QUANTITATIVE GEOMORPHOLOGICAL ANALYSIS OF AREA RAVNA MOUNTAIN AND PALE VALLEY

Jelena Golijanin
University of East Sarajevo, Faculty of Philosophy, Department of Geography, Alekse Šantića 1, Pale, Bosnia and Herzegovina
jelena.golijanin@ffuis.edu.ba
Emir Temimović
University of Sarajevo, Faculty of Science, Department of Geography, Zmaja od Bosne 33-35, Sarajevo, Bosnia and Herzegovina
emirtemimovic@yahoo.com
Mevlida Operta
University of Sarajevo, Faculty of Science, Department of Geography, Zmaja od Bosne 33-35, Sarajevo, Bosnia and Herzegovina
opertamevlida@yahoo.com

In this paper has performed quantitative geomorphological analysis of area Ravna Mountain and Pale Valley. By using GIS, cartographic and mathematical-statistical methods, were analyzed morphometric characteristics specified area. Analysis covered: hypsometric characteristics, vertical dissection, slope and aspect of relief. The advantage of this analysis is that obtained data have a numerical value and thereby is verifiable and multi useful in practice for daily and long-term purposes, whose task is to identify suitability area from the point of balance and stability (agriculture, water management, infrastructure, construction, urbanism, tourism, urban planning, etc.). Results of quantitative analysis of relief Ravna Mountain and Pale Valley are presented in thematic geomorphological maps and statistical charts.

Key words: *quantitative geomorphological analysis, relief, GIS, Ravna Mountain, Pale Valley.*

INTRODUCTION

Quantitative geomorphological analysis involves the expression of morphological processes, forms and relief, using the numerical parameters, whereby it is important to point out that its numerical value is practically unlimited (Marković et al., 2003). The primary characteristic of such analysis is that data are dimensioned and, thanks to this, verifiable and multiple useful 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.

As a result of dominant influence of endogenous processes (folding, faulting), which significantly directed action of exogenously-geomorphological processes (corrosion, slope and fluvial processes), relief of researched area has gained specific morphometric characteristics. Certain morphometric characteristics of the relief Ravna Mountain and Pale Valley (hypsometric features, vertical dissection, slope angles and aspect of relief), were analysed based on quantitative geomorphological analysis, cartographic and mathematical-statistical methods, by using software package ArcGIS Desktop 10.1.

The digital elevation model used for the quantitative geomorphological analysis, and for obtaining of specific relations, is presented by grid with resolutions 30×30 m. Raster is obtained from vectored topographic maps scale 1: 25000. Results of analysis allowed us an insight into the hypsometric relations and definition of orographic structure of studied area and cartographic insight into the surface layout of the various categories of vertical dissection, slope and aspect of relief.

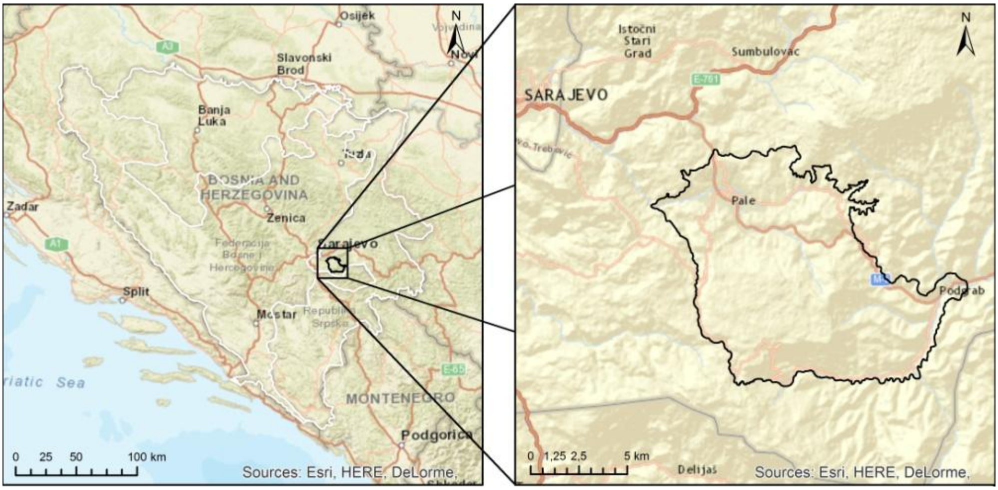

Fig. 1. Location of Ravna Mountain and Pale Valley in Bosnia and Herzegovina

Source: ESRI ArcGIS Resource Centers – World Street Map (http://services.arcgisonline.com)

CASE STUDY

The analyzed area is located southeast of Sarajevo, between 43°43'31" and 43°50'18" North latitude and between 18°31'01" and 18°43'09" East longitude (Fig. 1.). It covers approx. 117 km^2, and has a dominant mountainous character (the highest point of area is 1640 m, amplitude of altitude is 920 m, and the average height is 1064 m). In respect to geotectonic this area belongs to the fifth zone in Bosnia and Herzegovina (zone allochthonous Paleozoic and Triassic formations) (Hrvatović, 2005). Larger part of Ravna Mountain, is karstified elevated plane, which gradually descend to Pale Valley. It is part of large Jahorina massif on Northeast. Pale Valley has polygenetic origin, descent by faults in comparison to the surrounding area of positive morphostructures.

Quantitative geomorphological analysis

Analysis of relief characteristics based on GIS techniques refers primarily to the analysis of digital terrain models. To obtain insight into morphometric characteristics of studied area, it has been made four morphometric maps: hypsometric, vertical dissection, slope and aspect of relief and their associated charts with percentage ratio (Fig. 2.).

Hypsometric features of relief are the basis of all further research, and present a clear view of analyzed terrain. Knowing the altitude of area is important for the capability for planning and proper use of it. "Average altitude of terrain is an unavoidable figure in calculation of erosion intensity, sediment retention and is included in structure of a large number of empirical formula for calculation of erosion intensity " (Dragićević and Filipović 2009, 89). Hypsometric map of relief Ravna Mountain and Pale Valley, made in such a way, gives a clear idea about altitude characteristics of analyzed terrain (Fig. 2. (a)). Depending on the size of terrain it imposes his possibilities for planning and proper usage. Based on map data it provides the indicators that are given in a tabular form for better transparency (Tab. 1.).

Tab. 1. Values of hypsometrical categories of studied area

<table>
<tr><th>No.</th><th>Elevation (m)</th><th>Area (km²)</th><th>Share in total area (%)</th><th colspan="2">Relief classification (%)</th></tr>
<tr><td>1.</td><td>720 – 800</td><td>4,2579</td><td>3,65</td><td colspan="2" rowspan="3">low mountain (53,56%)</td></tr>
<tr><td>2.</td><td>800 – 900</td><td>25,7013</td><td>22,03</td></tr>
<tr><td>3.</td><td>900 – 1000</td><td>32,5206</td><td>27,88</td></tr>
<tr><td>4.</td><td>1000 – 1100</td><td>13,5675</td><td>11,63</td><td rowspan="5">medium mountain up to 1500 m (43,78%)</td><td rowspan="7">(46,44%)</td></tr>
<tr><td>5.</td><td>1100 – 1200</td><td>8,1081</td><td>6,95</td></tr>
<tr><td>6.</td><td>1200 – 1300</td><td>6,1002</td><td>5,23</td></tr>
<tr><td>7.</td><td>1300 – 1400</td><td>16,1811</td><td>13,87</td></tr>
<tr><td>8.</td><td>1400 – 1500</td><td>7,1181</td><td>6,10</td></tr>
<tr><td>9.</td><td>1500 – 1600</td><td>3,0627</td><td>2,63</td><td rowspan="2">medium mountain over 1500 m (2,66%)</td></tr>
<tr><td>10.</td><td>1600 – 1640</td><td>0,0396</td><td>0,03</td></tr>
<tr><td colspan="2">Total</td><td>116,6571</td><td>100</td><td colspan="2">100%</td></tr>
</table>

Source: Golijanin (2015)

Results of vertical relief dissection analysis of Ravna Mountain and Pale Valley give an insight into the layout, relationships and the size of areas for corresponding categories. Through correlation with other morphometric indicators (e.g. slopes), it is possible, with more reliably, to locate area with higher or lesser suitability for practical purposes such as agricultural, forest management etc.

The values of the relative height relations, in this case the vertical relief dissection, were obtained based on analysis of digital terrain models Ravna Mountain and Pale Valley, shown in Fig. 2. (b). The measured values represent the elevation difference between grid cells within area of 1 km^2, expressed in meters. In accordance with the intensity of tectonic movements and the effects of various geomorphological processes, vertical relief dissection is characterized by corresponding dynamics. Therefore, vertical stratification of the analyzed relief shows significant differences in individual relief entities, but also inside them. Map of vertical relief dissection is an indication of predisposition of terrain for the occurrence of erosive and accumulative process. Whether they will actually occur on the topographic surface and in what extent, depends on a number of physical-geographic parameters like properties of geological base, climate, forests cover of terrain, etc. (Manojlović et al. 2004).

Tab. 2. Values of individual vertical dissection categories of studied area

No.	Vertical dissection (m/km^2)	Area (km^2)	Share in total area (%)	Category of vertical dissection relief
1.	0 – 5	0	0	Flat relief
2.	5 – 30	0	0	Low dissected plains
3.	30 – 100	16,43241	14,09	Low dissected relief
4.	100 – 300	87,35151	74,88	Moderate dissected relief
5.	300 – 800	12,87318	11,04	High dissected relief
6.	> 800	0	0	Vary high dissected relief
Total		116,6571	100	-

Sources: Gams i dr. (1981); Bognar (1992); Lozić (1995); Golijanin (2015)

Although there is a number of algorithms used to determine the slope of relief, most of them are based on calculation of first derivative within the 3×3 square, used in this study. [1] The differences are mainly relating to number of cells in each direction, included in the calculation. For determination of erosive potential of area is very important to do slope map of terrain. The methodology of data preparation is known from earlier (Marković, 1983), and its making is simplified by using software package ArcGIS Desktop 10.1. Analysis of slope carried out in this paper, was based on a proposal contained in Unique key project for making detailed geomorphological map of the world (IGU, 1968), based on which were isolated following categories (classes) of slope:

Tab. 3. Values of individual slope categories of studied area

No.	Slope (°)	Area (km^2)	Share in total area (%)	Categories of slope
1.	0-2	6,2001	5,31	Flat terrain
2.	2-5	10,3311	8.86	Gently inclined terrain
3.	5-12	33,993	29,14	Inclined terrain
4.	12-32	64,2546	55,08	Significantly inclined terrain
5.	32-55	1,8702	1,6	Highly inclined terrain
6.	>55	0,0081	0,01	cliffs
Total		116,6571	100	-

Sources: IGU (1968); Bognar (1990); Golijanin (2015)

The importance of aspect for intensity of recent geomorphological processes is particularly reflected in the modification of solar radiation impact on amplitude of air and soil temperature, mechanical degradation of rock mass, duration of vegetation period, and uneven exposure of slopes towards showery winds etc. Maximum differences of exposure

[1] Calculation of slope based on elevation data of digital terrain models, is defined as the maximum change of height value between the central cell and its surrounding cells.

influence on those phenomena are observed in opposing exposures who have meridional direction, so-called shady and sunny slopes. Exposure is modifying the character of sun position above horizon, in such way that it allows an increase in incident angle of sun, sunny slopes, and its decreases on shady slopes (Dragićević, 2007). Sunny slopes are marked with higher insolation which is reflected through greater warming in relation to shady slopes, higher temperature daily amplitude and to shorter retention of snow cover. Analysis of relief exposure within the morphometric characteristics Ravna Mountain and Pale Valley is conducted on the basis of exposure map (fig. 2. d).

At latitudes characteristic of studied area, largest amount of heat gets relief whose slopes are exposed to south, where occurs largest warming of topographic surface and also highest amplitude. This is conditioned by the fact that these exposures for spring and autumn days are illuminated by a larger incident angle of sun, and on basis of the measurements it was found that during the winter period the rocky slopes with southern exposure in afternoon hours can be heated up to 50°C, and at the same time northern slopes have a temperature about 0°C (Šibalić, 1986; Dragićević, 2007).

Tab. 4. Values of aspect categories of studied area

No.	Aspect (°)	Area (km^2)	Share in total area (%)	Category of aspect
1.	horizontalne pov. (-0.5-0)	1,7991	1,54	Without expressed aspect
2.	N (0-22,5 i 337,5-359,5)	19,1241	16,39	Northern aspect
3.	NE (22,5-67,5)	19,0818	16,36	Northeaster aspect
4.	E (67,5-112,5)	14,9535	12,82	Eastern aspect
5.	SE (112,5-157,5)	14,148	12,13	Southeaster aspect
6.	S (157,5-202,5)	12,9546	11,1	Southern aspect
7.	SW (202,5-247,5)	10,7199	9,19	Southwestern aspect
8.	W (247,5-292,5)	11,2464	9,64	Western aspect
9.	NW (292,5-337,5)	12,6297	10,83	Northwester aspect
Total		116,6571	100	-

Source: Golijanin (2015)

Slopes of northern aspect and larger angle of inclination and approximately same altitude in summer (at period of highest sun position), may have a lower temperature than the south for more than 20° C (Penzar and Penzar 1989). Also, studies have shown that western aspects are warmer than eastern, due period of daily insolation. Eastern aspects are exposed to direct sunlight during the morning hours, when most of the heat is used for evaporation of moisture from topographic surface, while slopes with western aspect are exposed to sunlight in afternoon, when (due to increase in temperature), when most of moisture has evaporated from the soil. During the period of their exposure to sunlight, heat energy is directly spent on heating of topographic surface, and thus of air, which affects the number of interlinked phenomena and processes (temperatures of soils and air, and on this basis, and heat destruction of rocks). Also, it was determined that higher humidity occurs at slopes with northern aspect than with southern, which effects on expressed forests cover and thickness of soil cover, but also on density of river network (the intensity of denudation is smaller than on the southern slopes) (Dragićević, 2007).

For easier overview of slope aspect of Ravna Mountain and Pale Valley we have create aspect map. The map shows the spatial distribution and proportion of all eight aspect categories with category that shows horizontal surfaces, i.e. part of terrain without expressed orientation towards sides of world (Tab. 4.).

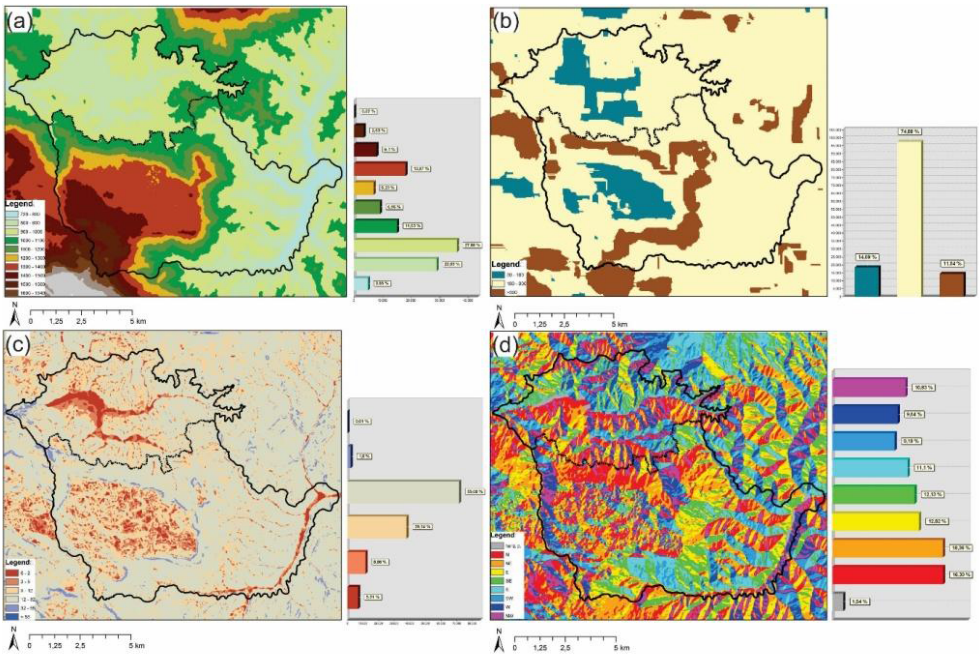

Fig. 2. Morphometric maps of relief Ravna Mountain and Pale Valley: (a) hypsometric map; (b) vertical dissection map; (c) slope map and (d) aspect map

DISCUSSION

By analysing hypsometric map of Ravna Mountain and Pale Valley, it was determined that relief of area has a predominantly mountainous features, with the lowest point at 720 m and the highest at 1640 m. We have highlighted 10 mountainous levels that clearly outline plastics of relief. Terrain altitude from 800 up to 1000 m are the most common (49.91%). The exception to this makes low plains around river flows (altitude below 800 m), with share of 3.65% and isolated peaks (altitude over 1400 m) with a share of 8.76%. Generally speaking, the relief with height up to 1000 m covers more than half of territory (53.56% - low mountain relief), while higher terrain, from 1000 m up to 1640 m altitude covers lesser part of the analysed area. Middle mountain relief, height from 1000 m up to 1500 m covers 43.78%, while terrains with medium mountain terrain over 1,500 m of altitude covers only 2.66% of the territory (Tab. 1.). In the southwestern part of Ravna Mountain, the spatial distribution of elevation zones indicates strongly expressed asymmetry. On the northern and eastern parts are observed lower areas, shaped in valley, while the surrounding higher parts of Ravna Mountain are presented by mountainous hills. Differences in altitude between the various tops of Ravna Mountain are relatively small. Most distinctive relief units in studied area is represented by flattened highlands of Ravna Mountain noticeably hollowed by numerous sinkholes. It is elongated in the direction of east-west, with a slight drop from south to north. The highest peaks are located directly along the southwestern edge of the plateau faced to Gola Jahorina. The highest, southwestern part of Ravna Mountain has a medium altitude of over 1500 meters (height of tops from 1552 m to 1640 m). Furthermore, to north and northeast medium height decreases, and for largest part the area it is from 1300 – 1400 m (altitude of tops from 1328 to 1422 m). Marginal areas of Ravna Mountain plateau are constrained by numerous river flows that greatly dissects relief. Pale Valley, on the other side, is presented by depression with a few small hills on east and south. It is elongated in direction east - west and makes extension of erosive flow of Paljanska Miljacka. Arched flow of Paljanska Miljacka from north to west around hill V. Koran (1013 m) indicates its neotectonic activity.

Out of a possible six categories of vertical relief dissection, in the studied area are present three categories. There are not present first two categories of small relief dissection (flat relief and low dissected plains), as well as sixth category (very high distinctly dissected relief). On the other side most frequent category makes relief of moderate dissection which participates with a share of 74.88% in total territory. This category of dissected relief is mostly present on areas where in geological structure is dominated clastic. High dissected relief (>300 m/km^2) dominates along northwest, northern, eastern and southeastern perimeter of Ravna Mountain plateau. It is present with a share of 11.04% of total studied area. Opposite from above, relief of lower absolute values of vertical relief dissection of is mainly present in central parts of Ravna Mountain and along part of Paljanska Miljacka flow and its tributaries. In the mentioned areas is dominated low vertical relief dissection. The lowest category of vertical relief dissection belongs to third category (low dissected relief 30-100 m/km^2). Present at the bottom of Pale Valley as well as in central and western part of Ravna Mountain (14.09%). It is noticeable that low relief dissection is presented on limestone terrain (central and western part of Ravna Mountain), while terrain dominated by clastic is characterized by higher vertical relief dissection. This transition is also caused by pattern of fault structures.

By analyzing values of angles of relief slope it has been established six categories. Spatial distribution and presence of certain categories of slope angles clearly characterize certain relief regions. In the area of Ravna Mountain and Pale Valley slopes are presented with all six basic categories of relief slope: 0-2°, 2-5°, 5-12°, 12-32°, 32-55° and more than 55°. Percent in share of slope, proportionately grow to the category 12-32°, after which it rapidly decreases. Slopes of the studied terrain largely reflect morphostructural features of the relief. Largest part of the terrain is characterized by slopes of fourth category (values from 12° to 32°), however, some differences are notable. In overview of share of individual categories of relief slope it is visible that the most common is terrain with significantly inclined relief, with a slope angle of 12-32° (55.08% of area), flat terrains and gently inclined terrains (0-5°) are presented with a share of 14.17%, while Inclined terrains (5-12°) take up to 29.14% of studied area. Terrain with extremely sloped relief (highly inclined terrain and cliffs) covers 1.61%. Mostly, highest values of slopes occur at marginal areas of Ravna Mountain plateau, by the flow of Bistrica River on west and on far western part of Pale Valley. Slopes are particularly expressed in locations of contact of limestone and clastic formations (32-55° and over 55°), and structural framed predisposed slopes (12-32° and 32-55°). Mostly, a slopes with relatively high value of angle are present in area of fluvial-denudate dissected clastic zone in eastern and southeastern part of Ravna Mountain and peripheral parts of Pale Valley (12-32°). Pale Valley and parts around flow of Prača and its tributaries are characterized by slopes less than 2°, and slopes whose values range from 2-5°. Slopes with such small angle values are present at area of central plateau of Ravna Mountain and localities of Dvorišta in west and Podovi in northeast. Central and western parts of the Ravna Mountain are slightly sloped towards the northeast. The lowest slope values are related to bottom of karst uvalas. This is a relatively flattened terrain crisscrossed by individual small areas with a bit higher slope values. Marginal areas of Ravna Mountain are represented by an extremely steep terrain with slope of 12-32° and 32-55°. Only in some smaller areas are presented extremely steep terrain with a slope values over 55 ° (locations: Hladilo, Dubovik, Ždrijela etc.). At marginal lower areas, high slopes are present in parts of the flow canyon of Paljanska Miljacka and Bistrica, close to point of their merging in northwestern part of studied area. From other slope angles dominate are slopes from 12° to 32°, especially in the northeastern and eastern parts of studied area. Greater presence of significantly inclined terrains (slope from 12° to 32°) in the area of Ravna Mountain and Pale Valley, it is possible to explain by larger number and length of stream flows that cuts deeply into the clastic sediments of this area. So on cartographic representation of slopes are clearly visible higher slopes of fluvio-derasion valley (slope 12° - 32°) whose direction, in some parts of area, is perpendicular to direction of dominant landforms (N-NW – S-SE). Also, there are clearly visibly bottoms of broad derasion valleys, whose slopes are in categories of less than 5°.

In terms of aspect of relief, in studied area are dominated northeast and north oriented slopes which covers a third of analysed area (32.75%). In a lesser extent are present eastern (12.82%), southeast (12.13%) and south (11.1%) oriented slopes, while in the lowest percentage are presented slopes oriented to southwest (9.19%), west (9.64%) and northwest (10.83%). At studied area there are also horizontal surfaces that are presented with a share of 1.54%. The slopes are significantly less oriented to southern and western sides (about 41%), and in higher percentage are oriented to northern and eastern sides (about 57%) which are considered colder.

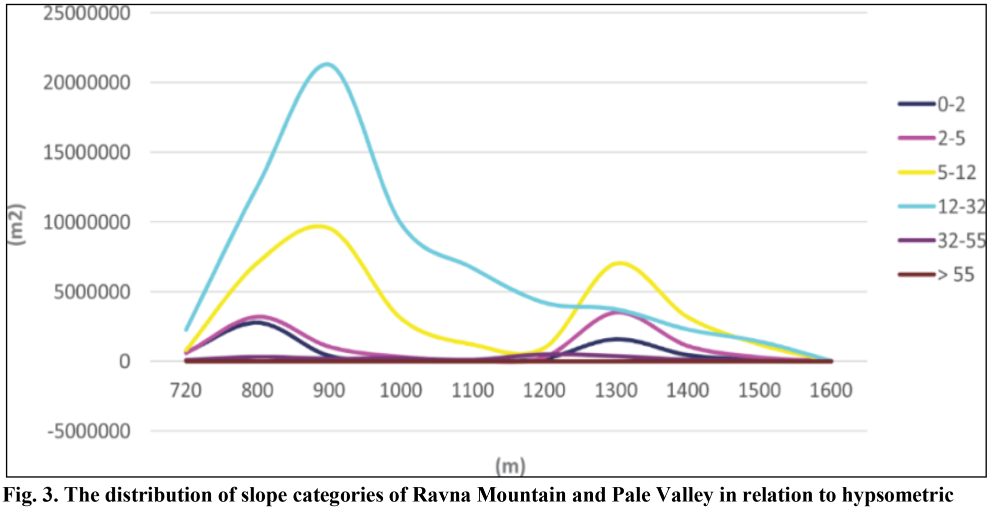

Fig. 3. The distribution of slope categories of Ravna Mountain and Pale Valley in relation to hypsometric characteristics

Distribution of slope categories of Ravna Mountain and Pale Valley in relation to hypsometry (Fig. 3) indicates a peculiarities of primary relief zones of observed area. Lowest category of slopes is linked to hypsometric levels up to 900 m (plateaus of Pale Valley and Podgrab) and it appear again at altitudes above 1200 m as flat parts fragments of Ravna Mountain. Contrary to altitude distribution of flatter slopes, main distribution of steep slopes is linked to hypsometric range from 1150 to 1400 m and refers to slopes of marginal areas of Ravna Mountain plateau. However, undoubtedly is noticeable domination of slopes with slope from 12° to 32°, which achieve its maximum at an altitude of 900 m (area around upper flow of Prača), and with grove of height, slope angles slightly decline.

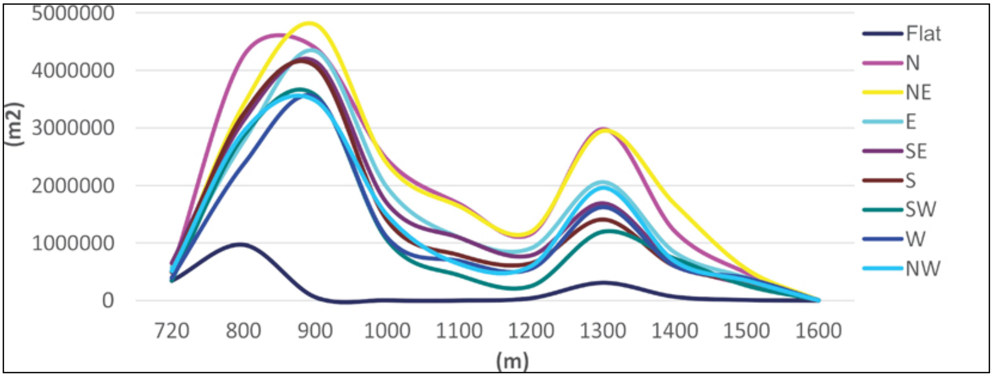

Fig. 4. Hypsometry distribution of Ravna Mountain and Pale Valley relief in relation to aspect

If we observe relationship of slope aspect and hypsometry (Fig. 4.), it is clearly evident domination of aspect in two hypsometric class (900-1000 m and 1300-1400 m) which are two main in studied area. However, it is evident that are dominated slopes with north-east and north direction while providing the least present are slopes of opposite - southwestern direction. To some amount, are present flat areas, especially in basin extensions of Prača and Paljanska Miljacka and plateau of Ravna Mountain, on which are, due to small asymmetry and mild terrain roughness, present all other values of slope. At the highest parts of plateau (over 1400 m), which are presented by small areas, layout of slope aspect is uniform, with no dominant direction. In the southeaster part (left side of Prača flow) slopes are oriented in a north-north-east and south-southwest and going more to west (towards Ravna Mountain) dominates orientation of slopes in direction of east-southeast.

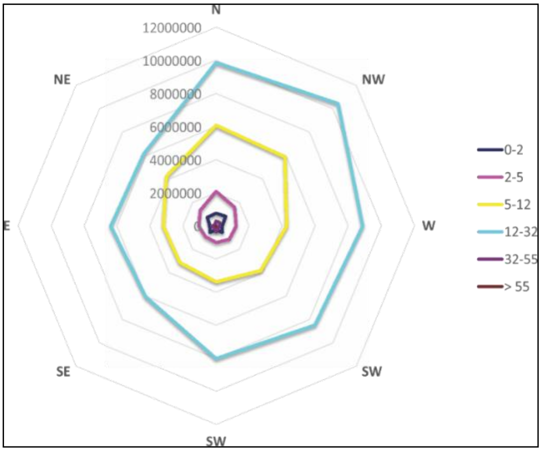

Fig. 5. Slope distribution of Ravna Mountain and Pale Valley in relation to aspect

Distribution of slope at researched

area in relation to the aspect (Fig. 5.) is characterized by clear orientation of significantly inclined slopes which dominate with aspects N-NE-E. This orientation of slopes is present partly because of Dinaric direction of the north-western part of Ravna Mountain (NW-SE). Due this dominant northeast oriented slopes take perpendicular direction in compared to Dinaric direction, while with south-west oriented slopes this is not case. On this situation, influence has had an active tectonics and intersection of orographic structure of Ravna Mountain in southeast in Prača valley, causing that this orographic unit gained direction of west-east, and the slopes of this part of the mountains have north-east and south-west aspects.

Basically there are dominate slopes with northern and eastern aspect at nearly all categories of slope. Curves of lower slope angles also shows dominant direction of north-oriented slopes. Category of slopes less than 2° has a mainly flat line in distribution diagram, i.e. uniform frequency of all aspect grades. Aspect of slopes over 32° is related exclusively to S, SW and NE orientation, while the distribution of slopes from 12-32° dominates and shows orientation of slopes partially perpendicular to Dinaric direction. Also, noticeable is the slightly larger presence of northeast slopes in relation to southwestern aspect, which is probably a consequence of asymmetric relief structures of Ravna Mountain, which dominates within studied area.

CONCLUSION

Quantitative parameters covered by analysis, are expression of morphostructural and morphogenetic relief characteristics of Ravna Mountain and Pale Valley area. These features have dynamic character and are used as indicators of form and recent processes occurred in relief. The synthetic character of quantitative geomorphological analysis increases its applicability in practice, in first place for daily and long-term purposes whose task is to identify area favorable from the point of balance and stability (agriculture, water management, infrastructure, construction, urban development, tourism, urban planning, etc.).

Detailed conducted quantitative geomorphological analysis of hypsometric, vertical dissection, slope and exposure of Ravna Mountain and Pale Valley relief is often used in the geoecological evaluation of natural resources, as an example can be listed slopes of relief which directly (in the evaluation of relief) and indirectly (e.g. in the evaluation for forestry) is affecting on geoecological value of certain area and as such is one of the important criteria of evaluation.

This kind of analysis commonly used geomorphological maps that may have different scale, and in this paper are used large scale maps which give a detailed view of the area based on 1km^2 cells. Also, considering that the database is based on the grid system, the possibility of overlapping data and their correlational analysis is wide and opens numerous possibilities of use and application of geospatial data.

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Authors

Jelena Golijanin, received PhD in 2015 at University of Belgrade, Faculty of Geography, Serbia. Since 2006 employed at Department of Geography at University of East Sarajevo, Faculty of Philosophy, B&H. Position: Assistant Professor. Her research interest are: physical geography, geomorphology, landscape ecology (geoecology), dendroclimatology, environment, GIS, natural potentials.

Emir Temimović, doctor of geographical sciences, associate professor at the Faculty of Science. University of Sarajevo, Bosnia and Herzegovina. Editor of the scientific journal Acta geographica Bosniae et Herzegovinae; author of 20 scientific papers and two books from the scientific domain of physical geography.

Mevlida Operta, was born in Tuzla, were went to school. She graduated in Geology at Faculty of Mining and Geology and also obtained master and PhD degree at the same University. Today, she is an Associate Professor at the Faculty of Sciences in Sarajevo. At the center of her scientific work are geological and mineralogical-petrographic studies. She has published over 80 scientific papers. Most of them represent original research papers, and some have an international review. She is author of four university textbooks. She has participated in the development of projects and studies in the field of geology.