Geomorphologic and satellite imagery approaches for the reconstruction of Neolithic Thessaly landscape

ALEXAKIS D.,[1] SARRIS A.,[2] ASTARAS TH.[1], OIKONOMIDIS D.[1]

ABSTRACT

Thessaly is a region of low relief in Greece where hundreds of Neolithic settlements called magoules were established from Early Neolithic period until Bronze Age. In this study filed survey, statistical analyses of coring data, spatial analyses of environmental parameters in GIS and image processing techniques of satellite images and DEMs were carried out to contribute to the detection of the Neolithic settlements.

Keywords: GIS, Remote Sensing, tells, Thessaly, Neolithic.

1. INTRODUCTION

Neolithic Thessaly has been traditionally studied for understanding human partitioning and territoriality of the landscape by non-hierarchical human groups. The distinct natural features of the Thessaly landscape are ideal for reconstructing the major habitation patterns of the first Neolithic farming groups of Greece. Thessaly is a region of low relief with extensive coastline and a great alluvial plain, where hundreds of Neolithic settlements/tells called *magoules* were established from Early Neolithic period since Bronze Age.

In order to proceed to an integrated geo-archaeological research and study the settlement patterns of the region in terms of the environmental resources multiple methodological approaches were explored. Field survey, statistical analyses of coring data, spatial analyses of environmental parameters in GIS and finally image processing techniques of satellite images and DEMs were carried out to cover the extensive study area and contribute to the detection of the low relief Neolithic settlements.

2. RESEARCH METHODS AND MATERIALS

Initially the study involved 3D detailed modeling of the Thessaly landscape by incorporating the following modules:

Topographic mapping through the use of Global Positioning Systems (GPS). The particular task was carried out to map a large percentage (more than 342 settlements) of the existing archaeological sites (Fig. 1).

A number of satellite images from various satellite platforms were employed in order to define the spectral signatures of the known archaeological sites which were ultimately used in the predictive modelling stage of research.

Digitization of 1:50.000 scale topographic and geological maps of the Geographic Service of the Hellenic Army and of the Institute of Geological and Mineral Exploration. The Digital Elevation Model (DEM) of the study area with a cell size of 20 m was based on the digitized 20m elevation lines. Geological formations were

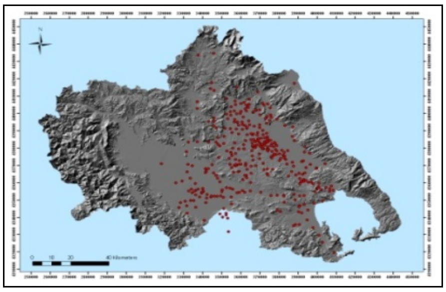

Figure 1: Spatial distribution of *magoules* in Thessaly

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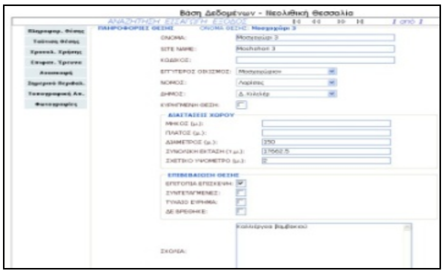
reclassified to form a unified geological map. Further details of the above maps, such as rivers, lakes, faults and modern villages were also included.

An archaeological information inventory was also constructed in SQL to include the basic information regarding the archaeological settlements (type of site, chronological phases, type of raw materials present in the sites, etc) (Fig. 2). Data were collected from already published gazetteers and recent fieldwork and excavation reports, representing a much better and complete distribution of sites than ever before. At the same time, cultural attributes and environmental information that may have played a significant role in the patterning and location of sites accompany the archaeological records. Following a common georeferencing of the available data to the local projection system of Greece (HGRS – Hellenic Geodetic Reference System), all the data were implemented into GIS environment.



Βάση Δεδομένων - Νεολιθική Θεσσαλία

ΑΝΑΖΗΤΗΣΗ ΕΙΣΑΓΩΓΗ ΕΞΟΔΟΣ

ΠΛΗΡΟΦΟΡΙΕΣ ΘΕΣΗΣ

ΟΝΟΜΑ:

SITE NAME:

ΚΩΔΙΚΟΣ:

ΕΓΓΥΤΕΡΟΣ ΟΙΚΙΣΜΟΣ:

ΝΟΜΟΣ: Λαρίσης

ΔΗΜΟΣ:

ΚΗΡΥΓΜΕΝΗ ΘΕΣΗ: ☐

ΔΙΑΣΤΑΣΕΙΣ ΧΩΡΟΥ

ΜΗΚΟΣ (μ.):

ΠΛΑΤΟΣ (μ.):

ΔΙΑΜΕΤΡΟΣ (μ.): 250

ΣΥΝΟΛΙΚΗ ΕΚΤΑΣΗ (τ.μ.):

ΣΧΕΤΙΚΟ ΥΨΟΜΕΤΡΟ (μ.):

ΕΠΙΒΕΒΑΙΩΣΗ ΘΕΣΗΣ

ΕΠΙΤΟΠΙΑ ΕΠΙΣΚΕΨΗ: ☑

ΣΥΝΤΕΤΑΓΜΕΝΕΣ: ☐

ΤΥΧΑΙΟ ΕΥΡΗΜΑ: ☐

ΔΕ ΒΡΕΘΗΚΕ: ☐

ΣΧΟΛΙΑ: Καλλιέργεια βαμβακιού

Figure 2: The archaeological data base included various information levels that were used for the statistical processing of the sites and their classification in the environmental context of Thessaly.

3. LANDSCAPE RECONSTRUCTION

3.1. Alluvial basins

Thessaly consists of two major basins, Larisa Plain with an area of 1,020Km^2 and Karditsa Plain with an area of 2,210Km^2. The two plains contain 181 out of the 342 known registered “Magoules”. This proves the crucial importance of the reconstruction of the two alluvial basins during the Neolithic period. The reconstruction of the particular alluvial basins was based on the synthesis of the geological maps, the archives of stratigraphic data from boreholes and indexing of past geomorphologic studies.

From a geological point of view, Thessaly belongs to the Internal Hellenides and specifically to Pelagonian massif to the east and the Pindos range to the west. A geological data base of 50 selected drill cores (based on the quality of data presented) out of a total of more than 400 drill cores collected and reported by the Prefectures of Karditsa, Larissa, Volos, and Trikala was constructed. The depth to the alluvial deposits was estimated based on the most credited drill cores (6 from Karditsa basin and 6 from Larisa basin). Provision of the local relief was taken into account for a more accurate and absolute estimation of the alluvium deposits depth.

Finally, estimates of the depth of the deposits (for the alluvial basins) for the three main Neolithic periods were obtained following Demitrack’s assumption (for Larisa basin) about deposition rates (Demitrack, 1986): 5.5m for Late Neolithic, 6.5m for Middle Neolithic and 8.5m for Early Neolithic.

Based on the above, the reduction of the drill core data concerning the alluvial deposits for the particular periods was based on the following algorithm:

$$X= (dy – y_{min}/(y_{max}-y_{min})) + y_{min'}$$

where X is the reduced depth of deposits (for the particular drill holes), dy is the current depth of deposits (from drill cores), y_{min} is the minimum depth of deposits (within the basin from drill cores), y_{max} is the maximum depth of deposits (within the basin from drill cores) and $y_{min'}$ is the minimum depth of deposits according to Demitrack (1986).

Although the Quaternary of Trikala - Karditsa basin is less well known than that of the Larisa basin, a similar procedure was followed, due to the fact that depositional processes in the area reflect a parallel history of floodplain deposition and incision, closely related to that of Larisa basin.

The above estimates were used for calculating (through a best fit line) a much more general equation for converting from the current elevation (namely current DEM of alluvial basins) to Sea, and it is the biggest island of the Sporades complex, with, Sea, and it is the biggest island of the Sporades complex, with Sea, and it is the biggest island of the Sporades complex, with Sea, and it is the biggest island of the Sporades complex, with the corresponding alluvial depths (reconstructed depths) for each one of the three major Neolithic sub-periods. Six linear equations were approximated to define the depth of the deposits for the three periods of Neolithic for Karditsa and Larisa basins independently (Fig. 3).

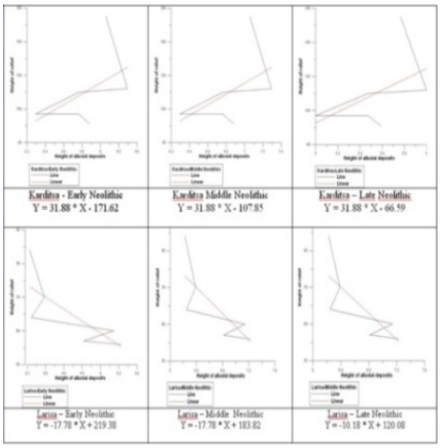


Figure 3: Linear equations estimating the reconstructed depths to the alluvial deposits of the three Neolithic periods (early, middle and late) for each one of the major basins of Thessaly (Karditsa and Larisa). In the above formulas, Y is the current elevation and X is the reconstructed alluvial deposits depth.

The above estimates were applied to all elevations of the two basins and a reconstructed DEM of the basins was formed for each one of the periods of Neolithic. The rest of the altitudes for the mountainous regions remained unaltered. Based on Boolean operations, the reconstructed DEM for the whole region of Thessaly was formed by subtracting the reconstructive alluvial deposits DEM of the Larisa and Karditsa basins (only) from the current DEM of the whole region of Thessaly. An overlay of the magoules on the reconstructed DEM provided valuable information regarding the location of the Neolithic settlements in terms of the altitude (Table 1).

After reconstructing the large scale topography of the Thessalian landscape, emphasis was given to the reconstruction of the micro–topography around the settlements. Two factors were taken into consideration: the height of the settlements, estimated through fieldwork activities and the excavation information provided for Platia Magoula Zarkou (Van Andel et al, 1992). The particular data were statistically processed following a classification of Magoules to 14 categories according to their duration of habitation. The reduction of the corresponding heights was based to the cross-section plan of Platia Magoula Zarkou provided by Van Andel et al (1992).

Table 1: Statistical results of the location of the Neolithic settlements (for the three major periods of Neolithic) in terms of the reconstructed depth of alluvial deposits for each period of interest. The classification of the depths is based on the concentration of the data within certain depth limits by taking in account the standard deviation of the samples.

	NumberOf Sites	Percentage %	Reconstructed depths to alluvial deposits (m)
Early Neolithic Settlements	67	37	< 8
	108	59,6	8 –10
	6	3,31	>10
Middle Neolithic Settlements	21	11,6	< 5
	123	67,95	5 –7
	37	20,44	> 7
Late Neolithic Settlements	58	32	< 4
	97	53,59	4 –6
	26	14,36	> 6

Taking also in account the mean diameter of Magoules (approximately 150 meters), three buffer zones of 50 meters each around each Magoula were created. The first (central) buffer zone kept the height of each Magoula as mentioned above, whereas in the second (middle) and third (outer) zones the height was gradually reduced by 50% and 25% of the initial height correspondingly (Fig. 4). In this way, the final estimate that was used for the reconstruction of the DEM within the vicinity of the Magoulas was given through the sum of the landscape reconstructed DEM, the 0-50m DEM zone, the 50-100m DEM zone and the 100-150m DEM zone.

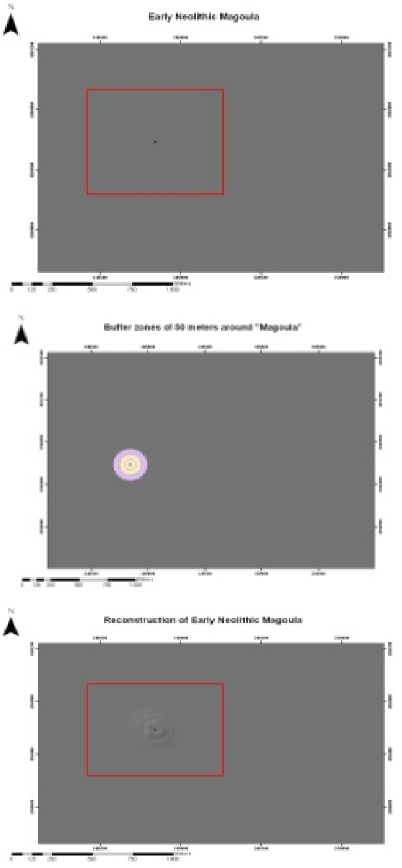


Figure 4: Reconstruction of the micro-topography around the Neolithic Magoules. Top: Point location of the magoula. Middle: buffer zones created around the magoula. Bottom: reconstructed DEM around the magoula.

3.2. Coastline

A rise of sea level by 100–120m has been noticed after the last glacial period of Wurm all over the Aegean Sea. This melt affected the coastline of Thessaly especially towards the coastal zone of Volos and Almyros plains within areas consisting of Holocene alluvium deposits. In order to examine the changes of the coastline during the Early Neolithic to the Late Neolithic period, the results of the study of Kampouroglou (1991) were adopted. Kampouroglou made approximate plans of the Neolithic coastline of Volos plain based on a number of drill holes within the Volos basin. The particular plans were geo-referenced with the help of multispectral imagery (ASTER) and compared to the current coastline. According to the spatial measurements carried out in different sections of the coastline, it was noticed that in the Early Neolithic period the coastline was about 650m seawards, whereas during the Late Neolithic period the coastline moved 300m inland – compared to the current coastline.

3.3. Lake Karla

The extent of ancient lakes is considered to be a crucial factor for the reconstruction of Neolithic landscape. Lake Karla to the SE of Larisa plain has been known to exist in antiquity, although its extent was extremely variable due to the different climatic conditions in different periods. Nowadays lake Karla has been dried, although there are plans for its re-creation. Due to its distinct settings, a completely different alluvial deposit model was used for the reconstruction of lake Karla during the Neolithic period. The model was based on the outline of its prehistoric extent provided by Grundmann (1937) and the

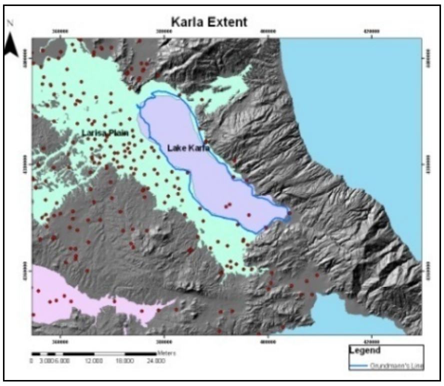


Figure 5: The area of lake Karla. The red dots represent the Neolithic magoules around the lake. The blue line is the suggested lake level according to Grundmann (1937). The purple color is the suggested lake extent according to the recent study. The green color represents the Larisa plain

spatial distribution of magoules around its shoreline, as they have been recorded by the latest GPS survey. The data suggested the lake level (during the Neolithic period) to extend at the 40m contour line in agreement to Halstead (1984), who considered the lake levels to exist below the 44m (Fig. 5).

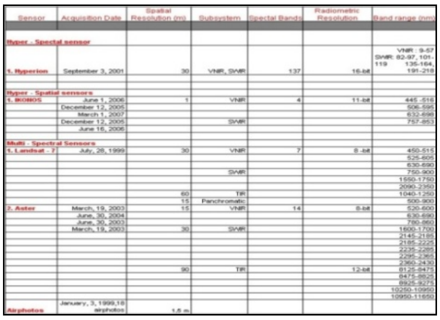
4. SATELLITE IMAGE PROCESSING

The study involved satellite image detection of Neolithic Settlements in Thessaly by incorporating the following digital satellite data (Table 2):

- 4 RASTER images
- 1 LANDSAT ETM image
- 1 HYPERION image
- 4 IKONOS images
- 5 Airphotos

It has to be mentioned that each set of imagery data had a different area coverage.

Table 2: Spectral, spatial and temporal attributes of the satellite sensors and airphotos that were used for the study.



Sensor	Acquisition Date	Spatial Resolution (m)	Subsystem	Spectal Bands	Radiometric Resolution	Band range (nm)
Hyper - Spectal sensor						
1. Hyperion	September 3, 2001	30	VNIR, SWIR	137	16-bit	VNIR : 9-57 SWIR: 82-97, 101-119 135-164, 191-218
Hyper - Spatial sensors						
1. IKONOS	June 1, 2006	1	VNIR	4	11-bit	445 -516
	December 12, 2005					506-595
	March 1, 2007					632-698
	December 12, 2005		SWIR			757-853
	June 16, 2006					
Multi - Spectral Sensors						
1. Landsat - 7	July, 28, 1999	30	VNIR	7	8 -bit	450-515
						525-605
						630-690
			SWIR			750-900
						1550-1750
						2090-2350
		60	TIR			1040-1250
		15	Panchromatic			500-900
2. Aster	March, 19, 2003	15	VNIR	14	8-bit	520-600
	June, 30, 2004					630-690
	June, 30, 2003					780-860
	March, 19, 2003	30	SWIR			1600-1700
						2145-2185
						2185-2225
						2235-2285
						2295-2365
						2360-2430
		90	TIR		12-bit	8125-8475
						8475-8825
						8925-9275
						10250-10950
						10950-11650
Airphotos	January, 3, 1999,18 airphotos	1,5 m				

4.1. Preprocessing of Satellite images

Before starting the image processing we masked the sea, the clouds and the snow areas of all the images. Then we proceeded with the construction of image mosaics and transformation of the projection systems to a common projection system (EGSA87/HGSR87). The final step of image preprocessing was the conversion of DN values of images to reflectances.

4.2. Composition of RGB composites

Several RGB composites were constructed in an effort to examine their efficiency in the detection of the Neolithic settlements. For the ASTER image with acquisition date 19-03-2003, where most of the magoulas are registered the RGB→1,2,3, RGB→3,2,5 and RGB→2,3,7 composites were the most successful for the detection of the Neolithic settlements (39 out of 239 settlements were highly visible, 49 average visible and 151 poorly visible). Similarly, RGB composites of IKONOS images were able to detect 27 in a total of 48 settlements within their area of coverage. It is worth mentioning that 19 of the detectable magoulas, namely the highest of all corresponding to an average altitude of 4.6m, were highly visible in all RGB composites. On the other hand, RGB composites of Landsat and HYPERION images were not very promising (for HYPERION composites only 5 settlements were detected in a total of 21). Finally, average altitude aerial images contributed to an excellent detection of all the 5 settlements that were inside the spatial limits of the airphoto mosaic. As a general conclusion however, the most crcial factors for the detection of magoules proved to be the acquisition date of the image due to the fact that the terrain of the majority of the settlements is cultivated (mainly soft/shallow cultivation).

4.3. Spectral Profile Comparison and Classification

The identification of spectral signatures was considered to be a crucial task for the detection of Neolithic settlements especially in the classification process. Signatures were collected from all the tells and were divided into two categories: Those collected from plain areas and those collected from mountainous areas due to different soil cover.

4.4. Principal Component Analysis

We applied PCA to ASTER, Landsat and Hyperion Images. PCA of ASTER images provided the best results where 39 settlements were highly discriminated and 47 were relatively discriminated in a total of 247.

4.5. Image Fusion

Image fusion is a standard satellite image procedure of combining images of different spatial resolution to obtain a single final composite image. Various fusion combinations were tried, such as ASTER (15 m) visible channels with the PCA product of HYPERION (30m) or the high resolution (1m) bands of IKONOS with the PCA product of HYPERION. The results were highly promising for the cases of fusion between high spatial resolution and high spectral resolution images.

4.6. Spectral Mixer Utility

In order to exploit the high spectral resolution of HYPERION images, we applied a spectral mixer utility of Erdas Imagine 9.1. Spectral Mixer produces three bands to be assigned to the red, green, and blue color guns, but in this case instead of just assigning each band to a color gun we could select a weighted average of spectral bands to be assigned to a color gun (Erdas Field Guide, 2006). For HYPERION images only the bands that have reflectance values above 0.3 were used and we assigned a weighting coefficient of 0.14 for each band. The new RGB that was created (RGB1) employed the mixing of the bands (38, 42, 48, 49, 50, 51, 52), (85, 86, 87, 88, 89, 90, 91, 92,) & (93, 94, 108, 109, 110, 111, 113, 114).

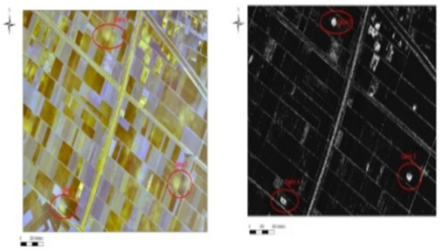


Figure 6: Appearance of 3 settlements in the original IKONOS image (left) and the radiometrically enhanced image where three Neolithic settlements are highlighted (right). To the north of Galini-3 settlement, shown at the lower right of the image), another smaller candidate magoula is suggested.

4.7. Radiometric Enhancement

Radiometric enhancement was vital for the appearance of the images. After applying radiometric enhancement to ASTER images (acquisition date of 19-03-2003) we managed to detect 57 settlements. A non-linear radiometric enhancement of the HYPERION PCA image, followed by an inversion of brightness was able to highlight 8 settlements from a total of 9. Similar type of non-linear radiometric enhancement of the high resolution Ikonos images through the modification of the histogram was able to outline the round shape of known magoules, as well as to identify 10 more targets of similar geometry that need to be verified by the ground truthing activities that will follow (Fig. 6).

4.8. Land Classification and Vegetation Indices

In the domain of predictive modeling, the specification of the environmental attributes that correlate to the location of the archaeological sites is of importance. For this reason, in order to investigate the regime of the land use surrounding the magoules, several methods of supervised classification were applied to Landsat and ASTER images. Mahalanobis classification proved to be the most efficient one in terms of the overall accuracy assessment compared to all the classification algorithms that were applied (8 in total). The Normalized Difference Vegetation Index (NDVI) was computed to analyze the difference of vegetation during various acquisition dates. As expected, the NDVI of the spring ASTER image was higher than the summer Landsat image.

4.9. De-correlation Stretch

The de-correlation stretch is a process that is used to enhance (stretch) the color differences found in the input pixels. After we applied de-correlation stretch to the ASTER images, we managed not only to detect easily 36 Neolithic settlements, but also to obtain estimates of their extent.

4.10. Spatial Enhancement

Spatial enhancement of images is considered to be a standard satellite image enhancement. Of the several types of filters that were applied in the specific study, only two of them, Sobel Right Diagonal 3x3 and Laplace 3x3, proved to be very useful for the detection of Neolithic settlements (Fig. 7).

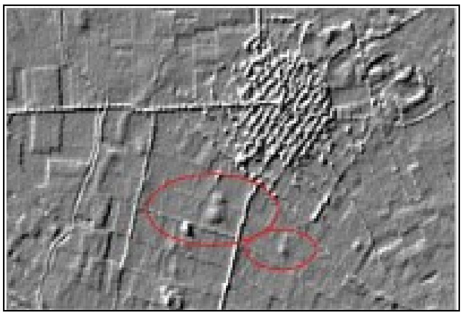


Figure 7: ASTER image around Halki area after the application of Sobel Right Diagonal filter. Neolithic magoules are indicated within the ellipses

4.11. Predictive Modeling:

The results of land use classification, NDVI estimates and those from the spectral signatures and classification of the ASTER image (acquisition date 19-03-2003) were combined together with a DEM constructed by digitization of 1:50.000 scale topographic maps. All data were reclassified and a certain weight factor was applied to each of the raster layers. After constructing the final map we estimated that 92 of the known settlements are laid on areas of high probability and 23 in areas of medium probability.

5. ANALYSIS IN GIS ENVIRONMENT

In order to proceed to extensive GIS analysis we used the Digital Elevation Model with pixel size of 20m, constructed from topographic maps. Initially, we proceeded to the extraction of statistics about the Neolithic settlements in relation to the aspect, the slope and the relief height of the place of settlement establishment. Additionally we estimated the distance of settlements from natural resources by applying buffer zones around the quaries and the water springs that we had already digitized from topographic maps. With the use of GIS, topographic maps and satellite images we constructed the watersheds and estimated the distance of each settlement from the neighbor watershed.

Moreover, we constructed 3 different cumulative viewshed maps for the 3 different Neolithic periods by taking in account that the average height of Neolithic man is 1.64 m (Fig. 8). By using Kolmogorov – Smirnoff statistic test, we concluded that the sites are not distributed irrespective of the number of other sites which are visible.

Density maps of the settlements were also created for each Neolithic period and with their help we constructed habitation zones (Fig. 9). For each of those zones we extracted both their geographic centroid and a second centroid according to the size and the temporarity of habitation.

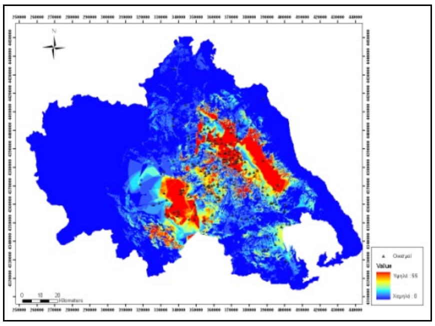


Figure 8: Cumulative viewshed map of Late Neolithic period.

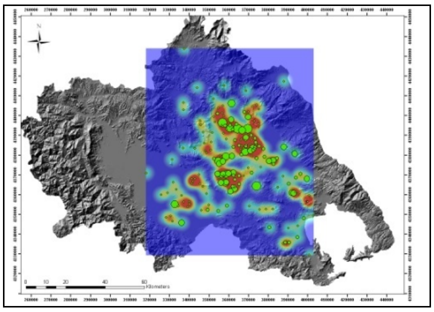


Figure 9: Density map for Early Neolithic period. With red colors are the areas with high density habitation.

Cost surfaces were formed in order to search the regime of communication between the different settlements. Based on this, least cost paths were also computed between the centroids of each zone (Fig. 10). These paths represent the communication routes between the habitation zones.

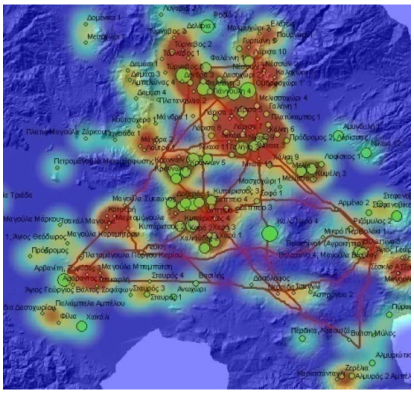


Figure 10: Least Cost path analysis of early Neolithic period

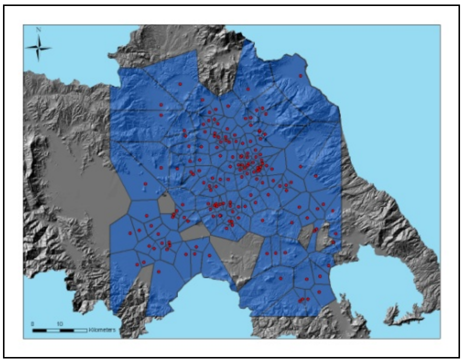


Figure 11: Thiessen polygons of Early Neolithic period

The relationship between the size of each settlement and the spatial territorial limits of them (site catchment analysis) were explored using the Thiessen polygons analysis (Fig. 11) and it was suggested that there is no specific relationship between the size of the settlements and their catchment area.

Finally, predictive models for all the periods of Neolithic were constructed in order to locate the areas of possible existence of settlements. Taking into account all the environmental factors (height, aspect, slope, distance from watersheds, distance from water springs, distance from quarries, geology, viewshed, distance from chert sources, distance through the use of least cost paths) that affected the choice of habitation in certain places in Thessaly, we applied certain weight factors to each of these variables. Then we rated each factor and applied them to a final equation. With the use of Boolean algebra and GIS tools we constructed the final DEMs for each period and surfaces that depicted the different probabilities for the existence of unknown settlements (Fig. 12).

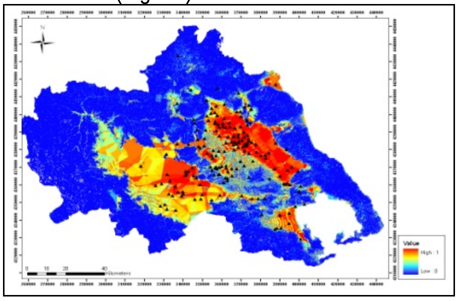


Figure 12: Prediction map for the Middle Neolithic Period

After the creation of DEMs we constructed tables with the number of settlements that are established in areas with different probability for the existence of settlements (Table 3).

6. DETECTION OF CHOCOLATE FLINT RESOURCES

The research team proceeded to an investigation at the fringes of Pindus Mountain for the detection of chocolate flint resources. This specific material was used for the construction of lithic tools in Neolithic society and the detection of their sources was a crucial task for the modeling of habitation regime at this period. The research team (team of archaeologists and geologists) located four places that were used as sources for lithic material and then we mapped them through the use of GPS (Fig. 13).

Figure 13: Chocolate flint found at the sloping hills of Pindus Mountain

7. APPLICATION OF SOPHISTICATED FITERS TO DEMS

The study involved detection of Neolithic Settlements through the use of Digital Elevation Models (DEM). For this purpose we used three different kinds of DEM: SRTM DEM of 90 m pixel size, ASTER DEM of 30 m pixel size and the DEM from digitized contours of 20 m pixel size.

For the detection of the Neolithic settlements we used three different methodologies to the above DEMs. The first methodology involved the estimation of the index of convexity according to Fry et al (2004). In this methodology we applied an index of convexity (CI) to the DEM according to the equation:

$CI = (x - x_{med}) / (x_{max} - x_{med})$

x = the initial DEM

xmed = DEM after the application of median filter

x_{max} = DEM after the application of maximum filter

The second methodology had to do with the creation and application of customized filters similar to those used by Menze et al (2006). The statistics for these filters proved that the specific methodology is really promising especially for the SRTM DEM in the area of Larisa (Table 4).

Table 4: Statistics about the settlements detected after the application of filters of Menze et al (2006).

Larisa SRTM DEM	
Filters	Detected Settlements/ Total 94
Filter 1	54
Filter 2	54
Filter 3	29
Filter 4	19
Filter 5	34

The third methodology followed the approach of Iwahashi and Kamiya (1995) for the estimation of geometric signatures of DEM which involved the integrated study of slope gradient, surface convexity and texture of the study area. To the final results of the filtered DEM, algorithms of fuzzy logic were applied in order to obtain better classification results (Fig 14).

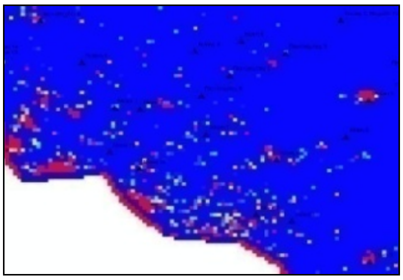


Figure 14: Application of geometric signatures methodology to SRTM DEM in the area of Larisa. With the red color are the areas of higher height where magoules could be established.

8. CONCLUSIONS

Geological studies and archaeological evidence contributed to the reconstruction of the landscape of Neolithic Thessaly. Each one of the local environments of the Thessalian plain was approached in a very different way to model the macro-topography of the Neolithic period. The micro-scale relief changes around the magoules were also taken into account through the existing archaeological evidence. Regarding the analysis in GIS environment we created predictive modeling surfaces for the detection of new Neolithic settlements. Additionally, we concluded that there is a relationship between the location of each settlement and its viewshed regime and we created habitational zones according to the spatial distribution and the density of the settlements. Thiessen polygons and the spectral signatures statistics of ASTER images proved to be the most reliable and efficient methods for studying the spatial distribution and the detection of Neolithic settlements. In contrast, Landsat images did not produced satisfactory results, mainly due to the summer acquisition date of it. The high spectral abilities of HYPERION, especially after merging it with the high resolution images of Ikonos, seem to have an increased potential not only for detecting but also for outlining the particular features. The image processes that proved to be more effective were the spatial filtering, the process of de-correlation stretch and the radiometric enhancement. In addition the results of the analysis of DEMs, especially the application of the three different filters to SRTM DEM, proved to be very promising and need further exploration.

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