in the sections below. The study initially gathers and pre-processes the required geospatial data. This step includes the geographic clustering and boundary delineation of settlements. Afterwards, the following geomorphological indicators are calculated after Table 1: (i) mean settlement aspect and slope, (ii) prevailing settlement Geomorphon class (Jasiewicz and Stepinski 2013) and (iii) mean settlement TRI (Riley et al. 1999). These indicators are then used to calculate the following set of environmental indicators for each settlement polygon: (i) proximity to forests, lakes and rivers, (ii) sea view and coastline vector, (iii) mean winter solstice insolation and (iv) mean annual wind velocity at 2 m above ground. These indicators are then analysed statistically and visualised in maps and graphs.

The study utilises a number of geospatial data available from different online sources. The Digital Elevation Model (DEM) of Greece was extracted from the ASTER GDEM V2 global DEM (USGS 2017) which has a 30 m resolution. The DEM was pre-processed with focal averaging of raster values were appropriate to remove some artefacts such as 'spikes' or 'holes' created by unrealistic elevation data. The Greek coastline, the Corine Land Cover 2006 dataset, the National Forest boundaries and the locations of all Greek settlements were obtained from the online geodata.gov.gr repository (IMSI-Athena 2017). Wind velocities at a height of 80 m above ground estimated through meteorological models and site measurements were provided by the Regulatory Authority for Energy (RAE) geoportal in a $150 \times 150\text{m}^2$ grid format (RAE 2015). Heating Degree Days for Greece (base temperature = 18 °C) were obtained from the Centre of Renewable Energy Sources (CRES) in a $900 \times 900\text{m}^2$ grid format (CRES 2010). The names of vernacular settlements and their respective administrative boundaries were acquired from the 'Archive of Vernacular Settlements and Preserved Buildings' of the Ministry of Environment and Energy (2018).

Geographic clustering and boundary delineation of vernacular settlements

Several vernacular settlement clusters are observed in both insular and continental Greece (Fig. 3).

The study proposes the grouping of vernacular settlements in eight distinct regions which will enable the statistical analysis and comparison of the geomorphological and environmental indicators across Greece (Fig. 3). The eight regions are the following (subsample is given in brackets): (1) Epirus [10%], (2) Ionian Sea [7%], (3) Macedonia—Thrace [7%], (4) Thessaly [8%], (5) Aegean Sea [34%], (6) Central Greece [3%], (7) Peloponnese [19%] and (8) Crete [10%]. The clustering takes into account the observed settlement concentrations, as well as the generally known differences in landscape, climate and architecture (Phillipidis and Lavvas 1995). It is also largely based on the ten distinct geographical regions identified in the first nationwide study of vernacular settlements conducted in the 1970s (TEE 1977).

The next step is the delineation of settlement boundaries. This is done through visual recognition using aerial photos from Google Earth (Google 2018) and the online Greek Cadastre orthophoto service (EKXA A.E. 2009) which in many cases offers a greater degree of detail. The approximate location of vernacular settlements is obtained by filtering the complete Greek settlement location geodataset with the name list found in the Archive of Vernacular Settlements and Preserved Buildings. Subsequently, settlement boundaries are drawn using visual cues such as the clusters of both standing buildings and ruins, roof typology, the vernacular street network and natural or man-made borders (e.g. cliffs, rows of trees or fortifications). Areas which exhibited clear signs of homogenous modern development (grid plan and new buildings) are excluded from the boundaries. On the contrary, areas where there is a mix of traditional and modern buildings and a vernacular street network are clearly evident are included.

Settlement location in relation to local geomorphology and landscape features

Settlements can be classified as coastal, flatland, semi-mountainous and mountainous depending on their distance from the coast, as well as their mean elevation and mean slope, according to Greek legislation (P.D. 24–4-85). These are easily calculated using standard QGIS functions. Under this classification scheme, 12% of settlements are coastal (distance < 500 m and mean elevation < 100 m), 47% lie on flatlands (mean elevation < 800 m, mean slope < 10%), 30% are semi-mountainous and 10% are mountainous (Fig. 4). It can be observed that despite Greece's extended coastline only a few vernacular settlements are classified as coastal. Even in the Aegean, coastal vernacular settlements constitute less than 20% of the total (Fig. 4). This trend might be associated with the fear of pirate raids that drove settlement development away from the shore (Mpouras 1992b; Phillipidis and Lavvas 1995). Epirus is mostly populated by mountainous settlements, more than half of Thessaly's settlements are semi-mountainous and over two thirds of settlements lie on flatlands in the clusters of Macedonia-Thrace and Crete (Fig. 4).

The Geomorphon classification process reveals more complex relationships between settlement location and the landscape (Fig. 6). Geomorphons are ten geomorphological typologies (flat, slope, summit, ridge, spur, valley, depression, footslope, hollow, shoulder) proposed by Jasiewicz and Stepinski (2013). The Geomorphon classification methodology employs a visibility analysis and pattern recognition approach, in contrast to conventional 'fixed window'

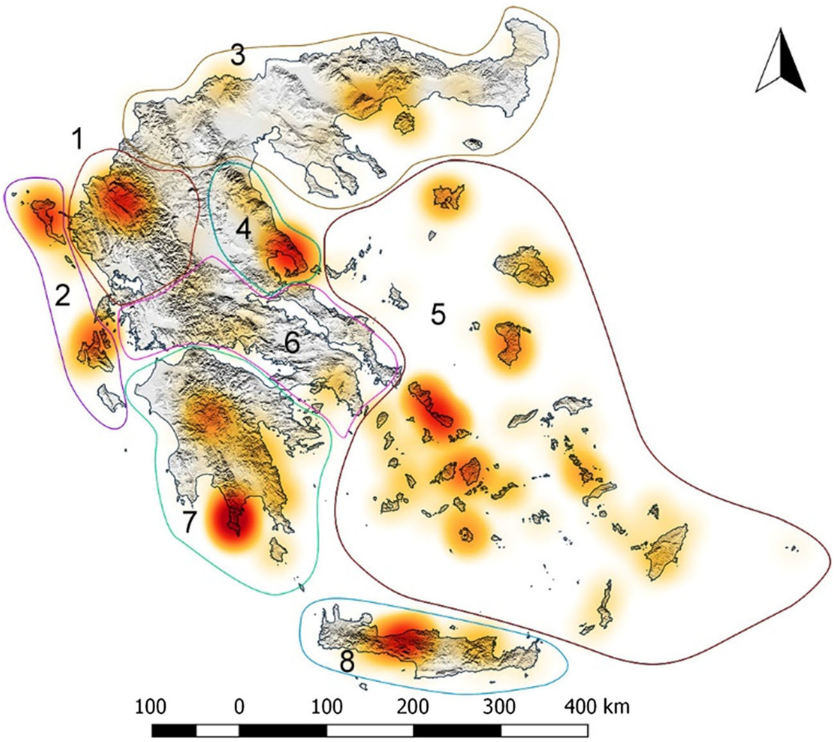


Fig. 3 Settlement density heatmap showing the eight proposed geographical clusters

algorithms. Another advantage of this method is that it is fast and can process large national DEMs. Geomorphon landform recognition uses two settings: search radius and flatness threshold. The search radius is relative to the scale of the study. Large radii identify only significant changes in landforms, while smaller radii can reveal finer details. However, a small radius may not be able to correctly classify larger terrain features. Flatness (or relief) threshold is used to discern flat terrain, by describing a minimum vertical line-of-sight angle difference from the horizon. This eliminates potential errors resulting from using a large search radius, as elevation differences at large distances and in low resolution DEMs may otherwise go unnoticed (Jasiewicz and Stepinski 2013). The study utilises the GRASS r.geomorphon add-on and applies the settings proposed by its developers (Jasiewicz and Stepinski 2013) for 30 m resolution DEMs (search radius of 20 grid cells and a flatness threshold of 1^{o}).

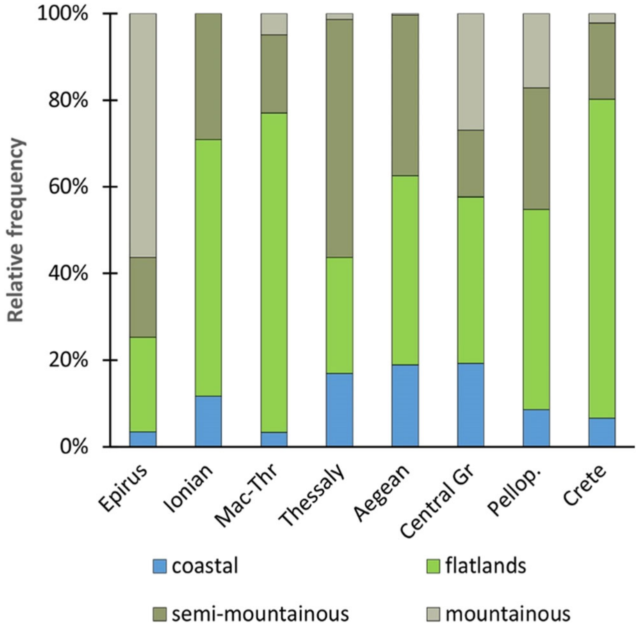


Fig. 4 Relative frequency bar chart of settlement classification per cluster according to the statutory classification scheme

The results show (Fig. 5) that most dominant class in Greece is slope [27%], followed by spur [17%], hollow [15%], valley [14%] and ridge [12%], while only 7% of the land was classified as flat. The classification reflects the mountainous character of the Greek mainland and the generally rugged terrain of the islands. The prevailing Geomorphon class for each settlement polygon is then calculated using the majority zonal statistic.

According to this classification, vernacular settlements are almost equally distributed between slopes [33%], valleys/hollows [33%] and spurs/ridges [30%]. The rest are located on summits, flatlands or other Geomorphon classes (Fig. 5). In contrast to the statutory classification method applied earlier, the Geomorphon analysis shows that settlements on flatlands constitute a minority over the entire sample. This can be attributed to the difference in flatland definition between the two methods. The former is simpler and relies on elevation and slope data, while the latter employs pattern recognition techniques. The validity of the Geomorphon analysis is further

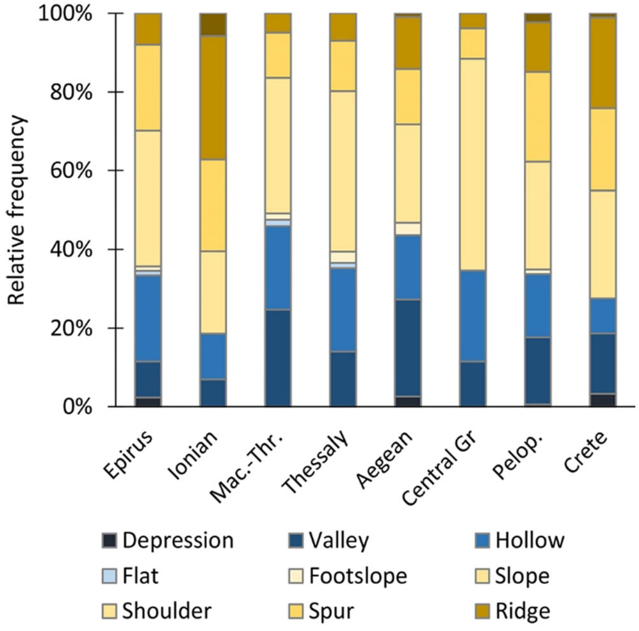


Fig. 5 Relative frequency bar chart of Geomorphon settlement classification per cluster

supported by the observation that few vernacular settlements in Greece were located on flat terrain during the examined historic period (Phillipidis and Lavvas 1995).

In addition, regional differences in settlement distribution are observed (Fig. 5). For example, in the Ionian Sea cluster, 55% of settlements are located on spurs and ridges which are less accessible but provide better defence, visual control and ventilation. The latter can be quite important considering the high relative humidity that characterises the Ionian Islands (TEE 2012). In the Aegean Sea cluster, 41% of settlements are located in valleys and hollows. These areas generally provide better shelter against the characteristic strong winds of the Aegean. These observations can also be related with findings from the wind velocity analysis in the "Settlement location in relation to the wind" section.

Terrain heterogeneity is then analysed using TRI which expresses the difference between the elevation of a cell and the mean elevation of neighbouring cells (Riley et al. 1999). TRI is calculated using the relevant SAGA module that is included in the QGIS geoprocessing toolbox. The study uses a fixed sampling neighbourhood size of five cells. The resulting TRI ranges from 0 to 260 m with an average of 58 m. The present study employs a different ruggedness classification scheme than the one proposed by Riley et al. (1999) in order to represent more accurately the variations observed within the Greek landscape. The study proposes five equal-range classes (Fig. 7), corresponding to a terrain ruggedness that ranges from 'none' for values less than 25 m to 'very high' for values over 100 m. Extensive areas with very high ruggedness are found in the mountainous parts of Greece, particularly in Epirus, Mt. Pelion in Thessaly, Central Greece and Crete. High ruggedness was also observed on

Fig. 6 Example of the Geomorphon classification result from the region of Epirus

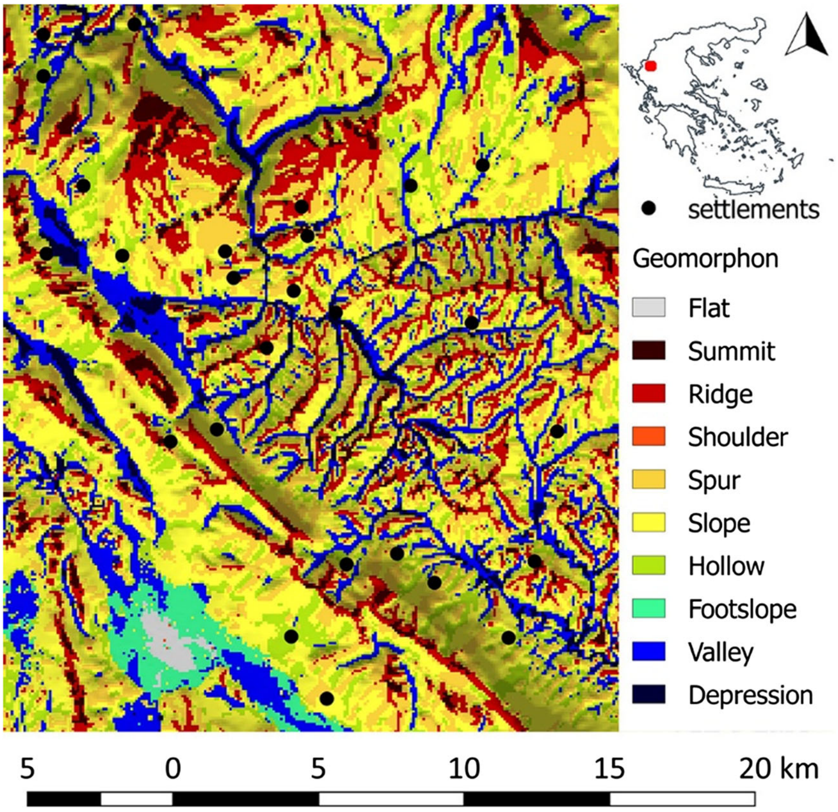
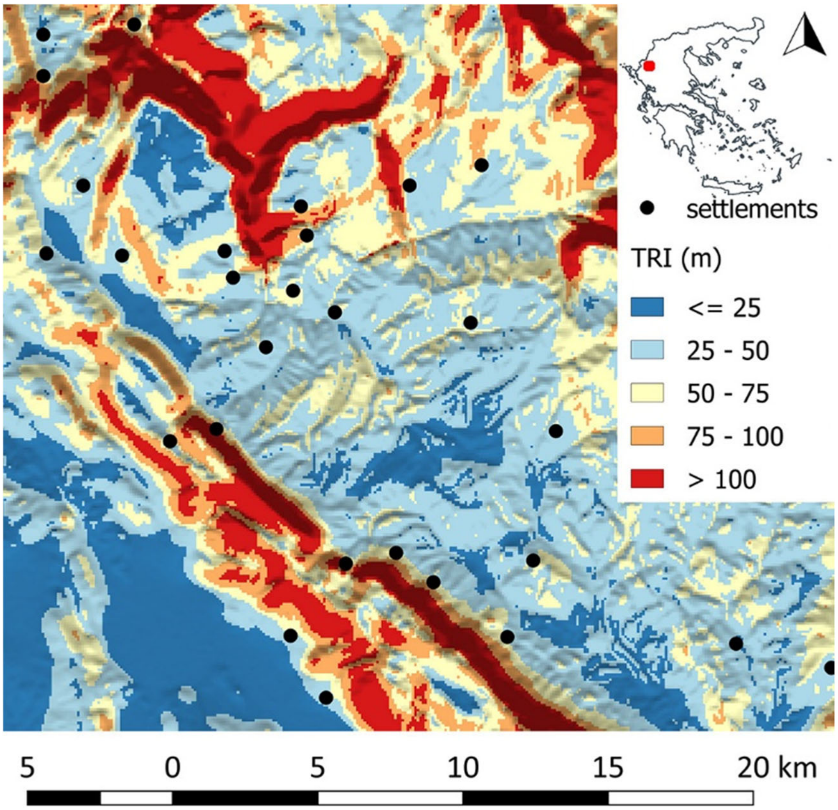


Fig. 7 Example of the TRI classification result from the region of Epirus



the coastline of smaller islands of the Aegean such as Santorini, Ikaria, Sifnos, Amorgos, Antiparos and Kalymnos.

The calculated mean settlement TRI supports the findings of the Geomorphon classification. It can be observed (Fig. 8) that more than half [55%] of the vernacular settlements are located on even or slightly rugged terrain. Approximately, one in three [31%] of settlements in Epirus is located on highly or very highly rugged terrain, which also reflects the general character of the landscape in that part of the country. Several settlements in Thessaly [28%] and Peloponnese [26%] are

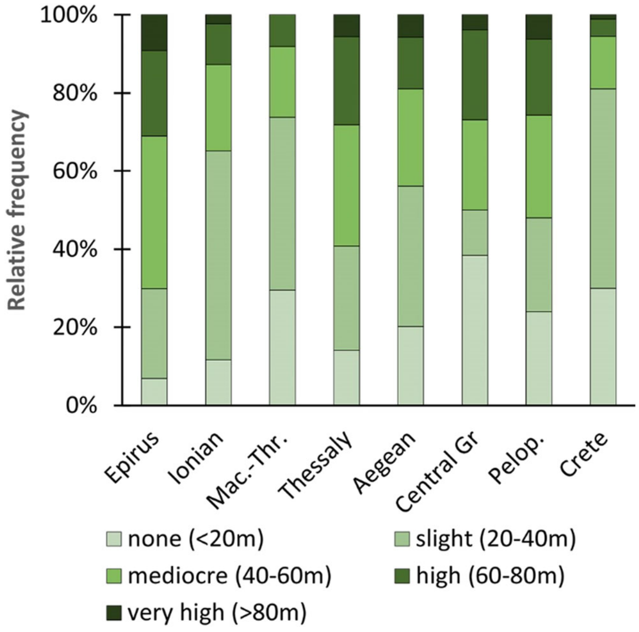


Fig. 8 Relative frequency bar chart of TRI classes for each cluster

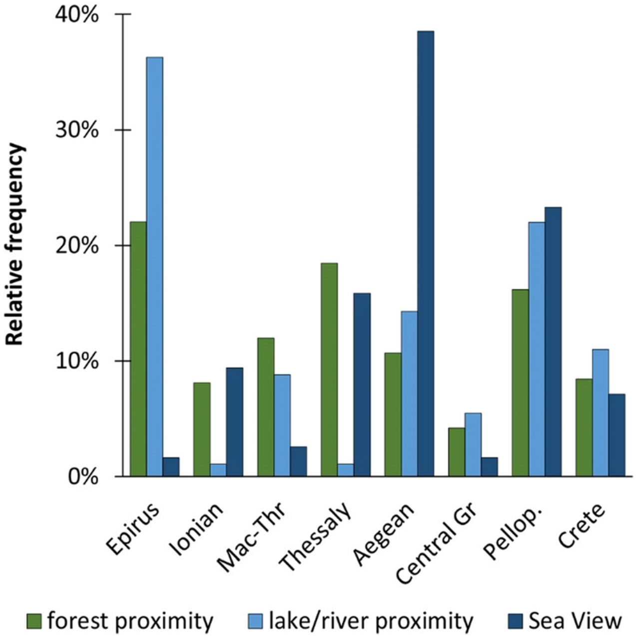
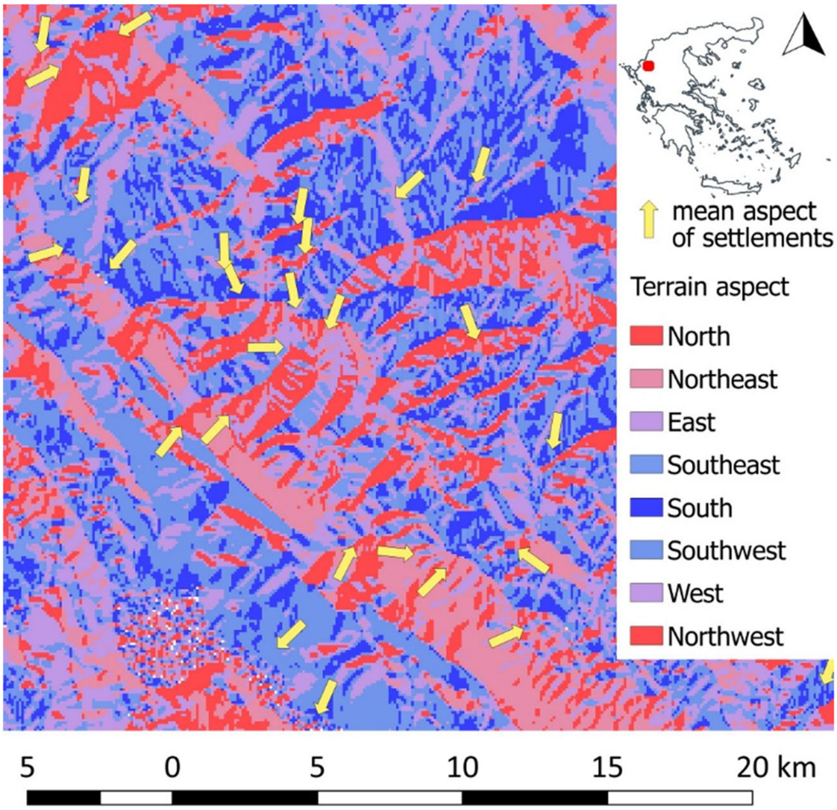


Fig. 9 Relative frequency bar charts of forest proximity, lake and river proximity and sea view for each cluster

Fig. 10 Example of the mean aspect calculation for part of the Epirus cluster



also located on similarly rugged terrains, which could offer a defensive advantage.

The next step is the estimation of the proximity of settlements to forests and fresh water sources such as rivers and lakes using a fixed 1 km radius buffer zone around each

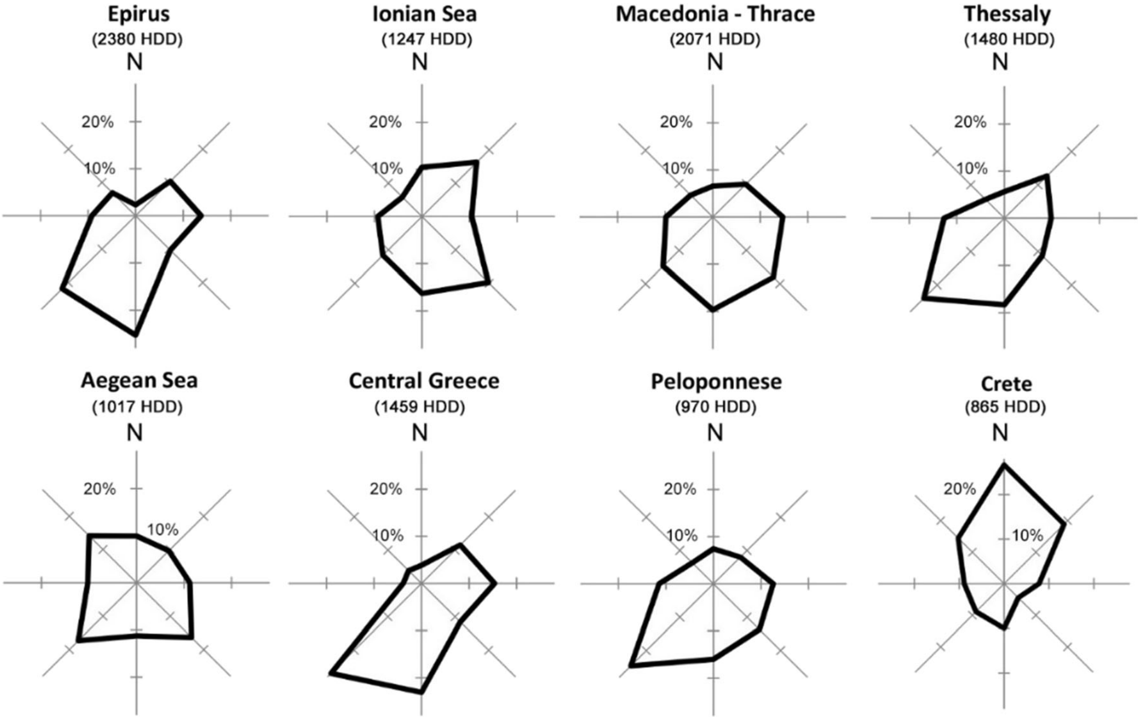
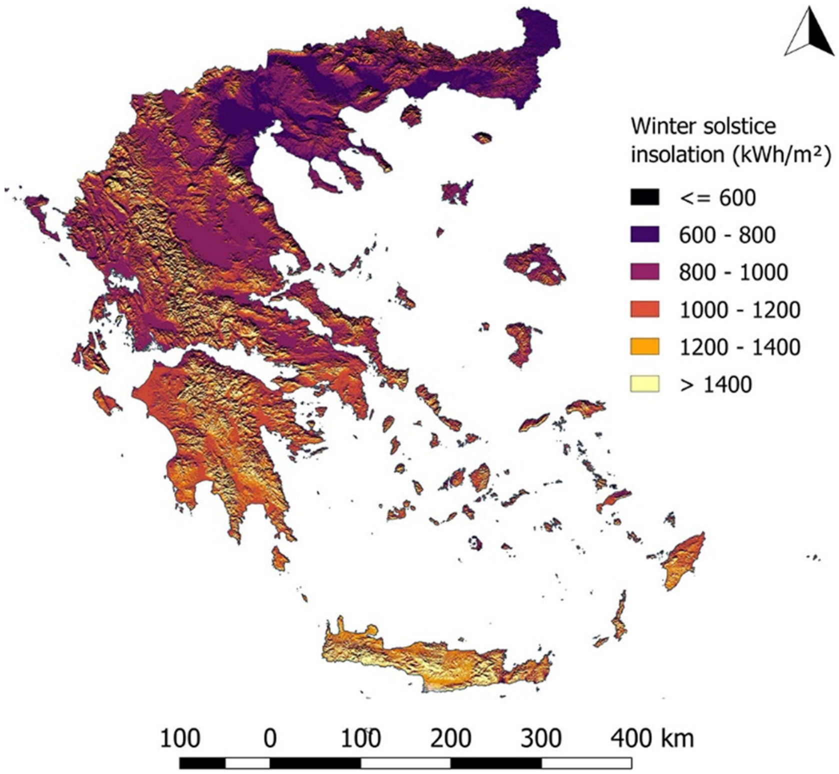


Fig. 11 Relative frequency compass roses of mean settlement aspect by cluster with North pointing up. The mean HDD for each cluster is also given in parentheses

Fig. 12 Winter solstice cumulative terrain insolation



settlement polygon. A significant obstacle in this step is the lack of a completed Greek forest cadastre that would provide the statutory forest boundaries. To overcome this obstacle, the study uses the polygon areas classified as forests and forested lands from the CLC datasets (codes 311–324) and merges them with the 'national forests' polygon areas which are available through the geodata.gov repository (IMSI-Athena 2017). The buffer radius of 1 km covers approximately a 10-min

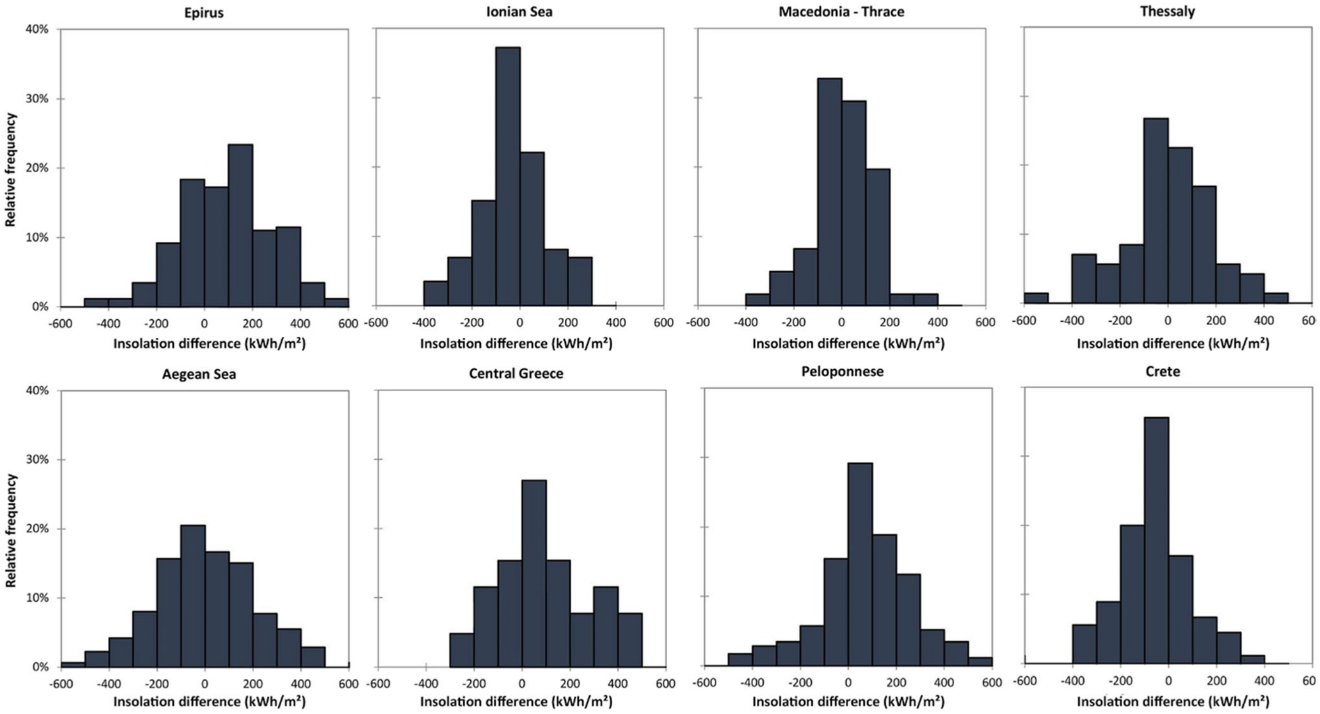


Fig. 13 Relative frequency histograms of the difference between mean winter solstice terrain insolation of settlement polygons and of a 5 km radius area around them

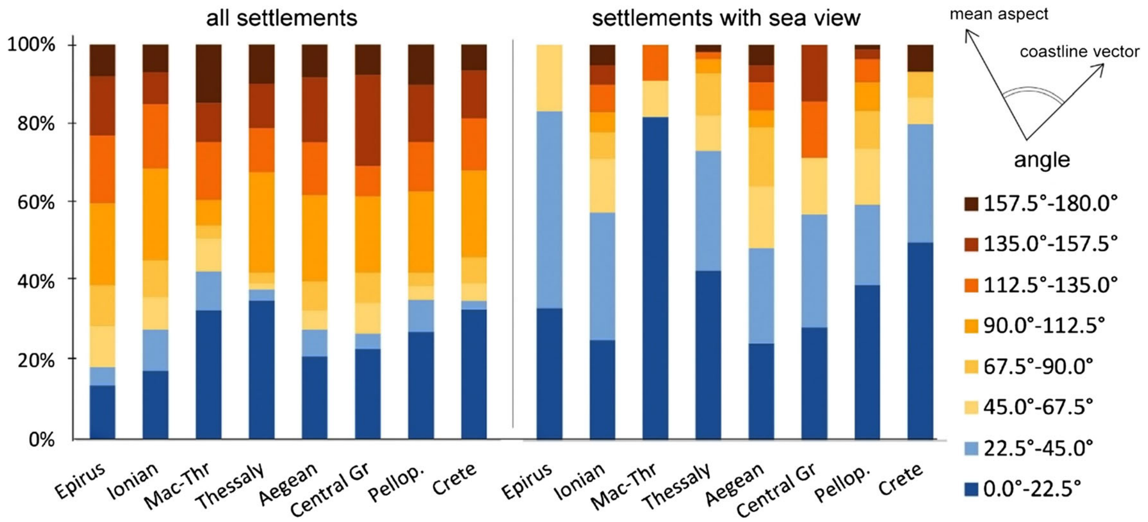
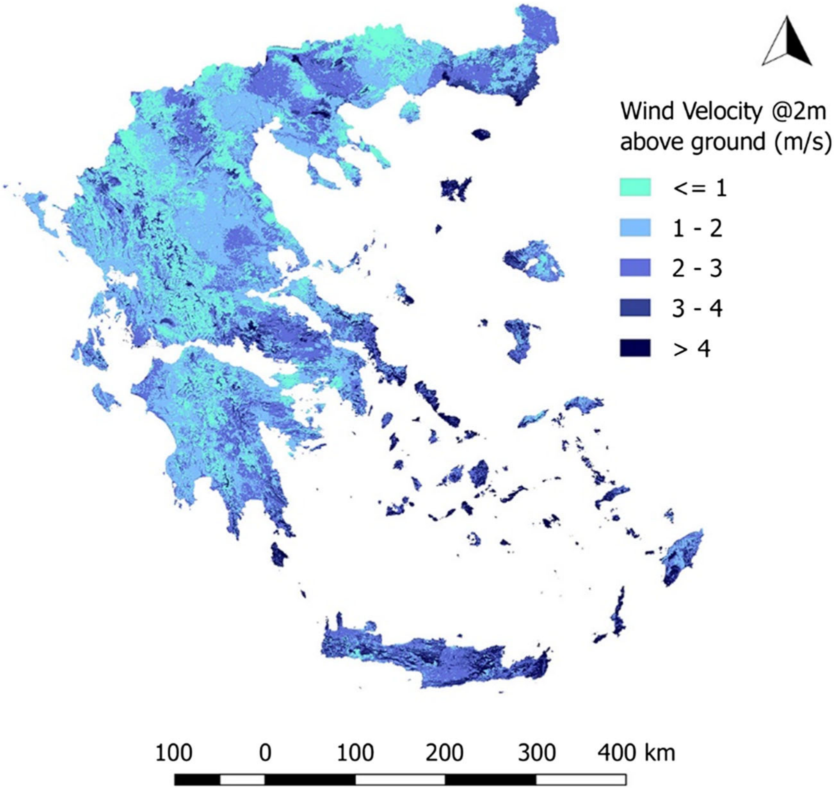


Fig. 14 Relative frequency bar charts of the angles between mean aspect and the coastline vector for the entire sample (left) and for settlements with direct sea view only (right)

walking distance from the settlement and thus reflects the closeness of the examined settlements to forests and fresh waters. This proximity is recorded using a Boolean true/false for each settlement depending on whether the buffer zones intersect these natural features.

It can be observed that 36%, 22% and 15% of settlements in Epirus, Peloponnese and the Aegean respectively are close to a fresh water source while in other clusters these percentages are lower (Fig. 9). Proximity to forests is more pronounced in Epirus [22%], Thessaly [18%] and Peloponnese [17%]. These findings are associated with the geographic distribution of settlements. The mountainous landscapes of both Epirus and Peloponnese, despite being rugged and less accessible, were naturally gifted with increased forest coverage and a denser river network than the rest of Greece. These advantages encouraged the growth of settlements and economic activities that utilised forest resources and pre-industrial applications of water power in these regions (Phillipidis and Lavvas 1995; TIMS Greece 2017). It is worth noting that the datasets used in the analysis depict forests in their current

Fig. 15 Wind velocity (m/s) calculated at a height of 2 m above ground



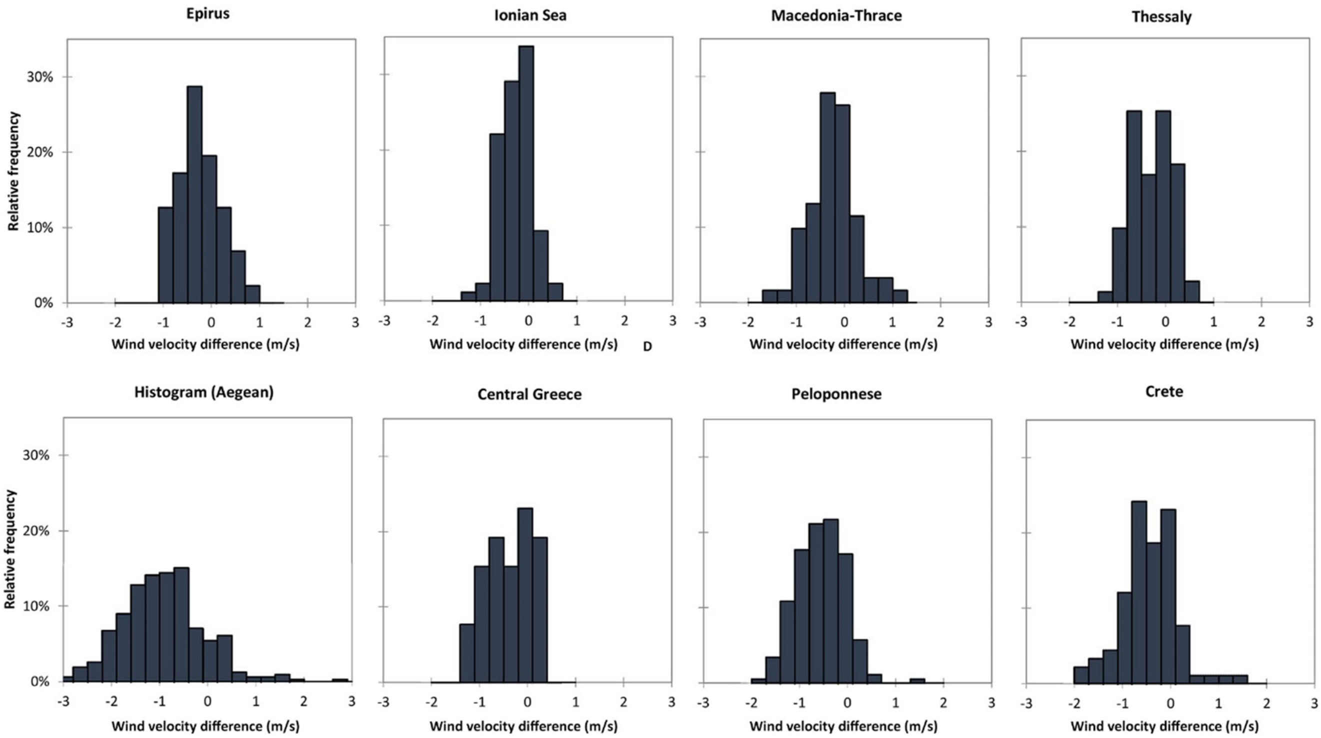


Fig. 16 Relative frequency histograms of differences in mean annual wind velocity between settlement polygons and their surroundings within a 5 km distance (m/s)

state and not in their historic state which would be ideal for this study. Unfortunately, such historic data does not exist. Considering the pervasive shrinkage of Greek forest lands in the past century (Minetos and Polyzos 2010), it can be assumed that proximity to forest lands would generally be higher in the examined historic periods.

Settlement location in relation to the sun

The orientation of each settlement as a whole can be estimated by calculating the mean terrain aspect for each settlement polygon. Although the terrain aspect map has already been produced (see the "Settlement location in relation to local geomorphology and landscape features" section), the calculation of mean aspect requires some additional steps. This is because the simple arithmetic mean of aspect values within a polygon can yield wrong results. The correct process is to first acquire the mean normal vector for each polygon (projected at the horizontal plane) and then calculate its azimuth. An easy way to achieve this, without resorting to full 3D geometric calculations, is to first calculate the mean sines and cosines of the aspect grid values for each polygon using zonal statistics and then calculate the 'four quadrant inverse tangent' of their ratio. This method ensures that the mean aspect angle is calculated for the correct quadrant. These calculations are done in the Raster Calculator of QGIS using regular Python expressions. Settlements located on flatlands (mean polygon slope $< 2.5\%$, 59 in total) are excluded from the aspect analysis since site orientation can become ambiguous on near-flat terrain. Aspects are then classified into eight basic orientations. A visual inspection (Fig. 10) of the resulting mean aspects reveals some general trends that were observed by previous qualitative studies, such as the avoidance of northern slopes in mountainous regions.

It is observed that almost half [48%] of the examined settlements lie on Southern, Southwestern and Southeastern slopes. A breakdown of results by geographical cluster reveals interesting local trends (Fig. 11). For example in Epirus, where heating needs are the greatest, approximately 25% and 22% of settlements lie on southern and southwestern slopes respectively while only 2% is facing North. A similar situation is also found Central Greece, Peloponnese and Thessaly. There are a number of hypotheses that may explain the prevalence of Southwestern over Southeastern orientations. The first is related to the adaptation to terrain contours and the orientation of settlements towards the sea, which is examined in the next section. The second is related to the advantage of receiving direct solar radiation during the later period of the day, thus retaining more heat in the building thermal mass to be released after the sun sets. Testing this hypothesis would ideally require knowledge of individual building orientations for all settlements and detailed building physics simulations; hence, it falls outside the scope of the present study. Northerly slopes are generally avoided in all geographic clusters except the Aegean Islands and Crete, where 60% of vernacular settlements face the northern part of its coastline. Notably, in both regions heating needs are small compared to the rest of Greece (Fig. 11).

In addition to mean aspect, the study calculates the cumulative terrain insolation for the winter solstice (21 December). The insolation analysis takes into account the shadows cast by terrain, something that cannot be analysed by the aspect study alone. This is done using the ArcGIS Solar Analyst (Fu and Rich 1999) with a half-hour timestep, 2800 sky subdivisions and assuming clear sky conditions. The elevation DEM is equally divided in eight horizontal stripes, each having a width of 1° (approximately 111 km in the Greek Grid projection). The radiation calculations are carried out for each stripe in order to account for the impact of latitude on the sun's apparent trajectory. The results range from as low as 350 Wh/m^2 found at some well-shaded northern slopes to 2200 Wh/m^2 recorded on some steep southern slopes in Crete (Fig. 12).

For each settlement, the study calculates the mean winter solstice insolation falling on its polygon and on a 5 km radius area around it. The difference in the two values allows for a more localised analysis of settlement siting in relation to the sun. The direct comparison of global insolation values would be less meaningful as these values vary by latitude. The relative frequency histograms of these differences (Fig. 13) reveal some interesting trends in the examined geographical clusters. The histograms in all clusters resemble a near-normal distribution which in some cases is slightly skewed to the left or the right. In Epirus, Thessaly, Central Greece, Macedonia-Thrace and the Peloponnese, the distribution is skewed towards positive local insolation differences.

This means that the settlement locations belonging to these clusters generally receive more insolation than their respective surroundings. In Crete, differences are mostly negative, while in the Ionian and Aegean Seas skewing is limited. These findings generally agree with the aspect study, although the terrain introduces shadowing that lessens the terrain insolation differences between different aspects. It is worth noting that landscape features such as forests that might influence results are not included in the calculations as both the degree of tree coverage and mean tree height are unknown.

The case of 'Morna' or 'Skoteina' (freely translated as 'dark place') in Pieria is characteristic since the placename reflects the relation of the settlement and the sun. Despite its successful lumber industry, Skoteina was eventually abandoned because, as its place name reveals, the topography and the tall vegetation blocked most of the winter sun. Its residents found in 1965 the new settlement 'Foteina' (freely translated as 'bright place') in a place not far away from Skoteina (Michani tou Chronou 2016). In the present study, Skoteina was found in a valley Geomorphon which had a mean winter solstice insolation of 364 Wh/m^2. The newer settlement of 'Foteina' is located on a southern slope with a mean winter solstice insolation of 1075kWh/m^2.

Settlement orientation in relation to the sea

The spatial relation of vernacular settlements and the sea can be further analysed with respect to settlement orientation and direct sea view. The two parameters introduced in this section are sea view and the 'coastline vector'. Whether a settlement has a direct view to the sea can be determined with a viewshed analysis using QGIS. The study assumes a point of observation from an average eye level of 1.7 m above ground located at the centroid of each settlement polygon. If the viewshed intersects the coastline polyline then its corresponding settlement is considered to have direct sea view. Sea view can be related with the orientation of settlements by calculating the 'coastline vector', which is the vector connecting the settlement centroids and the coastline with the shortest Euclidian distance. The angle between the mean settlement aspect (see the "Settlement location in relation to the sun" section) and the coastline vector can provide a measure of relative orientation in relation to the sea (Fig. 14).

Almost half [50.5%] of the settlements were found to have direct sea view. Consequently, there are several settlements that are not coastal, yet they can directly survey the sea. Settlements with direct sea view are found mostly in the Aegean Sea cluster, followed by the Peloponnese and Thessaly clusters (Fig. 14). It can be observed (Fig. 14) that approximately 30% of vernacular is oriented towards the sea within an arc of ± 45° regardless of sea view. When only settlements with direct sea view are considered, this figure rises to 68%. Consequently, even if coastal vernacular settlements are relatively few, there are several settlements with direct sea view that are also oriented in a way to maximise this advantage. This finding supports the argument of sea surveillance and security against pirate raids or other armed conflicts. The aesthetic advantage of sea view might also explain these spatial arrangements. Since terrain contours often tend to follow the direction of the coastline, these findings can also be indirectly related to the growth of settlements along contour lines. Development along terrain contours would reduce the street network slope and required earthworks and might explain the development of settlements without direct sea view along the general direction of the coastline.

Settlement location in relation to the wind

The average annual wind velocity at a near-ground height of 2 m is estimated from the average wind velocity grid provided by RAE which is referenced at a height of 80 m above ground. The estimation is possible using the logarithmic wind velocity profile function (Eq. 1), where z_0 is the 'Roughness Length', an indicator of terrain ruggedness similar to TRI, v_1 is the known wind velocity in m/s at a given altitude h_1 above ground in metres and v_2 the wind velocity that we want to find in m/s for a certain altitude h_2 above ground in metres.

This equation is suitable for altitudes within the surface layer of the earth's atmospheric boundary layer (Silva et al. 2007). The roughness length map for Greece is generated by reclassifying the Corine Land Cover (CLC) 2006 dataset according to the most likely z_0 values for each CLC (Silva et al. 2007). Urbanised areas are excluded from the classification process to remove their effect on wind speed. Roughness length values in the excluded areas are estimated through a simple inverse distance weighted (IDW) spatial interpolation from neighbouring grid values. The average wind velocity at 2 m above ground (Fig. 15) is then calculated using the logarithmic wind profile formula (Eq. 1) and the produced wind map (Fig. 15) reveals both the local and regional differences in mean annual wind velocity.

$$v_2 = v_1 \frac{\ln\left(\frac{h_2}{z_0}\right)}{\ln\left(\frac{h_1}{z_0}\right)} \tag{1}$$

The mean annual wind velocity is calculated for each settlement polygon and for a 5 km radius area around each settlement. This is done in a similar fashion to the insolation study which effectively allows the difference between the mean velocities inside and outside the settlement to act as a local measure of relative wind exposure. The mean wind velocity for the entire sample of vernacular settlements is 2.0 m/s at a height of 2 m. The strongest winds are recorded in the Aegean Sea cluster settlements ($v_{\text{mean}} = 3.3$ m/s) and in Crete ($v_{\text{mean}} = 2.7$ m/s), while the weakest winds were found in settlements of the Ionian Sea ($v_{\text{mean}} = 1.4$ m/s) and Thessaly ($v_{\text{mean}} = 1.3$ m/s). The mean wind velocity difference for each cluster is then visualised using relative frequency histograms (Fig. 16). Histogram distributions in most clusters resemble a normal distribution skewed to the left either slightly (e.g. Ionian Sea, Thessaly and Macedonia-Thrace clusters) or moderately (e.g. the Aegean Sea cluster). Consequently, while vernacular settlements in all clusters avoid exposed areas, this trend is more evident in the Aegean Sea, where regional winds are the strongest.

Discussion and conclusions

The findings of this study support and quantify the qualitative empirical observations made by previous studies on the relation between the landscape, climate and the location of vernacular settlements in Greece. The analysis demonstrated that climate, security and proximity to basic natural resources are three environmental factors that are related to the distribution and growth of vernacular settlements. In regions with cold winters, Northern slopes, windy mountain ridges or depressions where cool air accumulates were avoided and southern slopes with unobstructed sunlight were instead preferred. However, in regions with mild winters, this preference is less pronounced or even non-existent. In areas with strong winds, such as the Aegean Sea, sheltered locations such as valleys were preferred. On the contrary, in the more humid and less windy, Ionian Islands settlements were often located on more wind-exposed locations which offered a greater ventilation potential.

Safety, defence and surveillance also had a significant impact on settlement location. The analysis found that relatively few settlements are located near the coastline or on flat terrains. On the contrary, there almost half of the examined settlements have direct sea view and several of them are oriented towards the sea. There is also a considerable number of settlements that are located on rugged terrains or defensible places such as ridges and spurs. These findings support the argument that settlements were found in well defended locations, away from the coast but with direct sea surveillance. The rugged terrain guided the growth of settlements along the terrain contours, thus creating the characteristic organic street networks. Finally, settlements in Epirus, Central Greece and the Peloponnese were often located next to forests and rivers, which would provide valuable resources, such as fresh water and timber. The proximity to rivers may also be connected to the extended network of water mills found in these areas which supported the local crafting industries.

The present research is the first to take a geospatial analysis approach to the study of the relation between vernacular settlement location and the Greek climate and landscape. However, there are several points were future studies can improve upon. Firstly, the study does not confirm whether the selection of vernacular settlement locations was the results of conscious and well-planned actions and not of more spontaneous actions that relied on intuition and settlement locations of earlier eras. Consequently, the study only provides quantitative evidence that supports the qualitative observations made by previous studies. Future studies could take a more interdisciplinary approach by combining geospatial environmental analysis with cultural history and socio-geographical studies to better support the examined arguments.

Secondly, the study examines the vernacular settlements at the macroscale; thus, its scope is limited. Although there have been two nationwide and several case-specific studies of architectural and urban form in the past, there is now a need for an updated nationwide systematic study that, ideally, should be guided by a framework of state-of-the-art methods in multiscale surveying, documentation and environmental analysis. The necessity for an updated interdisciplinary study of the vernacular built heritage is now greater than in the past, considering the need to improve resilience against climate change. Such study would ideally not only limit itself to the documentation of built heritage, but should further expand into translating the environmental responsiveness of the vernacular into contemporary design strategies for increasing urban and rural climatic resilience. The relation of local morphoevolutive dynamics with respect to climate change–induced flash floods and associated erosion risks is also a significant topic that requires additional research if vernacular settlements are to be preserved and used as tourist destinations in an climate-conscious manner. Nevertheless, the development of an online webGIS platform of climate resilience analytics for vernacular settlements and preserved historic landscapes should be prioritised by future studies as it will enable a greater degree of collaboration between experts and non-experts alike.

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