DETERMINATION OF DISSECTION INDEX (DI) USING GIS & RS TECHNIQUES: A CASE STUDY ON DRENICA RIVER BASIN

Albert BERILA [A], **Florim ISUFI** [B*]

Received: October 17, 2020 | Revised: January 5, 2021 | Accepted: January 12, 2021
Paper No. 21-63/1-574

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. Dissection index (Di) is a morphometric parameter that indicates the degree of dissection or vertical erosion and the stage of landform development. 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 extreme values of Di for the Drenica River basin ranged from 0 – 0.46. 90.54% of the surface belongs to the low and very low values of Di, 9.11% belongs to the average values while only 0.35% belongs to the high values of Di. The high participation of small values of this index for the Drenica River basin indicates that river erosion is very low and the total area is increasing towards the creation of flat surfaces. The relief dissection index can be used for various purposes, such as contributing to a better understanding of the spatial distribution of morphogenetic processes, relief segmentation, and landscape units that serve as the basis for geomorphological mapping work, study the balance between pedogenesis and morphogenesis, and the assessment of environmental vulnerability.

Key words

Dissection index, morphometry, GIS, DEM, geoprocessing, Drenica River basin.

A University of Prishtina, George Bush, 31, 10000, Prishtina, Kosovo
https://orcid.org/0000-0003-0754-269X
albert.berila1@student.uni-pr.edu

B* University of Prishtina, George Bush, 31, 10000, Prishtina, Kosovo
https://orcid.org/0000-0002-1201-9484
florim.isufi@uni-pr.edu (corresponding author)

INTRODUCTION

Determining the quantitative (numerical) morphometric values of morphometric parameters, characteristic forms of relief, hydrography, slope exposure, etc., is today a requirement that is posed in many branches of technique, science, production, and process educational teaching of students. For the calculation of these parameters are used different methods and forms, which depend on the size and features of the territory, the scale of the map, the required accuracy, and the destination (use). Quantitative and measured quantitative values determine the qualitative changes of various physical-geographical phenomena and in some features, also in the transformation of the socio-economic environment. These numerical values measured from the map and reflected in the morphometric, graphic, histogram parameters up to the morphometric maps, can be determined for any territory in general, or for a watershed in particular, where the ways and methods of determination (measurements and calculations) are the same (Talani, 1997).

For the river basin, the morphometric characteristics are of great importance because they hold important information about the formation and development of the basin. Simply put, all geomorphic and hydrological processes happen within the river basin. The catchment area of a river is called the territory from which the river feeds. The surface basin is bounded by the watershed, which passes through the highest quota points between 2 or more neighboring basins.

As a result of geological and geomorphological processes occurring on the earth's surface, landforms have been created (Crevenna et al., 2005). Normally the basic requirement to study the landforms for each area is the analysis of morphometric characteristics. 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.

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, the 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.

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, besides, can be verified having numerous benefits in practice. The importance of the obtained results is quite large because they are inevitable during the process of determining the protection and improvement of the environment, determining the intensity of erosion, etc. The morphometric aspects stand out in this context for offering a set of quantitative parameters that, in addition to better explaining the processes, serve as a basis for space planning, with landforms as indicators (Ross, 1992; 1994).

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). GIS merged with Remote Sensing (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 RS 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; Oliveira et al., 2010; Rao Tamma et al., 2012].

Changes and variations of terrain shapes (form and size) are taken into account by morphometric parameters. There are a large number of morphometric parameters, the purpose of which is to reveal various aspects of the spatial geometry of the landscape. In the present study, an attempt has been made to determine the dissection index (Di) of the Drenica River basin from ALOS-PALSAR RTC DEM using GIS tools. Dissection index (Di) is an important parameter of the drainage basin which shows the scale of dissection or vertical erosion and expounds the step of terrain or landscape development in any given physiographic region or basin (Sarma et al. 2013). This means vertical erosion or the degree of fragmentation and reveals or highlights the stages of landscape development in a watershed or a certain physiographic region. This index gives us data on the degree of formation of relief forms under the influence of fluvial erosion.

For the river basin, morphometric characteristics are of great importance because they hold important information for the formation and development of the basin. Field analysis and modeling require the implementation and development of GIS tools and indicators that would adequately and correctly describe the terrain and its properties. Therefore, the purpose of this paper is to provide a clear and complete overview of the knowledge of the values of Di and the spatial distribution of categories of this parameter, as well as to find the stage of development of the Drenica river basin in the current context. Also, this study, with the methodology developed/brought will help students and experts in scientific fields that correspond to this paper in determining this parameter by helping them solve many problems in their studies. Also, since this paper incorporates the use of GIS, mathematical models, and geomorphological theories, it will radically improve the previous methods of quantitative geomorphic analysis and mapping.

The results of the calculation of this parameter (dissection index) will be presented in tabular and on thematic geomorphological maps.

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.

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 (Fig. 2).

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.

Fig. 1
Geographic position of the Drenica River basin
Source: Compiled by authors

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.

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 GIS environment with the help of ArcGIS 10.3 software.

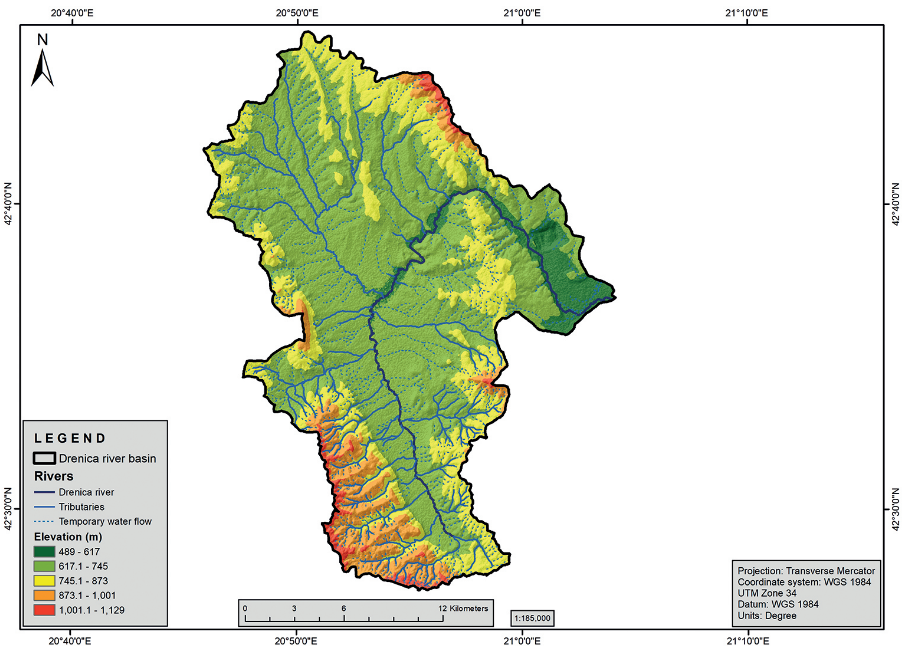

Fig. 2
Hypsometric map of the Drenica River basin
Source: Compiled by authors

Tab. 1 Values of hypsometrical categories of studied area

No	Elevation (m)	Area (km²)	%
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%

Source: *Compiled by authors*

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 relief dissection index has great applicability and importance, so far, there is no fully automated way to extract it based on the 2 morphometric variables proposed by Nir (relative and absolute relief). Thus, this paper presents a methodology that broadly and clearly shows how this parameter (Di) is derived. We did the calculation of the Di using the formula (Nir, 1957):

$$Di = Rh/Ra \qquad (1)$$

where, Di is Dissection index, Rh is Relative relief, and Ra is Absolute relief. The general workflow is shown in Fig. 3.

The HR ALOS-PALSAR RTC DEM from Alaska Satellite Facility is used in this study to determine the dissection index of relief using GIS tools. ALOS-PALSAR was launched in 2006 by the Japan Aerospace and Exploration Agency (JAXA) and

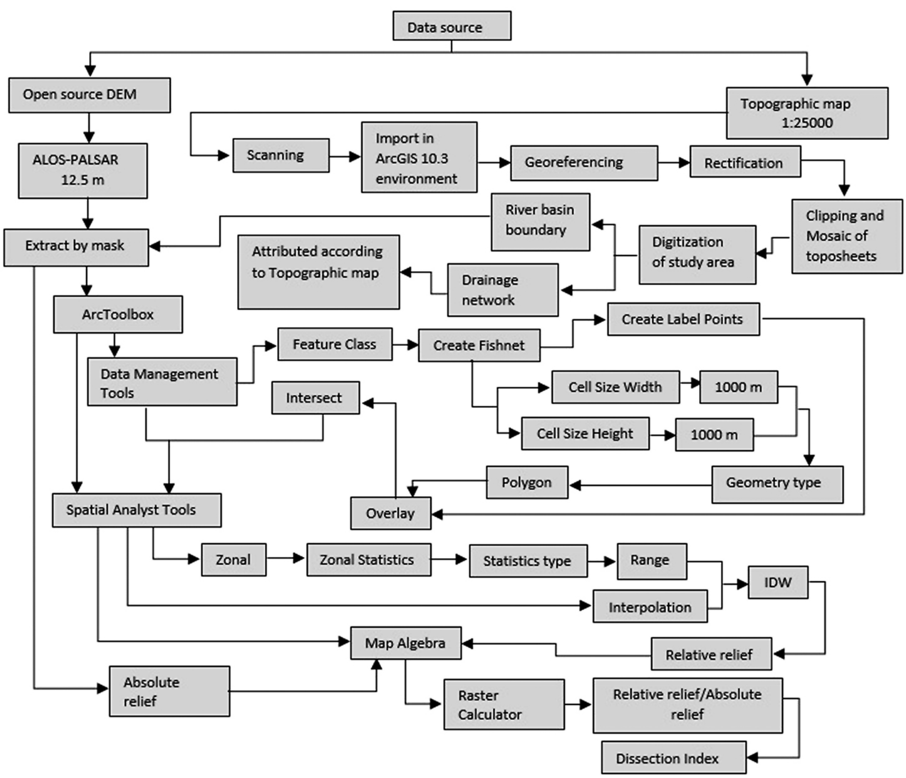

Fig. 3
Flow chart depicting methodology
Source: Compiled by authors

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 (Figure 4) in which the relative relief is defined. The calculation of relative relief (Ra) was made possible using tools in ArcGIS. More precisely, after the preliminary steps taken, we calculate the Ra 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 calculating the relative relief, 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 relative relief (Rh). The concept of the IDW method is based on the first law of geography (Tobler's first law) from 1970.

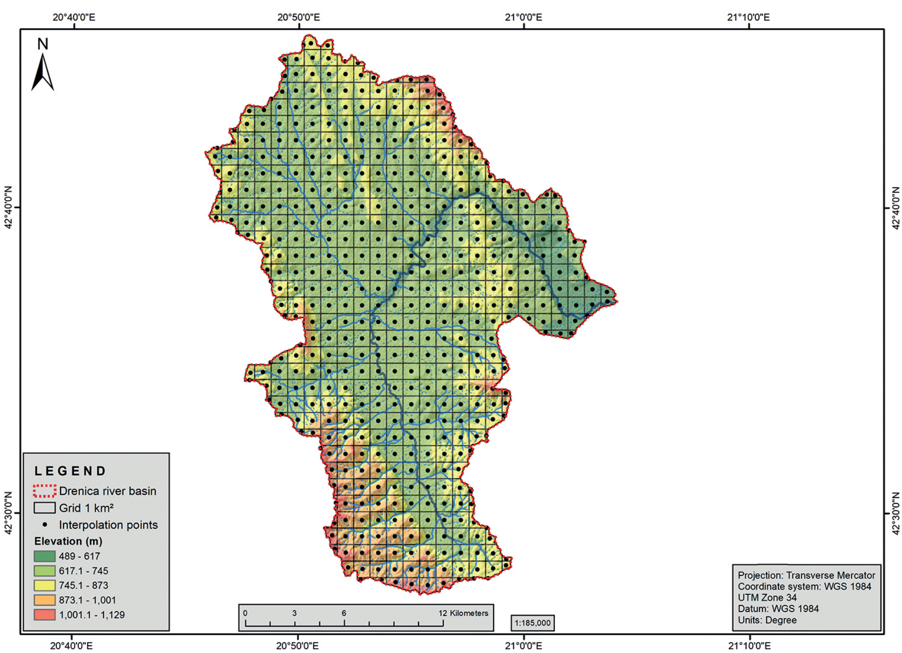

Fig. 4
Grid with interpolation points
Source: Compiled by authors

"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).

The interpolation function is as follows (Xie et al., 2011):

$$Z(x) = \frac{\sum_{i=1}^{n} w_i z_i}{\sum_{i=1}^{n} w_i}$$

in which

$$w_i = d_i^{-u}$$

where $Z(x)$ is the predicted value at an interpolated point, whereas z_i is the amount at a known points. n is the total number of known points used in interpolation, d_i is the distance between point i and the prediction point, w_i is the weight assigned to point i. Higher weighting values are assigned to those points which are closer to the interpolated points (Mirzaei, 2016). As the distance increases, the weight decreases and u is the weighting power that impose the amount of weight decrease with respect to the increase in distance (Xie et al., 2011). Undoubtedly, the advantage of the IDW is that it can be easily applied to any number of dimensions and provide reasonable estimates.

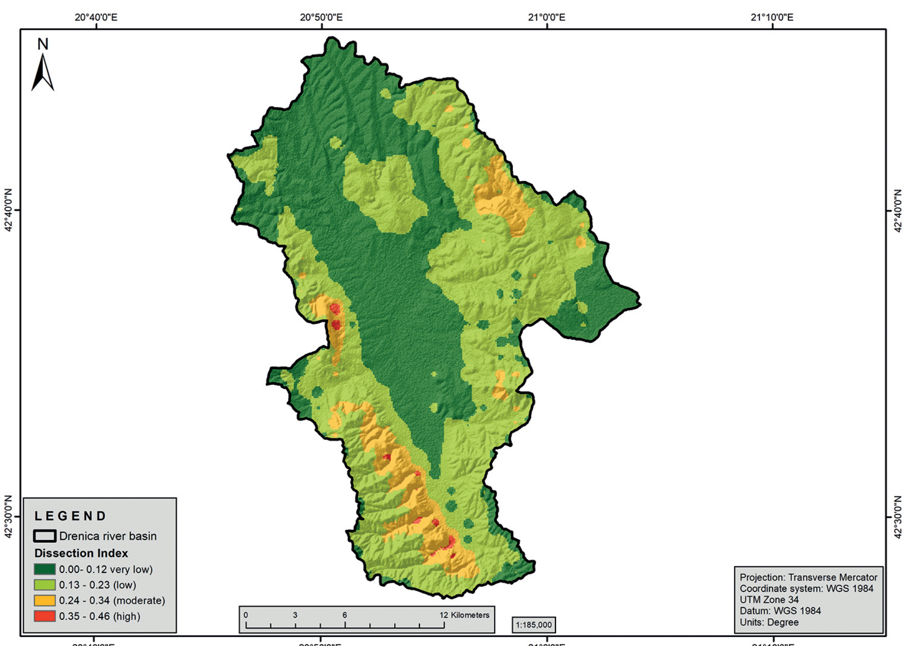

Fig. 5

Dissection index of the Drenica River basin

Source: Compiled by authors

The last step is to extract the dissection index. We do this through the "Raster Calculator" tool. After the dialog box appears, we write the dissection index formula (Ra/Rh). After calculating the Di, we classify the obtained values and compile the dissection index map (Figure 5).

RESULTS AND DISCUSSION

The Dissection index is a very important morphometric parameter of the river basin. This parameter indicates the degree of vertical dissection or erosion and highlights the stage of development of landforms (Sarma et al., 2013). Di values range between "0" and "1. If the value of Di is 0, then this indicates that in the given space where this value is displayed, there is a lack of vertical dissection and, for this reason, the surface is flat. So the complete absence of dissection implies a flat topography. Di value of "1" indicates the presence of vertical cliffs which it might be at the vertical escarpment of hill slope or at a shoreline (Alqahtani and Qaddah, 2019).

From the calculations we made, the Di values were obtained for each grid cell with dimensions of 1km^2. The values obtained were classified into 4 categories: extremely low (0.0 – 0.12), low (0.13–0.23), moderate (0.24–0.34), and high (0.35 – 0.46), and an isopleth map is prepared for the study of Di's spatial distribution (Figure 5).

The spatial distribution of Di of the Drenica River basin is shown in Fig. 5. Extreme values of this parameter range from 0 – 0.46. In general, this basin is characterized by very low and low values of this index, which together make up about 90.54% (Tab. 1) of the entire surface of this basin.

Tab. 2 Dissection index categories of studied area

Dissection index of relief		Area	Percentage
(Value)	(description)	(km^2)	(%)
0.0 – 0.12	Very low	188.5	42.99
0.13 – 0.23	Low	208.51	47.55
0.24 – 0.34	Moderate	39.93	9.11
0.35 – 0.46	High	1.53	0.35
TOTAL		438.47	100

Source: *Compiled by authors*

Such small values of this index indicate a very low fluvial action and that the flat surfaces in this basin are expanding. A lower value of Di implies the old stage of the basin and less degree of dissection. Small values of this index indicate that river erosion is very low and the total area is increasing towards the creation of flat surfaces. In this basin, the average and high values of this index, together, make up about 9.46% of the total area. Such values are more present in the western and southwestern parts, which, at the same time, represent the peripheral mountains of this basin.

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. In the present study, an attempt has been made to determine erosion intensity (Di) of the Drenica River basin from ALOS-PALSAR RTC DEM using GIS tools. 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.

GIS techniques have been proved to be an effective tool in computing Di for a given area. 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.

Through Di the stages of development of the soil forms of each physiographic region or watershed can be determined. Through such an analysis, geomorphological maps with different scales can be compiled. In our paper, a large-scale map has been compiled, which gives a detailed view of our study area based on 1km^2 cells and interpolation points. 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.

In the Drenica River basin, Di values ranged from 0 to 0.46. The very low and low values of Di occupy the central part of the basin and the lower sectors of the Drenica River. Small values of this index indicate that river erosion is very low and the total area is increasing towards the creation of flat surfaces. Such low values are, of course, related to the soft rocks of this area. From the analysis of the obtained results, it is concluded that the morphological longitudinal profile of the river has been processed, the erosive activity is very low and reduced. Thus, the area is being transformed into a series of soft forms, which are quite low in height, covered with a layer of destroyed soil material, and separated by valleys covered with alluvium. From the analysis made it is clear that such areas lie mainly in the central, northern, and eastern part of the basin (to a large extent) which correspond to low and very low Di values.

While the average and high values extend along the areas where strong rocks are highlighted. Such areas are located mainly in peripheral mountains of this basin.

The value of the results obtained from the determination of the values of the Di in the Drenica River basin is very useful and are 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, study the balance between pedogenesis and morphogenesis and the assessment of environmental vulnerability.

REFERENCES

ALQAHTANI, F., QADDAH, A. A. (2019). GIS digital mapping of flood hazard in Jeddah–Makkah region from morphometric analysis. *Arabian Journal of Geosciences*, 12(6), 11. https://doi.org/10.1007/s12517-019-4338-8

CREVENNAA, A. B., RODRIGUEZ, V. T., SORANI, V., FRAME, D. ORTIZ, M. A. (2005). Geomorphometric Analysis for Characterizing Landforms in Morelos State, Mexico. *Geomorphology*, 67(3-4), 407–422. https://doi.org/10.1016/j.geomorph.2004.11.007

DIKAU, R., BRABB, E. E., MARK. M. R. (1991). Landform classification of New Mexico by computer. *U.S. Dept. of the Interior, U.S. Geological Survey*, 1-15. 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.

HANCOCK, G.R., MARTINEZ, C., EVANS, K. G. and 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. 50.

KANTH, T. A. and 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(1), 30-41.

KHAL, M., ALGOUTI, A., ALGOUTI, A., AKDIM, N., STANKEVICH, A. 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), 236. 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*, Beijing, 1123 – 1127.

MAGESH, N. S., JITHESHLAL, K. V., CHANDRASEKAR, N., JINI, K. V. (2012). GIS based Morphometric Evaluation of Chimmini and Mupily Watersheds, Parts of Western Ghats, Thrissur District, Kerala, India. *Earth Science Informatics*, 5 (2), 111–121. https://doi.org/10.1007/s12145-012-0101-3

MARKOSE, V. J., DINESH, A. C. and 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

MIRZAEI, R., SAKIZADEH, M., (2016). Comparison of interpolation methods for the estimation of groundwater contamination in Andimeshk-Shush Plain, Southwest of Iran. *Environmental Science and Pollution Research*, 23(3), 2758–2769. https://doi.org/10.1007/s11356-015-5507-2

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.

MUKHERJEE, S., SHASHTRI, S., SINGH, C., 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

NIR, D. (1957). The Ratio of Relative and Absolute Altitude of Mt. Carmel. *Geographical Review*, 47(4), 564-569.

OLIVEIRA, P. T. S., SOBRINHO, T. A., 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. http://dx.doi.org/10.1590/S1415-43662010000800005

RAO TAMMA, G., RAO GURUNADHA, S. V. V. S., RATNAKAR, D., RAO MALLIKHARJUNA, S. T., RAO RAJA, 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 Geological Society of India*, 79(4), 383-390. http://dx.doi.org/10.1007/s12594-012-0059-2

ROSS, J. L. S. (1992). O registro cartográfi co dos fatos geomórfi cos e a questão da taxonomia do relevo. *Revista do Departamento de Geografia*, 6 (1), 17-30. https://doi.org/10.7154/RDG.1992.0006.0002

ROSS, J. L. S. (1994). Análise empírica da fragilidade dos ambientes naturais antropizados. *Revista do departamento de geografia*, 8 (1), 63-74. https://doi.org/10.7154/RDG.1994.0008.0006

SARMA, P. K., SARMAH, K., CHETRI, P. K., SARKAR, A. (2013). Geospatial study on morphometric characterization of Umtrew River basin of Meghalaya, India. Int J Water Resour Environ Eng 5 (8), 489–498. https://doi.org/10.5897/IJWREE2012.0367

TALANI, R. (1997). Laboratory manual for cartography and topography, Shkodër, *Camaj-Pipa*, 62 (In Albanian).

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(1). https://doi.org/10.2307/143141

XIE, Y., CHEN, T-B., LEI, M., YANG, J., GUO, Q-J., SONG, B., ZHOU, X-Y. (2011). Spatial distribution of soil heavy metal pollution estimated by different interpolation methods: accuracy and uncertainty analysis. *Chemosphere*, 82 (3), 469. https://doi.org/10.1016/j.chemosphere.2010.09.053