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The Influence and Impact of Bioclimatic Indicators on the Evolution of Biosociety. A Geoarchaeological approach

George Malaperdas

Department of History, Archaeology and Cultural Resources Management,
University of the Peloponnese, 24 100 Kalamata, Greece

E-mail address: envcart@yahoo.gr

ABSTRACT

The present paper attempts to attribute the role of bioclimatic indexes and their importance in the development and evolution of cultures. With the aid of GIS, a case study is presented aiming to point out the use of GIS is the study of bioclimatic indexes in theoretical study fields, such as, in this case, in Archaeology and more specifically, in the field of Geoarchaeology. Geoarchaeology is not a discipline, but an interdisciplinary approach, which has everything to gain by taking geomorphological methods and techniques into account (Fouache et al., 2010). The study area is the Prefecture of Messenia, located in south west Greece. The Prefecture of Messenia is one of the best documented areas of mainland Greece. It has been both extensively surveyed and excavated. The archaeological finds are numerous, dating from prehistory to the modern times. Thus, a vast amount of information has helped historians, archaeologists and other scientists to recreate the past.

***Keywords*:** GIS, Archaeology, Geoarchaeology, Bioclimatic Indexes, Humidity, TWI, Solar Radiation, Heat Load Index, Wind Intensity, Aspect

1. INTRODUCTION

The climate in Greece has not changed substantially since the Ice Age era, although, after that, a period of unusually intense rainfalls followed. The dominant climate is semi-arid Mediterranean climate, characterized by prolonged warm and dry summers and mild, largely without frost, winters with lots of rainfall. However, northern Greece has a more continental

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climate with extreme high or low temperatures and more rain. The western part of Greece, where the study area lies, also has more rainfalls than the rest of the country. Finally, as Dickinson in his book "The Aegean Bronze Age" claims, the Aegean islands present the least rains. The climate, setting and natural resources of Greece should always be studied in every historical study, as they are directly related to the evolution potentials of the societies.

Nowadays it is surely known that the ancient Greeks, at least since the Classical period onwards, had particular knowledge of the bioclimatic conditions dominating a location, and tried to exploit them. In example, in Memorabilia by Xenophon, Socrates speaks of the perfect solar house. Hippocrates, in his work "On Airs, Waters and Places", prorogued the principles of modern bioclimatic architecture.

The core of all the theories that evolved then was the establishment of a harmonic human-environment relation. Finally, Aristotle, in Politics, sums up that the establishment of the right climatological conditions is the fundamental priority for the establishment of the ideal city, as, apart from the subject of public health, the climatological conditions play a major role in the self-efficiency of food, determining the farming yields.

It would be an outstanding piece of knowledge to justify the hypothesis that this knowledge of the ancient Greeks was a continuation of the practices of their ancestors who dwelled in the same areas approximately 4,500 years before present.

This assumption could be verified or disproved by particularizing the conditions, and applying this model in more than one area. Therefore, it could be claimed, with high possibilities of being precise for such a statement, at least for the largest and most important residential sets, that the knowledge of the bioclimatic conditions in relation to the habitation site was inherited to the ancient Greeks and aspects of such practices were already known by the preceding Mycenaean societies.

2. MATERIALS AND METHODS

2. 1. Geographical Information System

A geographical information system (GIS) is "a computer-based information system that enables capture, modeling, manipulation, retrieval, analysis and presentation of geographically referenced data" (Worboys (1997).

The use of GIS software is ideal for the investigation of archaeological problems which involve the geographical distributions of sites. Its ability to combine qualitative and quantitative data and also to allow for effective categorization, multi-layering and distance-measurement renders it an indispensable tool for the investigation of archaeological issues concerning distribution patterns.

2. 2. Habitation Sites Sample.

For the present paper, 140 habitation sites (Malaperdas & Zacharias, 2018) were divided into four hierarchical categories (centers, large villages, villages and farms) based on the extent and the plurality of the tholos tombs that exist in the broader region and according to the hierarchical categorization used by the archaeologists who have studied the area (Simpson, 1965; Cosmopoulos, 2006). The analysis of Bioclimatic Indexes was carried out for the first two categories (centers and large villages), because of their significance, for a plurality of thirty habitation sites sample (Table 1).

Table 1. Habitation Sites sample.

Name	Category
1. Ano Eglianos	Center
2. Koryfasio-Beylerbay	Center
3. Iklaina	Center
4. Koukounara	Center
5. Nichoria	Center
6. Thouria-Ellinika	Center
7. Malthi-Gouves	Center
8. Mouriatada	Center
9. Peristeria	Center
10. Filiatra-Ayios Christophoros	Center
11. Agrilovouno-Ayios Nikolaos	Large Village
12. Ayios Dimitrios-Vigla	Large Village
13. Yialova-Palaiochori	Large Village
14. Diavolitsi-Loutses	Large Village
15. Kalamata-Kastro	Large Village
16. Kalyvia-Pano Chorio	Large Village
17. Kardamyli-Kastro	Large Village
18. Kato Melpeia-Krebeni	Large Village
19. Magganiako-Paliampela	Large Village
20. Metaxada-Kalopsana	Large Village
21. Myrsinochori	Large Village
22. Polichni-Ayios Taxiarchis	Large Village
23. Pidima-Ayios Ioannis	Large Village
24. Pyla-Vigles	Large Village
25. Romanos-POTA	Large Village
26. Sidirokastro-Sfakoulia	Large Village
27. Stenyklaros-Kato Rachi	Large Village
28. Stoupa-Ancient Lefktra	Large Village

29. Foinikounda-Ayia Analipsis	Large Village
30. Filiatra-Ayios Ioannis	Large Village

In order to estimate the coordinates of each site of interest with the highest possible accuracy, we visited all the sites and acquired the exact location (via GPS) using the Greek Geodetic Reference System (EGSA '87). In addition, satellite images of high resolution were used (Quickbird 0.6 pixel and IKONOS 1m). The correction of some minor deviations noted lead to the formation of a database of highly accurate points from which the Mycenaean Habitation Sites map was created (Figure 1).

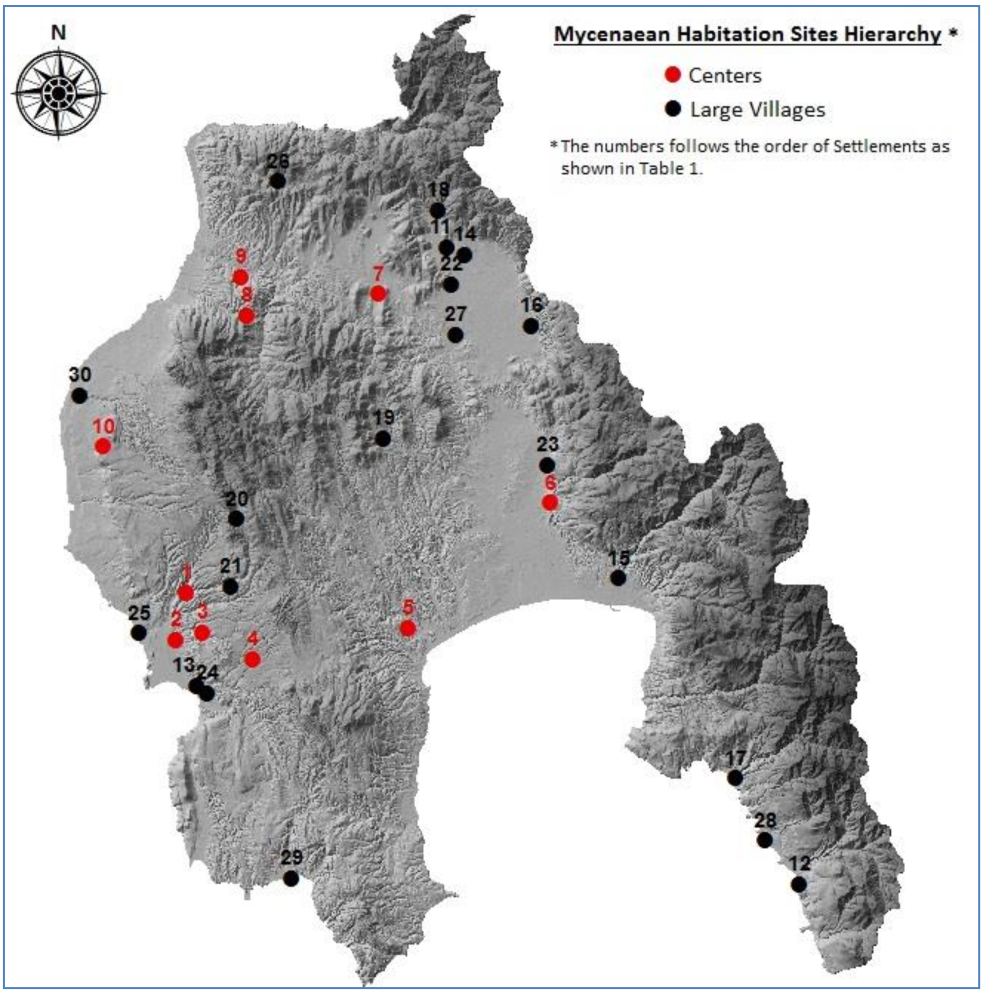

Figure 1. Mycenaean Habitation Sites Map.

2. 3. Bioclimatic Indexes

Climatic indexes are certain arithmetic expressions that define the limits and alterations of climates. Providing that these arithmetic expressions indicate a number and the effect of certain climatic elements or their combinations on the life and the evolution of various biosocieties, these indexes are referred to as bioclimatic indexes. The most important bioclimatic indexes in terms of their effect on living beings are temperature, moisture, exposure to sunlight and the wind intensity. These are the indexes that are going to be discussed upon in the present study.

2. 3. 1. Aspect

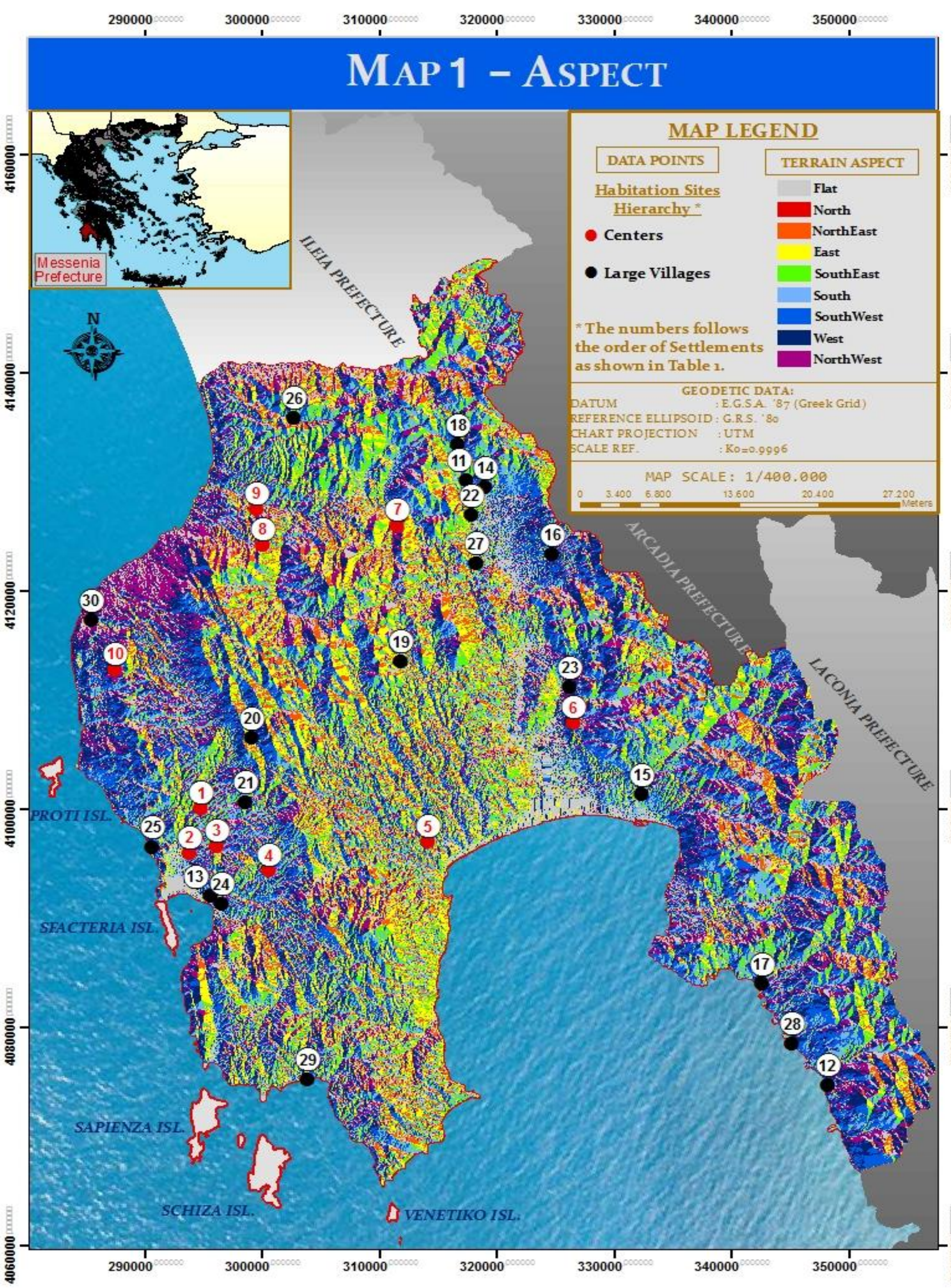

Figure 2. Terrain Aspect Map

Aspect is an intricate function in GIS terrain analysis and environmental/geographical modeling. It can be used in analysis throughout different fields of study. It offers insight on environmental factors, impact on the land area under examination while providing the means for deriving demonstrable conclusions on the future behavior or trends whether it concerns the possibility of an avalanche occurring, a fire starting or road erosion (Malaperdas & Panagiotidis, 2018).

The orientation or aspect of a surface corresponds to the direction in which the maximum rate of change of altitude is observed and is usually measured by the azimuth of that address, i.e. in degrees from 0 to 360 clockwise, with reference to the north. In the TIN triangular model, the slope and orientation are calculated for each triangle and grouped in larger areas, depending on the user's requirements, in order to produce thematic maps (Figure 2).

The map with the aspects of the lands (or sun exposure) plays a very important role for the needs of this study. In general, and as it is expected, areas with southern sun exposures provide the utmost sunshine and therefore greater heat. They are also more protected by strong northerly winds.

2. 3. 2. Solar Radiation

The amount of solar radiation that the surface of the ground receives in any given place depends on the latitude, on the time of the year, and on climatic and topographic factors. Theoretically the solar radiation in a place follows the annual course of the deviation of the sun. That is why the term "climate" derives from the Greek “κλίμα” (clima), which derives from the verb “κλίνω” (clino) for “tilt”, suggesting the relationship of the air temperature with the inclination of the rays of the sun. In the Northern hemisphere the maximum value of the gradient is observed on the day of the summer solstice-21 June and its minimum value during the winter solstice-21 December.

Although the climate of the prefecture of Messenia presents particularly large annual sunshine the purpose of the analysis is to describe the particular conditions that may exhibit small changes per location. Using DEM, the annual solar radiation was calculated for the entire prefecture of Messenia (Figure 3). The following factors interfere with the formation of real sunshine:

- Latitude (determines the length of the day).
- The relief (the peaks of the mountains accept more radiation than the valleys).
- Cloud cover (increases albegia and absorption).
- The altitude (in the middle latitudes the intensity of solar radiation increases about 5-15% for every 1000 meters of altitude increase).

Every photon carries energy. The flow of photons through surface A, is ultimately equivalent to radiant energy flux through surface A. This is a very basic value that shows how many Joules of energy are supplied per second from solar radiation when it passes through or illuminates a given surface A of 1 m^2 area. This size is called power density or much more frequently, irradiance denoted as FA and measured in (J/s) / m^2. Since 1 J/s = 1 Watt, finally the FA power density is measured in W/m^2.

Greece presents a particularly high solar potential, approximately 1,400-1,800 [kWh/(m^2 × yr)] annually on a horizontal level, depending on the latitude and terrain of the area. Solar radiation presents its maximum intensity at solar noon (maximum solar height), both during the summer and the winter season. Solar energy is greater during the summer period because of the position of the sun, but also due to the increase of sunshine hours-reduction of clouds (Santamouris et al, 1994).

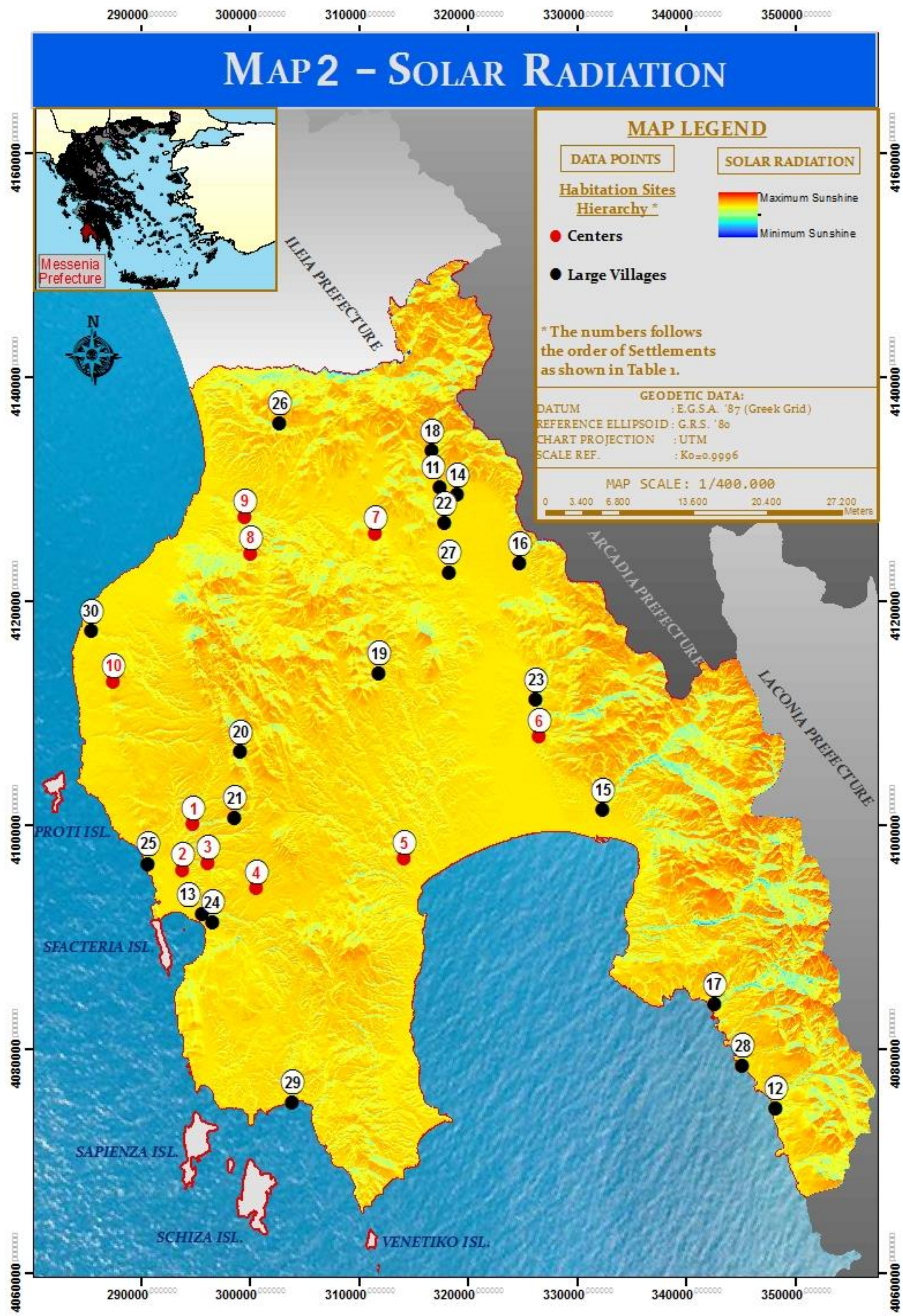

Figure 3. Solar Radiation Map.

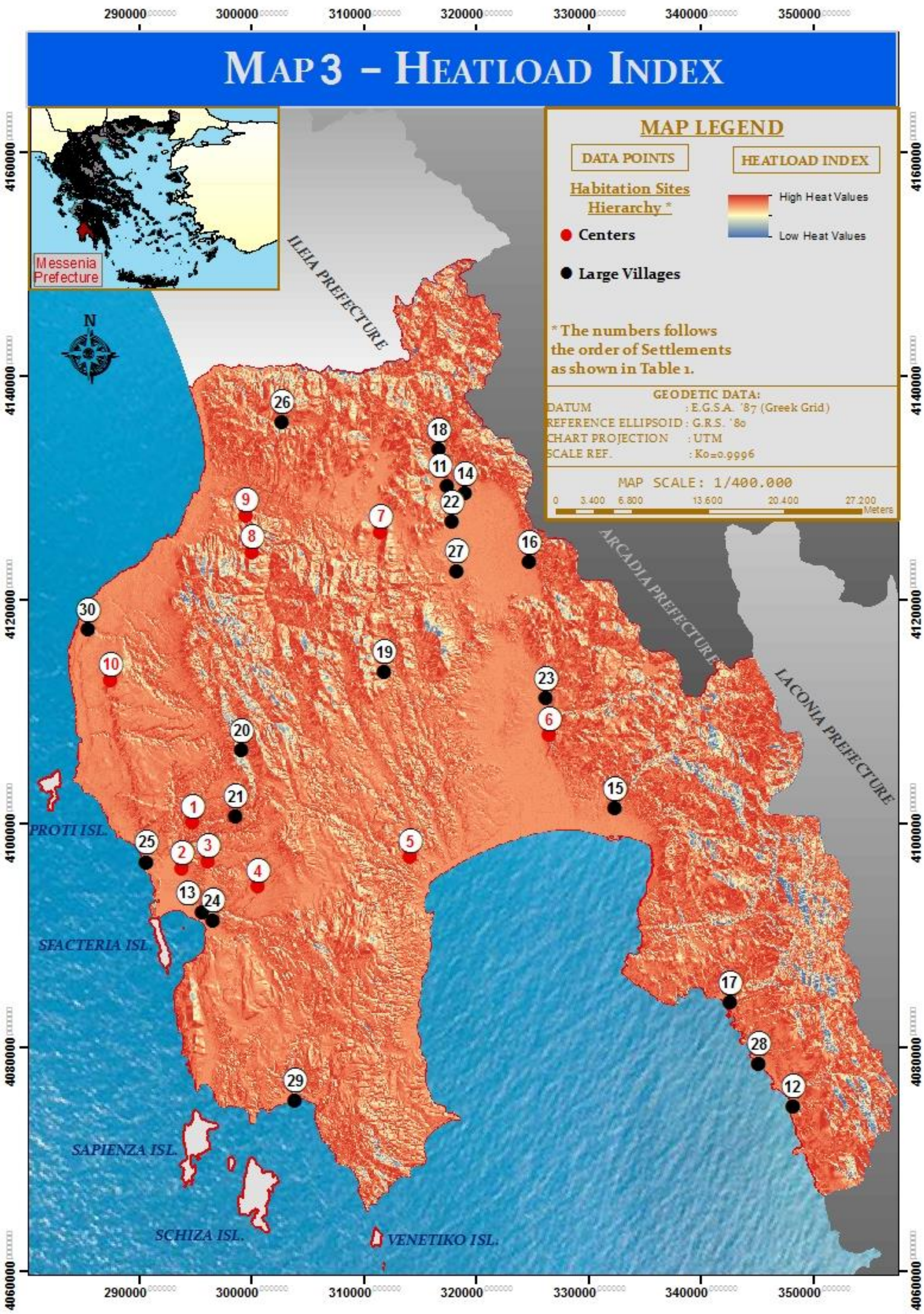

Figure 4. Heatload Index Map.

The average daily intensity of solar radiation per year was calculated through the Solar Radiation extension tool by ARC-GIS 10.3, expressed in Kwh/m^2. Taking into account the factor of elevated intensity values of solar radiation as well as their small changes, the graduated calibration is carried out with the lowest fixed values (10 for values > 6.0 Kwh/m^2) without the existence of large deviations between categories (9 for values 5.5-6.0 kwh/m^2, 8 for 5.0-5.5 kwh/m^2 and 7 for values < 5.0 kwh/m^2).

2. 3. 3. Heat Load Index

The examination of Heat Load Index performed on this study has a dual role. On the one hand, it gives a picture of the accumulation of soil heat in places of interest; on the other, it confirms that specific ground orientations produce more heat and foster the creation of residential positions, playing an important role in terms of bioclimatic conditions (Figure 4). This specific methodology was presented by McCune & Keon and connects the accumulation of heat that the ground presents in a classification from southwest territories for higher concentration values to the northeast territories for the lowest values (McCune & Keon, 2002; McCune, 2007).

The ground therefore functions as a solar collector and this indicator expresses this energy gain in a specific area. A solar collector offers a fusion energy gain factor, usually expressed with the symbol Q, which is the difference between the solar radiation absorbed by the collector plate (in the case the soil) and any form of losses and is reflected in the following equation:

Equation 1: Calculation of fusion energy gain factor Q

$$\mathbf{Q = FR \times AC\ [IT\ (\tau \times \alpha) - UL\ (Ti - T\alpha)]}$$

where:

FR = the thermal gain factor
Ac = the area of the surface of the collector expressed in m2
IT = the solar radiation that falls on the surface of the collector expressed in Watt/m2
τ = the permeability factor in solar radiation
α = the absorption coefficient in solar radiation
UL = the collector loss coefficient
Ti = the temperature of the collector inlet fluid
Ta = the ambient temperature

2. 3. 4. Moisture (TWI Index)

The concept of the topographic wetness index was first introduced by Beven and Kirkby. It is used to describe the effect of the topography on hydrological processes, as well as the extent of soil saturation zones created by water outflow relief. It is produced by the digital terrain model and is considered indicative of the available soil moisture (Beven & Kirkby, 1979).

The topographic wetness index was proposed within the context of the TOPMODEL hydrological model (Beven et al, 1995). Its specification in digital terrain models in the form of a grid, is achieved by the equation:

Equation 2: Topographic Wetness Index

$$TWI = \ln(\alpha / \tan b)$$

where:

α = the upslope area draining through a certain point per unit contour length (m2/m)
b = a parameter used for the estimation of hydraulic inclination (local drainage capacity) and is the value of inclination in degrees, at that point.

At this point, it is stressed that the values of the two parameters in the above equation depend on the flow routing algorithm and spatial analysis of the grid used.

To this end, the determination of this specific indicator was deemed appropriate as it is an indication of the spatial distribution of moisture (spatial distribution and stagnation of water) for the study area. Given that the index describes the water content of the soil due to the saturation of the earth surface, it can be used in the study of groundwater, while it may form the basis for estimates of water components (pH, concentrations of substances, biological applications). Thus it constitutes an important parameter for both indications of soil fertility and plasticity, important features for the choice of place of habitation by populations of any era (Figure 5). The index value indicates the tendency of each pixel to produce flow as areas with a high wetness index are more prone to saturation. Therefore, the spatial distribution of the index values indicates the spatial pattern of soil moisture in the area.

The wetness index is essentially a measure of saturation of the accumulation of water in the soil (Moore et al 1988). In the present paper, this index is considered as it has a direct role in the plasticity of soils and the suitability for the agricultural holding (nutritional value of soil), which are factors that influencing the habitation site choice by the residents.

Finally, it should be added that in the northern hemisphere, in the middle and large latitudes, it is generally considered that the northern slopes are the most shaded ones, and those with colder conditions. This favours the accumulation and preservation of soil moisture and their suitability for cultivation (Guzetti et al, 1999).

2. 3. 5. Wind Intensity

Doctor and philosopher Hippocrates in his work “On airs,waters and places” argues that "the life and health of the inhabitants of the cities are directly related to the winds that blow between the summer and the Winter sunrise".

PA power, or wind intensity (meaning the energy produced per unit of time) as it penetrates a surface S perpendicular to the velocity of V, is proportional to the third force of this velocity and the air density (ρ) and is given in the following equation:

Equation 3: Calculation of wind intensity

$$[PA = 1/2\ (\rho S v3)]$$

During the practical applications, the annual wind power was calculated as follows. The daily number of measurements of the wind speed is 24 (1/hour); for the whole year the total number of observations is Ty = 24 × 365 days.

The available annual wind power is:

Energy = Time × Power
Therefore,

EA = Ty × PA = 24 × 365 × 0.5 ρS (1 + 3I2) ∑ f(Vi)Vi3 KWh/year.
Therefore EA = 4.38 ρS (1 + 3I2) ∑ f(Vi)Vi3 Wh/year.

where :

f(Vi) – the incidence of each speed
I – air disturbance intensity parameter (I = σv/v)
σv – the variation of the wind speed of the average average value v.

The recording of the wind speed in many meteorological stations is done in Beaufort units. However, as the equations for the calculation of the intensity of an area need the speed expressed in m/sec, these units must be changed. This is done with the help of the following table:

Table 2. Beaufort scale and equivalent wind speeds expressed in m/sec.

Beaufort Number	Description	Wind Speed (m/sec)
0	Calm	0-0.2
1	Light Air	0.3-1.5
2	Light Breeze	1.6-3.3
3	Gentle Breeze	3.4-5.4
4	Moderate Breeze	5.5-7.9
5	Fresh Breeze	8.0-10.7
6	Strong Breeze	10.8-13.8
7	High Wind, Moderate Gale	13.9-17.1
8	Gale, Fresh Gale	17.2-20.7
9	Strong, Severe Gale	20.8-21.5
10	Storm, Strong Gale	21.6-28.4
11	Violent Storm	28.4-32.6
12	Hurricane Force	32.7-36.9

The primary information and background of wind intensity comes from the digital archive of the "Centre for Renewable Energy Sources and Saving" (Figure 6). It depicts the average annual wind intensity in the study area. The unit of measurement used is miles per hour (ml/h). It can be generally said that the intensity of the wind in the climate of each region certainly plays a role in the choice of habitation. In areas with winds of high intensity, difficulties arise with regard to the quality of life of the inhabitants (heating conditions, problems in agriculture and crops etc).

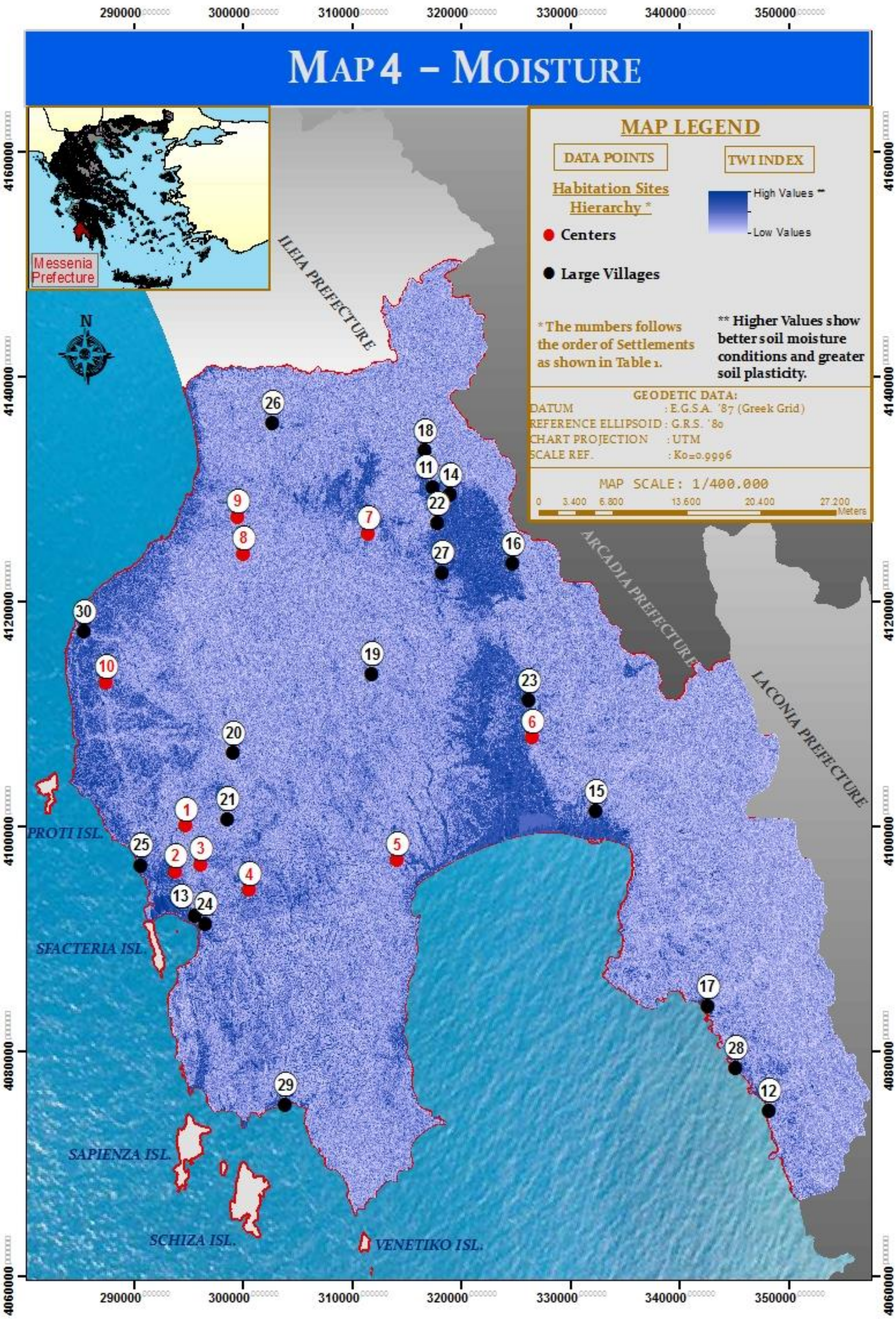

Figure 5. TWI Index Map

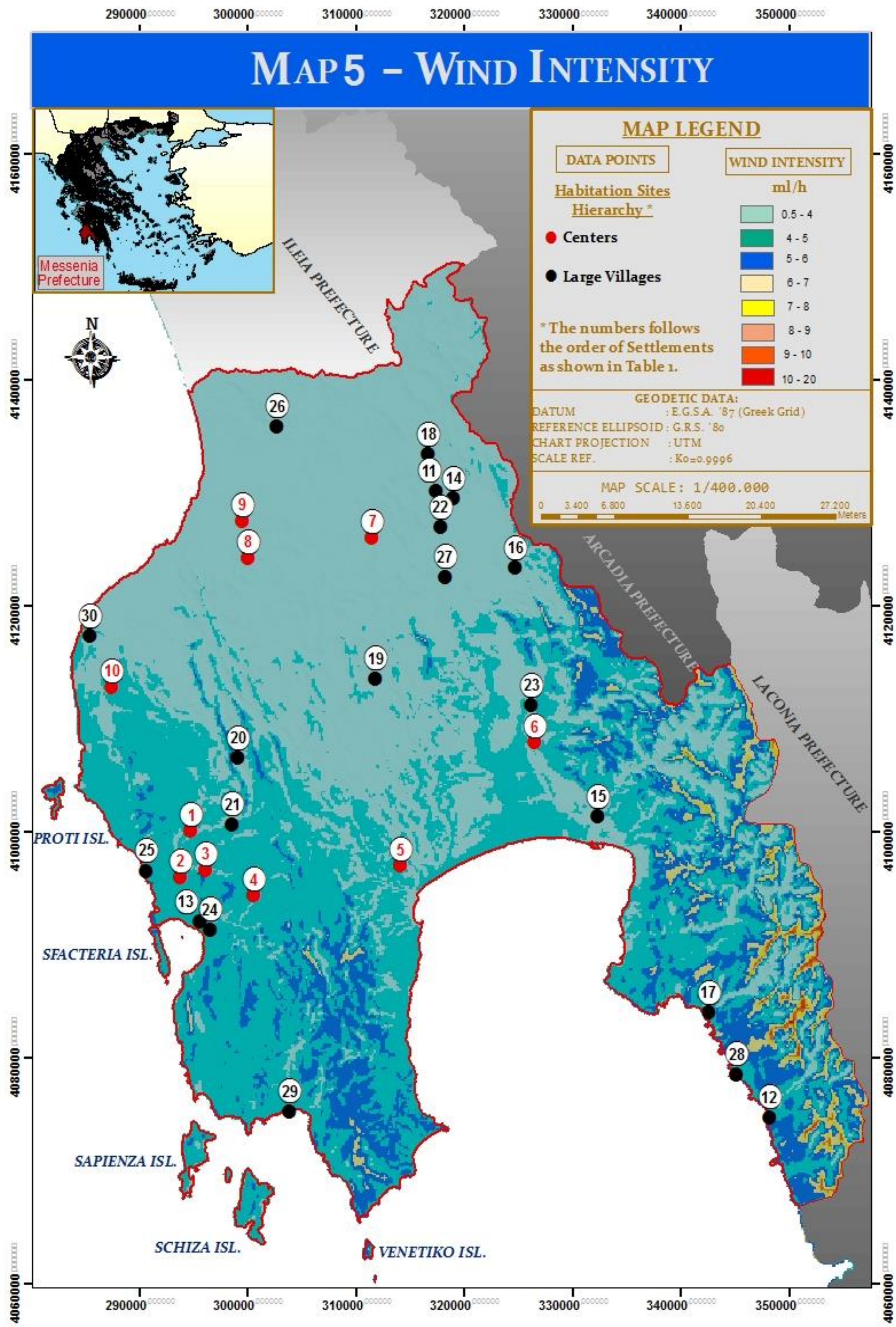

Figure 6. Wind Intensity Map.

3. CONCLUSIONS

Climatologically speaking, and taking into account the exposures of the lands, it was observed that the majority of the positions is on areas of a generally south orientation. As a result, maximum sunshine conditions prevail, and the locations are protected by the cold and strong northern winds, as it is confirmed by the analysis of the wind intensity.

For the complete verification of the above, a combined study was performed, on the intensity of the winds prevailing on the sites and on the parameters of the solar radiation and the thermal load, both for the immediacy of the solar inflow at the site as well as for the cumulative action it may have with regard to orientation (McCune, 2007).

The TWI index, which refers to the moisture held by the soil, can provide important information on the small scale soil changes per region, constituting a very important parameter for both indications of soil fertility and solar plasticity. These are important elements for the choice of place of habitation by populations of any era. The results of the analyses are presented separately for each position in Table 3.

Table 3. Bioclimatic Conditions per Habitation Site.

Habitation Site	Aspect	Wind Intensity (ml/h)	Heat Load Index	Solar Radiation (Kwh/m^2)	Humidity Index
1. Ano Eglianos	South	4-5	1.10	5971	10.30
2. Koryfasio	Southeast	4-5	1.05	5857	5.59
3. Iklaina	Southwest	4-5	1.11	5961	12.91
4. Koukounara	Southwest	4-5	1.13	5957	5.70
5. Nichoria	Southeast	4-5	1.09	5878	9.58
6. Thouria	Southwest	0.5-4	1.14	5840	5.93
7. Malthi-Gouves	Southeast	0.5-4	1.09	5831	6.74
8. Mouriatada	Southwest	0.5-4	1.13	5982	5.99
9. Peristeria	Southwest	0.5-4	1.13	5790	6.16
10. Filiatra	Southwest	4-5	1.08	5906	10.8
11. Agrilovouno	Southwest	0.5-4	1.07	5888	7.25
12. Ay. Dimitrios	South	4-5	1.11	5755	6.71
13. Yialova	Southwest	4-5	1.10	5844	7.49
14. Diavolitsi	Southeast	0.5-4	1.13	5888	5.49
15. Kalamata	Southwest	4-5	1.14	5859	4.21
16. Kalyvia	Southwest	0.5-4	1.10	5910	5.59
17. Kardamyli	Southwest	4-5	1.10	5838	6.98
18. Kato Melpeia	Southwest	0.5-4	1.12	5875	6.98
19. Magganiako	Southeast	0.5-4	1.12	6023	5.63

20. Metaxada	Southeast	0.5-4	1.15	5894	6.21
21. Myrsinochori	South	4-5	1.14	5955	7.65
22.Polichni	Southwest	0.5-4	1.12	5903	5.11
23. Pidima	Southwest	0.5-4	1.16	5554	4.76
24. Pyla-Vigles	South	4-5	1.18	5883	7.54
25. Romanos	South	4-5	1.17	5840	4.65
26. Sidirokastro	Southwest	0.5-4	1.09	6014	5.36
27. Stenyklaros	Southeast	0.5-4	1.04	5874	11
28. Stoupa	South	4-5	1.17	5850	5.99
29. Foinikounda	Southeast	4-5	1.12	5840	6.74
30. Filiatra	Southeast	0.5-4	1.08	5864	11

This paper highlights the necessity and contribution of GIS and spatial analysis in the field of Geoarchaeology as it is a modern tool that can provide the analysis of both individual positions as well as large areas. Through the specific methodology followed in this paper, and by using the appropriate bioclimatic indexes, common features of the parameters examined were attributed to create a pattern with the values and traits that appear to be repeated. Thus, according to the examination parameters, certain standards of residential installation appear to exist. This interpretation is made both on the basis of the above observations relating to the correlation of spatial parameters and through cross checking archaeological research by archaeologists who have worked in the study area. The proposed methodology could be used in other regions of the Mycenaean era to confirm the concept of the knowledge of bioclimatic conditions by the Mycenaean Greeks and whether they eventually played a role in the choice of place of habitation.

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