Understanding of the Geomorphological Elements in Discrimination of Typical Mediterranean Land Cover Types

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Abstract. Quantification of geomorphometric features is the keystone concern of the current study. The quantification was based on the statistical approach in term of multivariate analysis of local topographic features. The implemented algorithm utilizes the Digital Elevation Model (DEM) to categorize and extract the geomorphometric features embedded in the topographic dataset. The morphological settings were exercised on the central pixel of 3x3 per-defined convolution kernel to evaluate the surrounding pixels under the right directional pour point model (D8) of the azimuth viewpoints. Realization of unsupervised classification algorithm in term of Iterative Self-Organizing Data Analysis Technique (ISODATA) was carried out on ASTER GDEM within the boundary of the designated study area to distinguish 10 morphometric classes. The morphometric classes expressed spatial distribution variation in the study area. The adopted methodology is successful to appreciate the spatial distribution of the geomorphometric features under investigation. The conducted results verified the superimposition of the delineated geomorphometric elements over a given remote sensing imagery to be further analyzed. Robust relationship between different Land Cover types and the geomorphological elements was established in the context of the study area. The domination and the relative association of different Land Cover types in corresponding to its geomorphological elements were demonstrated.

1. Introduction

Morphometry was evolved due to the need in many disciplines for repeatable measurements of shape, and thus a mathematical description of form. Precisely Pike [1] and Parker [2] as the form and structure of an object or the arrangements and interrelationships between the parts of an object defined the term Morphology. Morphology is related to shape, and digital morphology describes and analyzes the shape of a digital object, mainly a raster object [3].

Recent directions of the discipline now include computer visualization through relief shading, surface modelling with the triangulated irregular network, fractal characterization of topography and the automatic recognition of terrain features from digital elevations and imageries by procedures adapted from image processing or by the application of customized algorithms [4,5]. A better explanation of spatial patterns with tools (fuzzy set logic, neural networks) that have proven useful in allied disciplines but until recently, not available in geomorphometry is now being developed for the recognition and quantification of terrains, and hence their discrimination [3].

Over the past decades, much effort has been devoted to describing agents of geomorphic changes and how it works, even to the extent of modelling physical processes at the expense of numerical representation of the topography itself. Moore et al. [6], Burrough and McDonnell [7] and El-Bastawesy et al. [8] attributed this problem to the less significant role of topography in process-oriented work, obstacles in quantifying terrain.

Geomorphometry can be diversely approached because the land surface can be quantified from several perspectives. According to Weibel and Breandli [9] and Panhalkar [10], there are two main approaches to the study of geomorphometry, namely: general and specific. General geomorphology focuses on continuous topography or landscape and it is applicable to a wide variety of geomorphic features. On the other hand, specific geomorphometry involves the use of quantitative measures designed for analysis of specific landscape features.

Remote sensing data can be combined with other data to address a specific practical data. This has been demonstrated in various applications, such as land use planning, mineral exploration, and water quality mapping [11,12]. McDermid and Franklin [13] also emphasized that remotely sensed data can provide useful surrogate information for geomorphic processes, which are products of complex interactions between agents of geology, climate, hydrology, soils, and organisms. However, the methods, previously employed for extracting geomorphologically significant information from digital data sets are segmented and relatively poorly developed and, in most cases, employ processing and classification techniques which have been developed for other purposes [14, 15].

Unsupervised classification can be defined as the identification of natural groups, or structures, within multispectral data [11, 16]. Unsupervised classification is the identification, labeling, and mapping of natural groupings within elevation data. This technique does not utilize training data as the basis for classification if values within a given geomorphologic unit should be close together in the measurement space, whereas data in different classes should be comparatively well separated [17]. Unsupervised classification proceeds by making thousands of distance calculations as a means of determining similarities between the many pixels and groups within an image. Nonetheless, distance measures are the central point of unsupervised classification. It must be noted that not all distances measured are based on Euclidean distance. Other distance measures have been defined for unsupervised classification, [18].

The aim of the current study is to estimate the spatial distribution of the different type of slope, steepness. Moreover, to examine the relationship between the geomorphology and the land cover types in the study area. The focus here is on the association between the relative occurrence and abundance of Land Cover types within the geomorphological units.

2. Materials and Methods

2.1. Study area

The study area located at peninsula Sithonia, Halkidiki. Most of the major forest cover types found in Greece is presented in the area [19]. Sithonia constitutes the middle of the three peninsulas of Halkidiki and occupies the place with latitude between 39˚ 56' up to 40˚ 14' N and longitude between 23˚ 36' up to 24˚ 00' E. The peninsula is considered as a continuation of the mountain Holomonta. Its acreage is about 450 km2, half of which are occupied by forests of Aleppo pine (*Pinus halepensis*), which settles its optimum development in Sithonia [20]. The elevation ranges from sea level up to 823 m (hill Polielaios). The relief is gently lapping but there are places with an inclination of 50-60%. The peninsula does not have any rivers, but only small, numerous water streams with seasonal activity, which create gully erosion phenomena (Figure 1).

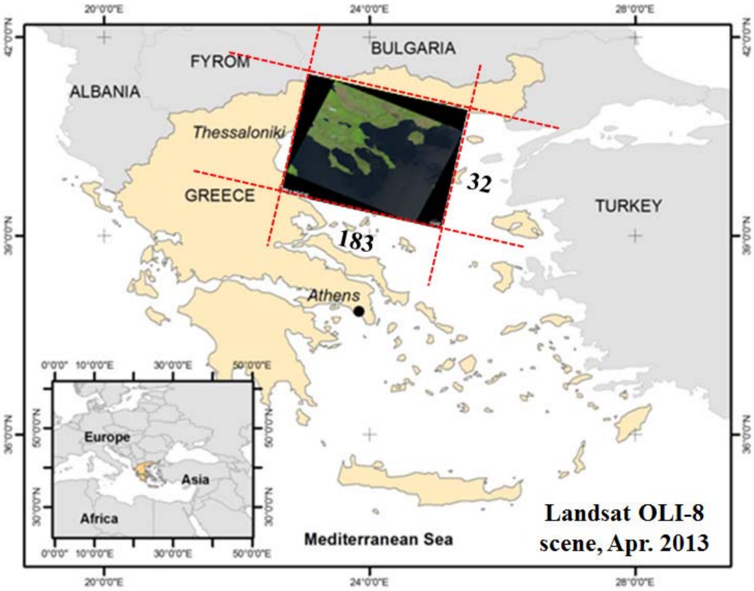

Figure 1. Location of the study area

2.2. DEM extraction

Digital data used in this study are the Digital Elevation Model (DEM) of Sithonia peninsula and its derived data (thematic maps) such as slope, aspect, and other morphometric maps. The DEM comes out from standard ASTER stereo pairs, generated by automatically correlating stereo ASTER or an images stereo pair. It exhibits a pixel with 30 m spatial resolution and is registered to UTM WGS-84 coordinate system. Other ancillary data used are the geological map and the satellite image of the study area.

2.3. Methodological Framework

2.3.1. Convolution Kernel

The methodological framework implemented in the current study is based on convolution kernel. The kernel course is to average quantified pixels across the entire image. According to Jensen [21], the kernel changes the spatial frequency features of the image (Table 1). The directional kernel of 3x3 pre-defined was used over the designated DEM with the intention of the topographic incline assessment utilizing the eight directions pour point model (D8) [22].

Table 1. The 8 coefficients value employed for the D8 directional pour point model.

Azimuth	ESRI code	3x3 pre-defined kernel			Azimuth	ESRI code	3x3 pre-defined kernel		
		-1.000	0.000	0.000			0.000	0.000	0.000
North West	32	0.000	1.000	0.000	South East	2	0.000	1.000	0.000
		0.000	0.000	0.000			0.000	0.000	-1.000
		0.000	-1.000	0.000			0.000	0.000	0.000
North	64	0.000	1.000	0.000	South	4	0.000	1.000	0.000
		0.000	0.000	0.000			0.000	-1.000	0.000
		0.000	0.000	-1.000			0.000	0.000	0.000
North East	128	0.000	1.000	0.000	South West	8	0.000	1.000	0.000
		0.000	0.000	0.000			-1.000	0.000	0.000
		0.000	0.000	0.000			0.000	0.000	0.000
East	1	0.000	1.000	-1.000	West	16	-1.000	1.000	0.000
		0.000	0.000	0.000			0.000	0.000	0.000

The convolution kernel starts from the upper right corner (NW) and processes clockwise to rearrange the neighbour pixels around the kernel center. The resulting values represent local pixel variations in the topographic features of the steepness, shape, and orientation. Moreover, the kernel expands to form eight layers in the consequential input dataset to qualify the multispectral classification techniques.

2.3.2. ISODATA classification

ISODATA classification is an analytical procedure based on clustering, using different algorithms. The whole image of the study area has been segmented into 10 spectral categories. Various techniques have been used to get information that is more detailed. The algorithm used to compute Optimum Index Factor (OIF) for reliable ISODATA classification at any subset of channels was carried out following Chavez et al. [23]. The channels combination with the largest OIF has the most information, as measured by variance, with the least amount of duplication, as measured by correlation [24, 25].

2.3.3. Statistical extraction

The classified thematic layer (ISODATA clustering output) was used as an input band and the elevation difference stack file consisting of eight layers was used as an input file under the ENVI environment. This procedure allowed us to obtain the mean values of the elevation variances between each of the D8 neighbour's model and its central pixel and for the 10 classes. Also, mean and standard deviations were extracted separately for each derived map; slope, aspect, and DEM.

2.3.4. Correspondence analysis

Correspondence analysis is a geometric-based technique used to show the columns and the rows of a given points matrix into vector spaces in dual low dimensional. Therefore, the correspondence analysis is an experimental/descriptive method intended to examine one-way and/or multi-way tables comprising correspondence measures between the columns and the rows of a given matrix. The correspondence matrix may distinguish any indication of confusion, affinity, interaction similarity or between the columns and the rows [26].

2.4. Accuracy assessment

The slope and the aspects extracted from the study area DEM were exercised to evaluate the different classes classification based on accuracy assessment identification. Mean and standard deviation of the DEM and its derived thematic layers in term of aspect and slope maps were also utilized in additional quantitative comparison with the resulted classification map. Field trips were carried out across the designated study area to collect ground truth data for a precise resolution of comparing the geomorphologic settings with the Land Cover type of the study area.

3. Results and discussions

3.1. Statistical interpretation

The eight mean elevation differences were obtained from the classified map (thematic layer). On the classified map in Figure 2, the different classes were depicted by 10 different colors for visual interpretation. To further verify the accuracy of the classified map statistical information, a numerical value was extracted from each derived data set DEM, slope and aspect, maps. These statistical values were compared with the statistics obtained directly from the classified thematic layer, which gave similar results necessary for the combined morphostructural interpretation.

The mean statistics of the derived data were matched with the corresponding class on the classified map. In summary, there was a corresponding relationship between the unsupervised classification map and spatial analysis of the DEM (slope, aspect, and elevation) based on pixel digital number observation [27].

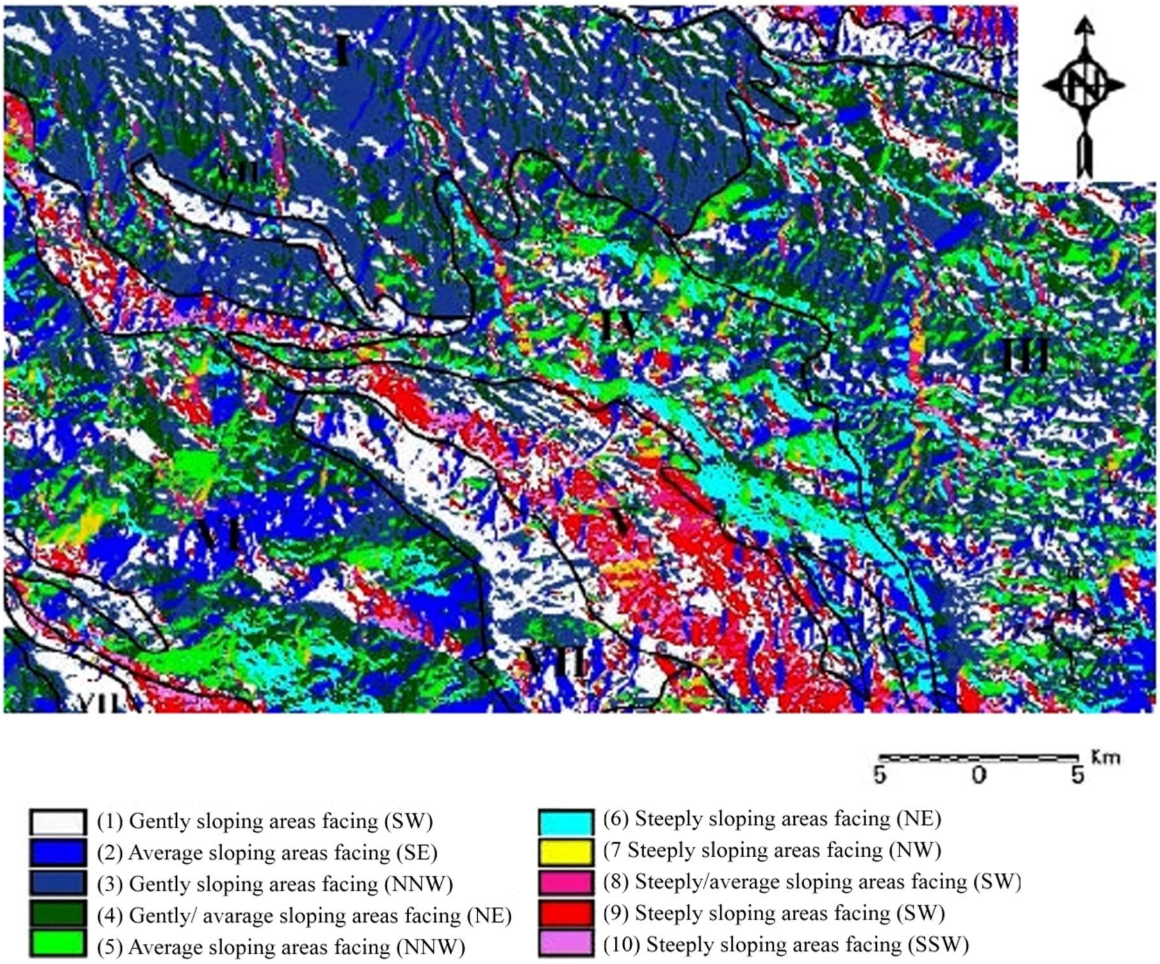

Figure 2. Morphometric ISODATA classification map of the study area

Aspect shows the eight major compass directions or the prevailing direction the slope faces, relative to the 10 classes. The aspect class frequency distribution plot better describes classes 3 and 5, where it is possible to verify that the main azimuth direction for both classes is around 315° (NNW trend).

It shows the minimum, maximum, the mean slope, and the standard deviation for the ten classes. The slope was not described only by degree, but also by the relative inclination of the slope elements.

Distinguished classification differences were noticed between the slightly inclined areas with aspect positioned to South West and the sharply inclined areas with aspect positioned to South, South West. Class number 10 with average elevation of 915 a.s.l. and 39 degrees of steep slope expressed sharp relief rather than class number 3 with an average elevation of 510 a.s.l. and average slight slope of 8.9 degrees. On the other hand, class 10 with aspect values of 192 degrees pointed to South, South West direction, and class seven with aspect value of 308 degrees and pointed to North West direction.

The unsupervised classification algorithm based on ISODATA classifier has generated 10 classes with different morphostructural elements variation. The ISODATA classification map demonstrated in Figure 2; is visually interpreted using different colour per class. The average of the elevation differences between the central of the 3x3 pre-defined kernel and its surrounding values were inferred. Also, the spatial distributions of the different classes and their association with the local morphologic characteristics have been examined and are presented in Table 2.

Table 2. Morphostructural interpretation of unsupervised classification algorithm.

Class	Colour	Interpretation
1	White	Slightly inclined areas fronting South West (SW)
2	Red	Averagely inclined areas fronting South East (SE)
3	Maroon	Slightly inclined areas fronting North, North West (NNW)
4	Olive Green	Slightly / Averagely inclined areas fronting North East (NE)
5	Light Green	Averagely inclined areas fronting North, North West (NNW)
6	Yellow	Sharply inclined areas fronting North East (NE)
7	Cyan	Sharply inclined areas fronting North West (NW)
8	Purple	Sharply / Averagely inclined areas fronting West (W)
9	Blue	Sharply / Averagely inclined areas fronting South West (SW)
10	Violet	Sharply inclined areas fronting South, South West (SSW)

3.2. Geomorphological units/Land Cover relationship

This part of the study examines the relationship between the Land Cover types and the geomorphological elements the of the designated study area. The Land Cover type's classification was derived from Sentinel-2 multispectral satellite image using CORINE project standards. Figure 3 shows the Land Cover type's classified map with its consistent legend displays the 11 Land Cover classes recognized in the study area. To understand the relationship between geomorphological elements and Land Cover classes a correspondence analysis was executed and is presented overleaf in Tables 3 and 4. The analysis revealed the following findings in terms of the association between the Land Cover type and geomorphological units.

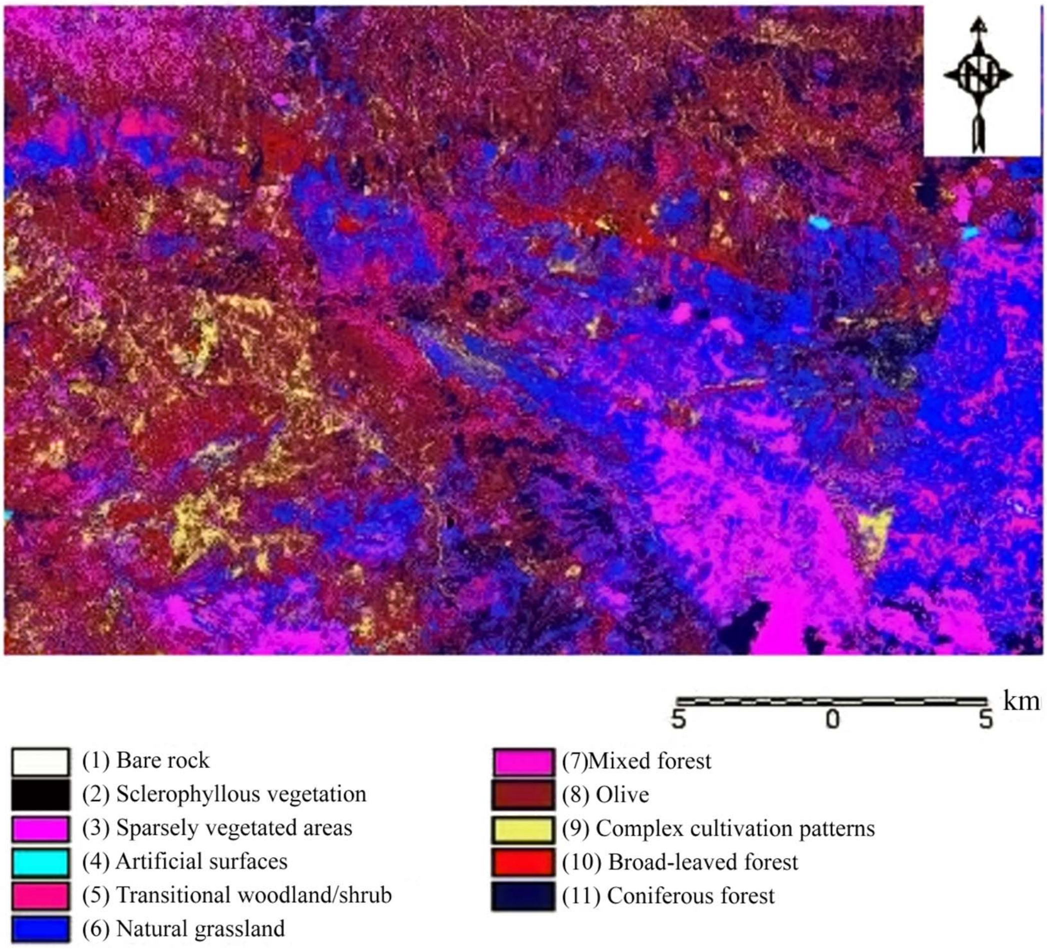

Figure 3. Land Cover classes map of the study area

The Land Cover type map is with 11 classes while the geomorphological unit's map has 10. Both maps have been displayed with their corresponding legend in different colours depicting various classes for visual interpretation.

The relative distribution of each Land Cover type in relation to geomorphological units examines the relative changes in Land Cover type abundance as a function of geomorphology. Data were obtained after a linear transformation that transforms the correspondence table into a standard scale, where the statistical bias was eliminated. Standardization is necessary because, without standardization, it is not possible to meaningfully compare the original values, since the geomorphological units are not evenly represented; for instance, class 1 (Slightly inclined areas fronting SW) accounted for 16.22% of the whole study area, while class 10 (Sharply inclined areas fronting SSW) accounted for 3.12%. Also, observations are often standardized from symmetric distributions to express them on a common scale [28]. To calculate the distribution of respectively Land Cover class within the geomorphological elements, the number of cases representative of each Land Cover class was divided by its total. This resulted in a new cross-tabulation showing the distribution of the Land Cover types within the geomorphological elements [29].

The variation of the distribution of the Land Cover classes between the geomorphological elements can now be explained by two variables; the first is the changes in Land Cover type due to geomorphology and the second the size of the geomorphological unit. To explain the relative change in Land Cover abundance as a single function of geomorphology, the effect of the variations in geomorphological unit size was eliminated by means of standardization. In the process, the calculated percentages of Land Cover types were divided by their corresponding geomorphological unit fraction area [30].

After standardizing, the association between the two variables was examined. It was noticed that, in geomorphological unit 1 (Slightly inclined areas fronting SW) the most dominant Land Cover class was class 9 (complex cultivation patterns), although in geomorphological element 4 (Slightly / averagely inclined areas fronting NE), the dominant Land Cover class was class 10 (broad-leaved forest) as demonstrated in Table 3.

Table 3. Summary of the relative relationship of the Land Cover type within the geomorphologic elements

Class	Geomorphologic units	Land Cover Type (Corine)
1	Slightly inclined areas fronting South West (SW)	Complex cultivation patterns (9)
2	Averagely inclined areas fronting South East (SE)	Sclerophyllous vegetation (2)
3	Slightly inclined areas fronting North, North West (NNW)	Bare rocks (1)
4	Slightly / Averagely inclined areas fronting North East (NE)	Broad-leaved forest (10)
5	Averagely inclined areas fronting North, North West (NNW)	Transitional woodland/shrub (5)
6	Sharply inclined areas fronting North East (NE)	Sparsely vegetated areas (3)
7	Sharply inclined areas fronting North West (NW)	Transitional woodland/shrub (5)
8	Sharply / Averagely inclined areas fronting West (W)	Coniferous forest (11)
9	Sharply / Averagely inclined areas fronting South West (SW)	Mixed forest (7)
10	Sharply inclined areas fronting South, South West (SSW)	Mixed forest (7)

The correspondence between the Land Cover classes and the geomorphological elements showing the relative distribution of the main Land Cover class in relation to the geomorphological element is summarized in Table 4.

Table 4 shows the results of examination of the foremost Land Cover class in each morphological unit. The problem to be addressed was to determine the foremost Land Cover class in each morphological element. This was accomplished by calculating the percentages of Land Cover types in each morphological unit. It was noticed from Table 5, Olive Land Cover class was the most dominant in all the geomorphological elements, followed by Natural Grassland Land Cover class. This was decidedly reliable with ground truth data collected from the field trip within the study area.

Table 4. The dominant land Cover class in each morphological unit

Land Cover \ Geomorphological unit	Geomorphological unit classes (%)									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	0.08	0.00	0.29	0.00	0.1	0.00	0.08	0.12	0.00	0.00
2	0.53	1.05	0.52	0.99	0.65	0.52	0.29	0.34	0.43	0.46
3	10.26	15.89	9.97	9.77	7.38	24.65	5.78	9.2	16.1	21.12
4	0.15	0.13	0.22	0.1	0.08	0.00	0.00	0.09	0.16	0.00
5	5.82	5.07	7.33	7.18	13.32	11.41	19.04	12.1	9.9	10.78
6	17.26	17.52	17.52	17.75	21.77	25.28	20.63	19.2	19.2	17.08
7	0.52	0.48	0.27	0.36	0.5	0.31	1.19	0.54	2.41	1.97
8	47.52	43.12	48.68	49.26	41.34	27.91	33.41	38.76	37.42	39.01
9	8.17	10.15	6.04	7.51	4.18	3.39	2.18	3.4	4.05	2.47
10	0.52	1.04	1	1.56	1.32	0.78	0.54	1.14	0.46	0.34
11	9.89	6.23	8.91	6.21	10.13	6.36	17.53	15.86	10.54	7.33

Explicitly, Table 5 pointed out the robust spatial correlation between the Sparsely Vegetated Areas class and the sharply inclined areas fronting North East. Sparsely Vegetated Areas Land Cover class was counted for 24.65% of the total coverage of the morphometric element. An evocative pattern was also distinguished between the sharply / averagely inclined areas fronting west. Artificial Surfaces class and Bare Rock class were imprecisely characterized. This could be explained since each class coverage was less than 1% in all the geomorphological elements.

Table 5. CORINE interpretation of the Land Cover maps with 11 classes

Class	Color	CORINE Interpretation
1	White	Bare rocks
2	Black	Sclerophyllous vegetation
3	Yellow	Sparsely vegetated areas
4	Cyan	Artificial surfaces
5	Orange	Transitional woodland/shrub
6	Green	Natural grassland
7	Gold	Mixed forest
8	Brown	Olive
9	Violet	Complex cultivation patterns
10	Red	Broad-leaved forest
11	Dark Green	Coniferous forest

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4. Conclusions

The computerized classification of geomorphometric features from Digital Elevation Model was demonstrated for the classification of geomorphological units in Sithonia peninsula. This approach should be adopted because it evaluates and discriminates the geomorphometric properties faster than manual methods. The utilization of digital data such as DEM in this study allowed for co-registration with other digital maps and imagery. Implemented methodology supported comprehensively the spatial distribution of the geomorphologic features. Conclusively, the current study has verified a reliable different information source that can be used in geomorphological applications. Moreover, the adopted methodology delivered evidence about the metamorphological structure delineation in theory and practice. Furthermore, the conducted results verified the superimposition of the delineated geomorphometric elements over a given remote sensing imagery to be further applied research. The prospect of geomorphometry as a field of study lies in its ability to better express terrain texture, effective characterization of non-fluvial areas, automated recognition of topographic units, mass-produced data from remote sensing, and the development of theory. Geomorphometric techniques using Digital Elevation Model, apart from discrimination of geomorphological units, hold great promise for other various applications such as the identification of landscape unit for soil-landscape, hydrological analyses, and the examination of the relationship between land-cover and the land-shaping process.

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References

[1] R. J. Pike, "Geomorphometry - process, practice and prospect," *Zeitschrift fur Geomorphologic*, N.F Suppl. Bd., vol. 101, pp. 221-238, 1995.

[2] J. R. Parker, "Algorithms for Image Processing and Computer Vision," New York: John Wiley and Sons, Inc. USA, 1997.

[3] P. D. Sreedevi, P. D. Sreekanth, H. H. Khan, and S. Ahmed, "Drainage morphometry and its influence on hydrology in a semi-arid region: using SRTM data and GIS," *Environ. Earth Sci.*, vol. 70, pp. 839–848, 2013.

[4] M. G. Turner, S. M. Pearson, and P. Bolstad, "Effects of land-cover change on spatial pattern of forest communities in the Southern Appalachian Mountains (USA)," *Landscape Ecol.*, vol. 18, pp. 449– 464, 2003.

[5] P. Singh, J. Thakur, and U. C. Singh, "Morphometric analysis of Morar River Basin, Madhya Pradesh, India, using remote sensing and GIS techniques," *Environ. Earth Sci.*, vol. 68, pp. 1967– 1977, 2013.

[6] I. D. Moore, R. B. Grayson, and A. R. Ladson, "Digital terrain modelling: a review of hydrological, geomorphological and bio- logical applications," *Hydrol. Process.*, vol. 5, pp. 3–30, 1991.

[7] P. A. Burrough, and R. A. McDonnell, "Principles of Geographical Information System," Oxford University Press, Oxford, UK, p. 333, 1998.

[8] M. El Bastawesy, K. H. White, and S. Gabr, "Hydrology and geomorphology of the Upper White Nile Lakes and their relevance for water resources management in the Nile basin," *Hydrol. Process.*, vol 27, pp. 196–205, 2013.

[9] R. Weibel, and M. Breandli, " Adaptive Methods for the Refinement of Digital Terrain Models for Geomorphometric Applications," *Zeitschrift fur Geomorphologic*, Suppl. Bd., vol. 101, pp. 13-30, 1995.

[10] S. S. Panhalkar, "Hydrological modeling using SWAT model and geoinformatic techniques," *Egyptian J. Remote Sens. Space Sci.*, vol. 17 pp. 197-207, 2014.

[11] J. B. Campbell, "Introduction to Remote Sensing," 2nd ed. London: Taylor and Francis, pp. 215-250, 1996.

[12] M. Elhag, "Inconsistencies of SEBS Model Output Based on the Model Inputs: Global Sensitivity Contemplations," *J. Indian Soc. Remote*, pp. 1-8. (2016a).
[13] G. J. McDermid, and S. E. Franklin, "Remote sensing and geomorphometric discrimination of slope processes," *Zeitschrift fur Geomorphologic*, Suppl. Bd., vol. 101, pp. 165-185, 1995.
[14] J. Eyquem, "Using fluvial geomorphology to inform integrated river basin management," *Water Environ. J.*, vol. 21, pp. 54–60, 2007.
[15] J. B. Ellis, and D. M. Revitt, "The management of urban surface water drainage in England and Wales," *Water Environ. J.*, vol. 24, pp. 1–8, 2010.
[16] M. Elhag, A. Psilovikos, and M. Sakellariou, "Detection of Land Cover Changes for Water Recourses Management Using Remote Sensing Data over the Nile Delta Region," *Environ. Dev. Sustain.*, vol. 15, pp. 1189-1204, 2013.
[17] M. Elhag, "Evaluation of Different Soil Salinity Mapping Using Remote Sensing Techniques in Arid Ecosystems, Saudi Arabia," *J. Sensors*, pp. 1-8, (2016b).
[18] P. H. Swain, and S. M. Davis, "Remote Sensing: The Quantitative Approach," New York: McGraw-Hill, pp. 396, 1978.
[19] S. Franklin, and M. Wulder, "Remote sensing methods in medium spatial resolution satellite data land cover classification of large areas," *Prog. Phys. Geog.*, vol. 26, pp. 173–205, 2002.
[20] M. Elhag, and J. Bahrawi, "Deliberation of Hilly Areas for Water Harvesting Application in Western Crete, Greece," *Global NEST J.*, vol. 18, pp. 621-629, 2016.
[21] J.R. Jensen, "Introductory Digital Image Processing: A Remote Sensing Perspective," 2nd ed. Prentice Hall, Englewood Cliffs, NJ, pp. 316, 1996.
[22] Tarboton, D. G., Bras, R. L. and Rodriguez-Iturbe, I. (1991). On the Extraction of Channel Networks from Digital Elevation Data. *Hydrol. Process.*, 5(1): 81-100.
[23] P. S. Chavez, Jr. Berlin, and L. B. Sowers, "Statistical method for selecting Landsat MSS ratios," *J. Appl. Photogr. Eng.*, vol. 8, pp. 23-30, 1982.
[24] R. S. DeFries, and J. C.-W. Chan, "Multiple criteria for evaluating machine learning algorithms for land cover classification from satellite data," *Remote Sens. Environ.*, vol. 74, pp. 503–515, 2000.
[25] D. R. Cutler, T. C. Edwards, K. H. Beard, A. Cutler, and K.T. Hess, "Random forests for classification in ecology", *Ecology*, vol. 88, pp. 2783–2792, 2007.
[26] B. Ghimire, J. Rogan, and J. Miller, "Contextual land-cover classification: incorporating spatial dependence in land-cover classification models using random forests and the Getis statistic," *Remote Sens. Lett.*, vol. 1, pp. 45–54, 2010.
[27] M. Elhag, and S. Boteva, "Mediterranean Land Use and Land Cover Classification Assessment Using High Spatial Resolution Data," *Earth Env. Sci.*, vol. 44, 042032, 2016.
[28] M. Elhag, and J. Bahrawi, "Soil Salinity Mapping and Hydrological Drought Indices Assessment in Arid Environments Based on Remote Sensing Techniques," *Geosci. Instrum. Meth.*, vol. 6, pp. 149—158, 2017.
[29] M. Elhag, H. K. Gala, and H. Alsubaie, "Understanding of Morphometric Features for an Adequate Water Resources Management in Arid Environments," *Geosci. Instrum. Meth.*, DOI: 10.5194/gi-2017-28, 2017a.
[30] M. Elhag, A. Bahrawi, H. Galal, A. Aldhebiani, and A. Al-Ghamdi, "Stream network pollution by olive oil wastewater risk assessment in Crete, Greece," *Environ. Earth Sci.*, DOI: 10.1007/s12665-017-6592-y, (2017b).