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APPLICATION OF GIS IN THE DETERMINATION OF VERTICAL RELIEF FRAGMENTATION: A CASE STUDY ON DRENICA RIVER BASIN (KOSOVO)

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ABSTRACT:
Advances in Remote Sensing (Digital Elevation Models) products and GIS techniques have made the calculation and analysis of morphometric indices much more accurate, effective, and less time-consuming. The energy of relief is a morphometric parameter that indicates the vertical variety of relief and represents the potential energy of a given terrain. Calculating morphometric parameters by manual methods is inconvenient because it takes a long time, is subject to mistakes that can be made by humans when extracting these parameters and, consequently leads to wrong conclusions. There is currently no fully automated method to calculate this parameter. The purpose of this paper is to define the procedures for extracting this parameter within a GIS environment using data from high resolution (HR) ALOS-PALSAR (Advanced Land Observing Satellite-Phased Array-Type L-band Synthetic Aperture Radar) Radiometrically Terrain Corrected (RTC) DEM with a spatial resolution of 12.5 m with the help of ArcGIS software. To calculate this parameter, a grid with 1x1 km cells with interpolation points in each cell was constructed. IDW was chosen as the most suitable method for the interpolation of points. Based on the obtained results, the maximum value of relief's energy for the Drenica River basin reaches 328 m/km^2. 57.19% of the surface belongs to the low and very low values of relief's energy, 42.72% belongs to the average values while only 0.09% belongs to the high values. The high participation of very small and small values of this parameter for the Drenica River basin indicates that the total area is increasing towards the creation of flat surfaces. The importance of deriving this parameter is reflected in the fact that the data obtained are quantitative (have numerical value), can be verified and applicable in practice for the purposes of the construction sector, tourism, spatial planning, etc.

Key-words: *GIS, energy of relief, ALOS-PALSAR DEM, geoprocessing, Drenica River basin.*

1. INTRODUCTION

GIS techniques are now widely used to calculate and analyze various morphometric parameters of river basins, providing a powerful tool for manipulating, and analyzing spatial information. River basins are presented as ideal units of the river landscape and are considered to be suitable for managing natural resources and subsequent planning, as well as for implementing various development plans. In recent decades, Geographic Information System (GIS) and Digital Elevation Models (DEMs) have become very efficient tools, both in the analysis of river basins and measures for their conservation.

The role of GIS in estimating various terrain parameters and manipulating spatial data related to river basins is very important. The increasing availability of DEM has led to considerable application in environmental, geomorphological, and hydrological investigations (Moore et al., 1991; Hancock et al., 2006; Liu, 2008). DEM is a digital representation of terrain in three dimensions and through existing GIS tools the terrain can be analyzed and accurate information can be obtained directly.

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Morphometric parameters represent a significant segment of the natural geographical base of each region. The geomorphological characteristics of a given morphological process, shapes, and relief in general can be given through a variety of quantitative parameters. Defining the morphological characteristics of a given whole through units of measurement determines the size of the forms. The way of researching and assigning these parameters is defined as morphometry.

Relief energy expresses the depth of valleys from ridges or the intensity of erosive cuts formed by surface runoff activity on the one hand, and the intensity of neotectonic uplifts on the other, including epirogenetic and eustatic movements, tectonic, etc (Talani, 1997). It means the parameter of vertical fragmentation of relief and represents the potential energy of a particular terrain defined by the vertical difference between the highest and lowest point within the observed unit surface of terrain (1 km^2). Relief energy, being correlated with the horizontal fragmentation of the relief, the slope of the relief, the average height, etc., express the degree of evolution of the relief and creates a close connection with the intensity of the current morphodynamic processes (Talani, 1997).

In recent decades, undoubtedly, in applied geomorphology, extremely great importance has been given to the development of quantitative physiographic methods to describe the evolution and behavior of surface drainage networks (Dobos et al., 2010). Quantitative geomorphological analysis, simply put, involves the presentation of morphological processes, relief, and its forms by applying or using various quantitative (numerical) parameters. The application of such an analysis is of great importance because such data are dimensioned and, in addition, can be verified having numerous benefits in practice. The results have broadly usable value and are unavoidable in the process of erosion intensity determination, protection, and improvement of area and environment, etc.

Due to its effective functions, such as data management, calculation, and analysis, GIS provides strong support to quantitative research. In many areas of geosciences, GIS has been extensively developed and implemented, with a particular emphasis on resource assessment and the environment and their management. Starting from the earliest works that have been carried out on the application of GIS in geomorphology, their focus or main point was on the digital classification of landforms, especially on digital relief models and their advantages (Moore et al., 1991; Dikau et al., 1991; Wilson and Gallant, 2000). GIS merged with RS data offers the possibility of creating a database for each watershed. This database is very important because it helps to conduct spatial analysis, thus helping decision-makers to formulate appropriate measures for these areas (Thakkar and Dhiman, 2007; Magesh et al., 2010; Mukherjee et al., 2007, 2009).

In the last decades, there were developed GIS technologies that allow quick and effective modeling of many derivations from DEM. The benefit of quantitative analysis of morphometric parameters is extraordinary in the conservation and further development of soils and waters at the catchment level (Kanth and Hassan, 2012). In this context, the use of data obtained from Remote Sensing associated with GIS has proven to be an important and quite efficient and powerful tool for managing and analyzing river basins (Markose et al., 2014; Patel et al., 2012; Oliveira et al., 2010; Tamma Rao et al., 2012). The shared use of GIS, mathematical models, and geomorphological theories radically improves on previous methods of quantitative geomorphic analysis and mapping.

In the present study, an attempt has been made to calculate the relief energy of the Drenica River basin from HR ALOS-PALSAR RTC DEM using GIS tools. The results of the calculation of this parameter will be presented in tabular and on thematic geomorphological maps.

2. STUDY AREA

The Drenica River basin is located in the central part of the Republic of Kosovo (**Fig. 1**). The catchment area is 438.47 km^2. The main river that flows through the basin is Drenica, with an average annual flow of 2.0 m^3/sec. The bed of this stream in the vast majority until its discharge in the river Sitnica lies in the basin of the same name, which has deepened and expanded in the thickness of Neogene and Quaternary deposits. The lithological composition of this basin is dominated by flysch rocks, followed by the Paleozoic schists and the Paleolithic to Quaternary igneous rocks, being distinguished by different degrees of hardness and permeability.

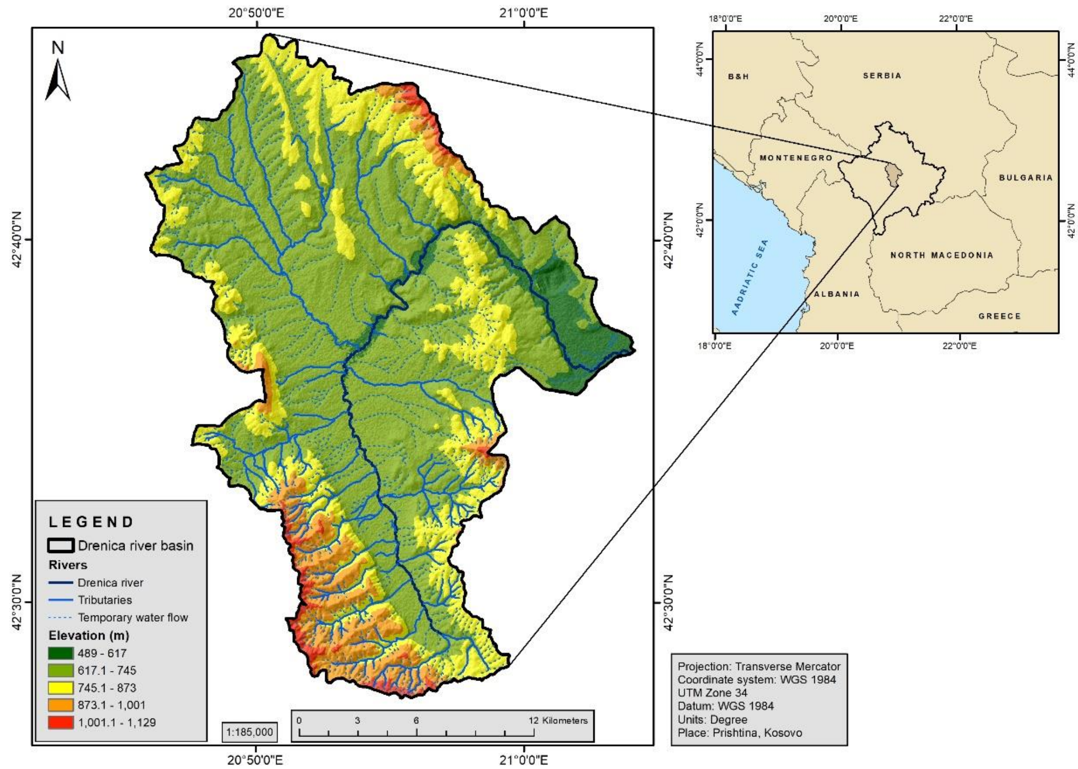

Fig. 1. Geographic position of Drenica River basin.

In the hypsometric aspect, the basin extends from an altitude of 489 m as the lowest point of the Drenica plain, while in the peripheral parts of the monocline ridges, the altitude exceeds 1,129 m, showing an average hypsometric amplitude.

From **Tab. 1** it can be seen that the hypsometric floor with a height of 489 - 745 m has high participation (66.6%). Such a high percentage indicates high extension/insertion of the hypsometric field floor within the Drenica plain. At an altitude of over 745.1 meters is located 33.4% of the basin, which make up the edges of the basin, including the lateral slopes bounded by detachment cliffs and the monocline ridges of the peripheral boundary mountains. The Drenica River basin belongs to the Sitnica river system, whose waters flow in the direction of the Black Sea. The main river that flows through the basin is Drenica. Drenica is the left tributary of Sitnica. From north of Petreshtica to Drenas, Drenica is wider and with a smaller slope with all the features of a plain river. Drenica from Drenas to Bardh i Madh, enters a narrow part, taking the appearance of a gorge. In this part of the river, the slope is greater. It originates in Bretenc on Mount Carraleva, flowing towards the central part of the Drenica valley, then takes a turn towards the east and through the transverse gorge of Dobroshec passes into the Kosovo valley and joins Sitnica.

Table 1.

Values of hypsometrical categories of studied area.

No	Elevation (m)	Area (km^2)	%
1	489 - 617	24.93	5.69
2	617.1 - 745	267.05	60.91
3	745.1 - 873	99.05	22.59
4	873.1 – 1001	38.64	8.81
5	1001.1 - 1129	8.8	2.00
Total		438.47	100%

3. RESEARCH METHODOLOGY

The Drenica River basin was delineated based on the water divide line concept. The next step was the digitalization of the entire river network. This was done based on the 1: 25000 scale topographic maps that we had available. Topographical maps were rectified/referenced geographically and mosaiced and the entire study area was delineated in a GIS environment with the help of ArcGIS 10.3 software.

Calculating morphometric parameters by manual methods is inconvenient because it takes a long time, is subject to mistakes that can be made by humans when extracting these parameters and, consequently leads to wrong conclusions. Although the energy of the relief parameter has great applicability and importance, so far, there is no fully automated way to extract it. Thus, this paper presents a methodology that broadly and clearly shows how this parameter is derived. We did the calculation of the relief's energy using the formula (Talani, 1997):

$$Cv = \frac{Hmax - Hmin}{S} (m/km^2) \quad (1)$$

where:

Cv	-energy of the relief;
$Hmax$	-maximum height in the square;
$Hmin$	-minimum height in the square;
S	-surface of a square (1 km^2);

The general workflow is shown in **Fig. 2**. The HR ALOS-PALSAR RTC DEM from Alaska Satellite Facility is used in this study to determine the energy of relief using GIS tools. ALOS-PALSAR was launched in 2006 by the Japan Aerospace and Exploration Agency (JAXA) and it was operational until May 12, 2011. ALOS was launched in a sun-synchronous orbit and circled around the Earth every 100 minutes, 14 times a day. ALOS-PALSAR returned to the original path (repetition cycle) every 46 days. The inter-orbit distance was about 59.7 km at the equator. ALOS-PALSAR has a spatial resolution of 12.5 m at 23.62 cm (1.27 GHz) wavelength with HV polarization and angle of incidence 38.7° (Khal et al., 2020).

Through GIS techniques, 1x1 km areas are formed together with the interpolation points (**Fig. 3**) in which the relief's energy is defined. The calculation of the energy of the relief was made possible using tools in ArcGIS. More precisely, after the preliminary steps taken, we calculate it using the tool "Zonal Statistics". After clicking on "Zonal Statistics", a dialog box opens in which we set the necessary parameters. A few different parameters appear in the dialog box, but we only need the "Range" parameter. This parameter calculates the difference between the maximum and minimum quota of each cell separately. After this calculation, the next step is the interpolation of points. Considering simplicity and accuracy, this study chooses the Inverse Distance Weighted (IDW) method to interpolate these points in order to extract relief's energy (Cv). The concept of the IDW method is based on the first law of geography (Tobler's first law) from 1970: It was defined as "everything is related to everything else, but near things are more related than distant things" (Johnston et al., 2001; Tobler, 1970).

4. RESULTS AND DISCUSSIONS

Relief energy or vertical fragmentation of relief is an expression of the difference in terms of height between the lowest level (valley bed) and the highest level (peaks of a complex) and represents the potential energy of a given terrain, determined by the vertical difference between the highest and lowest point within the observed unit of terrain surface. The depth of vertical fragmentation of the relief expresses the degree of the relief and creates a close connection with the intensity of the current morphodynamic processes.

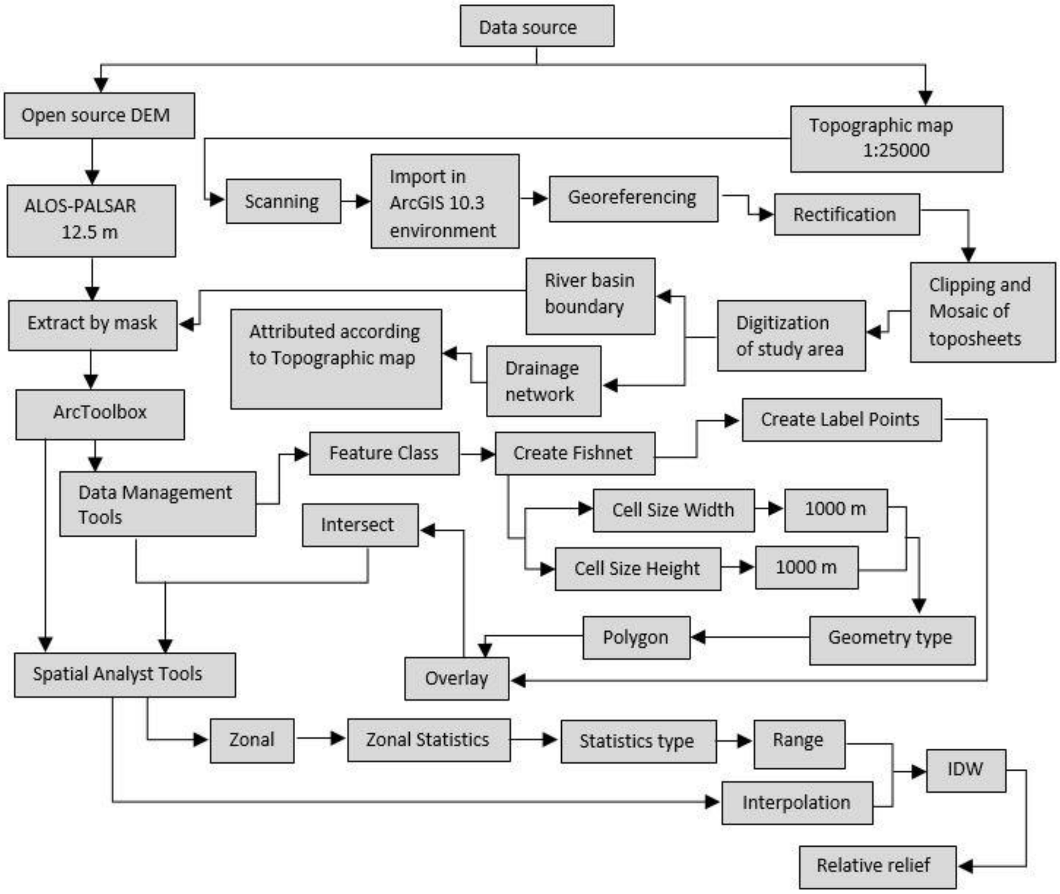

Fig. 2. Flow chart depicting methodology.

The energy of the relief is determined by parameters such as the geological composition, the susceptibility of the substrate to be eroded, the presence of disjunctive structures, and the slope of the terrain, which allows differentiating areas of greater or lesser amplitude (Román and Castillo, 2017).

Through the map of relief energy, the territories with high or low relief energy that are closely related to the detachment deformations are determined. Specifically, in those areas where the relief energy is high, tectonic, longitudinal, or transverse tectonic phenomena are very pronounced, while in areas with low relief energy the deformations are less pronounced (Talani, 1997).

Areas with high relief energy have a stronger or more pronounced erosion, while terrains with lower energy represent areas in which accumulation is expressed, which can affect the cause of flooding in the river basin. Vertical relief fragmentation has a direct effect on soil cover. This is because, in an area with high values of relief fragmentation, a restriction of soil spread and pedogenetic processes is caused.

The spatial distribution of relief energy of the Drenica River basin is shown in **Fig. 4**. Based on the use of the ArcGIS 10.3 program, for the analysis of the Drenica River basin, the classification of relief energy classes is done based on hypsometric levels. The maximum energy values of this parameter reach 328 m/km^2. From the analysis of the spatial distribution of relief energy in the Drenica River basin (**Fig. 4**) and from **Tab. 2**, we notice that in this basin small to moderate values of relief energy prevail. Terrains with very small and small energy, together, occupy about 57.19%. Areas with very low values of relief energy (< 50 m/km^2) are areas of expected deposition. These territories occupy about 17.7% of the total surface of the basin. Terrains with these values are found mainly along the lower sectors of the Drenica River and they mainly lie along the central part of the Drenica plain. Low energy terrains (50.1 – 150 m/km^2) occupy about 173.13 km^2 or expressed in percentage 39.49%. From the map showing the spatial distribution of relief energy, it is clear that the terrains with low relief energy lie, in the vast majority, around the terrains with very low relief energy. Such terrains are mainly the lower parts of the watershed in which there are no large relief differences. While terrains with high relief energy (300.1 – 328 m/km^2) occupy a very small area (0.09%) of the total area of the basin. In these territories, the erosion process is more intensified. Terrains with these values are found mainly in areas where the valley bed contacts the highest level of a complex. The small action (to a small extent) of exogenous (external) forces in the modeling of the dimensions created in the basin has made the territories with high energy to have a small spread in this basin.

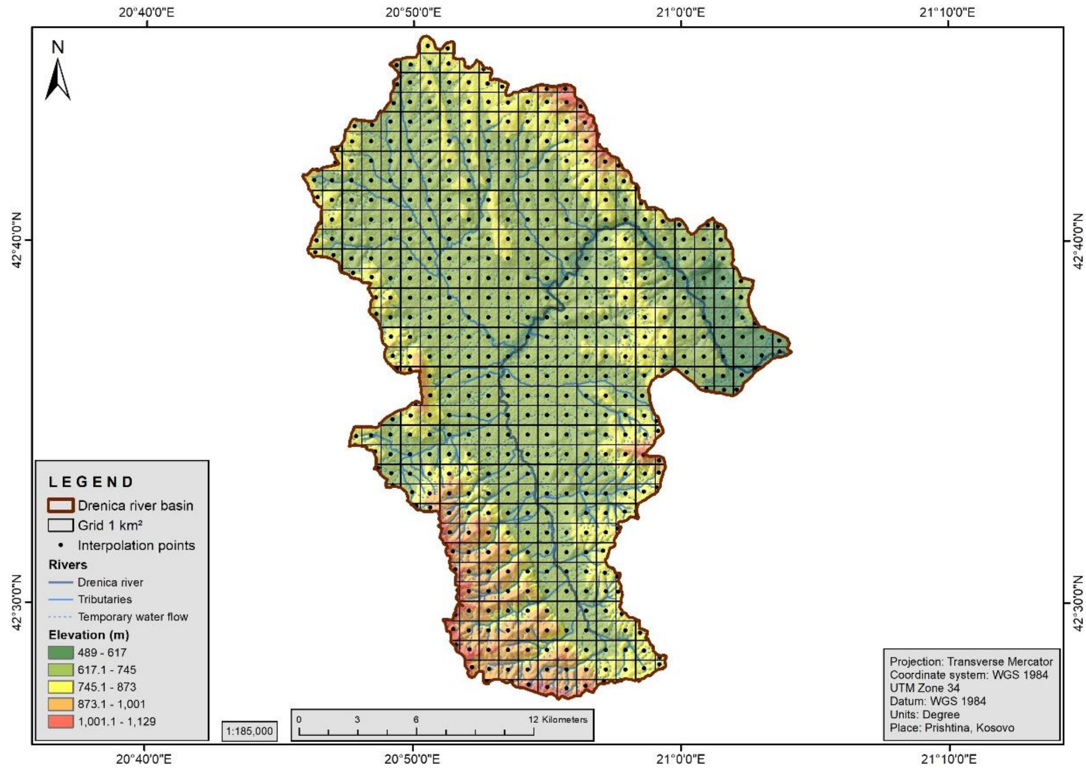

Fig. 3. Grid with interpolation points.

Table 2.

Values of relief energy in Drenica River basin.

No	Relief energy values	Area (km^2)	%
1	<50 m/km^2	77.64	17.7
2	50.1 – 100 m/km^2	173.13	39.49
3	100.1 – 150 m/km^2	98.6	22.49
4	150.1 – 300 m/km^2	88.70	20.23
5	300.1 – 328 m/km^2	0.4	0.09
Total		438.47	100

The terrains with average relief energy in this watershed occupy about 187.3 km^2. These terrains extend mainly along the peripheral parts of the basin and at the same time represent the hilly-mountainous areas, in which the relief differences begin to be highlighted.

5. CONCLUSIONS

In recent decades, DEMs have been the object of increasing use and attention to them. This has come as a result of the convenience they offer in calculating the various morphometric parameters. The objective of our study was to calculate the relief energy from the DEM through GIS techniques. Working in the ArcGIS program, a database system based on the grid system has been created, which provides an opportunity to overlay geospatial data, extract certain parameters, and analyze them.

The reason why it is important to calculate the relief energy of territory lies in the fact that it highlights the rate of relief evolution. So simply put it shows the degree of aging of the territory. Another importance of calculating relief energy through GIS is human socio-economic activity. All this activity is directly affected by the values of this morphometric parameter because the construction and placement of all the necessary infrastructure require that they be placed in full compliance with the width, depth, and slope of the valleys. GIS techniques have been proved to be an effective tool in computing relief energy for a given area

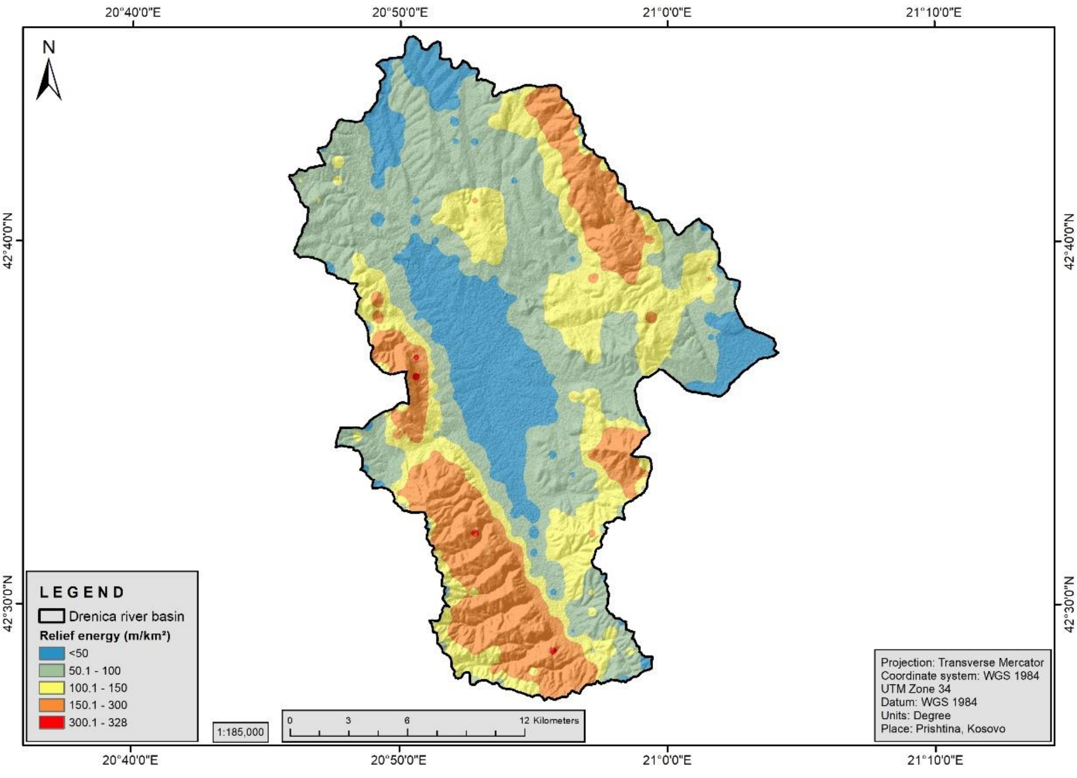

Fig. 4. Relief's energy map of the Drenica River basin.

The use of digital relief models through GIS has been shown to be a powerful tool for analyzing topographic features because it allows different methods to analyze them with operational advantages and high quality.

The relief energy values show the degree of fluvial erosion action in the modeling of the Drenica River basin. Through such an analysis geomorphological maps can be compiled that can have different scales. In our paper, a large-scale map has been compiled, which gives a detailed view of our study area based on $1km^2$ cells. Also, given that the database is based on the created grid system, the possibility to overlay data and perform correlative analysis is very wide thus enabling the widespread use and application of geospatial data.

From the analyzes made with GIS, it appears that in the basin of the river Drenica dominates the terrains with small and very small values of energies, which, together, constitute more than half of the whole territory (57.19%) followed by the territories with medium energy (42.72%) and, at the very end, come the territories with high energy which occupy only 0.4 km^2. The low values of relief energy occupy the central part of the Drenica plain and along with the lower sectors of the Drenica River. Such low values are of course related to the soft rocks of this area. While the average and high values extend along with the areas where strong rocks are highlighted.

The value of the results obtained from the determination of the values of the relief energy in the Drenica River basin is very useful and is inevitable, both in determining the intensity of erosive processes, as well as in the protection and improvement of the living environment. In addition, the results obtained can be applied to problem-solving when drafting spatial plans and planning other economic activities.

REFERENCES

Dikau, R., Brabb, E. E., & Mark, R. M. (1991). Landform classification of New Mexico by computer. In Open-File Report. US Geological Survey. https://doi.org/10.3133/ofr91634

Dobos, E., Daroussin, J., & Montanarella, L. (2010). A quantitative procedure for building physiographic units supporting a global SOTER database. *Hungarian Geographical Bulletin*, 59(2), 181-205. Available: https://ojs3.mtak.hu/index.php/hungeobull/article/view/3092 [Accessed March, 2020]

Hancock, G. R., Martinez, C., Evans, K. G., & Moliere, D. R. (2006). A comparison of SRTM and high-resolution digital elevation models and their use in catchment geomorphology and hydrology: Australian examples. *Earth Surface Processes and Landforms*, 31(11), 1394‐1412. https://doi.org/10.1002/esp.1335

Johnston, K., Hoef, J. M. V., Krivoruchko, K., Lucas, N. (2001). Using ArcGIS geostatistical analyst. New York: Environmental systems research institute Inc. Available: https://dusk.geo.orst.edu/gis/geostat_analyst.pdf [Accessed April, 2020]

Kanth, T .A. and ul Hassan, Z. (2012). Morphometric Analysis and Prioritization of Watersheds for Soil and Water Resource Management in Wular Catchment Using Geo-Spatial Tools. *International Journal of Geology, Earth and Environmental Sciences*, 2, 30-41. Available: https://www.cibtech.org/J-GEOLOGY-EARTH-ENVIRONMENT/PUBLICATIONS/2012/Vol%202%20No%201/17%20Zahoor.pdf [Accessed March, 2020]

Khal, M., Algouti, A., Algouti, A., Akdim, N., A. Stankevich, S., & Menenti, M. (2020). Evaluation of open Digital Elevation Models: estimation of topographic indices relevant to erosion risk in the Wadi M' Goun watershed, Morocco. *AIMS Geosciences*, 6(2), 231‐257. https://doi.org/10.3934/geosci.2020014

Liu, Y. (2008). An Evaluation on the Data Quality of SRTM DEM at the Alpine and Plateau Area, North-western of China, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 37, 1123‐1127. Available: https://www.isprs.org/proceedings/XXXVII/congress/1_pdf/191.pdf [Accessed 13 March, 2020]

Magesh, N. S., Chandrasekar, N., & Soundranayagam, J. P. (2010). Morphometric evaluation of Papanasam and Manimuthar watersheds, parts of Western Ghats, Tirunelveli district, Tamil Nadu, India: a GIS approach. *Environmental Earth Sciences*, 64(2), 373‐381. https://doi.org/10.1007/s12665-010-0860-4

Markose, J.V., Dinesh, A. C., & Jayappa, K. S. (2014). Quantitative analysis of morphometric parameters of Kali River basin, southern India, using bearing azimuth and drainage (bAd) calculator and GIS. *Environmental Earth Sciences*, 72(8), 2887‐2903. https://doi.org/10.1007/s12665-014-3193-x

Moore, I. D., Grayson, R. B., & Ladson, A. R. (1991). Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. *Hydrological Processes*, 5(1), 3‐30. https://doi.org/10.1002/hyp.3360050103

Mukherjee, S., Sashtri, S., Gupta, M., Pant, M. K., Singh, C., Singh, S. K., Srivastava, P. K., Sharma, K. K., (2007). Integrated water resource management using remote sensing and geophysical techniques: Aravali quartzite, Delhi, India, *Journal of Environmental Hydrology* 15 (4), 1-10. Available: http://www.hydroweb.com/protect/pubs/jeh/jeh2007/mukh.pdf [Accessed June, 2020]

Mukherjee, S., Shashtri, S., Singh, C. K., Srivastava, P. K., & Gupta, M. (2009). Effect of canal on land use/land cover using remote sensing and GIS. *Journal of the Indian Society of Remote Sensing*, 37(3), 527‑537. https://doi.org/10.1007/s12524-009-0042-6

Oliveira, P. T. S. de, Alves Sobrinho, T., Steffen, J. L., & Rodrigues, D. B. B. (2010). Caracterização morfométrica de bacias hidrográficas através de dados SRTM. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 14(8), 819‑825. https://doi.org/10.1590/s1415-43662010000800005

Patel, D. P., Gajjar, C. A., & Srivastava, P. K. (2012). Prioritization of Malesari mini-watersheds through morphometric analysis: a remote sensing and GIS perspective. *Environmental Earth Sciences*, 69(8), 2643‑2656. https://doi.org/10.1007/s12665-012-2086-0

Quesada Román, A., & Barrantes Castillo, G. (2017). Modelo morfométrico para determinar áreas susceptibles a procesos de ladera. *Investigaciones Geográficas*, 94. https://doi.org/10.14350/rig.57318

Talani, R., 1997: Laboratory manual for cartography and topography, CP, Shkodër. (In Albanian)

Tamma Rao, G., Gurunadha Rao, V. V. S., Dakate, R., Mallikharjuna Rao, S. T., & Raja Rao, B. M. (2012). Remote sensing and GIS based comparative morphometric study of two sub-watershed of different physiographic conditions, West Godavari District, A.P. *Journal of the Geological Society of India*, 79(4), 383‑390. https://doi.org/10.1007/s12594-012-0059-2

Thakkar, A. K., & Dhiman, S. D. (2007). Morphometric analysis and prioritization of miniwatersheds in Mohr watershed, Gujarat using remote sensing and GIS techniques. *Journal of the Indian Society of Remote Sensing*, 35(4), 313‑321. https://doi.org/10.1007/bf02990787

Tobler, W. R. (1970). A Computer Movie Simulating Urban Growth in the Detroit Region. *Economic Geography*, 46, 234. https://doi.org/10.2307/143141

Wilson, P. J., Gallant, C. J., 2000: Digital Terrain Anaysis (eds.): Terrain analysis: principles and applications, John Wiley & Sons, New Jersey, 520. Available: https://johnwilson.usc.edu/wp-content/uploads/2016/05/2000-Wilson-Gallant-Terrain-Anaylsis-Chapter-1.pdf [Accessed July, 2020]