POLISH ASSOCIATION FOR SPATIAL INFORMATION
ANNALS OF GEOMATICS 2009 ○ VOLUME VII ○ NUMBER 2(32)

CLASSIFICATION OF MORPHOMETRIC UNITS FROM DIGITAL TERRAIN MODELS: APPLICATIONS IN LAND COVER CLASSIFICATION

KLASYFIKACJA JEDNOSTEK MORFOMETRYCZNYCH NA PODSTAWIE NUMERYCZNYCH MODELI TERENU: ZASTOSOWANIA W KLASYFIKACJI POKRYCIA TERENU

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Keywords: geomorphology, Mediterranean, morphometry, rangelands, vegetation cover
Słowa kluczowe: geomorfologia, Morze Śródziemne, morfometria, pastwiska, pokrycie roślinne

Introduction

In low-vegetated Mediterranean areas a close relationship exists between landforms and vegetation. Morphology and topography determine elevation, orientation, slope, curvature and roughness which in turn influence species distribution, plant density and vegetation type. Equally, land use is also affected by geomorphic factors. In areas with Mediterranean type climates, characterized by a hot and dry summer and a temperate moist winter, forests were converted into a variety of land cover types with diverse uses. In the southwestern part of the Iberian Peninsula rangelands occupy more than 3 million hectares, ranging from treeless pasture lands to open woodlands (Fig. 4). Land use is diverse with different combinations of livestock rearing, forest and agricultural exploitation. In ranches, with surface extensions typically ranging from 200 to 1,000 hectare, vegetation cover is diverse. For example, dense grasslands cover small valley bottoms or concavities and dense scrubland is found on steeper slopes, inaccessible to livestock.

Geomorphometry analyses the relief in a quantitative way (Hengl, Reuter, 2008). The recent advances of geomatics techniques together with the widespread availability of elevation data (e.g. SRTM project; http://www2.jpl.nasa.gov/srtm/) have encouraged the development of geomorphometry. In this, Digital Terrain Models (DTM) represent a powerful tool. Digital Elevation Models (DEM) allow the generation of a great quantity of information above the surface (such as slope, curvature, aspect, roughness, etc.) which can be used in relief description and classification (Felicísimo, 1994).

In this work a methodological purpose for landforms classification is proposed, based on the analysis of DTMs. In addition, land use and vegetation cover units in the farm were mapped. Finally, the relationship between landforms and land use-vegetation cover units was explored.

State of the art

Recently, several methodological strategies have been proposed to classify landforms, e.g.: Pike (2000), Azańón et al. (2004), Bolongaro-Crevenna et al. (2005), and Tagil and Jennes (2008). Methods and Techniques related with geomorphometry have been applied to natural risk analysis (Ioannilli and Paregiani, 2008) and environmental research (Hörsch, 2003).

Adediran et al. (2004) used multivariate statistical methods to classify landforms and unsupervised classification methods to map land use and vegetation cover units on north-central Crete (Greece). Then, they analysed the relationship between both landforms and land use units. Later, Abbate et al. (2006) tried to establish similar relationships in Central Italy.

Study area

This study was carried out in a farm (1,023 ha) located in the SW of the Iberian Peninsula (Fig. 5). The topography of the farm is undulating with an average elevation of 354 m above sea level and ranging from 230 m to 435 m, with an average slope of 10.3ş, varying from 0ş in the valley bottoms to 102.3ş in the hill slopes and river banks. SSW is the dominant aspect of the catchment.

Climate is Mediterranean with a pronounced dry season. Average temperatures vary from 8.1şC in July to 25.6şC in August. Annual and interannual rainfall variation is high with an annual average of 510 mm. The farm belongs to the savanna-like wooded rangelands that occupy large parts of the southern half of the Iberian Peninsula (called dehesas). The tree layer is dominated by Holm oaks *(Quercus rotundifolia)* of varying density and the herbaceous layer is characterized by therophytes. Shrubs are frequent in the farm, mainly *Retama sphaerocarpa, Cytisus multiflorus* and *Genista hirsute*. The land is grazed by sheep and seasonally by pigs.

Material and Methods

Classification of morphometric units

The topography of the study area was represented by 3 variables obtained from a DEM with a resolution of 5 m. The DEM was initially generated from contour lines and elevation points of the digital topographical map (Mapa Topográfico de Espańa, 1:10,000) and using the *topo to raster* algorithm as the interpolation method (Hutchinson, 1993), as implemented in ArcGIS 9.0 (ESRI Inc., http://www.esri.com). This algorithm is specially designed for obtaining DEMs from contour elevation data and allows for creating hydrologically correct models (e.g. without sinks). The DEM quality was analysed and the root mean square error was estimated as 0.66 m. The pixel size (5 m) was selected taking into account the minimum separation between contour lines in topographical maps, computational demands (calculation and storage) and the scale of the resulting maps.

From this DEM maps of the following morphometric variables were generated: slope gradient (Digital Slope Model: DSM), curvature (Digital Curvature Model: DCM), and roughness (Digital Roughness Model: DRM).

The DSM represents the slope angle and was calculated as the maximum rate of change between the altitude of each cell and its 8 neighbours, expressed in degrees.

The DCM represents the concavity or convexity of a surface and was calculated using the method described by Zevenbergen and Thorne (1987), based on a fourth degree polynomial function fitted to the surface. Values close to 0 are expected for flat surfaces, positive values are expected for upwardly convex areas, while negative values are expected for downwardly concave areas.

The roughness can be defined as the variation rate of the slope in a specific area, and no standard method exists to calculate it . The method used here to obtain the DRM is based on the spherical variance values of perpendicular vectors in relation to the terrain surface (Hobson, 1972). The values of these indices vary from 0 to 1, but for gentle topography they are always close to one, which is the value for a completely flat surface.

DTMs were used as input to an unsupervised classification algorithm to obtain cartography of morphometric units in the study area. The algorithm used here was the Iterative Self Organizing Data Analysis Technique (IsoData Cluster; Duda, Hart, 1973). Some requirements are demanded by this technique in the input data: DTMs should present a similar range of values and a non-zero average value. Therefore, it was necessary to transform the values of the DTMs, adjusting their range of values from 0 to 1,000, using the following expression (1):

$$P_v = \frac{(O_v - O_{\min})(N_{\max} - N_{\min})}{O_{\max} - O_{\min}} + N_{\min} \tag{1}$$

Where:

P_v – is the transformed value of each pixel in the new DTM,
O_v – is the original value of each pixel,
$O_{\min}$ and $O_{\max}$ – are the minimum and maximum values of the original model respectively,
$N_{\min}$ and $N_{\max}$ – are the minimum and maximum values of the transformed model.

In addition, it was necessary to shift the minimum value of the DCM to 0, and then, transform their values using equation (1). Having taken into account the range of original DTMs (from 245 m to 230 m for DEM, from 0ş to 102.3ş for DSM, from 7.9 m·m^{-2} to –4.9 m·m^{-2} for DCM and from 92.0 to 100 for the DRM) the range of the new model was defined between 0 and 1,000.

Before running the algorithm, the number of clusters must be defined, *(k)*. The optimal value of *k* (k_{op}) is unknown and several methodologies have been proposed in the literature to estimate k_{op}. In this paper, we have used the following scheme to determinate k_{op}:

- defining relief interpretation limits, this is, the maximum and minimum number of relief classes that could be found in the study area. In this paper, relief interpretation limits were defined between 4 and 10. Therefore field work was necessary for this part of the work.

- running the algorithm for values between k=4 to k=10 (relief interpretation limits).
- analysing the intercluster minimum distance.
- selecting the k_{op} value as the one where the classification presented the highest value for the intercluster minimum distance. This procedure ensures the maximum separation between classes.

The analyses were developed using the multivariate tools implemented in ArcGIS 9.2 (ESRI Inc., http://www.esri.com).

Elaboration of land use and vegetation cover maps

A catalogue of possible land uses and associated vegetation covers in the study area was constructed using information from different sources: field observations (since 2001), interviews of historical witnesses (owners and farmers) and studies performed by Plieninger (2006). Starting from this catalogue, a hierarchical legend was built. Afterwards, an orthophotograph (with a pixel size of 0.5 m) of the study area was interpreted and homogeneous vegetation cover units were delimited based on texture, colour-tonality and presence of elements (analysing their density, size and form). Finally, each homogeneous vegetation cover unit was associated with a land use category, obtaining in this way the map of land use and vegetation covers (Fig. 1).

Finally, the relationship between homogeneous vegetation cover units and morphometric classes was analysed.

Results

Morphometric units

The maximum value of the intercluster minimum distance between the relief interpretation limits was reached for a classification with 5 clusters (Fig. 2). The 5 resulting clusters were interpreted using their statistics of altitude, slope, curvature and roughness (Fig. 3).

The cluster 1 (*k1*; 81.9 ha) was associated with river banks. The *k1* presented low values of altitude, curvature and roughness and the highest slopes in the study area.

Areas with high slopes and low curvature values were associated with the cluster 2 (*k2*; 212,0 ha). This cluster was characterized by the highest values of roughness in the study area. The areas included in the *k2* occupied contiguous areas to *k1*.

The cluster 3 *(k3;* 263.5 ha) presented low slope values while curvature or roughness values were high. The *k3* represented undulated transitional areas between river banks and peneplains.

The cluster 4 *(k4)* matches with peneplain areas presenting the lowest slope values with a surface of 289.5 ha. Flat areas with intermediate values of curvature are included in the *k4*.

Finally, the cluster 5 *(k5)* corresponds with hilltops and presents an area of 176.4 ha.

Land use and vegetation cover

A total of 18 land use and vegetation cover units were delimited in the farm, each of them with a different density of shrubs and trees. These 18 classes were grouped into 3 main classes to facilitate the interpretation and analysis: Grasslands with scarce wooded vegetation *(I)*, grasslands with moderate wooded vegetation *(II)* and densely vegetated areas *(III)*.

Grasslands with scarce wooded vegetation occupied 13.3% of the study area and presented a cover of grasslands with a disperse cover (usually bellow 35%) of shrubs or trees.

Grasslands with moderate wooded vegetation occupied 19.7% of the farm and presented a cover of grasslands with a moderate dense cover of shrubs and/or trees.

Finally, densely vegetated areas presented a dense cover of trees and shrubs, occupying the 67.0% of the farm.

Relationship between morphometric units and land use and vegetation cover units

The results showed a relationship between land use and vegetation cover units and relief (Table). Grasslands with scarce and moderate wooded vegetation were mainly located in peneplain areas *(k4)*. The favourable topography of these areas is reflected in their current and past land use, as pasture and for crops, respectively (Gómez Gutiérrez et al., in press).

Areas with the steepest topography within the farm were covered by a dense layer of wooded vegetation (III). These areas have been associated during the last century with forestall and hunting uses (Gómez Gutiérrez et al., in press).

Table. Distribution of each vegetation cover unit within each morphometric unit

Vegetation Cover units	Landforms					Total [ha]
	K1	K2	K3	K4	K5	
I	11.42%	4.21%	17.17%	51.67%	15.51%	135.99
II	0	0.84%	17.98%	61.84%	19.28%	201.76
III	9.57%	29.81%	29.84%	13.76%	17.00%	685.56
Total [ha]	81.9	212.0	263.5	289.5	176.4	1023

Conclusions

A methodology for mapping relief units has been proposed in this paper. This methodology was based on the use of DTMs and the IsoData algorithm. To determinate the k_{op} the intercluster minimum distance criteria was used.

A relationship between morphometric units obtained and land use and vegetation cover units map was found. The steepest areas presented a dense cover of wooded vegetation associated with forestall uses, while flat and undulated surfaces were related to pasture lands.

The approach used here allows the determination of morphometric units to guide sampling strategies. However, previous knowledge about the terrain is needed to define relief interpretation limits.

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Streszczenie

Formy terenu tradycyjnie były analizowane przez kartowanie analogowe, jednakże rozwój komputerów umożliwił wprowadzenie informacji cyfrowej, opartej na danych odniesionych przestrzennie. Informacja ta może być wykorzystana do tworzenia precyzyjnych modeli zmiennych morfometrycznych, które wyrażają ciągłe przestrzennie zjawisko bądź konkretne cechy terenu. Na podstawie tych właśnie modeli można wykonywać złożone analizy krajobrazu oparte na parametrach ilościowych, takich jak: wysokość nad poziomem morza, nachylenie, krzywizna, czy chropowatość. Głównym celem niniejszej pracy jest sklasyfikowanie terenu w jednorodne geomorfometryczne jednostki za pomocą numerycznych modeli terenu (NMT) i ich pochodnych oraz odniesienie tych jednostek do *obszarów pokrytych roślinnością. Badanie przeprowadzano na terenie gospodarstwa rolnego, typowego dla pastwisk w południowo zachodniej Hiszpanii. Numeryczne modele terenu utworzono na podstawie warstwic i wysokości z wielkością piksela równą 5 metrów, a formy terenu na obszarze badania skartowano przy użyciu algorytmów klasyfikacji nienadzorowanej (grupowanie ISOdata i K-średnich). Metody te pozwalają na grupowanie wartości w dowolnie określonej liczbie klas, czego skutkiem jest klasyfikacja jednostek morfometrycznych. Wynikowe jednostki morfometryczne okazały się użytecznym narzędziem w procesie wyjaśniania rozmieszczenia roślinności. Dominującą formą rzeźby terenu na badanym obszarze są penepleny – faliste powierzchnie erozyjne z głęboko wrytymi rzekami, tworzącymi strome zbocza dolin. Na stromych zboczach dolin, ze względu na orientację terenu, pokrywa roślinna jest gęsta i zróżnicowana gatunkowo. Wyraźne zróżnicowanie w pokryciu roślinnym pojawia się również w wypukłościach i wklęsłościach terenów równinnych, a spowodowane jest to różną wilgotnością gleby wynikającą z morfologii terenu.*

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http://www.unex.es/unex/grupos/grupos/giga

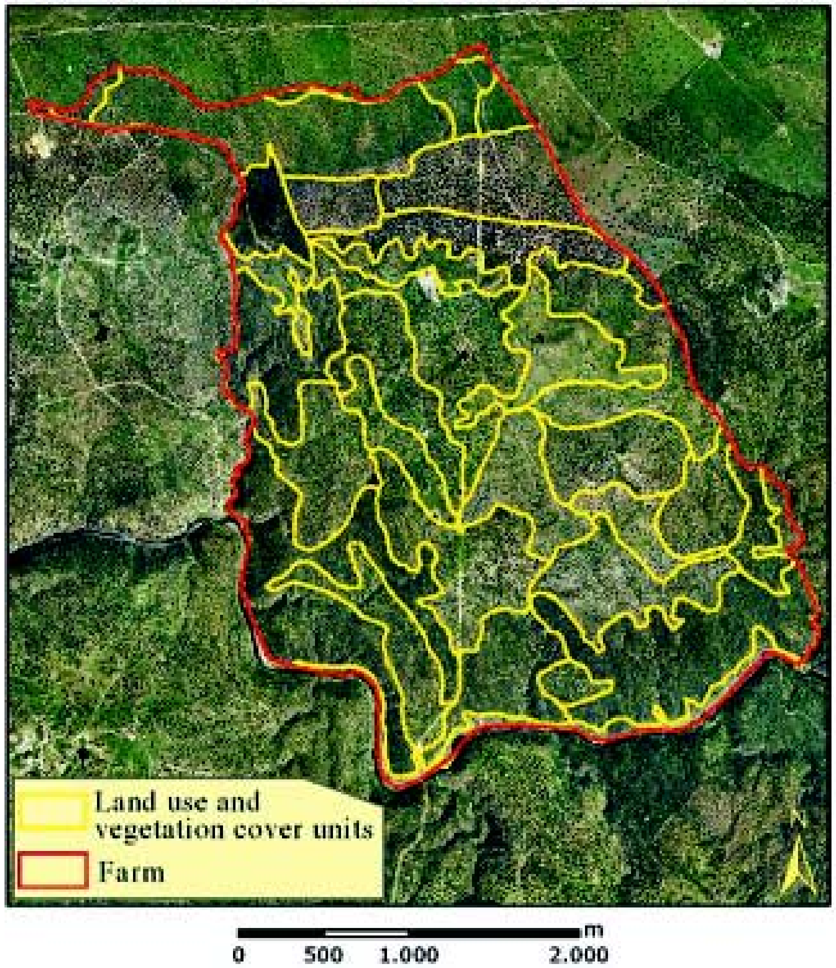

Figure 1. Delimitation of land use and vegetation cover units

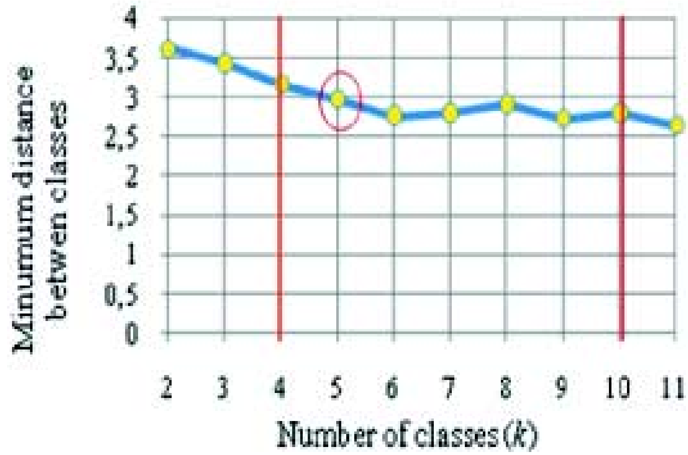

Figure 2. Values of the intercluster minimum distance between the relief interpretation limits

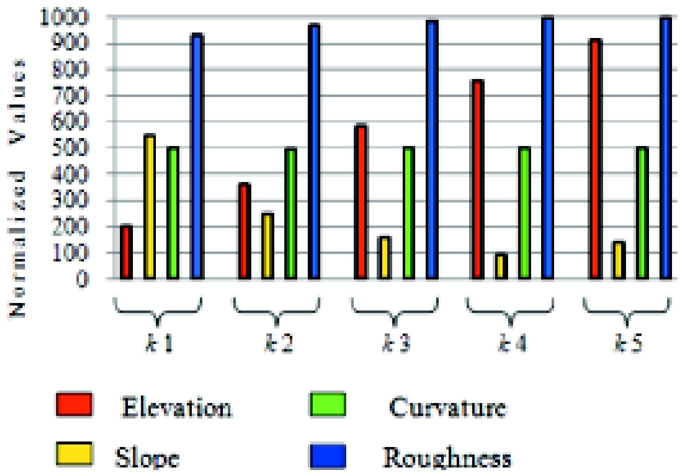

Figure 3. Values for the components elevation, slope, curvature and roughness of each resulting cluster

Figure 4. A typical rangeland area in Extremadura region, SW Spain

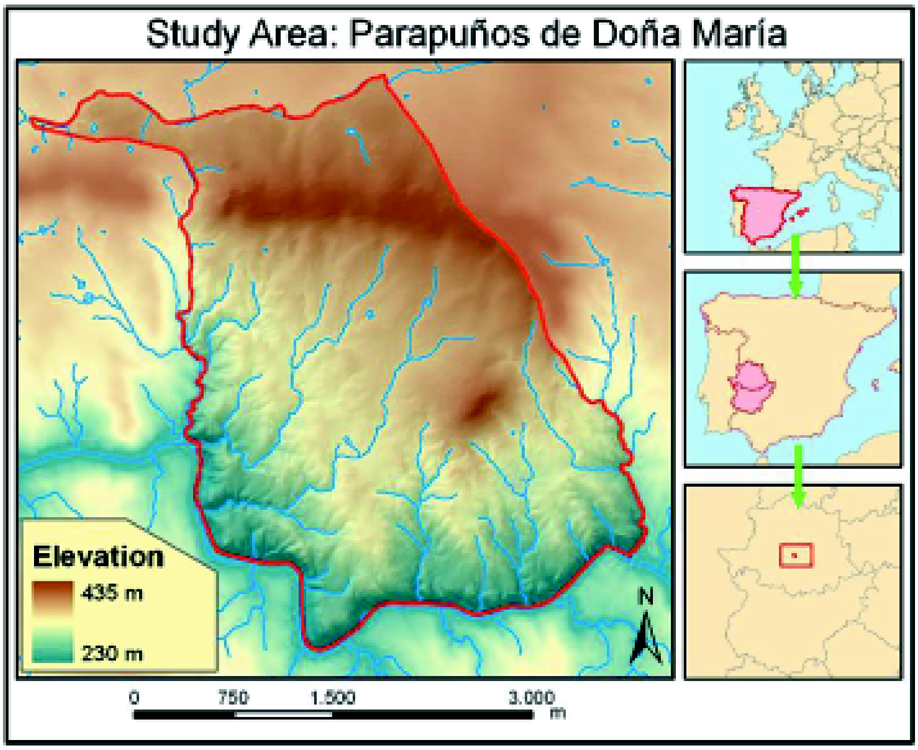

Figure 5. Location of the study area