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GIS ANALYSIS OF VULNERABILTY FROM LANDSLIDES: A CASE STUDY OF SOKOBANJA MUNICIPALITY

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Abstract: This paper analyses area endangered by the process of landslides is in the municipality of Sokobanja. The process of landslides is very important from the aspect of environmental protection, considering that it can occur both naturally and under the influence of anthropogenic factors. For the purposes of this analysis data about geological structure, relief characteristics of the terrain (slope, aspect and terrain curvature), distance from rivers, land cover and values of the bare soil index were processed in the GIS environment. The Probability Method (PM) and the Landslide Susceptibility Index (LSI) were used to calculate the predisposition in relation to existing landslides in the study area. The obtained results indicate a high degree of reliability of these statistical methods for landslide prediction.

Key words: landslide, endangerment, Probability Method (PM), Landslide Susceptibility Index (LSI)

Introduction

Landslides represent a geomorphological process of movement of the surface loose layer and occur as a result of the interaction of certain natural conditions and processes, but also by the action of anthropogenic influences (Драгићевић and Филиповић, 2016). They also play a significant role in the evolution of relief. The impact of man on the occurrence of landslides today plays a significant role because in many areas, although they have a natural predisposition to the occurrence of the landslide process, they will not occur if all of the factors that cause this process are in balance.

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The term "landslide" includes a wide range of slope movements, such as landslides, mudslides, rockslides, etc. (Varnes, 1978; Pierson and Costa, 1987; Hutchinson, 1988; Cruden and Varnes, 1996; Hungr, Evans, Bovis and Hutchinson, 2001). Landslides are usually associated with triggers, such as earthquakes, sudden snowmelt, or heavy rainfall (Malamud, Turcotte, Guzzetti and Reichenbach, 2004). Like other natural disasters, landslides seriously endanger the safety of life and property of people and directly affect harmonious stability of society and sustainable economic development (Song, Srinivasan, Sookoor and Jeschke, 2017).

Various qualitative and quantitative methods in the GIS environment are used in the contemporary literature to analyse landslide susceptibility (Yalcin, 2008; He, Beighley, 2008; Rabby and Li, 2020; Li, Wang and Chen, 2021). For the purposes of this research, the quantitative statistical method *Probability Method (PM)* was used. Probability method is based on the assumption that landslides are caused by certain factors and that future landslides will occur under the same conditions as existing ones (Новковић, 2016). The analysed factors in this paper are geological structure, slope, aspect, curvature, distance from river flows, land cover and bare soil index.

Also, the *Landslide Susceptibility Index (LSI)* was used to integrate these factors and classes into a single index of susceptibility to the process of landslides. This well-known and widely used statistical method for zoning landslide susceptibility (Tien Bui, Lofman, Revhaug and Dick, 2011; Chalkias and Ferentinou, 2014; Polykretis, Ferentinou and Chalkis, 2015) results in a susceptibility map of the study area and the probability level of landslide occurrence.

In this paper, the research was conducted using open source software QGIS. Geographic Information Systems (GIS) are systems that enable the entry, search, analysis, manipulation, management and presentation of geographic information. Although GIS provides the use of additional information from various sources (Ракић, 2007), today, according to many authors, one of the biggest problems in Serbia is the lack of quality and up-to-date data (Stojković, 2017; Vagić, 2018).

The main goal of this paper is to create landslide susceptibility map of Sokobanja municipality using statistical methods in the GIS environment. The map obtained was used to identify roads and facilities that are subjected to damage from future landslides, and can be used to take the necessary measures to prevent landslides.

Materials and methods

Study area

The study area is located in the region of Eastern Serbia in the Zaječar district (Figure 1). The municipality of Sokobanja is located in the southwestern part of the Zaječar district between 43°31´41.1´´N and 43° 46´51.9´´N and 21°40´33.2´´E and 22°5´36´´E. It borders the municipality of Ražanj in the northwest, the municipality of Knjaževac in the northeast, the municipality of Aleksinac in the southwest and the municipality of Svrljig in the southeast.

The area of the municipality of Sokobanja occupies 525 km^2, and according to the 2011 cnesus it has 16 021 inhabitants, while the average population density is 27.95 inhabitants/km^2 (Republički zavod za statistiku, 2011). There are a total of 25 settlements in the municipality. The center of the municipality is the settlement of Sokobanja, which has the largest number of inhabitants, occupies the biggest area and also represents the administrative, economic and cultural center of the municipality. The most important roads within the municipality are the state roads of the second A order with the labels 217 and 218 and the state road of the second B order with the label 420, which connects to the state road with the label 217 (JP "Putevi Srbije", 2021).

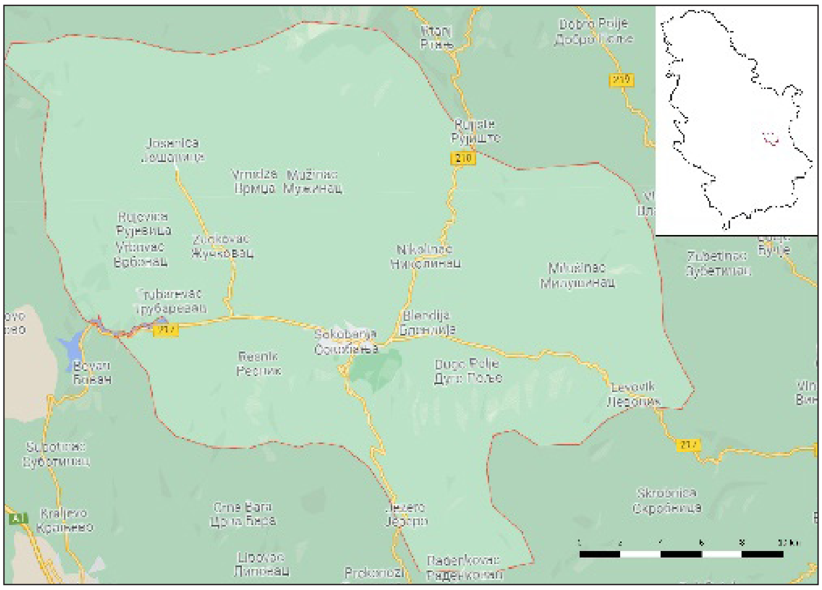


Figure 1. Geographical position of the municipality of Sokobanja in Serbia

On the territory of the municipality the most common relief type is the karst relief form. The river network is well developed, but most of it consists of occasional flows. The most important river, as well as the largest, which flows through this municipality is the river Moravica. The municipality of Sokobanja is also known for its thermal springs, which are used for balneological purposes.

Methodology

The used methodology includes the application of the Probability Method and the Landslide Susceptibility Index. Probability method determines the possibility of the landslides occurance in a particular class and is calculated by the formula (Van Westen, 1997):

$$Wij = \frac{Aij' * (A - A')}{A' * (Aij - Aij')}, \qquad (1)$$

where *Wij* – is the value of class i of the parameter *j*; *Aij′* –landslides surface in a certain class *i* of the parameter *j*; *Aij* –area of a certain class *i* of the parameter *j*; *A′* –total landslide surface in the study area; *A* – total are of the study area.

The higher the obtained value is, the stronger the dependence of the landslide occurrence is on a given factor and vice versa (Lee and Pradhan, 2006). The integration of different factors and classes into a single Landslide Susceptibility Index is achieved based on the formula (Voogd, 1983):

$$LSI = \sum n \; W_j * W_{\substack{ij \\ j=1}} \qquad (2)$$

where W_j – parameter value; W_{ij} – value of the class *i* of the parameter *j*; *n* – number of parameters.

Finally, all of the obtained index values are divided into four classes which represent four categories of landslide potential (low, medium, high and very high). There are no established rules for this division, so it is done subjectively, either on the basis of the researchers assessment or on the basis of some statistical method that is contained in the GIS software – e. g. based on equal intervals, natural breaks, standard deviation etc. (Новковић, 2016)

The application of the Probability Method was performed based on the data about geological structure, relief characteristics (slope, aspect and curvature), distance from rivers, land cover (CORINE Land Cover[2]) and values of BSI (bare soil index[2]).

The basis of the calculation consists of a raster digital model with a resolution of 25 m from which the data about slope, aspect and curvature were extracted and then divided into classes based on the importance of participation in the emergence and development of the landslides process. Data on the value of bare soil index were obtained by analysis of multispectral images from Landsat 8 satellite. Geological structure, land cover and distance from rivers were rasterized based on a vector data model because of the calculation needs. Tables 1-7. shows all used parameters.

Table 1. Display of LSI values for geological formations

	Area		**Landslides**		**Wij**
	km2	%	km2	%	PM
Landslides	529	100	62.1	11.74	
Geological formation					
Rock creep	6.2	1.17	1.18	1.9	1.76
Tuff rock	0.55	0.1	0.28	0.45	7.61
Alluvial sediment rocks	13.13	2.48	0.46	0.74	0.27
Sediments of the river terrace	2.74	0.52	0.16	0.26	0.47
Tertiary carbonate sediment rocks	1	0.19	0	0	0
Tertiary clastic sediment rocks	214.26	40.5	51.26	82.54	2.36
Mesozoic clastic sediment rocks	8.26	1.56	0.32	0.52	0.3
Mesozoic clastic and carbonate sediment rocks	75.95	14.36	3.93	6.33	0.41
Mesozoic carbonate sediment rocks	105.41	19.93	1.46	2.36	0.11
Volcaniclastics	5.13	0.97	0	0	0
Igneoous rocks	1.47	0.28	0.33	0.53	2.16
Paleozoic clastic sediment rocks	36.3	6.86	0.89	1.43	0.19
Paleozoic carbonate sediment rocks	1.8	0.34	0.03	0.05	0.14
Metamorphic rocks	56.79	10.74	1.8	2.9	0.25

[2] The map of geological structure of the study area was obtained by digitizing the contents of basic geological maps, sheets: Boljevac K34-8, Zaječar K34-9, Žagubica L34-140 and Bor L34-141, scale 1: 100,000, issued by the Federal Geological Survey in 1975, using an interpreter to analyse the contents of the map. The river network was digitized from topographic maps of the sheets Aleksinac 1, 2, 3, 4 and Zaječar 3. The digital elevation model and land cover were downloaded from the website https://land.copernicus.eu/, and satellite images from https://www.usgs.gov/

Table 2. Display of LSI values for slope

	Area		Landslides		Wij
Slope	km2	%	km2	%	PM
<2°	27.33	5.17	2.3	3.72	0.7
2-5°	90.6	17.13	10.39	16.83	0.98
5-10°	186.5	35.25	28.84	46.72	1.38
15-20°	118.95	22.49	13.38	21.67	0.96
15-20°	61.29	11.59	3.86	6.25	0.51
20-30°	39.47	7.46	2.38	3.86	0.49
>30°	4.88	0.92	0.59	0.96	1.04

Table 3. Display of LSI values for aspect

	Area		Landslides		Wij
Aspect	km2	%	km2	%	PM
N	61.32	11.59	15.74	25.49	2.61
NE	59.76	11.3	4.18	6.77	0.57
E	54.21	10.25	2.91	4.71	0.43
SE	60.99	11.53	5.55	8.99	0.76
S	84.46	15.96	4.88	7.9	0.46
SW	87.65	16.57	3.99	6.47	0.36
W	66.34	12.54	4.49	7.28	0.55
NW	53.6	10.13	4.74	7.68	0.73
Not exposed	0.69	0.13	15.26	24.71	0

Table 4. Display of LSI values for curvature classes

	Area		Landslides		Wij
Curvature	km2	%	km2	%	PM
1 - vertically concave, horizontally concave	131.29	24.82	15.74	25.49	1.03
2 - vertically flat, horizontally concave	33.12	6.26	4.18	6.77	1.09
3 - vertically convex, horizontally concave	31.8	6.01	2.91	4.71	0.76
4 - vertically concave, horizontally flat	40.45	7.65	5.55	8.99	1.2
5- vertically flat, horizontally flat	37.39	7.07	4.88	7.9	1.14
6 - vertically convex, horizontally flat	35.45	6.7	3.99	6.47	0.96
7 - vertically concave, horizontally convex	37.92	7.17	4.49	7.28	1.02
8 - vertically flat, horizontally convex	37.41	7.07	4.74	7.68	1.1
9 - vertically convex, horizontally convex	144.19	27.26	15.26	24.71	0.9

Table 5. Display of LSI values for distance from rivers [m]

	Area		Landslides		Wij
Distance	km2	%	km2	%	PM
<100	128.91	24.37	18.68	30.07	1.27
100-200	112.76	21.32	15.85	25.52	1.23
200-300	89.01	16.83	11.43	18.4	1.11
300-400	62.81	11.87	7.11	11.45	0.96
400-500	41.49	7.84	4.33	6.98	0.88
>500	94.03	17.77	4.7	7.58	0.4

Table 6. Display of LSI values for Corine land cover 2018

	Area		Landslides		Wij
Land Cover	km2	%	km2	%	PM
Bigger settlements	8	1.51	2.56	4.16	3.57
Sport and leisure facilities	0.33	0.06	0	0	0
Agricultural areal	40.7	7.69	3.21	5.21	0.65
Orchards	0.27	0.05	0	0	0
Meadows	5.96	1.13	1.72	2.78	3.06
Complex of agricultural plots	67.12	12.69	20.62	33.47	3.36
Agricultural areas with a significant share of natural vegetation	95.5	18.05	23.73	38.51	2.51
Deciduous forests	180.22	34.07	6.8	11.04	0.3
Coniferous forests	2.17	0.41	0.04	0.06	0.13
Mixed forests	11.95	2.26	0.16	0.27	0.11
Grasslands	44.68	8.45	0	0	0
Transitional woodland-shrub vegetation	66.76	12.62	2.77	4.49	0.33
Sparsely vegetated areas	4.19	0.79	0	0	0
Water bodies	1.15	0.22	0.01	0.01	0.04

Table 7. Display of LSI values for BSI

	Area		Landslides		Wij
BSI	km2	%	km2	%	PM
<0.5	0.52	0.1	0.01	0.01	0
0.5-0.6	44.35	8.38	3.74	6.02	0.06
0.6-0.7	209.55	39.61	16.77	27	0.27
0.7-0.8	100.09	18.92	15.32	24.66	0.25
0.8-0.9	94.39	17.84	15.26	24.56	0.25
0.9-1.0	65.27	12.34	8.8	14.17	0.14
1.0-1.1	14.35	2.71	1.83	2.94	0.03
>1.1	0.17	0.03	0.02	0.04	0

The PM method application implies the existence of landslides spatial distribution data and for the purposes of this paper landslides data for Eastern Serbia were used. (Dragićević, Novković, Carević, Živković and Tošić, 2011). The landslide distribution data were overlapped with all individual parameters according to the formulas for each parameter. The pixels in each of the rasters representing the parameter classes were then reclassified. The value of the spatial distribution of LSI for the study area was obtained by summing the raster of all parameters.

Results and discussion

The results of the statistical (LSI) analysis for the study area, as well as the distribution of existing landslides are shown in Figure 2.

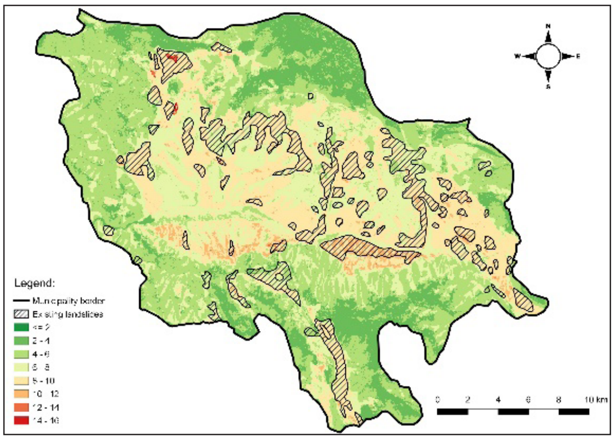


Figure 2. Spatial distribution of LSI on the territory of the municipality of Sokobanja

After the LSI index classification, 4 classes of susceptibility to the sliding process were obtained (Figure 3), and the average value of LSI for the territory of the municipality is 6.91.

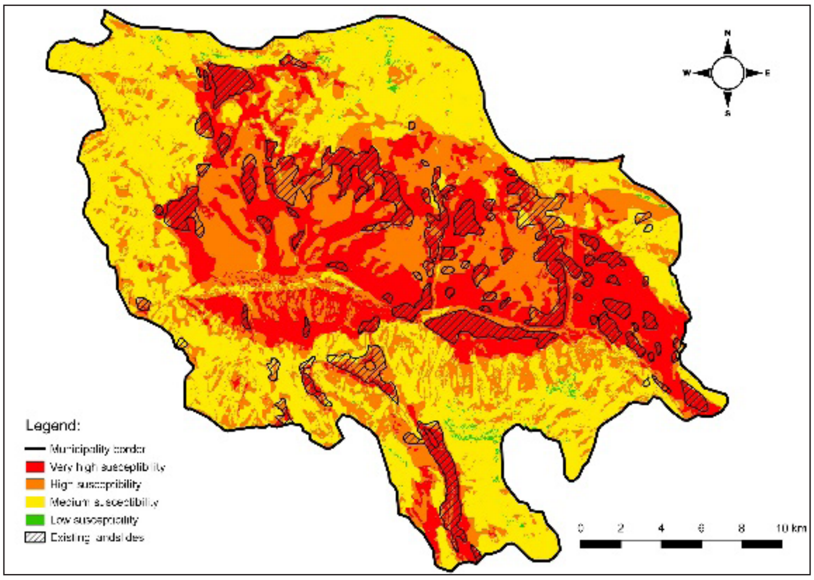


Figure 3. LSI by susceptibility classes

According to the estimations, very high susceptibility occurs in 28.19% of the territory, while low susceptibility occupies the smallest part of the territory (table 8). The largest part of the territory belongs to the class of medium susceptibility (41.02%).

Table 8. Contribution of susceptibility classes to the process of landslides in the Sokobanja municipality

Landslides susceptibility	km^2	%
Very high	148.80	28.19
High	159.70	30.26
Medium	216.51	41.02
Low	2.78	0.53
Total	527.79	100

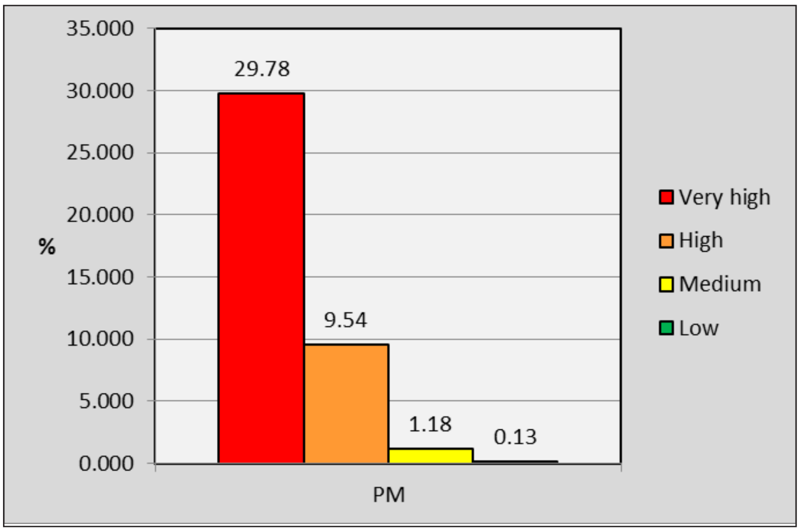
Further comparison of the obtained PM values was performed by overlapping the existing landslides and the formed classes of susceptibility to the soil sliding process (table 9).

Table 9. Contribution of soil susceptibility classes in Sokobanja municipality landslides

Landslides in susceptibility classes	km²	%
Very high	44.31	71.36
High	15.24	24.54
Mediuma	2.55	4.10
Low	0.00	0.01
Total	62..09	100

Based on Table 9, it can be concluded that the most common is the very high susceptibility within the already existing landslides.

Graph 1 shows the percentage of each susceptibility class that landslides occur in. In the class of very high susceptibility, landslides occur on 29.78% of the territory, and in the class of low susceptibility, only 0.13%.



Graph 1. The share of landslides in the classes landslides of susceptibility

Based on the LSI value for the municipality territory, it is possible to determine the average value of vulnerability for each cadastral municipality. Table 10 shows the average values of LSI by cadastral municipalities.

Table 10. Overview of LSI average values by settlements

Name of cadastral municipality	Average value of LSI
Beli Potok	8.08
Blendija	6.77
Bogdinac	7.77
Vrbovac	5.69
Vrmdža	5.87
Dugo Polje	6.69
Žučkovac	7.87
Jezero	5.56
Jošanica	5.62
Levovik	5.84
Milušinac	6.46
Mužinac	5.64
Nikolinac	7.59
Novo Selo	4.92
Poružnica	5.58
Radenkovac	5.22
Resnik	6.29
Rujevica	5.26
Sesalac	6.47
Sokobanja	7.00
Trgovište	7.94
Trubarevac	5.78
Cerovica	6.76
Čitluk	7.86
Šarbanovac	5.89

Based on Table 10 and Figure 4, it can be concluded that in the municipality none of the average value fall into the low category. Six cadastral municipalities are in the category of very high susceptibility according to the mean value, 18 in the category of high susceptibility, and only one is in the category of medium susceptibility. The highest susceptibility according to the mean value is found within cadastral municipalities where landslides already exist, which are mostly located within tertiary clastic sediment rocks.

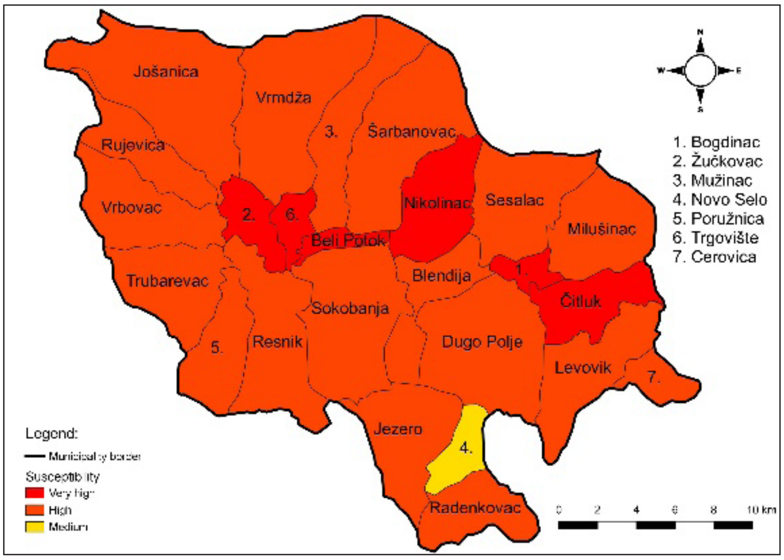


Figure 4. Mean value of LSI by cadastral municipalities

The endangerment of traffic infrastructure and facilities on the territory of the municipality is shown in Figures 5 and 6. Figure 5 shows that landslides mostly occupy areas within uncategorized roads or directly next to state roads of the second order. The length of roads endangered by landslides is 369.5 km.

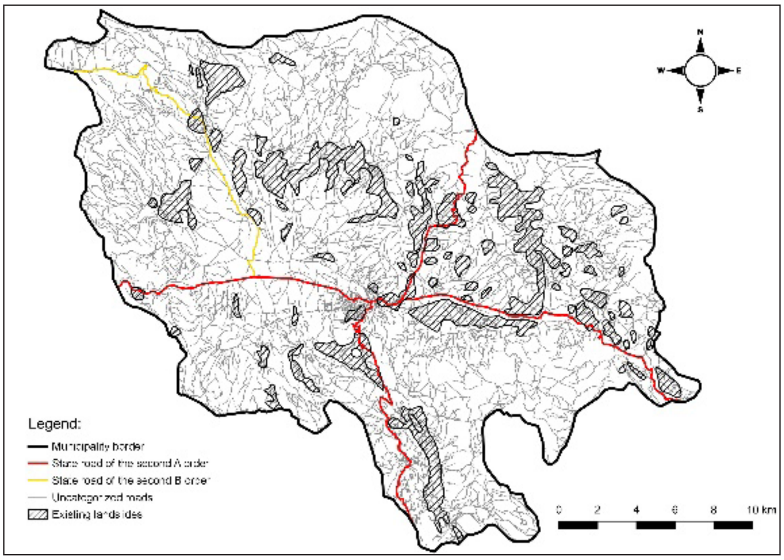


Figure 5. Endangerment of traffic infrastructure with landslides

Figure 6 shows the facilities overlapping with the existing landslides.

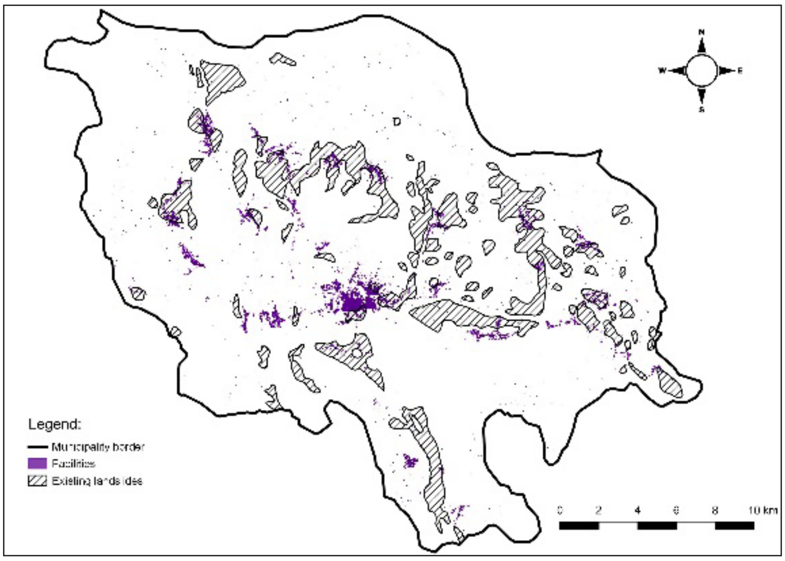


Figure 6. Vulnerability of facilities to landslides

The area of the landslide occupied by the facilities is 0.71 km^2. This may indicate that landslides were caused by anthropogenic impact on terrains that were already naturally predisposed to the occurrence of a landslide process.

Conclusion

Landslide susceptibility mapping is extremely important for the identification of landslide susceptibility areas in order to reduce future landslides and damage to infrastructure and facilities. The application of statistical analysis in the GIS environment evaluate the relationship between the occurrence of landslides and various influencing factors. In this paper, seven factors that affect the occurrence of landslides were used (geological structure, slope, aspect, curvature, distance from rivers, land cover and bare soil index), which were collected and processed in the GIS environment.

The choice of these factors plays a major role in the relative accuracy of the analysis outcome, regardless of the model applied. Based on the obtained results, it is obvious that the most important factors for the occurrence of landslides in the municipality of Sokobanja are the geological structure and the manner of land use. A large number of already existing landslides occur on built and agricultural areas, which indicates omissions in the analysis of the terrain during process of land use decisions making.

The applied methodology, more specifically the Probability Method, shows a high degree of reliability in predicting the occurrence of landslides, because already existing landslides are in classes in which the value of PM is highest, or in classes of very high or high susceptibility. In a very high susceptibility class there are 71.36% of already existing landslides, and a very small percentage are in the middle and low susceptibility class.

Regardless of the high quality of the obtained results, it is necessary to point out some limitations of the applied methodology. Adequate data are most important for quality GIS analysis. The problem arises if required data are not available or do not exist. Given the changes in natural and anthropogenic factors that are important for these processes, it would be best to establish a system of periodic or continuous monitoring and verification of the situation on the terrain. Also, it should be noted that, according to this analysis, the output map represents only the predicted spatial distribution of landslides, and not their time probability.

By applying modern technologies, it is possible to collect detailed data on the analyzed area, and then, using GIS, perform both the processing of such collected data and the development of a model of the future situation. This way of analysis can prevent potential disasters if implemented in time or at least reduce their negative effects. Despite the observed limitations, the produced map could be very useful for the selection of suitable locations for future land use planning and the development of the municipality of Sokobanja.

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OBJECT DETECTION IN ORDER TO DETERMINE LOCATIONS FOR WILDLIFE CROSSINGS

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Abstract: The intensive construction of road infrastructure due to urbanization and industrialization around the world carries with it negative environmental impacts, primarily due to increased emissions of gases, but also due to the separation of natural habitats and ecosystems. In order to overcome this problem, without affecting the mobility of the population, it is necessary to allow wild animals to cross over or below the roads, i.e. to create wildlife crossings, which requires knowledge of the locations where the corridors of animal movements intersect with existing or planned roads. This paper analysis the establishment of a camera system and the application of a deep learning methodology for the automatic identification of animals by species and number, in order to determine locations for the construction of crossings for large wildlife. Also, the paper presents the possibility of using geographic information systems to analyze information obtained by monitoring built wildlife crossings.

Keywords: deep learning, GIS, object detection, wildlife crossings.

Introduction

Throughout recent history, people's lifestyles have changed rapidly. Modern world trends bring a huge risk of degradation of environment in which people live (Vagić, 2018). A great deal of scientific research shows that life on Earth depends on maintaining much fragile equilibrium with a series

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of complex processes between them (Milinčić et al., 2015). The cities are growing, the industry is diversifying, there are more and more vehicles on the roads, resulting in intense degradation of environment in which we live, but also that we share with other living beings. There are constant changes in the environment that have a direct impact and consequences on species, their communities and ecosystems as a whole (Đurđić et al., 2015). Due to modern activities and modern lifestyles, the mobility of the population is constantly increasing. With a production trend of 50 million vehicles per year, it is estimated that there will be around one billion passenger cars in the world in two decades (Mihajlović & Marinković, 2016). In order for a society with so many vehicles to function optimally, the existence of an extensive network of transport infrastructure is necessary. Just in period of 2015-2019, 320 kilometers of highways were built in Serbia (Srna, 2019), which can certainly represent the progress of our society, but only if implemented properly.

By building transport infrastructure, we think first of all of our needs, and only later on, of the needs of other living beings, and often we neglect them. As new roads emerge, many animal migration corridors are being intersected. It is very important for healthy ecosystem that large mammals have possibilities for free movement through the large areas. The migrations are essential for keeping the balance between animal populations, maintaining sufficient genetic diversity or preventing the temporary lack of food (Matuska et al., 2018). It is only when the survival of a certain species is called into question that we begin to think about the possible consequences and steps needed to repair the damage, but in many cases it is too late.

As already indicated, the modern way of life carries with it many negative consequences for our society as a whole. However, relevant elements of modern society can also be used to mitigate or even eliminate harmful anthropogenic environmental impacts. The development and expansion of computer systems has reached a level that could not have been imagined since the beginning of the 20^{th} century. The development of artificial intelligence is growing exponentially, and this trend should, among other things, be directed towards preserving a healthy or, in difficult circumstances, towards healing the damaged environment.

In order not to limit the mobility of the population, while preserving healthy ecosystems of large wildlife, it is necessary to allow the crossing of the human movement corridors with the animal migration corridors, but in such a way that both humans and animals do not interfere with each other in these constant processes. The simplest solution to this problem is construction of wildlife crossings. Wildlife crossing structures help wildlife move between habitats by connecting fragmented habitats (Seo et al., 2021). The number of wildlife crossings built in North America and worldwide has increased during the last decade and their design and performance as mitigation measures has received considerable attention (Clevenger, 2005).

Many large wildlife such as chamois, mouflon, roe deer, deer, wild boar, fox, jackal, wolf, lynx and bear are found on the territory of Serbia (Službeni glasnik RS, 2010a). However, although in Serbia the law and project documentation stipulate the existence of such structures (Službeni glasnik RS, 2010b; JP Putevi Srbije, 2012), so far none have been built. One of the positive examples that things are beginning to change is the international project for the revitalization and management of the ecological corridors of large mammals in the Carpathian region and in the Republic of Serbia named "Connect grin" (RTS, 2019). According to this project, in the future, we should have a map of a clearly defined ecological corridor that will help planners to identify places where wildlife crossings will be over, for example, the Đerdap highway. On the other hand, in some states, such structures are an integral part of the roads design, and so, currently in California (USA), it is planned to construct a wildlife crossing over a 10-lane highway that will be 60 meters long, and as such will be the largest in the world (Aleksić, 2019).

The main goal of this paper is to represent possibilities of a deep learning methodology application on images obtained from camera systems, for the automatic identification of animals by species and number, in order to determine locations for the construction of crossings for large wildlife.

Research methodology

Wildlife crossings can provide linkages, improve connectivity, and mitigate the incidence of road kills, and it can generally be divided into overpasses and underpasses (Ernst, 2014; Pierik et al., 2016). Overpasses or "green bridges" provide open views and sufficient space for animals, which is generally more suitable for species that instinctively avoid narrow and dim spaces. On the other hand, underpasses are intended for small mammals, amphibians, and reptiles, often taking the form of tunnels or small culverts (Zhang et al., 2019).

However, the problem that arises is how to determine the locations where these crossings should be built and what type they should be, because we cannot just place a crossing over a road in a place that seems appropriate to us or that is the easiest or most convenient for construction and that afterwards we hope that some animals will use it. Due to their costs, wildlife crossing structures are usually installed sparsely and at strategic locations along transportation networks (Bhardwaj et al., 2020). An important fact to keep in mind is that making adequate decisions regarding the protection, preservation and improvement of the environment depends in part on quality information and their expert interpretation (Sredojev et al., 2011). With the use of computer vision technology, we can efficiently and accurately monitor wildlife (Lu & Lu, 2022).

This paper proposes the monitoring of roads through the establishment of a camera system that will cover all parts of roads where it is possible to build wildlife crossings, as well as the surrounding area, in order to detect the movement of different species of large wildlife. Cameras can be installed on the pillars of existing energy, telecommunication, or traffic signalization infrastructure where possible, and where such a possibility does not exist, special pillars should be placed for the installation of cameras.

The next question that arises here is how to review hours and hours of videos in order to find the ones which captured certain animals moving near roads or even on the roadway, thus endangering the safety of road users as well as their own safety. Manual detection relies on observers, and observers can be subject to biases and other factors, including fatigue, interest, skill level, training, eyesight etc. (Ulhaq et al., 2021). Fortunately, with the proper use of technology and software engineering, those hours of footage do not even have to be viewed in their entirety, but different deep learning methods can be used to identify objects in videos, where it is very easy to get information at what location, at what time, how much, and which animals were recorded.

Object detection is an important technology that enables computers to have object detection ability such as human vision by recognizing each object in an image (Lee & Hwang, 2021). One methodology that can be used for this purpose is YOLO (You Only Look Once) (Redmon et al., 2016). Processing images with YOLO is simple and straightforward. System resizes the input image runs a single convolutional network on the image, and thresholds the resulting detections by the model’s confidence (Figure 1).

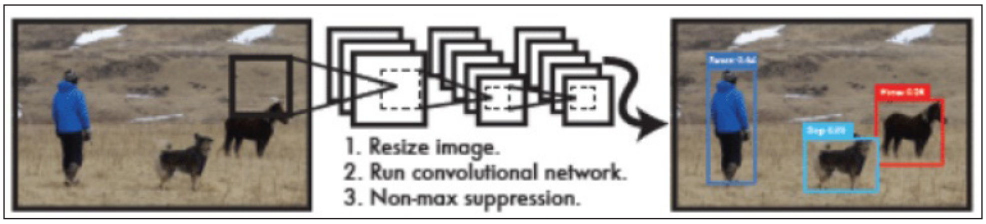

Figure 1. YOLO processing images (Redmon et al., 2016)

A single convolutional network simultaneously predicts multiple bounding boxes and class probabilities for those boxes. YOLO trains on full images and directly optimizes detection performance. This unified model has several benefits over traditional methods of object detection (Figure 2).

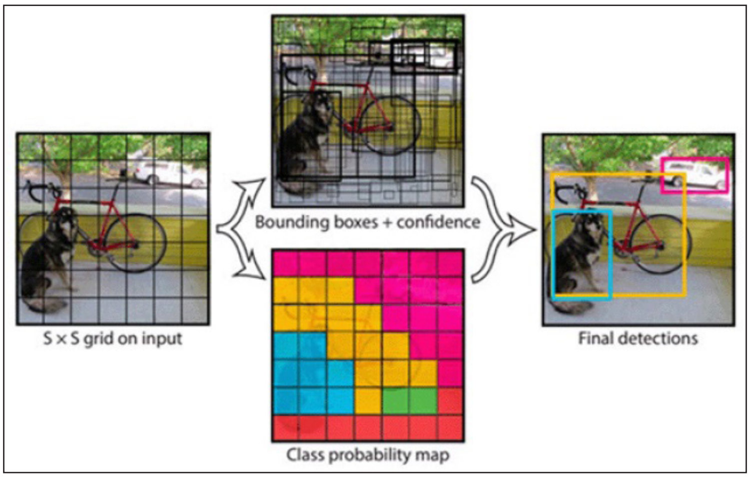

Figure 2. A simplified illustration of the YOLO object detector pipeline (Redmon et al., 2016)

Object detection is reframed as a single regression problem, straight from image pixels to bounding box coordinates and class probabilities. Using YOLO, you only look once (YOLO) at an image to predict what objects are present and where they are. YOLO trains on full images and directly optimizes detection performance. YOLO models detection as a regression problem divides the image into an *SxS* grid and for each grid cell predicts *B* bounding boxes, confidence for those boxes, and *C* class probabilities. These predictions are encoded as an $S \times S \times (B * 5 + C)$ tensor. YOLO is extremely fast. Since frame detection is performed as a regression problem it doesn't need a complex pipeline, simply run neural network on a new image at test time to predict detections.

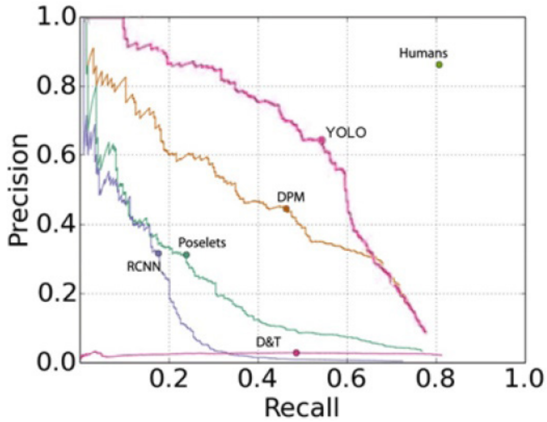

Figure 3. The precision-response relationship of the YOLO method for detecting objects and other methods on a Picasso image set (Ginosar et al., 2014)

In Figure 3 curves showing the precision-response relationship of the YOLO method for detecting objects and other methods on a Picasso image set, and it can be seen that the YOLO object detection method displays the best results on this test (Ginosar et al., 2014).

An alternative way of collecting data on animal movement locations which is not requiring large financial investments as a previously explained method in terms of the purchase of surveillance equipment, its placement, power, maintenance, etc., involves incorporating the presented algorithm into advanced smart systems in vehicles.

The automotive industry has undergone significant changes in the last ten years. The level of vehicle autonomy is increasing every day and autonomous vehicles are becoming a daily reality. Also, there are systems in place to minimize human errors while driving, reduce road accidents, and thus provide people with greater safety. The name of such systems is ADAS (Advanced Driver Assistance System). Autonomous vehicles need to perform their functions without the need for driver intervention, and in order to be able to do so, they need to incorporate some form of artificial intelligence. Therefore, it is necessary to have different sensors that provide information from the environment and a computer system that based on that information and appropriate algorithms make decisions when driving autonomously. One of the basic functions that autonomous vehicles need to perform is the detection of objects in front of the vehicle. There should be information at all times about the objects in front of them. This function can be achieved by using the information obtained from the camera image on the front of the vehicle (Ciberlin, 2018).

Cars have been equipped with camera systems for several years now that cover the entire vehicle environment. The capabilities of such systems are best illustrated with a bird's eye view and a 360° view, where in both cases the vehicle itself is shown in real time and space, based on the merging of different images from cameras on the vehicle which are working as a single system (Figure 4).

Figure 4. A bird's-eye view of the car and an outline of the car's environment with 360° rotation (DeMuro, 2018)

If automakers include the object detection algorithm presented in this paper in their smart systems, it would open wide opportunities for collecting animal movement data near or even on the roadway. In the case of an animal detection, the system could send data about the time, location, type and number of animals detected to the central base of each state with a video clip from the cameras that detected the animals, which could help verifying whether the detection is correct or some errors may have occurred. Of course, there are no such vehicles on the Serbian roads in enviable numbers, so initially, most of the time the roads will be unmonitored. However, in the future, their numbers will grow very fast, and with them the opportunities for putting this system into practice will grow too.

The locations of the so collected data can be mapped and analyzed in the geographic information system (GIS) with a goal to propose the best sites for wildlife crossings. In contemporary literature, many authors emphasize the importance of GIS application for locating and monitoring wildlife crossings (Alexander, 2008; Aquino & Nkomo, 2021; Clevenger et al., 2002; Karlson et al., 2017; Leoniak et al., 2012). By finally constructing wildlife crossings at locations that would be best according to the presented methodology, the same camera system can monitor them, which gives an insight into whether animals use a placed overpass or underpass and, if so, to what extent. Such monitoring can collect data from a network of all crossings in the country, and even more broadly if the system is established at regional or even continental level.

Further, such results can be linked so the movements of animals across large areas can be tracked through geographical information systems. For example, if a certain number of animals of one species is detected at one crossing, and after a certain time, the same number of animals of the same species is detected at another crossing, and by checking the recordings we find that they are identical animals, their path and speed of movement can be counted by GIS and generally predict their further migratory movements, which is essential for understanding the functioning of ecosystems and determining measures for their conservation and protection.

Research results

For real-time deep learning-based object detection in this paper we used OpenCV and Python. YOLO trained on the COCO dataset consists of 80 labels, including animals, cats, dogs, birds, horses, cows, and sheep. The YOLO object detector divides an input image into an *SxS* grid where each cell in the grid predicts only a single object (Figure 5).

Figure 5. Animal detection using YOLO

The research of the possibility of using the presented methodology for the detection of roadside animals was conducted on February 22, 2020, where a fixed camera simulation on the front of a moving vehicle was done. The camera from a Xiaomi Mi 8 Lite mobile device with 4K resolution at

30 FPS (frames per second) was used. Certainly, the quality of the camera can significantly affect the final results of object detection, especially when it comes to shooting from a moving vehicle, because as the speed of the vehicle increases, the quality of the shot decreases, more precisely the objects are more and more difficult to recognize. Therefore, the higher resolution of the camera and the number of frames per second of the video implies the greater possibilities for obtaining high quality results of object detection in poor shooting conditions and circumstances.

To demonstrate the possibility of using the YOLO object detection algorithm, stray dogs were taken as an example, as the only realistic option that doesn't require significant financial investment and high risk exposure, both for humans and animals that can potentially be recorded roadside and on the pavements in Serbia.

Figure 6. Detection of dogs on the road from the moving vehicle using YOLO

The result of the survey is shown here in the form of the image obtained from the processed video, which shows dogs running on the roadway in front of the moving vehicle from which the shooting was made. Using the object recognition algorithm, it is clearly marked that there are two dogs, but also other objects that the algorithm is "trained" to recognize can be marked, such as in this case a parked car (Figure 6).

Conclusion

Modern lifestyle patterns are causing the need for increasing population mobility, sometimes to such an extent that it looks as the planet we live on is getting smaller. If we already can't give up many aspects of our lifestyle today, we can at least try not to be negligent on the environment in which we live and give the next generations at least the same chance we had, if we could not already provide them the better one. One of the essential elements of preserving a healthy environment is non-interference of wildlife ecosystems with anthropogenic activities. Nevertheless, the construction of each road opens the possibility of a detrimental effect on the freedom of steady movement of wildlife.

This paper offers a simple solution for determining the appropriate locations where it is necessary to build wildlife crossings so that humans and animals can navigate even with crossing their paths, but without interfering with and mutually affecting each other. The solutions presented can be of great importance for the conservation and advancement of different animal species under the conditions of expansive road construction in Serbia in recent years and show how the application of different algorithms through geographic information systems can be a powerful and affordable tool to protect many animal species as well as the environment as a whole.

The great advantage of using the YOLO object recognition algorithm in general is that, in addition to standard objects (humans, animals, vehicles, etc.) the algorithm can be "trained" to recognize anything that can be isolated as an object in a particular image or video. Therefore, the algorithm can be shaped to the user's specific needs. The training of the algorithm can be done by using images with different variations (by types, recording angles, etc.) of the object that we want to recognize in different videos in perspective. According to that, if much more different images are entered into the algorithm, the better quality and accuracy of object recognition will be later, and recommended minimum is 1000 images. This is precisely the biggest obstacle to improving and designing this methodology for our own needs, as it is necessary to provide and process more than 1000 images on the same topic.

However, this is certainly not an insurmountable obstacle, and the degree of engagement to overcome it will depend primarily on the subject matter for which the algorithm is designed, that is, the availability of images on the chosen topic and the ability to collect them. In future, it is plan to create our own training model and demonstrate object detection based on it, as the next research step in this area.

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LIMNOLOGY OF PROFESSOR STEVANA M. STANKOVIĆ

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Abstract: Natural and artificial lakes are hydrographic objects of multiple importance, time of creation, dimensions and evolution. They are significant for a number of natural phenomena and processes, as well as for numerous human activities. The science of lakes is called limnology and is a part of terrestrial water hydrology. The first scientific data, from a geographical aspect, about the large lakes of Old Serbia, Macedonia and Greece was presented by Jovan Cvijić in his geomorphological studies. From the biological aspect, the limnological works of Siniša Stanković are significant. Based on the works of these scientists, research and publication of works by professor Stevan M. Stanković, who in his own way revitalized the limnology of our expanses. In this paper, we present his oeuvre from the domain of limnology.

Key words: Stevan M. Stanković, limnology, natural lakes, artificial lakes, genetic classification, protection, valorization, bibliography.

Introduction

Lakes as hydrographic objects of multiple importance and purpose, manner and time of their formation, morphometric and evolutionary characteristics, attracted the attention of Stevan m. Stanković already in the first years of his assistantship at the Faculty of Geography, University of Belgrade. First, in 1965, he published a work on Lake Bor and thus began limnological research, linking to the enormous wealth of the written word of Jovan Cvijić, which partly refers to the large tectonic lakes of Macedonia and

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Greece, as well as to the glacial lakes of the highest mountains of the Balkan Peninsula.

At the scientific meeting, held in 1982 at the Serbian Academy of Sciences and Arts, in a report entitled Cvijić's contribution to the development of limnology in Yugoslavia, Professor Stevan. M. Stanković, stated that „Studying the geological structure, the origin and evolution of the relief, the macrotectonics of the Balkan Peninsula, the karst process in all its manifestations, abrasion and traces of the Pleistocene glaciation, in different parts of our country and the Balkan Peninsula, Jovan Cvijić repeatedly "... entered into the problems of limnology - lake science. From the great work of Jovan Cvijić, it is difficult to single out works with exclusively limnological issues, but in many works it is easy to discover data very important for the knowledge of lakes in our country and the development of limnology in it... In 1902, Jovan Cvijić published the Atlas of the Lakes of Macedonia, Stare Serbia and Epirus. It represents a kind of whole with the book Basics of Geography in the Geology of Macedonia and Old Serbia. The Atlas, and the three volumes of the aforementioned book, were, and still remain, the most significant limnological literature on the lakes of the southern part of the Balkan Peninsula" (Станковић, М. С. 1982).

Magisterium degree on artificial lakes of Serbia

As a postgraduate student, Stevan M. Stanković wrote and defended his master's thesis under the title Tourism Valorization of Artificial Lakes of Serbia. When the manuscript of the master's thesis was submitted for printing, the reviewers Professor Dušan Dukić and Professor Tomislav Rakićević submitted the written review to the Serbian Geographical Society. In it, among other things, they wrote the following: "At the session of the Editorial Board of the Serbian Geographical Society on November 6, 1974, we were appointed as reviewers of the work of Stevan M. Stankovića Tourism valorization of artificial lakes of Serbia. The work was submitted to the Serbian Geographical Society with a request to be printed as 41 volumes of the Special edition.

Stevan M. Stanković started from the basic principles of the theory of tourism valorization, assessing the importance of attractiveness of motifs, their geographical location and distance from tourist dispersants. Using the comparative method, however, he established mutual relations in this grouping of tourist values of Serbia. Highlighting the three areas of artificial lakes (the Drina basin, the South Morava basin and the Western Morava basin) and the lake in Đerdap as a separate entity, Stevan M. Stanković presented their basic features. The characteristics of the geographical and tourist-geographic position according to the main communication routes, according to urban settlements and densely populated areas and the increase with other types of tourist motives were discussed in more detail.

In the section on climate-hydrographic properties (air temperature, precipitation, cloudiness, insolation, winds, physical and chemical properties of water, shoreline movement, color and transparency of lake water), Stevan M. Stanković pointed out a number of specificities and individualities of artificial lakes that must be taken into account when activating them for tourism. The most concrete and, from the point of view of tourist practice, the most notable considerations in the work refer to the analyzes of coastal lines. In this regard, the lakes are defined in relation to each other and certain sectors of their coastal lines. Based on the above, the Commission considers that the work of Stevan M. Stankovića Tourist Valorization of Artificial Lakes of Serbia represents a special scientific contribution to tourism-geographical literature and can be useful in the practical solution of a number of problems of economic valorization of artificial lakes, of which there are more and more in Serbia.

Doctorate about the mountain lakes of Montenegro

On the recommendation of professor Dušan Dukić, Stevan M. Stanković chose the topic Mountain Lakes of Montenegro for his doctoral dissertation. After four years of field research and insight into domestic and foreign literature in the domain of limnogogy, he wrote and defended his dissertation at the Geography Faculty of the University of Belgrade. He published his master's thesis and doctoral dissertation in 1975, his master's degree at the Serbian Geographical Society in Belgrade, and his doctorate at the Society for Science and Art of Montenegro in Titograd.

In the conclusion of the report on the doctoral dissertation Mountain Lakes of Montenegro, Stevana M. Stanković, which was submitted to the Scientific and Teaching Council of the Department of Geographical Sciences of the Faculty of Science, University of Belgrade, on January 21, 1974, professors Dušan Dukić, Ph.D., Milorad Vasović, Ph.D., Tomislav Rakićević, Ph.D., and Dragutin Petrović, Ph.D., among other things, pointed out and the following: "Mr. Stevan Stanković devoted his attention to the study of lakes in the mountains of Montenegro for many years. Regardless of whether something was written about some of them or not, he visited each of the 28 lakes, and some even more than once, always bringing new data from the field. The result of those researches, started in 1967, is this doctoral dissertation, which is original and the first of its kind in our physical-geographical and limnological literature in terms of its problems and content. The candidate studied 28 mountain lakes, the total water area of which is 3,898 km2, and according to St. Stanković has a total of 22,909 million m^3 of water in them. Therefore, these lakes are small in area, but from a scientific point of view, they are very interesting, and for the local population and herders, they are an important source of water supply. In recent years, they have become more and more attractive for tourists, so the problems of their modern valorization arise from that."

The reviewers of the monograph Mountain Lakes of Montenegro, professor Dušan Dukić, professor Milorad Vasović and professor Dragutin Petrović, stated several important elements. The monograph has 228 pages of text, a table of morphometric indicators of the lake, 39 tables in the text, 30 sketches and 37 photographs. The material is divided into 12 chapters. "In the introduction, Dr. Stevam M. Stanković pointed out that the mountain lakes of Montenegro were not the subject of more exhaustive physical-geographical studies and presented the methodology of studying those lakes. In the analysis of previous studies, he presented an overview of the literature in which some data were given about the mountain lakes of Montenegro, starting with Jovan Cvijić. However, none of the researchers of our mountains noticed the importance of those lakes or took them as the subject of their studies, so the results in the monograph of Stevan M. 90 percent of Stanković is his. It is well done that the description of the studied lakes is given by the mountains on which they are located. Dr. Stevan M. Stanković first gave the physical-geographic characteristics of each mountain, and then their lakes; 10 on Durmitor, 6 on Bjelasica, 5 on Prokletije and Visitor, 3 on Volujak, 2 on Sinjavina and 2 on Lukavica. For each of the 28 studied lakes, its location and accessibility are given, then its morphometric characteristics are presented with tables of the surface and volume of the lake under individual isobaths and the total, then the genesis of the lake basin and the level regime with a brief description of the physical and chemical properties of the lake water. That part of the work, in which he presents data about each lake individually, is the basis of the monograph and its most extensive part. Monograph of Dr. Stevan M. Stanković on the mountain lakes of Montenegro would remain incomplete without sections IX and X, which represent a synthesis of previous presentations.

In the section Genetic and hydrological classification of the studied lakes, 5 groups of lakes were distinguished according to the genesis of the formation of lake basins, and 7 groups according to hydrological classification. In the section Problems of protection and valorization of the studied lakes, Stevan M. Stanković notes that protection does not mean conservation and prevention of any human activity. Stevan M. Stanković proves the unjustification of projects to use the basins of these lakes for energy purposes. The Monograph Mountain Lakes of Montenegro represents a solid independent scientific contribution, primarily to the physical-geographical and limnological knowledge of this part of our country. At the same time, this is the first book of its kind in our country, so it is very original". In the book dedicated to the biography and bibliography of Professor Stevan M. Stanković (Devedžić, M., Pavlović, S. 2016), in the section devoted to the contribution of its development to limnology, and on the example of the mountain lakes of Montenegro, the following was stated: "Before the research, S. Stanković about the mountain lakes of Montenegro, apart from Crno lake on Durmitor and Plavsko lake below Prokletije, very little was known, or not even a little, only a note by a hydrobiologist or a mountaineer gave some general information.

There was mostly no information about the genesis of the lakes, their basin, water volume and feeding method. now that gap in our scientific literature has been filled, even though Dr. St. Stanković is certainly aware of the fact that these lakes can be the subject of further research, preferably by experts in other specialties. However, for all such research, the results of Stanković's studies will represent the basis, without which it is impossible."

Positive reviews of books about lakes

The books Tourism Valorization of Artificial Lakes of Serbia, Mountain Lakes of Montenegro, as well as some other monographs and special limnological works by Stevan Stanković, were occasionally shown and quoted, on different occasions and in different magazines. A series of six lectures by professor Stevan M. Stanković at the Ilija Molosavljević Kolarc Foundation in Belgrade, which attracted a large number of listeners.

On the occasion of the aforementioned series of lectures on lakes, Marko Lakić, on page 26 of "Politics" for March 18, 2000, among other things, wrote the following: "The latest Gazette of the Serbian Geographical Society is dedicated to one of the most prolific geographers in our country, a prominent scientific worker and university professor, Dr. Stevan M. Stanković, who received the Jovan Cvijić Medal for his results in the field of geography. In the introductory text written by Dušan Dukić, we learn that Dr. Stevan M. Stanković, during 35 years of scientific and research work, showed an extraordinary sense of working in the field. This professor of the Faculty of Geography of the University of Belgrade, after mapping the artificial lakes of Serbia, conducted a field survey of 28 mountain lakes of Montenegro, including the names of lakes, tributaries, islands, springs, hot springs and other hydrographic objects. He focused his research on mountain areas, where there are glacial lakes, to which he devoted himself completely. For these needs, I constructed certain instruments and perfected the methods of working in the field, as well as processing the obtained data. For the purposes of the monographs Lakes of Yugoslavia, Lakes of the Balkan Peninsula and Lakes of the World, he visited a large number of lakes in more than 20 countries on three continents.

Basic scientific determinations of Stevan M. Stanković are limnology, tourism valorization of natural values and environmental protection. Dedicating himself to these areas, he carried out the genetic classification of the studied lakes, determined the elements of the water balance, analyzed the thermal regime, chemical properties and stages of evolution of the lake basins, created isobath maps and profiles, defined protection measures and the expediency of using lake water. Stanković laid the foundations for modern biological research of the flora and fauna of the lake and the foundations of tourism valorization of nature".

In order to learn the basics of limnology, he studied extensive literature, but his personal observations in the field were the basis for collecting material. He studied to the finest detail the book Ohrid Lake and its Living World (Kultura, Skopje, 1957) by the academician Siniša Stanković, and he often returns to it, as well as to the works of Jovan Cvijić, especially his Atlas of Multicolored Maps of the Large Lakes in the South of the Balkan Peninsula, as well as a study on crypto depressions in Europe. He stayed at the Hydrobiological Institutes on Lake Ohrid and Lake Skadar and established good collegial relations with the researchers there.

He has lectured several times on the Skadar Lake and the mountain lakes of Montenegro at relevant scientific gatherings in Titograd, Žabljak and Plav.

Professor Stevan M. Stanković stayed on a number of lakes in the Alps. He stayed on the shores of Lake Balaton several times and on one occasion in Siofoh, he gave a lecture to the participants of the excursion of the Serbian Geographical Society about the spacious, shallow Hungarian lake, which is very important for tourism. He was at Lake Baikal in Siberia and the Institute of Limnology in the town of Listvainki next to the world's deepest jetty, not far from its island of Angara, as well as at the large artificial lake Brat and the then largest hydroelectric power plant on it.

During a twelve-day voyage on the Volga and Don, from Kazan to Rostov, he got to know the large artificial lakes on the lowland rivers of Russia. From the south of Tunisia, he made an excursion to the aeolian lake Shot el Jerid, which is on the edge of the Sahara. He collected valuable data about the lakes of Austria, Switzerland, Greece, Bulgaria, Italy and Russia and interpreted them in the book Lakes of the World.

Scientific, professional and popular works, about natural and artificial lakes, by professor S. M. Stankovića were printed in Belgrade, Kragujevac, Pirot, Novi Sad, Sokobanja, Kladovo, Zagreb, Ljubljana, Titograd, Cetinje, Žabljak and Bern. The shortest works have one to two pages, and the most voluminous 356 pages. Several books have been printed in multiple editions (Eight Lakes of the World, Five Lakes of Yugoslavia, Three Lakes of the Balkan Peninsula, Three Lakes Protection, Two Serbian Lakes, Two Mountain Lakes of Montenegro, Two The Lakes on Mount Durmitor two).

In addition to the emphasized physical-geographical and limnological content, the works that we present in this contribution refer to the tourist valorization of the lake, the problems of endangerment and protection, the changes that condition the surrounding area, etc. Part of such presentations is applied limnology, because natural and artificial lakes have multiple importance for the life and work of people and society, especially in continental countries such as Serbia.

In the book dedicated to the development of geographical science in Serbia, which resulted from the symposium of the same name, on the occasion of marking the ninetieth anniversary of the work of the Geographical Institute of the University of Belgrade, the forerunner of today's Faculty of Geography, the importance of the study of lakes was pointed out and the following was highlighted in connection with it: "Stevan Stanković out of all geographers, he studied lakes the most and achieved significant results in that field, which is confirmed by his monographic works - Mountain Lakes of Montenegro, Lakes of Yugoslavia and Tourism Valorization of Artificial Lakes of Serbia" (Ракићевић Т. 1985).

Revitalization of limnology

In the aforementioned book, the following was also written: "In relation to rivers, the study of lakes does not have a long tradition." Before World War II, this work was completely neglected. After Cvijić's researches in Old Serbia and Macedonia at the beginning of this century, which were not purely limnological, there are no geographical works on lakes. Much later, only after 1960, the first contributions of this type appeared in Serbia. It has been written about certain natural and man-made lakes, and Stevan Stanković publishes two interesting monographs Tourist Valorization of Man-made Lakes of Serbia and Lakes of Yugoslavia. In this way, all important limnological objects were processed, the basic morphometric characteristics were given and their economic importance was indicated" (Гавриловић Љ. 1985).

At the beginning of April 1990, Professor Dušan Dukić, Ph.D., presented Stanković's book Jezera Yugoslavia in an article entitled The Beauty and Power of Water, published in the "Educational Review" in Belgrade. Among other things, he also wrote the following: "Deciding to study the artificial lakes of Serbia in his master's thesis and the mountain lakes of Montenegro in his doctoral dissertation, Stevan M. Stanković successfully snatched from oblivion a part of hydrology – limnology, which before him was successfully nurtured by geographer Jovan Cvijić and biologist Siniša Stanković. Through field research and a detailed insight into the existing literature, the author successfully presented to the readers the unusual world of our lakes - natural and artificial, mountain and plain, tectonic and glacial, originally clean and endangered, mapped in detail and those that are still known only to rare nature lovers" . In reviewing the work of Stevan M. Stanković, on the occasion of receiving the Jovan Cvijić Medal, professor Dušan Dukić wrote in the Gazette of the Serbian Geographical Society, volume LXXX, number 1, for the year 2000, among other things, that "The basic scientific determinations of Dr. Stevan M. Stanković's limnology, tourism valorization of natural values and environmental protection. In the domain of limnology, he established himself with the books Tourist Valorization of Artificial Lakes of Serbia, Mountain Lakes of Montenegro, Lakes of Yugoslavia, Lakes of the World, Lakes of Durmitor and Lakes of the Balkan Peninsula. He revitalized the science of lakes and the volume of construction is the first not only in Serbia and Yugoslavia, but also on the Balkan Peninsula. He carried out the genetic classification of the studied lakes, determined the elements of the water balance, analyzed the thermal regime, chemical properties, stages of evolution, created isobatic maps and profiles, defined measures of protection and purposeful use of lake water. Established a formula for calculating the flow rate of lakes with tributaries and estuaries. He laid the foundations for modern biological research of the plant and animal life of the lake, and his works were often cited in hydrological, geographical and biological publications" (Дукић, Д. 2000).

Often cited author

In 2005, the Faculty of Philosophy, Institute of Geography from Nikšić published a book (390 pages) by Professor Branko Radojičić under the title Waters of Cena Gora. On the pages of this book, the limnological monographs of Professor Stevan M. Stanković Mountain Lakes of Montenegro from 1975 and Lake Durmitor from 1992 were mentioned 39 times. Professor Branko Radojičić, among other things, notes the following: "As part of numerous works and special studies in the field of geomorphology, glaciology, geology, hydrology and related sciences, the mountain lakes of Montenegro were also studied. Jovan Cvijić also laid the foundation in this narrower scientific field, and then Stevan Stanković (1975) studied the mountain lakes of Montenegro more thoroughly, whose work "Mountain Lakes of Montenegro" represents the basis of all further research into these extremely important natural objects of Montenegro".

In the list of literature, in the monograph on artificial lakes of Vojvodina, four works by Stevan M. Stanković (The Lakes of Yugoslavia, Artificial Lakes of Serbia, Tourist Valorization of Artificial Lakes of Serbia, Tourism as a Resulting Activity on Artificial Lakes of Serbia), which served the author to present himself with an interesting book (Бугарчић, П. 2007).

In the university textbook Hydrology, in the section on lakes, among other things, it is pointed out: "Geographer Stevan Stanković, who published several monographs, worked very successfully on the study of our lakes." (Дукић Д., Гавриловић Љ. 2006).

In the Serbian encyclopedia, volume III, book 1, published by Matica srpska and SANU, Novi Sad – Belgrade, 2018, in the Geography heading, among other things, on page 178, the following was noted: "The results are particularly significant work of S. Stanković from the field of limnology, a discipline that has been neglected for a long time in Serbia".

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* Објашњење скраћеница у тексту: СГД = Српско географско друштво, ПМФ = Природно-математички факултет, ГФ УБ = Геоографски факултет Универзитета у Београду, HPD = Hrvatsko prirodoslovno društvo, GDH = Geografsko društvo Hrvatske, SGDH = Savez geografskih društava Hrvatske, САНУ = Српска академија наука и уметности, ЦАНУ = Црногорска академија наука и умјетности, ЈДОН = Југословенско друштво за одводњавање и наводњавање, ЈДЗВ = Југословенско друштво за заштиту вода, НП = Национални парк, ЗР = Зборник радова, св. = свеска, бр. = број, стр. = страна у књизи.

Conclusion

Stevan M. Stanković, professor emeritus of the Faculty of Geography, University of Belgrade, belongs to the group of our scientists known for numerous professional and scientific works, textbooks and monographs in several geographical disciplines. His works on lakes are of particular importance, since he revitalized limnology - the science of lakes - in his own unique way in Serbia. He defended his master's thesis under the title Tourism Valorization of Artificial Lakes of Serbia and his doctoral dissertation under the title Mountain Lakes of Montenegro. Both of these works were published as scientific monographs, the first in the Serbian Geographical Society (Belgrade, 1975) and the second in the Society for Science and Art of Montenegro, the forerunner of the Montenegrin Academy of Sciences and Arts (Titograd, 1975).

The works of Stevan M. Stanković on natural and artificial lakes were published in several magazines, cities and publishers, in Serbian and English. They have been analyzed, quoted, commented on, shown and awarded several times. Among other things, it was noted that geographer Stevan M. worked very successfully on the study of our lakes. Of all the geographers, he studied lakes the most and achieved significant results in that field, which is confirmed by his monographic works Mountain Lakes of Montenegro, Lakes of Yugoslavia, Lakes of Serbia, Lakes of the Balkan Peninsula, Lakes of the World and Tourism Valorization of Artificial Lakes of Serbia. The results of Stevan M. Stanković in the monograph Mountain Lakes of Montenegro are 90 percent his own, because they were brought from many years of field research.

Works on lakes are particularly important, because limnology in Serbia was neglected for a long time. Scientific, professional and popular works, as well as monographs on natural and artificial lakes, by Stevan M. Stankovića were printed in Belgrade, Kragujevac, Pirot, Novi Sad, Sokobanja, Kladovo, Zagreb, Ljubljana, Titograd, Cetinje, Žabljak and Bern. The shortest works have one to two pages, and the most voluminous 356 pages. Several books have been printed in multiple editions (Eight Lakes of the World, Five Lakes of Yugoslavia, Three Lakes of the Balkan Peninsula, Three Lakes Protection, Two Serbian Lakes, Two Mountain Lakes of Montenegro, Two The Lakes on Mount Durmitor two).

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EXAMPLE OF THE IMPORTANCE OF EARLY WARNING OF EXTREME WEATHER EVENTS IN MONTENEGRO IN THE CONTEXT OF RECENT CLIMATE CHANGE

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Abstract: In the last two decades, there has been no year in Montenegro in which some weather extreme has not been registered. The aim of this paper is to highlight the importance of an early announcement of potentially dangerous weather phenomena in the example of one case in Montenegro. The prognostic material including ocassionally storm surges, heavy rainfall and the occurrence of severe local instability in Montenegro on July 28, 2019 was considered. Based on the analysis of the synoptic material, the warning of the expected weather conditions was given two days before. The warnings of the competent institutions should be respected in order to adapt the population to the expected extreme weather situations and thus avoid or mitigate the negative consequences.

Key words: extreme weather event, significance of early warning, Montenegro

Introduction

Contemporary climate changes and global warming are increasingly attracting attention. The key questions in relation with this topic (or rather say problems) that scientists are trying to answer are: why is today's climate changing, what is the cause, what consequences for humankind could possible

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changes in today's climate cause? With very high confidence, the IPCC points out that human influence has been the dominant cause of observed warming since the mid–20th century. Certainly climate change mitigation is impossible without reducing effects of greenhouse gas emissions. A significant form of mitigation is the afforestation and the slowdown of deforestation. ''Through afforestation, land could collect CO_2 from the atmosphere'' (IPCC, 2021).

There is a general belief that the most striking consequences of contemporary climate changes are the increase in the frequency and intensity of extreme weather phenomena. There are numerous works highlighting the increase in the frequency of extreme climate events in almost all parts of the world (Vose et al., 2005; Alexander et al., 2006; Ahmed et al., 2017; Garreaud, 2018; Faiz et al., 2018; Engström & Keellings 2018). In the Mediterranean Basin of the (European and African part), in the period 1958–2008, there is an increasing trend of both maximum and minimum temperatures, but the tendency is more intense in the Western Mediterranean Region (Efthymiadis et al., 2011). By doing analysis of several extreme climatic indices for the Eastern Mediterranean Region, Kostopoulou & Jones (2005) found that in the period 1958–2000, the most pronounced warming trend is during the summer. Regarding precipitation, the authors point out that there are contrasts, but that the overall picture is such that the western part of the study region (Central Mediterranean Region – Italy) registers significant positive trends of intense rainfall, while the eastern half records negative trends of all rainfall indices, indicating a tendency of aridity. And Brunetti et al. (2006) points out that in the second half of the 20th century, Italy recorded a significant increase in extreme temperatures, while a negative tendency was observed in precipitation. Similar results were obtained by Caloiero et al. (2017) for southern Italy as well as for the central part of this state for the period 1951–2012. In the period 1961–2006, a bigger part of Spain registers a trend of rising maximum and minimum temperatures (Del Rio et al., 2012).

In the last two decades, there has not been a year in Montenegro where no time extreme has been registered – high temperatures, heat waves, floods, prolonged droughts, fires. Some extreme weather phenomena in Montenegro were described in the papers of Ducić et al. (2012) and Burić et al. (2014a, 2021). The extremely high temperatures and a series of heat waves stand out especially in the summer of 2003 and 2007, and 2010 is the record year for heavy rainfall and unprecedented floods in Montenegro (Burić et al., 2011).

By virtue of more reliable products of numerical modeling (prognostic or synoptic material), the degree of accuracy of the short–term weather forecast is very high today. The main aim of the paper is to emphasize the importance of early announcement of potentially dangerous weather disasters ona concrete example. The early warnings given by competent services for such events (hazardous weather events) are of great importance to the local community and should be respected in order to avoid human victims and mitigate material damage. In an era of contemporary climate changes and the increased incidence of extreme weather events, there is no doubt that the role of national meteorological services will be increasingly important in the future.

Area of interest, databases and methodology

The study covers the territory of Montenegro, a country with an area of 13 812 km2. Montenegro is a Mediterranean country, reaching the Adriatic Sea in the length of about 100 km. It is very heterogeneous in relief (Figure 1), the highest peak in this country is on the mountain range of Prokletije (Zla Kolata) in the northeast of the country, whose altitude is 2534 m, while the lowest point is the level of the Adriatic Sea (0 m). This pronounced relief fragmentation influences the formation of local convective clouds, convective precipitation, the appearance of fog, etc. (Burić et al., 2013). Thus, most of Montenegro has the Mediterranean climate characteristics (Burić et al., 2014b).

Figure 1. Montenegro's position in Southern Europe

For the purposes of analysis, the data about ground and altitude structure of the atmosphere were used, as well as the outputs of global (GFS and ECMWF) and operational (WRF–NMM) models, then the composite synoptic parameters of instability, an emagram, a SYNOP report from meteorological stations, and other analytical and prognostic material. The sounding and the wind hodograph in the form of emagrams with a resolution of 1.0km were obtained on the basis of the operational WRF–NMM model, which uses ECMWF data from Reading (UK) as input parameters. Standardized deviation and percentile methods were used to categorize precipitation.

Results

On Sunday, July 28, 2019, in the afternoon and evening, Montenegro was hit by a severe storm. The coastal and central parts of Montenegro were particularly affected, where in a short time a large amount of rainfall was emitted, there were storms and strong thunderstorms were recorded. Prognostic material with initialization of as much as three days before the storm indicated the possibility of a dangerous meteorological phenomenon. The following two days, especially the day before (July 27, 2019), prognostic models confirmed the lability of the atmosphere over Montenegro and indicated a higher probability of an extreme weather event. We have done a detailed analysis of the prognostic material with the initialization two days before the storm that hit Montenegro on July 28.

The analysis of the synoptic material from 0:00am UTC (2am according to Central European time) for July 28, 2019, indicates the existence of a shallow cyclone on the ground floor, centered over the Gulf of Genoa. At altitude (AT 500 hPa) wide low pressure area was active, which was extending from the northwest in the direction of the Ligurian and Tyrrhenian seas (Figure 2a). The area of Montenegro and the southwestern Balkans was located in the front of both pressure areas, both at the ground and at the altitude. The analysis of the synoptic map of the total cloudiness indicated high cirrus clouds (Ci and Cs – Cirrus and Cirrostratus) above Montenegro, which indicated the arrival of a frontal wave. Synoptic material from 6am UTC indicates that the ground cyclone and the elevation valley have shifted eastward. There was also a deepening of the ground cyclone, whose center was then located above northern Italy (Figure 2b), but there was still no precipitation. Frontal wave (cold front) was indicated by the change of the cloud system, i.e. the appearance of medium (As and Ac – altostratus and altocumulus), and later low clouds (Cu – Cumulus and Sc – Stratocumulus) above Montenegro. Global synoptic material for the mentioned period showed a rain zone west of Montenegro, but after examining the SYNOP report from meteorological stations in Montenegro from 10am UTC, one station in the southwest (Herceg Novi) registers the light rain.

The products of the numerical models from 12pm UTC showed further displacement of the pressure fields toward east and northeast, so during this period the center of the ground cyclone was located above the northern Adriatic, and the axis of the altitude area of the instability was increasingly gaining a general direction from west to east–southeast i.e. toward the Ionian Sea. (Figure 2c). According to the existing structure of the atmosphere, it was to be expected that the rain zone would move from the west to Montenegro, but the SYNOP report showed that only a few meteorological stations in the coastal and western part of the country registered light rain. For the last 6 hours (06–12 UTC) these few stations registered a negligible amount of precipitation, up to 0.5 mm. So, obviously there was a so–called delay or slower movement of the process from west to east compared to what was simulated by the prognostic material, but this phenomenon (occurrence of process delay) is quite common in weather forecasting, even when analyzing synoptic maps of better (larger) resolution. The next two hours, rain zone spread from the west and southwest to the rest of Montenegro, but still with sporadic and occasional light rain. The analysis further revealed that several stations at the coast and north of the country register intensified strikes of eastern and southeastern wind – up to 11 m/s, which is later more intensified. However, around 3pm UTC (5pm according to the Central European Time), central and most coastal areas record heavy rain, local showers, thunderstorms and wind gusts – up to 23 m/s.

Based on the analysis of the Synoptic material from 6pm UTC, the process was further shifted to the east (Figure 2d). At that time, the axis of the pressure area was covering the southern parts of Montenegro. In most of Montenegro, the process was weakened, except in the far eastern and southeastern regions, which were then under heavy rain and thunderstorms. In the next term (7pm UTC), in the west, southwest and in the most of central Montenegro, the intensity of rain was already weakened, that is, there was light rainfall only in some places, and an hour or two later, rainfall was weakened in the east and southeast of the country. Thus, around 7pm UTC, weakening of the process started over Montenegro, which was confirmed by the structure of the atmosphere from 00am UTC for July 29, 2019.

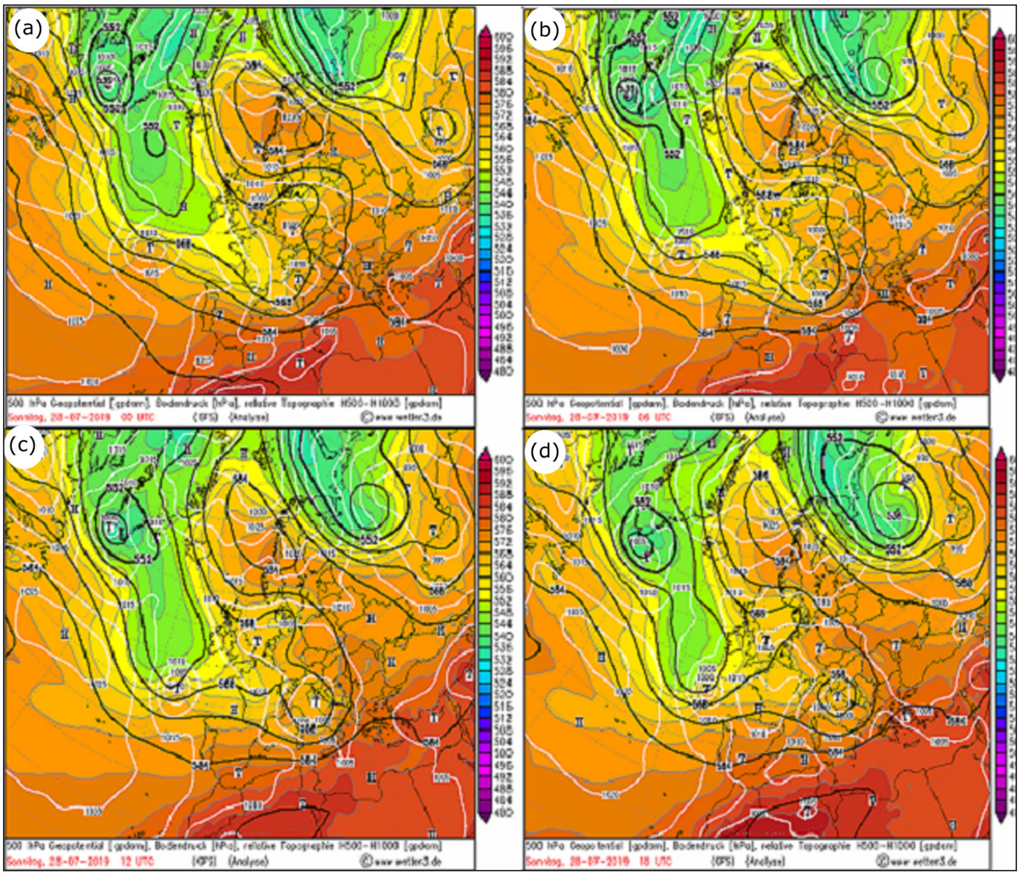

Figure 2. Structure of the atmosphere at ground level and at 500 hPa at: 12am (a), 6am (b), 12pm (c) and 6pm (d) UTC

Thus, the analysis of synoptic maps of global models, which cover the whole of Europe, North Africa and parts of the Atlantic, indicated that the process should be most turbulent in the early afternoon (around 13–14 UTC). It has already been mentioned that process delays are a common occurrence in weather forecasting. In order to more accurately estimate the terms of expectation of the most turbulent process, generally announce the best possible weather forecasts, the analysis of additional synoptic material and prognostic maps of better (larger) resolution is approached. Since it was determined that the main deterioration of the weather was related to the afternoon hours, the analysis for the periods of 12 and 18 UTC is given below. The AT 700 hPa map at 12pm and 6pm UTC (Figure 3) shows an area of extremely high relative humidity in the west and northwest of the Balkans, in the north of Italy and in the Alps region – about 80–90%, and humidity above Montenegro was between 90–95%, which indicated a pronounced lability of the atmosphere.

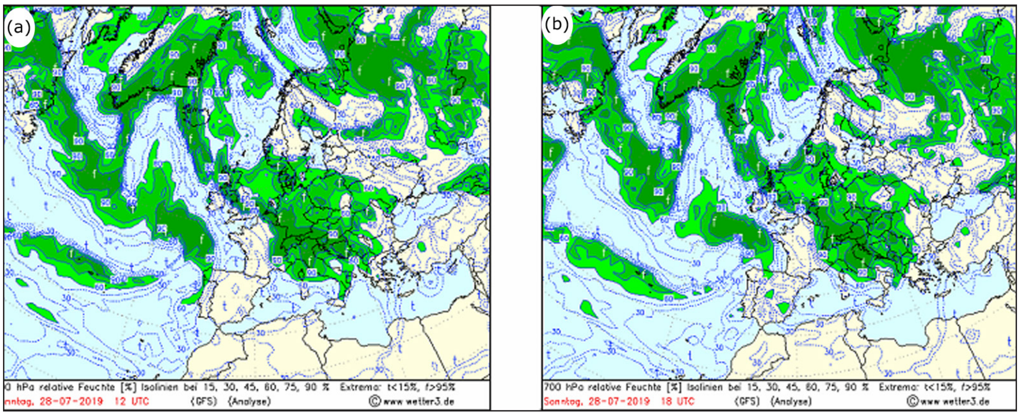

Figure 3. Relative humidity at 700 hPa at 12pm (a) and 6pm (b) UTC July 28, 2019

On the analytical charts of the ground pressure from 12 pm and 6pm UTC (Figure 4), there is a low pressure field above Western and most of southern Europe, and a vast discontinuity surface (frontal wave) extends from Iceland, via Britain, to the Benelux States, part of Central Europe and it turns in the direction of the Ligurian Sea. The northwestern part of the Balkans is influenced by the occluded front and the center of the shallow cyclone is above the northern Adriatic Sea. After 6pm the UTC frontal system continues to move eastward and gradually weakens, and to the west of it, the pressure begins to grow.

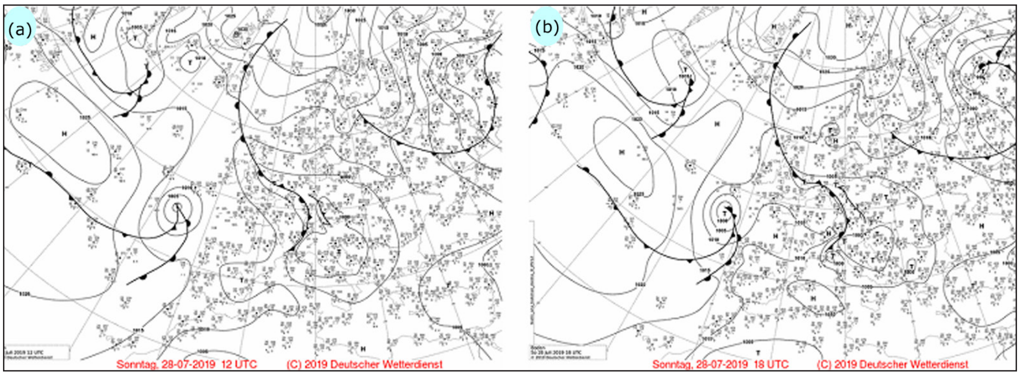

Figure 4. Ground analytic chart above Europe at 12pm (a) and 6pm (b) UTC on July 28, 2019

Previously considered prognostic and analytical charts clearly indicate that Montenegro is located in the front part of the cyclone and altitude pressure field, that is to say, under the influence of moist and unstable south–southwest current, but they do not indicate such a tumultuous development of weather which was indicated by additional prognostic material. Namely, on the 12pm UTC instability chart, an increased value of the CAPE index is observed above the southern Adriatics – about 2000 J/kg. This zone with increased convective energy of instability up to 6pm UTC is moving towards the coastal and central part of Montenegro (Figure 5), just in the period when heavy rainfall, strong wind and thunderstorms are registered.

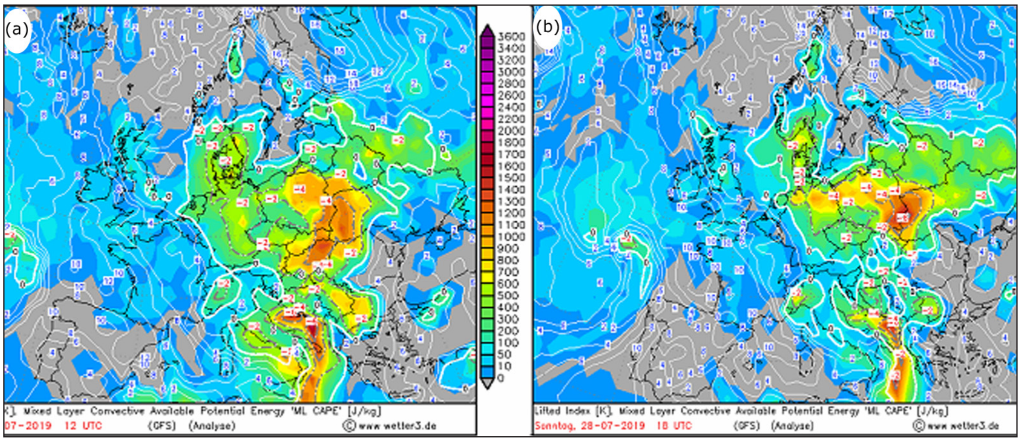

Figure 5. CAPE instability index at 12pm (a) and 6pm (b) UTC on July 28, 2019

The strength of the process is also indicated by the composite chart, and the instability was recorded by the Gematronik–type radar from a radar center on Jastrebac Mountain in central part of Serbia. The products of the global GFS model are only available in the main sinoptic periods (12am, 6pm, 12pm and 6pm), while the outputs of the operating WRF–NMM model are hourly available. By analyzing the maps of better resolution of maximum reflection, where the initialization started two days before (from 26.7.2019), a rapid development of cumulonimbus (Cb) cloudiness can be seen first in the southwestern part of Montenegro at 4pm and 5pm UTC on July 28, 2019, where the maximum intensity of reflectivity is at a radar reflection of about 45 dbZ (decibels). In the next period (6pm UTC) Cb reflection spreads and intensifies, reaching up nearly to 50 dbZ (Figure 6). From 7pm UTC onwards, the zone of high instability moves towards east and reaches only the very eastern parts of Montenegro at 8pm and 9pm UTC. After 9pm the UTC zone of severe instability disappears completely. Therefore, based on this analysis, it can be concluded that the culmination of the instability process started between 4pm and 5pm UTC, first in southwestern and western part of Montenegro, and then the zone with heavy rain, showers, storm wind and thunderstorms moved east to 8–9pm UTC. The analysis of SYNOP weather station reports for July 28, 2019 confirmed the forecast which had been given two days before, when during this period (4pm – 7pm UTC on July 28, 2019) the strongest wind gusts were registered, reaching up to 23 m/s (about 83 km/h) at the coast and in the central part of Montenegro.

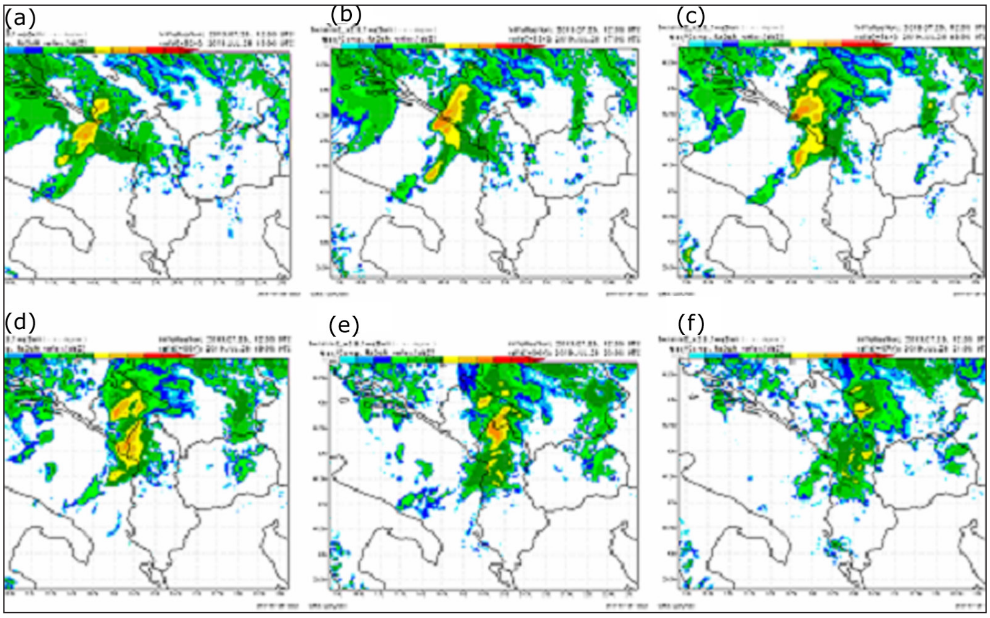

Figure 6. Radar image of maximum reflection of cumulonimbus instability at: 4pm (a), 5pm (b), 6pm (c), 7pm (d), 8pm (e) and 9pm (f) UTC on July 28, 2019

Finally, the analysis of the emagram confirmed the previously stated. Namely, on the basis of the WRF–NMM model, which uses the data of the global ECMWF model as input data, an emograph and a holograph were made for Podgorica (the capital of Montenegro) at a resolution of 1 km for the time of 4pm UTC, when the maximum turbulence of the process began. The increased vertical gradients of meteorological parameters are observed on the emagram – decrease in temperature with altitude, increased air humidity at the ground area and a sudden increase in wind speed with altitude and its shear (Figure 7).

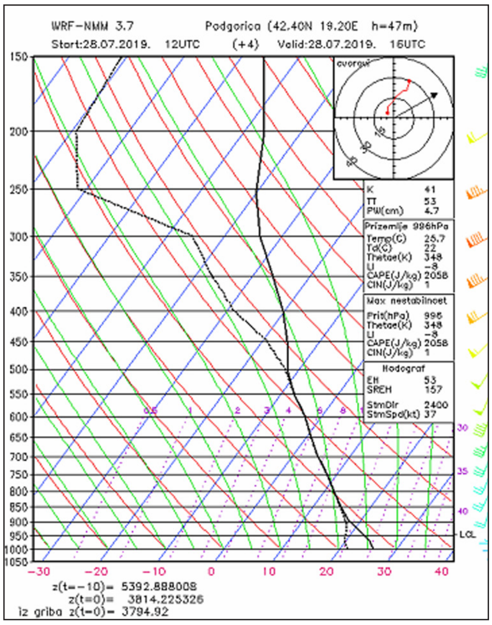

Figure 7. Emagram and hodograph of wind WRF–NMM resolution model of 1.0 km for 4pm UTC on July 28, 2019

The vertical atmospheric profile above Podgorica in the observed term indicates adiabatic instability from the lowest layers (LCL), through the entire vertical profile, to the highest layers of the troposphere. The ground air temperature is over 25.7^{0}C and dew point temperature is around 22^{0}C, while air pressure is around 996 hPa. The zero isotherm height is at H_0 = 3.8 km and the isotherm height of –10^{0}C is H_{-10} = 5.4 km. The maximum instability is on the ground area, at an altitude of 996 hPa, where the CAPE index value is about 2058 J/kg. Also, other indices indicate strong instability, so the K index (41) and the TT index (53) on the emagram show that there is convective potential and conditions for storm–thunderstorm processes.

The hodograph (polar diagram in the upper right corner of the Figure 7) shows an increase in wind speed with height, as well as wind shear in the cumulonimbus at an altitude of about 900 hPa. The storm is moving at a speed of 37 knots and the direction of the storm is about 240 degrees, that is, from southwest to northeast. Indicators of rotation within the storm, EH (53 m^2/s) and SREH (157 m^2/s), indicated values of thunderstorms by their values. Based on the mentioned parameters, there was a high probability for the occurrence of leeches or waterspouts; the truth is that meteorological stations did not register it, which does not mean that it did not actually happen, because it is an exclusively local vortex.

Discussion

In most parts of Montenegro, July has the lowest rainfall on average during the year. For example, in Podgorica in July, it rains on average 38 mm of rain. During the mentioned day (July 28, 2019), 43 mm of rain fell in less than 3 hours (between 3pm–6pm UTC), hence a greater amount of precipitation than the average for the whole month. It was raining during the night and the following day (July 29, 2019), but with less intensity. In July, the Cetinje station in the southwest of Montenegro registers a total of 66 mm of rain on average, and 135 mm of rain fell in this place in the period from 3pm on July 28, 2019 to 6am UTC on July 29, 2019, or twice the monthly average. For the same period of 15 hours, 62 mm of rain were measured in Podgorica (Figure 8).

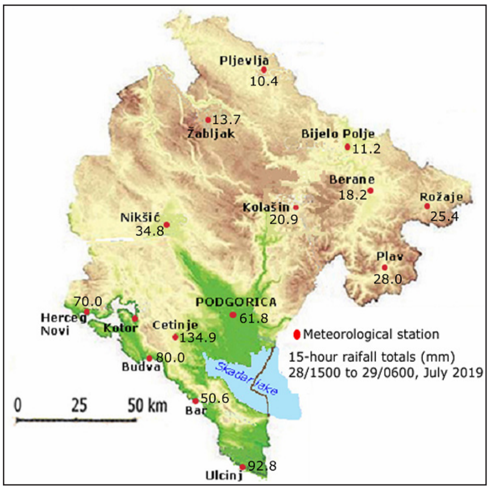

Figure 8. Precipitation in Montenegro for the period of 15 hours (from 3pm on July 28 to 6am on July 29, 2019)

The research presented in this study is in support of the fact that modern climate change and extreme weather events have not bypassed Montenegro. During the previous 20 years, records of temperature, precipitation, wind and other potentially dangerous weather events were registered in Montenegro (Burić et al., 2011; Burić, 2014; Burić et al., 2015, 2021). In the paper Mihajlović et al. (2021) gives an exhaustive description of an extreme weather situation in Montenegro (water leech in Tivat). Burić et al. (2021) point out that ʼʼ In early February 2019, Montenegro was hit by a severe wind storm. During the afternoon, as a result of stormy winds, large waves formed on Skadar Lake which overturned a boat and caused the loss of four lives. Fortunately, during the potentially dangerous weather phenomenon analyzed in this paper, apart from minor material damage, there were no human casualties. Climate projections for the south (Podgorica) and north (Kolašin) of Montenegro indicate that a further trend of rising temperatures and more frequent weather extremes should be expected by the end of the 21st century (Burić & Doderović 2020, 2021; Doderović et al., 2020).

The other parts of the Balkan Peninsula are also getting warmer with more frequent extreme weather events, such as high temperatures, heat waves, droughts, and heavy rainfall (Stagge et al., 2017). In Serbia, during the second half of the 20th and the beginning of the 21st century a negative trend of seasonal and annual precipitation, more frequent droughts, a positive trend of extreme daily temperatures and precipitation (Stanojevic et al., 2014; Arsenovic et al., 2015; Bajat et al., 2015; Luković et al., 2015; Pecelj et al., 2020). Croatia is not set aside from the more frequent potentially dangerous weather phenomena (Mihajlović et al., 2016). Also in Bosnia and Herzegovina there is a trend of rising temperatures and increasing extreme weather and climate events (Trbic et al., 2018; Popov et al., 2019). Changes in temperature and precipitation also occur in Slovenia (Milošević et al., 2016, 2017).

Conclusions

During each year in the last two decades, Montenegro recorded weather extremes – high temperatures, heat waves, floods, prolonged droughts, fires. In an era of contemporary climate change and the increasing frequency of weather extremes, the early predictions of potentially dangerous weather events will be increasingly significant. The purpose of this research was to highlight the importance of early warning of dangerous weather events, the necessity of observing the warnings given by the competent services in order to preserve human lives and to avoid consequences, based on a specific weather disaster, which occurred on July 28, 2019.

Analysis of synoptic material with initialization two days before the storm showed that potentially dangerous weather phenomena can be predicted in time. Numerical models clearly indicated that in the afternoon of 28th July 2019, stronger rain showers, thunderstorms, stormy winds and sea leeches were possible. Subsequent data from the SYNOP report showed that in the afternoon of the mentioned day, in just 2–3 hours in the southern and western part of Montenegro, a higher amount of precipitation than the average for the whole month of July was measured. Torrential currents have appeared in the coastal and central part of the country, wind gusts of up to 23 m/s (83 km/h) have been registered locally, and waves about 3 m high have been recorded along the coast (during the bathing season). There is no doubt that the described weather phenomenon had the character of an extreme event, but thanks to the warning of the competent services, which were communicated by the media, there were no human victims.

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CHANGES IN SOIL EROSION INTENSITY IN JABLANICA REGION

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Abstract: The aim of the paper is to analyse the changes in erosion intensity in Jablanica region between 1971 and 2018, using the Gavrilović method. Study area covers the catchment of three left tributaries of South Morava river, which have vary unstable river regimes. Natural conditions have a negative impact on intensity of the erosion process with unfavourable geological and pedological structure, precipitation regime, high slope values and significant vertical dissection of the terrain. Changes in erosion process are caused by changes in agricultural production as well as anti-erosion works, that have been carried out during the second half of the 20th century.

Keywords: Jablanica, Pusta reka, Veternica, Gavrilović method, soil erosion

Introduction

Soil erosion is the main degradation process of agricultural soils by antropogenic interference. Erosion process is influenced by the characteristics and distribution of rainfall, soil type, topography, soil cover and management, and by conservationist practices supporting agricultural production (Panagos et al., 2015).

According to Telles et al. (2013), erosion has contributed to the impoverishment and reduction of the sustainability of agroecosystems by causing the loss of soil, water, nutrients and organic carbon. Beside causing

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the degradation of agricultural areas, erosion results in economic, social and environmental damages that can be minimized with the adoption of soil conservation practices important in the control of erosion. For such economically underdeveloped regions, such as Jablanica, soil erosion is one of the main natural limiting factors for future regional development.

Excessive erosion of the land surface can have limiting consequences on regional development, especially considering the use of natural resources such as agricultural land. In some regions of Serbia, excessive erosion represents a significant natural risk (Dragićević et al., 2011). Among the most endangered regions is South Serbia, located in the basin of South Morava river. Erosion affects increased soil degradation, reduction of its productivity, as well as the volume and quality of agricultural production. Anthropogenic factors that contribute to soil erosion are: intensive agricultural production, especially on steep agricultural areas, irrational logging and mining.

Serbia is covered with hard erosive processes and about 86% of its area is at some risk of erosion. More intensive erosion processes cover 35% of the territory of Serbia (Lazarevic, 1983), from the south of the Sava and the Danube (hilly-mountainous part of Serbia).

Soil erosion in the Jablanica region is the result of natural and anthropogenic factors. Since the 1950s, the Jablanica region has been identified since the 1950s as one of the areas most threatened by erosion in Serbia. The intensity of erosive processes was influenced by the unfavorable geological structure dominated by easily eroding crystalline schists on the mountain rim of the region and weakly bound sediments at the bottom of the Leskovac Basin. Intense rainfall and an unfavorable pluviometric regime, the great fragmentation of the relief as well as the destruction of the forest cover contributed to the development of erosive processes.

Vasović (1998) singled out several periods of intensive deforestation during the 20th century, which also affect the recent state of erosion. The long-term destruction of forests was in the period 1912–1928 during the Balkan Wars and the First World War, as well as due to the later immigration of the population and the creation of agricultural areas on barren land. The second period of deforestation (predominantly oak forests) was between 1930 and 1935. It was especially pronounced in lower basin of Jablanica river. The third period of deforestation was during the German occupation in the Second World War (mostly in the Šumanka river basin). Due to this sparseness of forests, the land was exposed to intensive denudation (Vasović, 1998).

Materials and Methods

Study area

Study area consists of three river catchments: Jablanica, Veternica and Pusta reka in the geographical region of Jablanica in South Serbia. All three rivers are left tributaries of South Morava. Study area covers 1624.1 km^2 and can be divided into five micro-regions: Pusta reka, Upper Jablanica, Lower Jablanica, Porečje and Poljanica. Administratively, area covers the municipalities of Bojnik, Medveđa and Lebane as well as parts of the City of Leskovac and the City of Vranje.

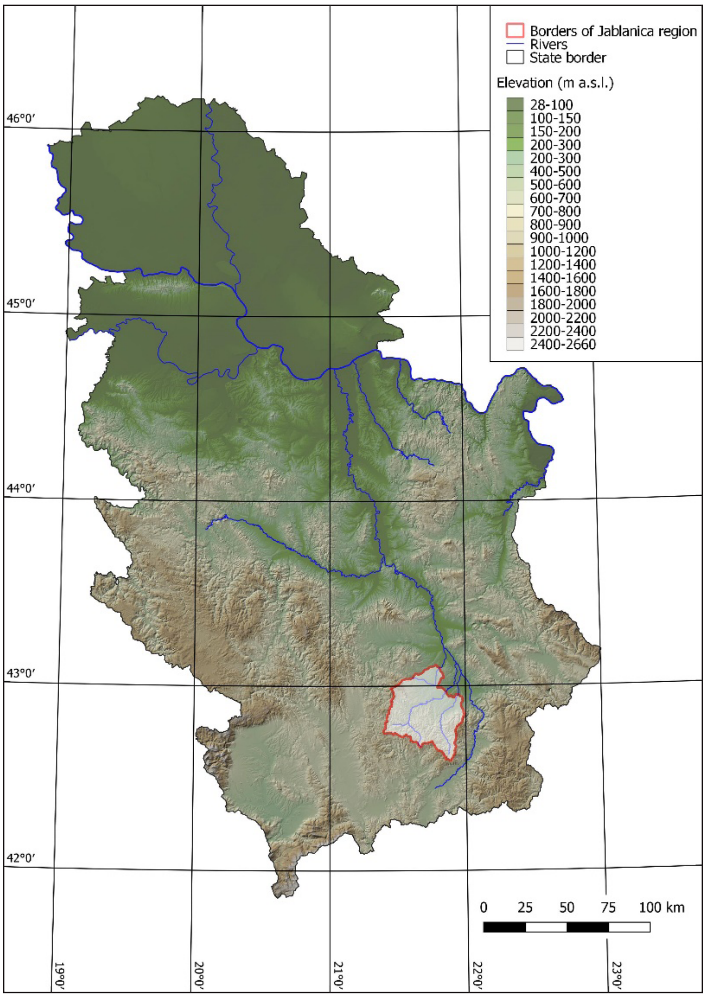

Figure 1. Geographical position of Jablanica region within Serbia

The Jablanica region is mostly located within the Serbian-Macedonian massif (Karamata, Dimitrijević and Dimitrijević, 1998). Several dominant lithological formations can be distinguished in the structure of the region. The largest area is occupied by crystalline slates and granitoids. Crystalline schists belong to the lower complex of the Serbian-Macedonian Mass, which forms its core, and are mostly of sedimentary origin. In the southern part of the region, in the area of Poljanica, deposits of Paleogene sediments were found. Volcanites are developed in the Lece andesite massif, in the west of the region. The northeastern part of the region, the Leskovac basin, is covered by Neogene and Quaternary sediments. The geological structure of the region also has a negative effect on erosive processes. Dominant crystalline schists (gneisses, micaschists, leptinolites, etc.), unbound pyroclastic material and Neogene sediments are subject to weathering and erosion. Due to the deforestation and removal of the pedological cover, they are exposed to the action of external forces.

The main valleys in the region have southwest–northeast orientation, and the elevation varies from 219 m a.sl. in the northeast part to 1445 m a.s.l. in the south (mountain Kukavica). Mean slope of the study area is 12.5°, while in the mountainous parts the maximum value of the slope is 50°, which has a significant impact on the intensity of the soil erosion.

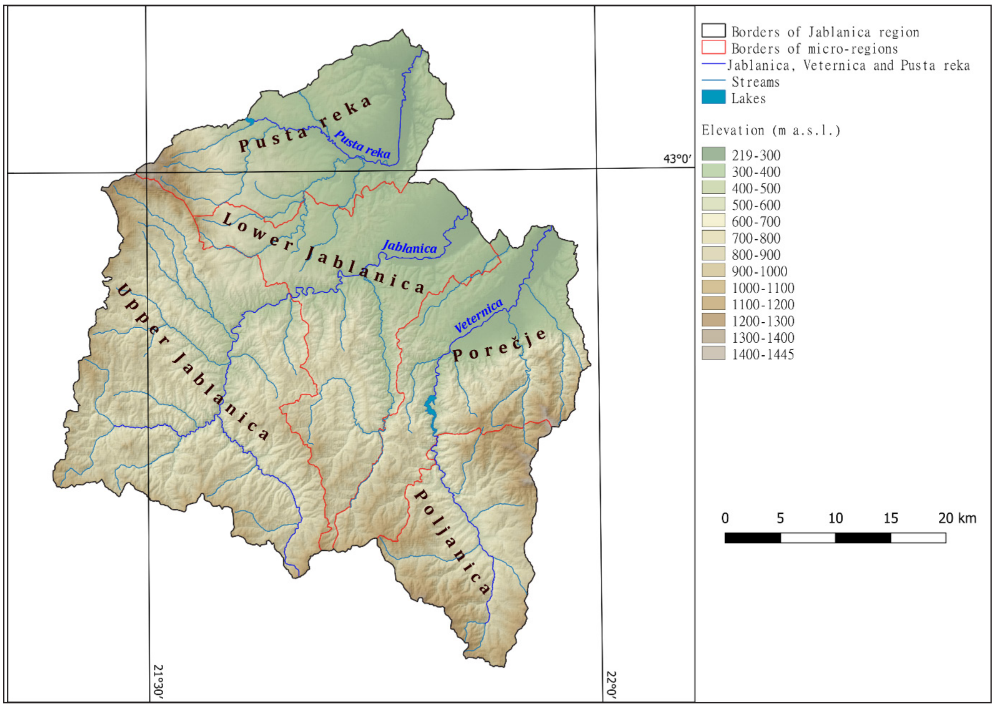

Figure 2. Map of Jablanica region and its micro-regions

Another factor that affects soil erosion is intense and short-term rainfall. This kind of precipitation causes the formation of torrential flows. The most dangerous torrential areas are the Šumanka river basin and the Veternica basin. In the mountainous part of the region, the mean annual temperature (period 1991–2018) was 6.2°C (Kukavica), while in the lowland north-eastern part it was significantly higher (11.5° - Leskovac). Mean annual precipitation varies from 661 mm in Leskovac to 1011 mm on Kukavica mountain.

Methodology

Soil erosion represents a complex process, which is affected by a number of factors. One of the most accurate ways to combine DEM and satellite images regarding land erosion research is to correctly classify spatial parameters, which are represented through a smaller number of classes or units (Milevski et al., 2007). The Gavrilović method, which will be used in this paper, belongs to the group of regional methods, and has been characterized in the world literature as a semi-quantitative method (de Vente et al., 2005).

The erosion coefficient (Z) is calculated on the basis of the following formula (Gavrilović, 1972):

$$Z = Y \cdot X \cdot (\varphi + \sqrt{I}), \text{ where:}$$

Z - erosion coefficient; Y - coefficient of land resistance to erosion; X - coefficient of land protection from atmospheric factors and erosion; φ - coefficient of type of the erosion; I - average drop in surface area for which the erosion coefficient is calculated.

The coefficient of land resistance to erosion (Y) was obtained by digitizing and analyzing the sheets of the Pedological Map of the SFRY at a scale of 1:50,000. On the territory of the region, eutric and distric cambisols and rankers are the most dominate types of soil, and are also very susceptible to erosive processes.

Table 1. Coefficients of land resistance (Gavrilović, 1972)

Erosion resistance coefficient of the substrate	Y
Fluvisol	0.3
Deluvium	0.8
Eutric Cambisols	0.7
Lithosol	0.4
Pseudogley	0.9
Dystric Cambisol on magmatic rocks	0.7
Dystric Cambisol on metamorphic rocks	0.8
Vertisol	0.7
Ranker	0.7

The coefficient of the land protection from the atmospheric factors and erosion (X) was calculated by the processing and analysis of the Corine Land Cover Data, issued by the European Environment Agency (EEA). The lowest coefficients are represented in the areas that are most protected from weathering and erosive processes (coniferous forests, mixed forests and deciduous forests), while the areas of mineral exploitation, areas with scarce vegetation and irrigated arable agricultural areas have the highest coefficients. Forests are an important regulator of the erosive process, especially in the areas with high slope values.

Table. 2. The coefficient of the land purpose

Substrate protection coefficient	X
Coniferous forest	0,15
Mixed forest	0,15
Broad-leaved forest	0,2
Discontinuous urban fabric	0,25
Transitional woodland shrub	0,4
Natural grassland	0,4
Fruit trees and berry plantations	0,4
Pastures	0,5
Land principally occupied by agriculture	0,55
Vineyards	0,6
Complex cultivation patterns	0,7
Non-irrigated arable land	0,8
Sparsely vegetated areas	0,9
Mineral extractions sites	0,9

The coefficient of erosion type (φ) was determined by using the bare-soil index (BSI). For that purpose, the multispectral satellite images of the LANDSAT 8 satellite (United States Geological Survey - USGS) were used. Satellite images were downloaded from the website of the US Geological Survey (USGS) for July 26, 2018 (summer period during the maximum development of vegetation). The bare-soil index was calculated by the following formula:

$$BSI = \frac{((B6 + B4) - (B5 + B2))}{((B6 + B4) - (B5 + B2))} + 1$$

where B6 is the shortwave infrared spectral channel (SWIR 1), B4 is the red spectral channel, B5 is the near infrared spectral channel (NIR), and B2 is the blue spectral channel. The BSI index in the region ranges from 0.43 to 1.15.

The average surface slope (the terrain slope) (I) was calculated in GIS environment by using the 30 m DEM, in the form of a percentage expressed in decimal notations. As the slope increases, the stability of the slopes decreases, the intensity of erosion increases, and the likelihood of torrential floods rises (Novković, 2016).

Results and Discussion

The erosion map of SR Serbia was made on the basis of field research conducted in the period 1966-1971 (on a scale of 1:500,000). Based on the erosion intensity coefficient, five categories were distinguished: excessive erosion, strong, medium, weak and very weak erosion. It was concluded that in that period, the beginning of decreasing and stagnation of erosive processes can be observed. As the authors of the map point out, such a tendency is a consequence of social changes, and to a lesser extent anti-erosion works that have been carried out (Lazarević, 1983). In the second half of the 20th century, there was a decline in livestock and a decrease in anthropogenic pressure on the soil of hilly and mountainous areas, which were exposed to the most intense erosion processes. The most intensive erosive processes in the region were recorded in the area of Porečje, i.e. in the lower Veternica basin (erosion coefficient 0.653), as well as in the Poljanica area, i.e. in the upper Veternica basin (0.596). In Upper Jablanica, the erosion coefficient was 0.405, and in Lower Jablanica 0.487. Pusta reka region had the lowest erosion coefficient of 0.327. Weaker erosive processes in this region are explained by smaller values of terrain slopes.

By analyzing the soil erosion map from 2018, it is concluded that there have been significant changes in the intensity of the erosive processes. The goal of applying the Gavrilović method was to gain insight into the recent state of erosion in the region by taking into account the current climate conditions and land use patterns. The biggest changes occurred in the way land is used (reduction of anthropopression), especially in the hilly and mountainous parts of the region. During the last three decades, the process of deagrarization has intensified. As a result, there was an increase in the area under deciduous forests and especially under vegetation that represents scrub and young forest. The degree of afforestation of the region in 2018 was 64% (excluding young forest and scrub, it is 57%). The spontaneous abandonment of agricultural production and the reforestation of former arable land had a most important impact.

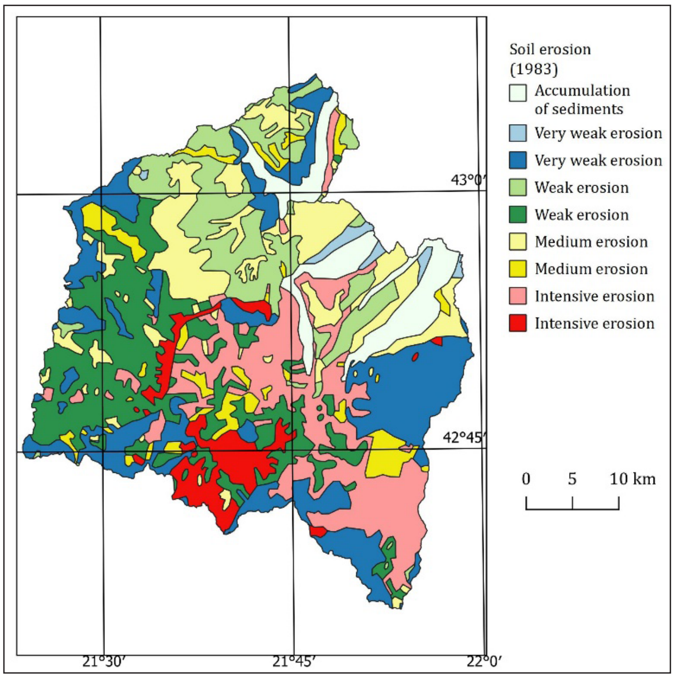

Figure 3. Soil erosion intensity in Jablanica region in 1983

According to the situation in 2018, very weak and weak erosion are most prevalent in the region (73.4% of the region's territory, compared to 51.2% in 1971). Medium erosion was recorded on 371.1 km2 (22.9%), and severe erosion on 60.6 km2 (3.7% of the territory). The Banjska river basin represents a good example of the reduction in the intensity of erosion in the period 1971–2018. According to Lazarevic (1983), this part of Upper Jablanica was affected by strong and moderate erosion. However, according to the current situation, low and medium erosion dominates. In this hilly-mountainous area, strong erosion is present only in the vicinity of Sijarinska Banja, i.e. in the smaller valley expansions of the Banjska river, where agricultural land is still cultivated. Despite the fact that erosive processes in the region are less intense, agricultural production did not develop. It is a consequence of depopulation and lack of labor force.

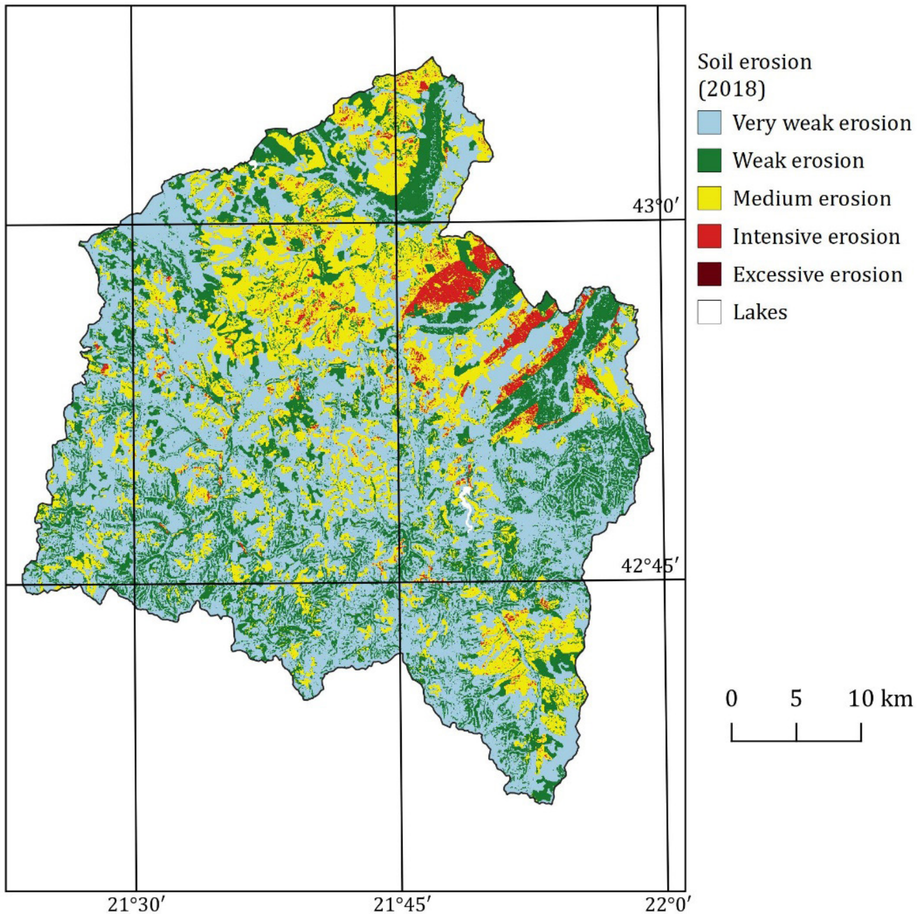

Figure 4. Soil erosion intensity in Jablanica region in 2018

Strong erosion is characteristic of low-lying parts of the region in the northeast, i.e. low slopes that form the watershed between Veternica, Sušica, Jablanica and Pusta Reka. These are areas of intensive agricultural production (farming and vegetable growing). In places, excessive erosion was recorded in this area, which was not the case in 1971 (although the areas under this category of erosion are negligible). Such data indicate that the process of soil erosion has stabilized in most of the region. Depopulation and cessation of agricultural production in the higher parts of the region are the main factors that have influenced the state of erosion and regional development. Natural conditions continue to influence the intensity of erosive processes. This is best seen on the example of the Poljanica basin, where processes of depopulation and deagrarization are the most intense. In addition, in this microregion, there is still moderate erosion with smaller areas under strong erosion (due to unfavorable natural conditions). The average erosion coefficient for 2018 in the area of the entire region is 0.293.

Conclusion

In the second half of 20th century as well as in the first decades of 21st century significant changes have occurred regarding the intensity of soil erosion in the study area. In the Poljanica basin, Upper Jablanica and in the higher parts of the Pusta reka region, it is necessary to convert arable land that is threatened by erosion. By converting degraded arable land into meadows and pastures, the development of animal husbandry would be enabled. For this branch of agriculture, there are significantly more favorable natural resources and conditions. The most intensive erosion takes place in the lower parts of the region, in Porečje, Lower Jablanica and low areas of Pusta reka region. Intensive production of vegetables and industrial plants (tobacco and sunflower) leads to rapid soil degradation and loss of fertility. Degraded areas that are on higher slopes must be replaced with perennial agricultural crops. The high level of groundwater in the alluvial plains of the rivers leads to oversaturation of the surface layers of the soil and the initiation of landslides.

Therefore, it is necessary to carry out land melioration of landslides, regulation and maintenance of drainage channels. In the area of Porečje, it is necessary to increase the areas under grass vegetation (meadows and pastures), raise orchards and apply measures of afforestation, in order to improve the water regime of the soil. The mentioned measures would reduce the direct damage caused by the triggering of landslides. Indirectly, agricultural production in the region would improve, because agricultural crops would be grown on adequate areas, with an increase in total production.

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