Carpathian Journal of Earth and Environmental Sciences, May 2012, Vol. 7, No. 2, p. 249 - 254

OBJECT-ORIENTED IMAGE ANALYSIS FOR DETECTION OF THE BARREN KARST AREAS. A CASE STUDY: THE CENTRAL SECTOR OF THE MEHEDINȚI MOUNTAINS (SOUTHERN CARPATHIANS)

Marcel TÖRÖK – OANCE & Florina ARDELEAN
West University of Timişoara, Department of Geography, Vasile Pârvan Blvd, No. 4, 300223-Timişoara, ROMANIA
torok@cbg.uvt.ro, ardelean_f@yahoo.com

Abstract: The barren karst areas are not typically for the karst regions of the morphoclimatic system of temperate zone. Nevertheless the importance of assessing the extension and degree of compactness of bare karst is grounded by the fact that these areas represent both particular geomorphological landscape, with specific implications in the karstic processes, and diverse and fragile ecosystems. The touristic potential of barren karst is important too. The paper presents a method for automatic detection of the barren karst using Object – Based Image Analysis (OBIA) in the central sector of the Mehedinți Mountains, an area where bare limestone have a large extent. The object-based classification offers the advantage that it takes into account both spectral and qualitative data. Thus we have used in analysis a complex set of data: multispectral SPOT images, two derived indices – Normalized Difference Rock Index (NDRI) and Normalized Difference Vegetation Index (NDVI) - geological data and the digital map of built-up areas and roads. Results were compared with very high resolutions SPOTView colour images and GPS field data. The high accuracy of the classification, over 94%, demonstrated that the method is precise enough to be used in geomorphological mapping of the karst.

Key words: barren karst, karst mapping, OBIA, satellite imagery, classification, Mehedinți Mountains, Southern Carpathians.

1. INTRODUCTION

The karst regions of Romania are part of the morphoclimatic system of temperate zone and are mostly made up of ”green karst”, vegetated soil-covered karst – grassy, forested or even cultivated (Bleahu, 1982, Gunn, 2004). Barren karst areas are of limited extent, and are most common to limestone cliffs. Despite the numerous karst related studies on a national scale (Bleahu & Rusu, 1965; Trufaş & Sencu, 1967; Goran, 1983), and although a map of the Romanian karst regions has been drawn up (Sencu, 1968, 1973), no study has been conducted to assess the extent of the barren karst areas in Romania. This is understandable, as the manual delineation of karst areas, even on aerial photographs, is a very difficult and time consuming process.

Even though the use of satellite images, when analyzing karstic areas, is a method often employed lately for determining certain geomorphological features or for mapping the land coverage (Hung et al., 2005; Kokalj & Oštir, 2007; Siart et al., 2009), detection of bare karst areas through remote sensing is rather difficult and does not provide accurate results (Huang & Cai, 2009).

Recent studies (Wu et al., 2011) have revealed the importance of knowing the size and degree of compactness of bare karst surfaces, as well as their evolution in time, acting as an indicator of desertification and land degradation in the context of climate change.

Although currently one cannot speak of such a scenario unfolding in Romania, awareness of the matter is important from numerous points of view. Firstly, because the areas covered with barren karst make up a particular geomorphological landscape, of great touristic potential, particularly if these areas occupy large and compact enough surfaces. Secondly – these areas play a different role in the karstification process: water infiltrates faster under ground, and due to the lack of the soil and vegetation, it is less aggressive. Last but not least, the fragility of the ecosystems specific to these areas demand that these be known and monitored (Baiping et al., 2006).

The present paper offers a method of delineation and automatic classification of barren karst areas. The obtained results have a high degree of accuracy, of over 94%. The method features the classification of high resolution multispectral satellite images through Object-Based Image Analysis (OBIA) and by the integration of qualitative data (geological layer and built-up areas and roads layer).

2. STUDY AREA

The study area is the central part of the Mehedinți Mountains (Fig. 1), which are located in the south-western part of the Retezat – Godeanu range within the Southern Carpathians. The area of research lies between the Arşasca and Brebina Valleys to the North and the Țăsna Valley to the South.

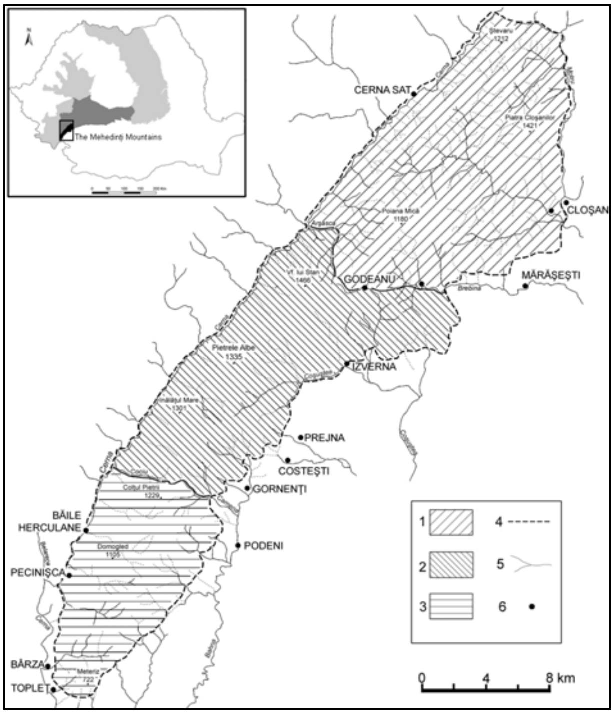

Figure 1. The study area location: 1, the Northern Sector; 2, the Central Sector; 3, the Southern Sector; 4, the limit of the Mehedinți Mountains; 5, hydrographical network; 6, settlements.

The study area is characterized by a high degree of petrographic and structural complexity. The limestone which crops out at the surface on over 63km² is of Barremian Aptian age in Urgonian facies, its estimated depth being 400-600 m (Diaconu, 1984). The limestone texture enables the karstification process, as the base limestone is massive and the surface limestone is layered, the width of these layers ranging from 0.6 to 2.5 m.

The main morphological feature is a rise karst plateau (Török - Oance, 2001), bounded by scarps, most of which are of tectonic origin. The altitude ranges between 200 m and 1466 m (the height of the Stan Peak). The karst plateau is located at approximately 1100-1200 m and is most wide in this area, its width reaching almost 7 km, thus representing the largest, most compact karst area of these mountains. Parallel to the Cerna Valley and to the limestone scarp overlooking it, a series of large negative karstic features have developed along a fault line: open karstic depressions, uvalas and dolinas, which are called „Poienile Închise" („Closed Glades").

This area was chosen for the present study due to the large extent of bare limestone in the plateau, where it forms karrenfelds, as well as in the scarp areas, thus creating a unique geomorphologic landscape.

3. DATA

In this study we used 10 m spatial resolution SPOT multispectral images, recorded on 27 August 2007. We used in analysis all four spectral bans of the SPOT scene: B1 - green (0.50 - 0.59 µm), B2 - red (0.61 - 0.68 µm), NIR - near-infrared: (0.78 - 0.89 µm) and MIR - mid-infrared (1.58 - 1.75 µm).

For the delineation of limestone rocks from other types of rocks we used the digital geological map achieved by digitizing the analogue geological map for the study area at 1:50000 scale.

For the accuracy assessment of the classification we used 2.5 meters resolutions SPOTView colour images and GPS field data.

4. METHODS

Supervised classification of multispectral satellite images for the detection of land cover types is a frequently employed method at present. However, the detection of barren karst using this method raises a series of issues. Firstly, the spectral response of the bare limestone is very close to the response of other rocks lacking vegetation. Also, there is high similarity in terms of spectral response between built-up areas and areas with road infrastructure and bare limestone. Furthermore, the eroded terrains that are void of vegetation in many cases have a spectral signature very similar to bare limestone. The analysis of the spectral signatures (software IDRISI Andes), based on information extracted from 45 training sites conveys this aspect very clearly (Fig. 2). There are two groups of spectral signatures. One group is formed by two easy to differentiate spectral signatures which correspond to the vegetated areas: grasslands and deciduous forests. The second one is formed by the spectral signatures of the areas without vegetation: barren karst, built-up areas and barren rocks. We can notice that these three spectral signatures almost overlapped.

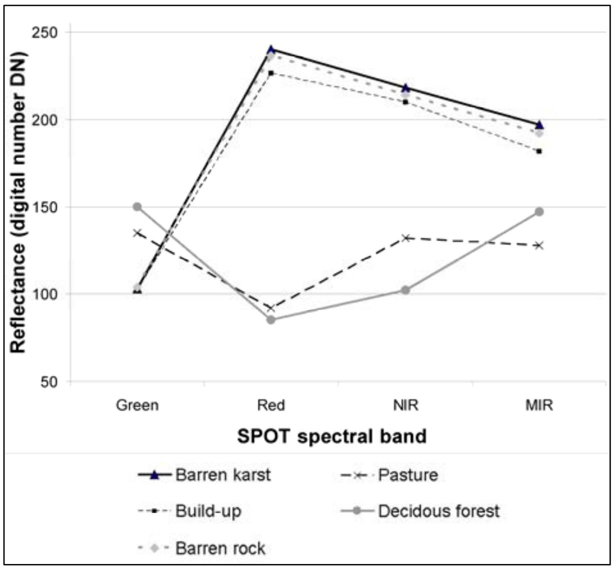

Figure 2. Spectral signatures curves for five land cover classes in the study area.

Another problem is the topographic effect which represents the difference in radiance values from slopes facing to the sun compared to shadowed slopes. Even there are some methods for the mitigation of the topographic effect (Eastman, 2009), in extreme terrain conditions, in the shadowed areas, the meaningful spectral information could be almost lost (Fig. 3).

Even usually the barren karst has a great radiance value it could appear misclassification of them because of the topographic effect.

In order to allow a more accurate detection of objects on the terrestrial surface, a series of normalized indexes have been developed during the last years. The first such normalized indexes were developed on Landsat satellite images and the basic principle for calculating these indexes is represented by calculating the difference between the spectral band with the highest reflectance and the band with the lowest reflectance for the object that is to be detected, normalized to the sum of these two bands. Band ratioing is also the simplest technique for the mitigation of the topographic effect.

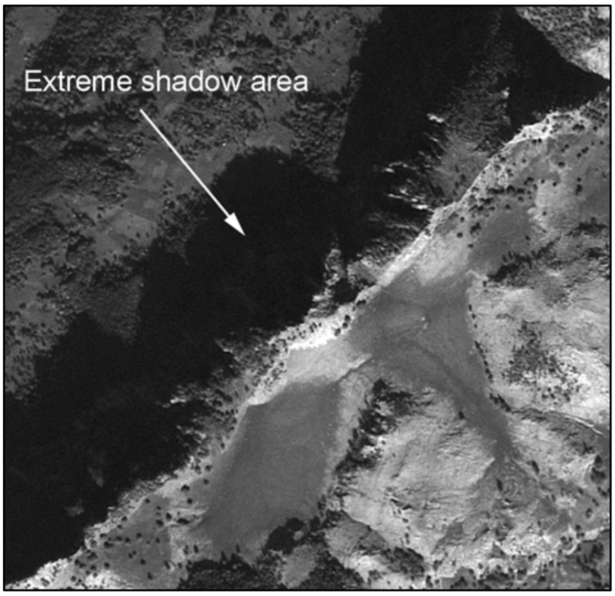

Figure 3. Topographic effect induced by the limestone scarp (detail).

One of the most commonly index used to separate green vegetation from bare soil is the Normalized Difference Vegetation Index (NDVI). It is calculated by difference between NIR and RED bands normalized by the some of those bands. Normalization is necessary in order to avoid possible errors generated by the division by “0” (Equation 1).

NDVI = (NIR – Red) / (NIR + Red) (1)

Barren karst areas could not be detected only by using NDVI but this index was derived for the study area as a complementary factor in the classification algorithm.

An index special derived for the mapping of the barren karst is the Normalized Difference Rock Index (Huang & Cai, 2009) developed and tested in the karst mountain region of Southwest China. The index was derived using Landsat spectral bands (Equation 2).

NDRI = (MIR – Red) / (MIR + Red) (2)

The classification based on the NDRI enables the mapping of the barren karst at a higher degree of accuracy (82%) in comparison with supervised classification (Huang & Cai, 2009).

The tests we made in our study area using the supervised classification based on the NDRI demonstrated that even the results are better; there are still many incorrect classifications due to problems mentioned above (Fig. 4).

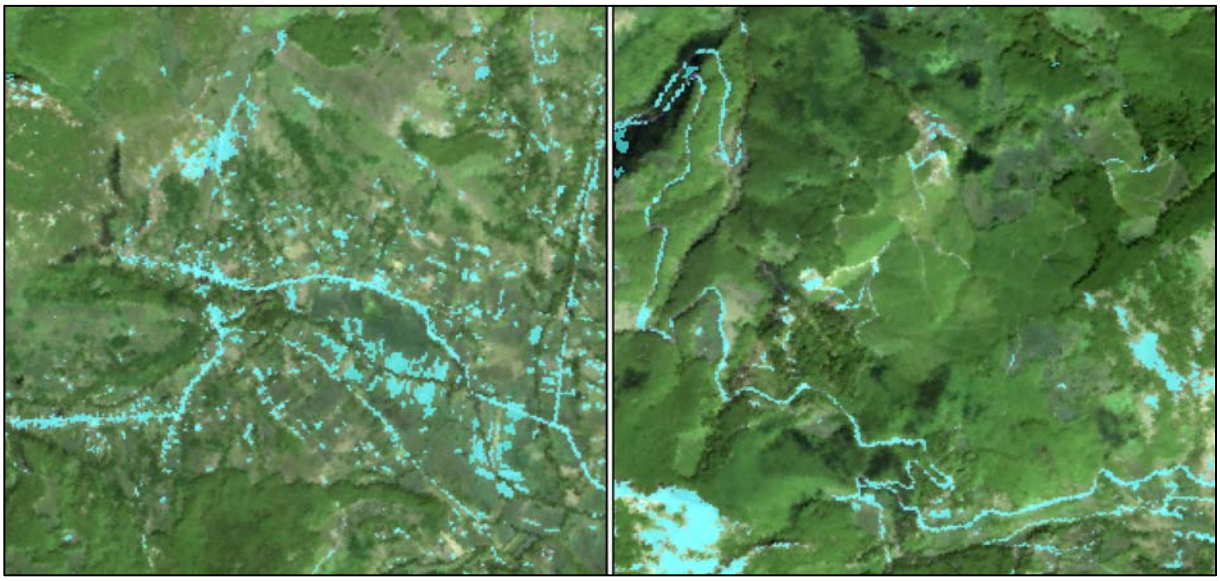

Figure 4. Settlements (left) and roads (right) incorrectly classified as barren karst. Maximum likelihood classification based on the NDVI and NDRI (IDRISI Andes software).

The high degree accuracy of the classification obtained by Huang & Cai (2009) could be explained by the fact that built-up areas are very limited in that area and they didn't consider it as a distinct class and secondly, because that area is monotonous in terms of geology – there are only limestone.

For a better delineation of the barren karst areas we used an object-based classification method which leads to more accurate results than traditional methods of classification (Platt & Rapoza, 2008). There are few studies that has been used OBIA in karst either for detection of some land cover types or for the automatic detection of specific landforms (Török – Oance et al., 2009) but not for the detection of the barren karst.

This method offer the advantage that it takes into account both spectral and contextual information, like shape and topological properties of the objects. Therefore we added as layers in analysis the digital geological map and the digital map of the roads and built-up areas.

The first step of the process is the segmentation of the image. It represents the transformation of the raster image from the pixel level to the *object* or *spatial primitives* level. Both the segmentation and the classification were realized in eCognition Definiens v.8.7 software. For the multiresolution segmentation process first must be set some dimensionless parameters: the scale factor, which determines the size of the image object, and the parameters of shape and compactness which determine the extent of spectral heterogeneity.
In order to choose the best segmentation parameters values we made a series of tests with different values. The evaluation of the test's results was made by visual analysis, overlaying the objects over the satellite image. Finally, we have chosen following values: 3 for the scale factor, 0.1 for shape and 0.8 for compactness (Fig. 5).

Because the barren karst areas are best observed in the red band, in contrast with the vegetation which appears in dark tones because of the great absorption of the red visible radiation in the photosynthesis process, this band was set as segmentation layer.

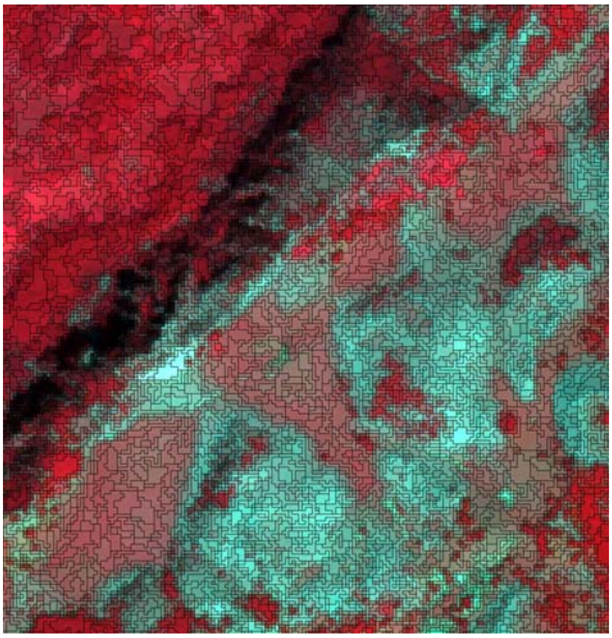

Figure 5. The result of the segmentation process draped on the false-color image (detail).

In the classification algorithm we used as input data all the SPOT spectral bands, NDRI, NDVI, geological layer and built-up/roads layer.

Because of the topographic effect the classification process was made in two steps: the classification for the extreme shadowed areas and, second, the classification for the rest of the study area.

In the first stage were used for classification following criteria: a brightness value greater than 140, (brightness is a specific value computed in eCognition software based on the reflectance values of the selected spectral bands), NDRI value lower than 0.05 and NDVI value below 0.01. Normally nude karst areas should have negative values of NDVI but there are areas where limestone is partially covered by discontinuous herbaceous vegetation or shrubs. In these areas the NDVI values are slightly positive. The best results in classification were obtained by using a linear monotonically decreasing fuzzy membership function for the NDVI with two characteristic points: 0 and 0.01 (Fig. 6).

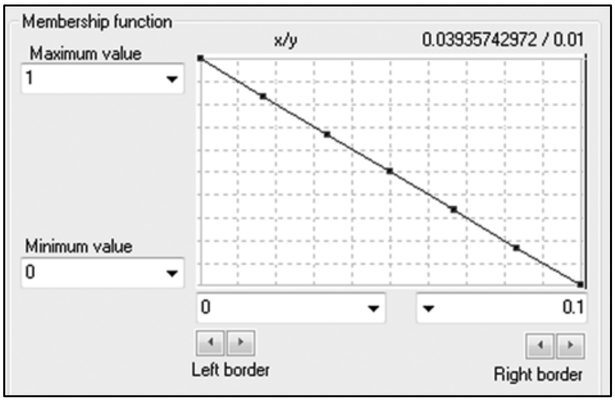

Figure 6. Linear monotonically decreasing fuzzy membership function used for the delineation of barren karst based on NDVI.

We also used as constrains (boolean criteria) the rock types form the geological layer (we consider only limestones) and the digital map of the built-up areas and roads. So we excluded the object which are not located in the limestone area and the objects that have intersected built-up areas or roads.

The classification of the barren karst from the extreme shadowed areas was made considering the same criteria as in the first step, including constrains, but with the adjustments of the values: brightness lower than 100, NDRI value lower than 0.02 and NDVI value below 0.

5. RESULTS AND DISCUSSIONS

The object-oriented classification method was used for the automatically mapping of barren karst based on complex data set: 10 m resolution SPOT multispectral satellite images, geology layer and the digital map of the built-up areas and roads. (Fig. 7). The detected barren karst has an area of 8.27 km^2 which represent about 13% of total karst.

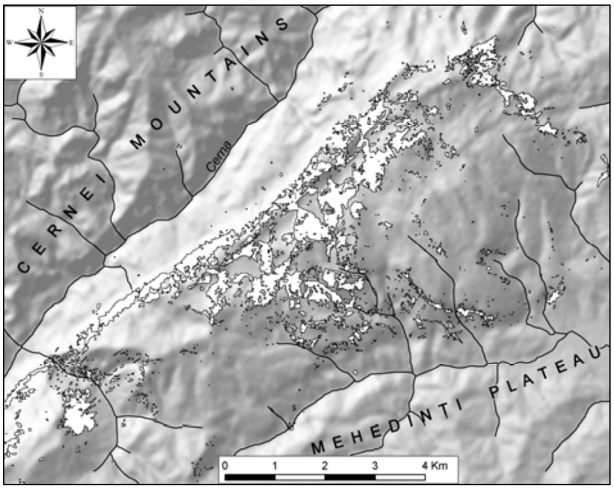

Figure 7. The barren karst (white polygons) detected by object-based image classification.

Accuracy assessment was made in two ways: statistically, by using control points and manually, by visual analysis.

First, we used 90 control points randomly generated by the software for the estimation of the classification accuracy. The accuracy assessment was made by using 2.5 meters resolution colour SPOTView images and, for the shadowed areas, GPS data. The final accuracy is very high and exceeds 94 %.

The other method used for validation was the visual analysis of the coincidence between the barren karst areas automatically detected and the barren karst areas that could be visual detected on the SPOTView images (Figure 8). This method allowed qualitative errors estimation.

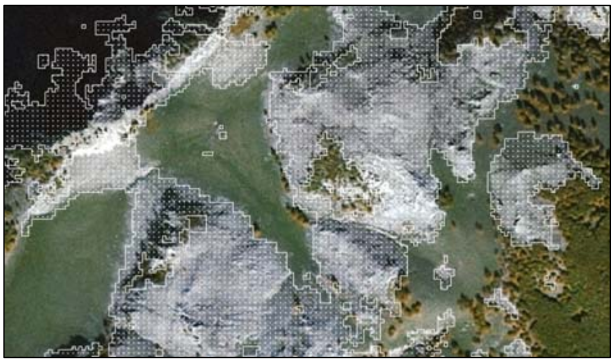
Figure 8. Visual analysis of the classification results (white border polygons) draped on the 2.5 meters resolution colour SPOTView images (detail).

So we could establish that most errors occur in the limestone scarp due two reasons: because of the topographic effect that couldn't totally mitigated and because there is a sub-pixel mixture:

barren limestone, shrub vegetation and small pine woods.

A similar situation occurs in the case of the karst plateau grasslands where the presence of the half-buried karren lead to errors.

The disadvantage of the proposed method is that it requires in addition to remote-sensed data the existence, for the analyzed area, of two digital maps: geology and built-up/roads map. Without them, the result will not be as precise.

6. CONCLUSIONS

The presented method offer a robust classification rule-set for the automatic detection of the barren karst in an OBIA environment. The accuracy assessments demonstrated that the object-based classification leads to a more accurate result than traditional methods of classification because it takes into account both spectral and contextual information. The method could be applied also for the monitoring of the evolution of the barren karst areas through images from different periods of time.

For the future studies it could be useful to integrate more accurate satellite images and to improve the classification algorithm for the extreme shadowed areas. Also further studies could be driven to a regional scale.

ACKNOWLEDGEMENTS

This work was supported by CNCS–UEFISCDI, project number PNII–IDEI 1075/2009.

REFERENCES

Baiping, Z., Fei, X., Hongzhi, W., Shenguo, M., Shouqian, Z. & Lifei, Y., 2006. *Combating the fragile karst environment in Guizhou, China.* Ambio*,* 35, 2, 94-97.

Bleahu, M. & Rusu, T., 1965. *Karst in Romania (Carstul din România).* Lucr. Inst. Speol. „Emil Racoviță", IV, 59-73, in Romanian.

Bleahu, M., 1982. *The karst relief (Relieful carstic)*. Ed. Albatros Bucureşti, pp 296, in Romanian.

Diaconu, G., 1984. *Considerations regarding the genesis of clays on limestones of the "Clo□ani Zone" Mehedinți Mountains (Considérations concernant la genèse des argiles sur les calcaires de la "Zone Cloşani" – Monts Mehedinți)*, TAK 1, 13-22.

Eastman, R., 2009. *Idrisi Andes. Guide to GIS and Image Processing.* Clark University, pp 342.

Gunn, J., *Encyclopedia of caves and Karst science.* Fitzroy Dearborn, New York, pp 902.

Goran, C., 1983. *Karst types in Romania (iLes types de relief karstique de Roumanie)*. Trav. Inst. Spéol. „Emile Racovitza", XXII, 91- 102.

Huang, Q. & Cai, Y., 2009. *Mapping karst rock in Southwest China.* Mountain Research and Development*,* 29, 1, 14-20.

Hung L.Q., Batelaan O. & De Smedt F., 2005. *Lineament extraction and analysis, comparison of LANDSAT ETM and ASTER imagery. Case study: Suoimuoi tropical karst catchment, Vietnam.* Proc. SPIE 5983, 59830T.

Kokalj, Z. & Ostir, K., 2007. *Land cover mapping using Landsat satellite image classification in the Classical Karst - Kras region*, ACTA CARSOLOGICA, 36, 3, 433-440.

Platt, R.V. & Rapoza, L., 2008. *An evaluation of an object-oriented paradigm for land use/land cover classification.* The Professional Geographer, 60, 87–100.

Sencu, V., 1968. *La carte du karst et du clasto-karst de Roumanie.* RRGGG, Geogr., 12, 1-2, 35-41.

Sencu, V., 1973. *Karst (Carstul),* Atlasul geografic național, Fasc. III-4, Ed. Academiei Bucureşti, in Romanian.

Siart, C., Bubenzer, O. & Eitel, B., (2009). *Combining digital elevation data (SRTM/ASTER), high resolution satellite imagery (Quickbird) and GIS for geomorphological mapping: A multi-component case study on Mediterranean karst in Central Crete*, Geomorphology, 112, 1-2, 106-121.

Török – Oance M., 2001. *The types of karst relief in the Mehedinti Mountains,* Lucrările celei de-a IV-a Ediții a Conferinței Regionale de Geografie "Cercetări geografice în spațiul Carpato-Danubian", Ed. Brumar Timişoara, 219-223 (in Romanian).

Török - Oance M., **Ardelean F. & Onaca A.,** 2009. *The Semiautomated Identification of the Planation Surfaces on the Basis of the Digital Terrain Model. Case Study: The Mehedinti Mountains (Southern Carpathians).* Geographical Phorum, 8, 5-13.

Trufaş, V. & Sencu, V., 1967. *Lithological karst types in Romania* (*Tipuri litologice de carst din România).* Analele Univ. Bucureşti, seria geol.-geogr., XVI, 1, 115-122 (in Romanian).

Wu, XQ., Liu, HM., Huang, XL., & Zhou, T., 2011. *Human driving forces: Analysis of rocky desertification in karst region in Guanling County, Guizhou Province, Chinese.* Geographical Science, 21, 5, 600-608.

Received at: 20. 12. 2011
Revised at: 20. 02. 2012
Accepted for punlication at: 21. 02. 2012
Published online at: 25. 02. 2012