©2022 Published in 6th International Symposium on Natural Hazards and Disaster Management
21-23 October 2022 (ISHAD2022 Bursa - Turkey)
https://doi.org/10.33793/acperpro.05.02.9300

The Impact of Depopulation on Reduction of the Peaks of Torrential Floods in Selected Watersheds of the Southeastern Serbia

*[1]Ana M. Petrović, [2]Stanimir Kostadinov, [3]Sanja Manojlović
*[1]Geographical Institute „Jovan Cvijić" of the Serbian Academy of Sciences and Arts, Belgrade, Serbia
[2] University of Belgrade – Faculty of Forestry; Institute of Forestry, Belgrade, Serbia
[3]University of Belgrade – Faculty of Geography, Belgrade, Serbia

Abstract

The processes of emigration, depopulation and deagrarization in hilly-mountainous border areas in Serbia have intensified in last several decades. These processes have resulted in land use changes which means that anthropogenic impact on environment has diminished so the agriculture areas have decreased and have made room to the other land use types. These changes should entail lower soil erosion, slower generation of surface runoff during rainfall episode as well as reduction of the peak discharges and destructiveness of a torrential flood event. In this paper, we quantified the influence of land use changes on surface runoff indicators for 15 watersheds in the Southeastern Serbia. The greatest reduction of the curve number (CN_R) happened in the Toplodolska watershed (2.34), then the Korbevačka (1.98) and the Dojkinačka (1.60) watersheds. The decrease of maximal discharge of 100-year return period is presented on example of a small watershed of the Ravna reka and it equals to 11%. It is expected that noticed land use changes will have the same trend, meaning that CN numbers will continue decreasing. Alongside these spontaneous positive anthropogenic impact on lowering the peaks of torrential floods, there should be a set of other preventive measures implemented.

Keywords: land use changes, runoff, watershed

1. Introduction

Sudden occurrence of torrential floods with their harmful consequences severely disturbs normal functioning especially in small local communities, so the examination of this phenomenon is of great importance in terms of mitigation of future torrential flood events. The focus in a research of torrential flood phenomenon should be on the causality between multiple natural processes and environment and multiple societal processes and aspects [1, 2, 3].

The extent of consequences of torrential flood phenomenon which is followed by excessive soil erosion and sediment transport processes are not only highly dependent on physical-geographical factors and extent of torrent and soil erosion control in a watershed, but are also closely connected to the local economic development. If a transformation from rural to urban areas is dominant, favourable conditions for intensification of this natural phenomenon and process are then created. This trend is typical in lower parts of a watershed where growing towns and cities are located,

*Corresponding author: address: Geographical Institite „Jovan Cvijić" of the Serbian Academy of Sciences and Arts, 11000 Belgrade SERBIA. E-mail address: a.petrovic@gi.sanu.ac.rs

attracting more, especially young people from the villages in the upper, hilly-mountainous part of a watershed. Abandonment of the settlements and negative population growth in border areas are specifically noticed and registered in the last several decades. This trend would mean leaving the active agricultural areas that make conditions for their turn to grass vegetation and forest areas in the course of time. In this way, the anthropogenic pressure on arable land and forest areas shall be reduced having the positive effects related to mitigation of the severe effects of torrential floods in lower parts of a watershed as well as intensity of soil erosion processes (that intensifies during the extreme rainfall episode).

Manojlović [1] found the constant decrease of intensity of erosion process, sediment production and transport in the Nišava watershed (A = 2,091 km^2) during last decades, 1971–2011 and searching for causes the author reveals the following: the dynamic emigration from the settlements especially in the upper part of watershed (average decrease of population was 30 %) as well as the effects of earlier extensive erosion control works. The second factor of land use changes is also high index of the population aging. Later, Manojlović et al. [4, 5] demonstrated similar results in research for the Južna Morava river basin (A = 15,469 km^2, comprising the Nišava watreshed) and for the Velika Morava river basin encompassing the Južna Morava river basin (A = 37,561 km^2). In both studies, it is shown that the decrease of rural population and areas of agricultural and arable land were directly related to the decline of suspended sediment.

Therefore, land use changes determine the soil erosion intensity as well as generation of the surface runoff in the watershed. The task of this research is to measure that impact of anthropogenic processes on the surface runoff indicator for several watersheds in the Southeastern Serbia.

2. Study area, datasets and methods

This research is an extension of the study of Manojlović et al. [5]. The Figure 1 refers to the spatial presentation of depopulation/population growth and deagrarization/agrarization growth in the Velika Morava river basin (which is 42.5% of the territory of the Republic of Serbia) located in the Central Serbia. Here, the areas with high depopulation and deagrarization are marked and belong to the Južna Morava river basin. Marked area is characterized by a hilly-mountainous relief which together with other geological, soil, land use and climatic conditions is very subject to torrential flood phenomenon with peaks of their occurrence in spring season – June, April and May [6]. Therefore, study area is the torrential mainly ungauged watersheds near the border with Bulgaria and North Macedonia.

In physical-geographical examination of the watersheds we used topographic maps with scale 1:25000 and EUDEM 25m resolution as well as soil and geology data for studied watersheds [7, 8]. To examine the land use changes, we used datasets of the CORINE 1990 [9] and CORINE 2018 [10] so we had time difference of 28 years.

Given that there are no hydrological measurements in majority of subject watersheds for the computation of changes of maximal discharge between 1990 and 2018, the combined conceptual model of the Soil Conservation Service and synthetic unit hydrograph theory, SCS-SUH [11, 12] is employed. The main tool for measurement of the changes of surface runoff in different land use conditions was computation of *curve numbers – CN* of watersheds which is a core of SCS method. Following the Figure 2, this method is presented in detail in research of Petrović et al. [13] as well as in Kostadinov et al. [14].

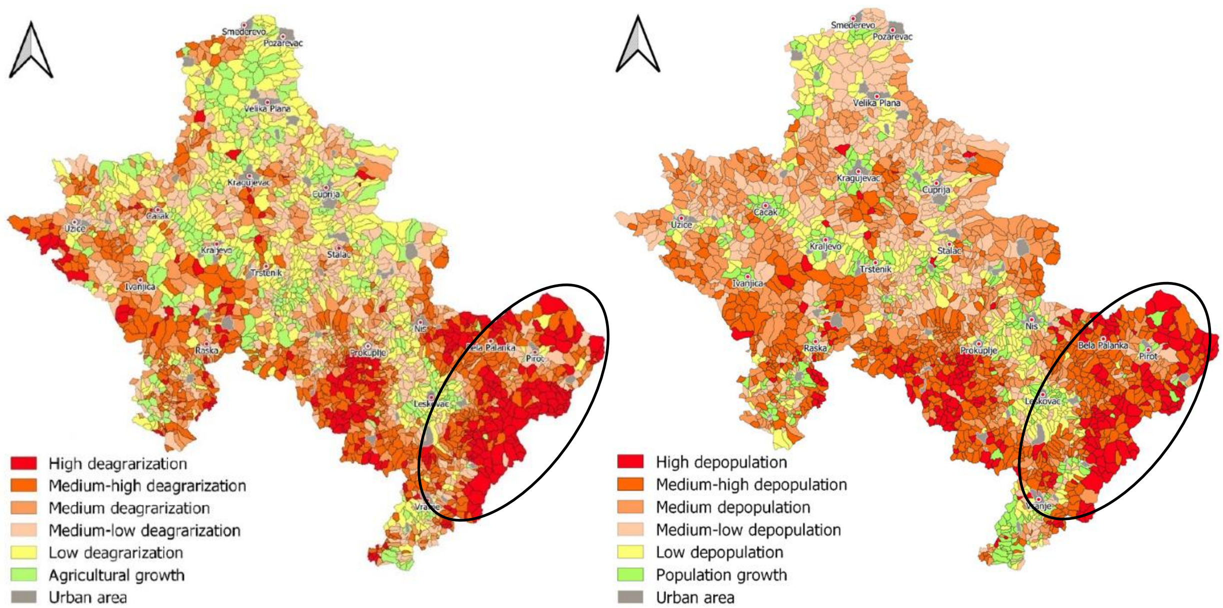

Figure 1. Depopulation and deagrarization in the Velika Morava river basin
(Source: 5)

The most important, watershed geology, soil and land use data are used to define the watershed *curve number (CN)*. The next step is to determine the potential maximum retention, so the effective rainfall amount which made the direct, surface runoff can be computed. Results of precise watershed morphometry analysis are the input data for calculation of the watershed *lag time*, a core of unit hydrograph. Then, the synthetic unit hydrograph and peak ordinate can be determined. At last, this calculation procedure enables the computation of the peak discharge.

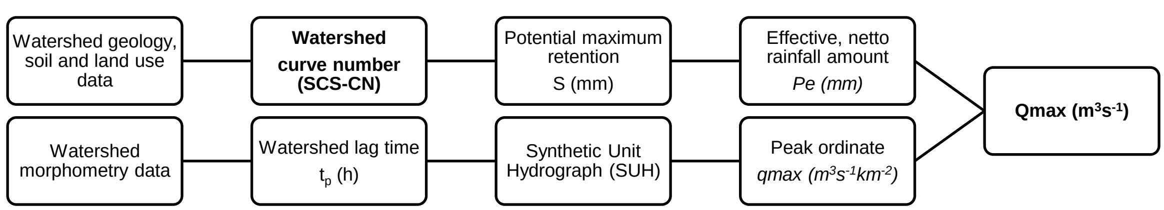

Figure 2. Description of the SCS-UH methodology for reconstruction of the maximal discharges
(Source: 11, 12, 13)

3. Results

After identification of the study area, the analysis of watersheds with progressive processes of depopulation and deagrarization is conducted. The watershed lines are created and land use types are defined for 15 watersheds with areas in the range from 5.59 to 817.34 km^2. Curve numbers for average soil moisture conditions (CN_{II}) are defined with regard to land use situation from 1990 and 2018. For all selected watersheds, the decrease of CN_{II} is noticed. In the SCS methodology, that means the lower runoff on slopes and the lower peak discharges in river beds. The greatest reduction of the curve number (CN_{IIR}) happened in the Toplodolska watershed (CN_{IIR} = 2.34), then the Korbevačka (CN_{IIR} =1.98) and the Dojkinačka (CN_{IIR} = 1.60) watersheds. The lowest curve number reduction is obtained for the Vlasina (profile Svođe, CN_{IIR} = 0.50) and the Ljubatska watersheds (CN_{IIR} = 0,33). Table 1 shows the regressive changes of the curve numbers of studied watersheds from the highest to the lowest reduction.

Table 1. Reduction of curve numbers in time span of 28 years

No	Watersheds	River basin	Profile	Area (km^2)	**CN_{IIR}**
1	Toplodolska	Nišava / J.Morava	Staničenje	137.81	**2.34**
2	Korbevačka	Južna Morava	Klisurica	56.43	**1.98**
3	Dojkinačka	Nišava / J. Morava	V. Ržana	137.43	**1.60**
4	Prisjanska	Nišava / J.Morava	Rasnica	52.48	**1.48**
5	Ravna reka	Vlasina / J. Morava	Strelac	5.59	**1.42**
6	Rosomačka	Nišava / J. Morava	Slavinja	23.42	**1.28**
7	Jelašnica	Južna Morava	Jelašnica	68.18	**1.28**
8	Banjska	Južna Morava	Vr. Banja	108.37	**1.21**
9	Vrla	Južna Morava	Surdulica	76.69	**1.11**
10	Temštica	Nišava / J. Morava	Šipkovica	817.34	**0.86**
11	Jerma	Nišava / J. Morava	Strezimirovci	110.85	**0.72**
12	Romanovska	Vrla / Južna Morava	D. Romanovce	17.44	**0.61**
13	Masurička	Vrla / Južna Morava	Masurica	46.15	**0.59**
14	Vlasina	Južna Morava	Svođe	430.53	**0.50**
15	Ljubatska	Dragovištica / Struma	Bosilegrad	199.01	**0.33**

The Figure 3. shows the land use situation of the observed watersheds in 1990 and 2018. Since the highest lowering of the *CN* is obtained for the Toplodolska, but also for the Dojkinačka and Rosomačka watersheds, we examined the CN difference for the Temštica watershed that encompasses previous three. The CN_R for the Temštica watershed (with a largest watershed area in the study area) is somewhat lower – 0.86. The highest CN_{IIR} among direct tributaries of the Južna Morava has the Korbevačka watershed, then Jelašnica (CN_{IIR} = 1.28), Banjska (CN_{IIR} = 1.21) and Vrla (CN_{IIR} = 1.11). Only the Ljubatska watershed having the lowest CN_{IIR} (0.33) belongs to the Struma, i.e. Egej basin. The rest of watersheds belongs to the Južna Morava / Velika Morava, i.e. Danube river basin. The observation of land use changes for all studied watersheds lead to conclusion that agricultural areas were replaced with transitional woodland-shrub (belonging to class forest and semi natural areas) in time span of 28 years.

Similar results are obtained in the research of Ristić et al. [15] for a small left tributary of the Južna Morava – the Kalimanska watershed taking into account larger time span in terms of land use changes of 81 years. In addition, measurement data shows that there is a decrease of average of the annual maximal discharges per periods for the Nišava (station Dimitrovrgrad $Q_{max1963–1989}$ = 45.04 m^3s^{-1} and $Q_{max1990–2010}$ = 34.07 m^3s^{-1}), the Vlasina (station Vlasotince $Q_{max1963–1989}$ = 177.04 m^3s^{-1} and $Q_{max1990–2010}$ = 123.12 m^3s^{-1}) and the Temštica (station Staničenje, $Q_{max1963–1989}$ = 83.82 m^3s^{-1} $Q_{max1990–2010}$ = 70.8 m^3s^{-1}).

Torrential floods which happened in some of studied watersheds took historical place in the Inventory of torrential floods in Serbia encompassing the period from 1915 to 2019 [6]. For instance, the torrential flood event of the Korbevačka river in May 1975 had the tragic consequences, since it took 12 human lives and injured 169 persons due to a train accident near Vranjska banja making cataclysmic damages to a local community. The torrential floods of Korbevačka as well as Jelašnica, Banjska, Vrla and Vlasina interrupted very often in the past the transport and traffic at two major international routes, railway and motorway Belgrade – Skopje – Athens, which is situated in Southern Morava valley (after the World War II when those interruptions lasted up to 15 days). The catastrophic 26th June 1988 flood in the Vlasina watershed with a specific maximal discharge, q_{maxsp} = 1.1 $m^3s^{-1}km^{-2}$ had 4 casualties.

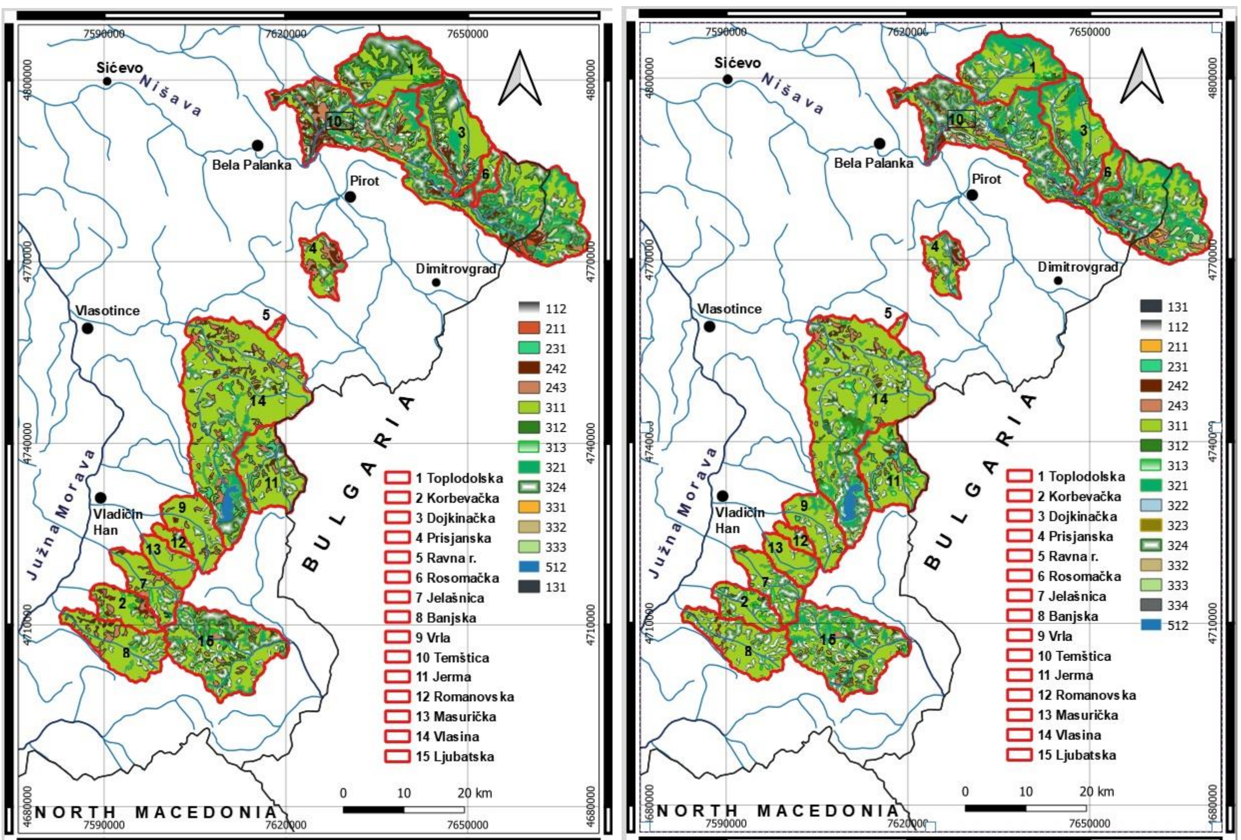

Figure 3. Studied watersheds with their land use patterns in 1990 (left) and 2018 (right)

According to the Inventory of torrential floods in Serbia in the Južna Morava river basin the highest number of registered torrential flood events is recorded in the Nišava watershed [16]. As Figure 4 refers, steep slopes in hilly mountainous regions contribute to the faster runoff process. A death toll of torrential flood of a small tributary of the Rasnička reka – the Balvan (Nišava river basin) in August 1929 was several people. In July 1952, a sudden flood of Dolina, a small tributary of the Jerma took 1 human life near Trnski Odorovci. The extreme specific maximal discharge are registered or reconstructed for some severe floods: the Prisjanska reka in June 1988 (q_{maxsp} = 1.42

$m^3s^{-1}km^{-2}$), Dojkinačka in April 2000 (q_{maxsp} = 0.88 $m^3s^{-1}km^{-2}$) and August 2007 (q_{maxsp} = 0,99 $m^3s^{-1}km^{-2}$) [14, 17, 18].

One of the most extreme torrential flood events in Serbia happened in a small catchment of the Ravna reka in June 1988 that was also followed by many landslides. The extreme rainfall episode with 220 mm registered at two rainfall stations (Rakov Dol and Radinjinci) made an extreme specific maximal discharge, q_{maxsp} = 10.1 $m^3s^{-1}km^{-2}$ with a return period, T = 1430 years which means the probability of occurrence, p = 0.07% [19].

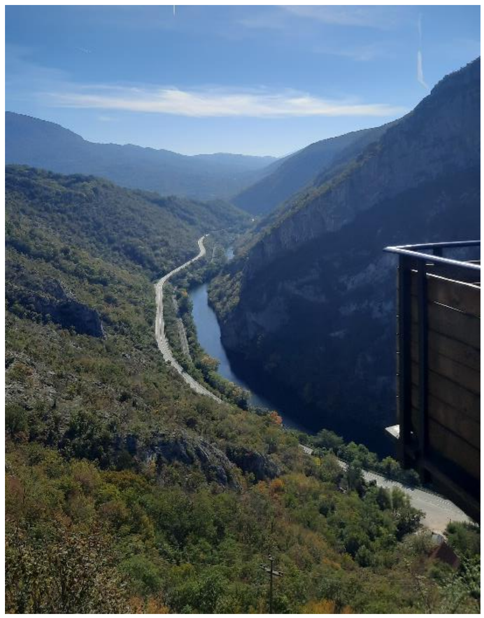

Figure 4. The Nišava River – steep slopes of the Sićevo George
(Photo: Ana M. Petrović, October 2022)

On the example of the Ravna reka watershed, we will present the changes of peak discharges with regard to the land use situation from 1990 and 2018. As defined in the study of Kostadinov et al. [19], geological substrate in the Ravna reka watershed are slates, marls, conglomerates and arenilitic flysch, while soil types are sierozem, brown eroded eutric soil and brown illimerized soil.

This watershed is located between 551 and 1257 m a.s.l and is almost unpopulated except at the confluence to the Murgovica river. The hydrographic parameters of the watershed are computed in the GIS analysis of the topographic maps and EUDEM (European Environment Agency 2016). The lag time of the Ravna reka watershed is defined, t_p = 1.02 h (watershed length, L = 5.59 km, watershed length to the centroid, L_c = 2.88 km and mean slope of river bed, S_{rb} = 10.1%), so the synthetic unit hydrograph is ready for the computation of maximal discharges according to the combined SCS–SUH methodology. The Log Pearson Type III technique is applied for the calculation of rainfall of different probability of occurrence using data of annual maximal rainfall of station Rakov dol.

Figure 5 shows the maximal discharges in an event of torrential flood of the Ravna reka with a return period of 100 years. The 100-return period maximal discharge with land use conditions from

2018 is lower than in case of land use patterns from 1990. Specific maximal discharge is then, $q_{maxsp1\%2018}$ = 4 $m^3s^{-1}km^{-2}$ and $q_{maxsp1\%1990}$ = 4.5 $m^3s^{-1}km^{-2}$, which means the reduction of specific maximal discharge $q_{maxsp1\%R}$ for 0.5 $m^3s^{-1}km^{-2}$ which equals to 11%. This is a result of a dominant share of forest and semi natural area in 2018 in comparison with earlier land use pattern.

Studied watersheds are located in the hilly mountainous, border area with Bulgaria and the North Macedonia, so the settlements are less accessible and economically developed. Rural population in the upper border region has been attracted by the intensive urbanization in lower areas of the watersheds and larger cities.

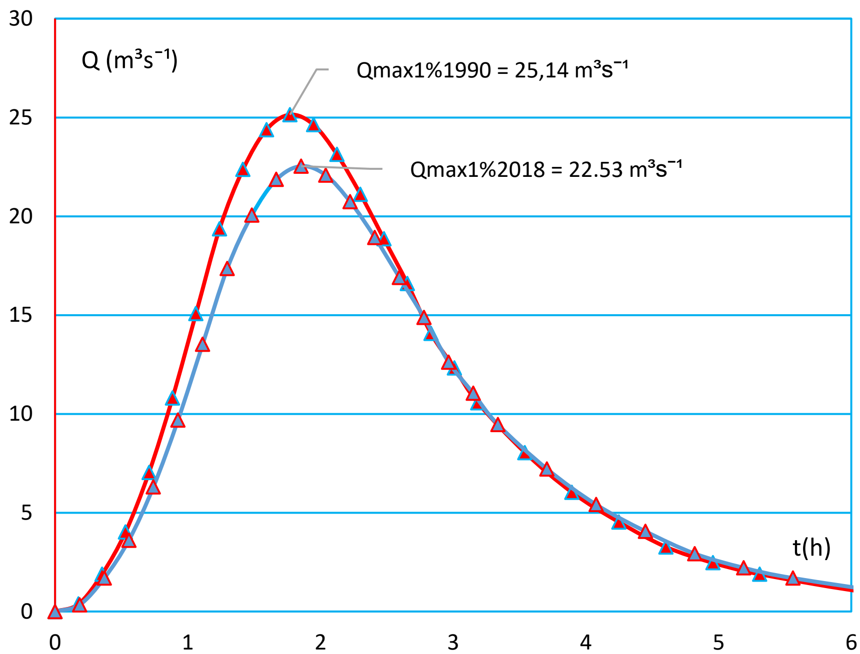

Figure 5. Peaks of the torrential floods with 100 return period of the Ravna reka in 1990 and 2018

In such a situation, not only mechanical component of population change in terms of emigration is noticed, but also a biological one that refers to the deep demographic age of villages in the upper border area. As a result of this trend there are many villages on the verge of the demographic extinction. Furthermore, results of the projected population presented for medium and zero migration variant for the settlements in the southeastern Serbia and the period up to 2041 are in line with the trend of depopulation in the last decades, according to the Statistical Office of the Republic of Serbia [20].

4. Conclusions

In this research, the main spatiotemporal changes that occurred in the last three decades in the watersheds with torrential water regime and that influenced the surface runoff are examined. The impact of land use changes in the time period 1990–2018 on a maximal discharge of torrential flood events in the small and medium watersheds in the Southeastern Serbia (mainly belonging to the Južna Morava) is quantified by the computation of curve numbers – CNs for 15 torrential watersheds. The lowering of curve numbers is found as a consequence of the abandonment of agricultural areas which have turned to other land use types that decelerate the generation of surface runoff in the episode of extreme rainfall. The greatest regressive change of the computed curve number is found for the watersheds of the Toplodolska reka and the Korbevačka reka. The decrease of maximal discharge of the 100-year return period is presented on example of a small watershed of the Ravna reka and it equals to 11%.

It is expected that noticed land use changes will have the same trend, meaning that CN numbers will continue decreasing. However, bare lands, sparsely vegetated and burnt areas should not be abandoned, yet reforested. Alongside these spontaneous diminishing of anthropogenic impact and lowering the peaks of torrential floods, there should be a set of other preventive measures implemented [c.f. 21, 22, 23].

Acknowledgements

This research and conference participation is financed by the Ministry of Education, Science and Technology of the Republic of Serbia.

References

[1] Manojlović S Uticaj geografskih faktora na promene intenziteta vodne erozije u slivu reke Nišave [Impact of geographical factors on intensity changes of the soil erosion in the watershed of the Nišava River]. Belgrade: Faculty of Geography – University of Belgrade; 2018.

[2] Erol U, Kızmaz Y, Özden A, Ceyhunlu AI. Evaluation of the Transportation Infrastructure Vulnerability in Kaynarca, Sakarya Basin from a Flood Spread Risk Perspective. APJHAD 2022; 3(1): 20–31. https://doi.org/10.52114/apjhad.1128037

[3] Mahnamfar F, Abdollahzadehmoradi Y, Ağıralioğlu N. Flood risk analysis of residential areas at downstream side of Elmali dam. APJHAD 2020; 1(1): 49–58.

[4] Manojlović S, Sibinović M, Srejić T, Hadud A, Sabri I. Agriculture Land Use Change and Demographic Change in Response to Decline Suspended Sediment in Južna Morava River Basin (Serbia). Sustainability 2021; 13(6): 3130. https://doi.org/10.3390/su13063130

[5] Manojlović S, Srejić T, Sibinović M, Milošević M, Bajat B, Kostadinov K. Impact of precipitation and human activities on suspended sediment transport load in the Velika Morava River Basin (Serbia). Arab J Geosci 2022; 15: 1209. https://doi.org/10.1007/s12517-022-10475-x

[6] Petrović AM. Bujične poplave u Srbiji [Torrential floods in Serbia]. Belgrade: Serbian Geographical Society, 2021. https://www.researchgate.net/publication/355646649_Bujicne_poplave_u_Srbiji_-_Torrential_floods_in_Serbia

[7] Military Geographic Institute (1968-2001) Topographic maps (1:25000).

[8] European Environment Agency (2016) European Digital Elevation Model (EU-DEM 25 m, version 1.1) Retrieved from https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1 Accessed 18 May 2022

[9] European Environment Agency (2020). CORINE (Coordination of Information on the Environment) Land Cover 1990 (version 2020, 20u1). Retrieved from https://land.copernicus.eu/pan-european/corine-land-cover/clc1990 Accessed 15 September
[10] European Environment Agency (2020). CORINE (Coordination of Information on the Environment) Land Cover 2018 (version 2020, 20u1). Retrieved from https://land.copernicus.eu/pan-european/corine-land-cover/clc2018 Accessed 14 September
[11] Snyder FF Synthetic unit-graphs. Eos Trans AGU 1938; 19(1): 447–454. https://doi.org/10.1029/TR019i001p00447
[12] Soil Conservation Service Hydrology. National Engineering Handbook. Washington, DC: Soil Conservation Service; 1956.
[13] Petrović AM, Manojlović S, Kostadinov S. How extreme were the torrential floods in smaller watersheds in Serbia in September 2014. Proceedings of the 5th International Symposium on Natural Hazards and Disaster Management – ISHAD, Academic Perspective Procedia 2021; 116–124. https://doi.org/10.33793/acperpro.04.02.41
[14] Kostadinov S. Analysis of torrential flood of Prisjanska River on 26.06.1988. Šumarski list 1990; 114: 159–169.
[15] Ristić R, Kostadinov S, Radić B, Trivan G, Nikić Z. Torrential floods in Serbia – man-made and natural hazards. Conference Proceedings of the 12th Congress “Interpraevent” 2012; 771–779.
[16] Petrović A, Kostadinov S, Dragićević S. The Inventory and characterization of torrential flood phenomenon in Serbia. Pol J Environ Stud 2014; 23 (3): 823–830.
[17] Republic Hydrometeorological Office of Serbia. Hydrological annual report. RHMO Serbia, Belgrade; 2000.
[18] Republic Hydrometeorological Office of Serbia. Hydrological annual report. RHMO Serbia, Belgrade; 2007.
[19] Kostadinov S, Popović M, Marković S Analysis of the conditions of flood formation in the torrent Ravna reka in June 1988. Tagungspublikation des internationalen Symposiums “Interpraevent” 1992; 1: 241–252.
[20] Statistical Office of the Republic of Serbia. Projected population at the beginning and at the end of the projected period by municipalities (Database); 2017. https://data.stat.gov.rs/Home/Result/180202?languageCode=en-US Accessed on 18 September 2022
[21] Cvetković V, Martinović J. Innovative Solutions for Flood Risk Management. International Journal of Disaster Risk Management 2020; 2(2): 71–99. https://doi.org/10.18485/ijdrm.2020.2.2.5
[22] Kostadinov S, Dragićević S, Stefanović T. Torrential flood prevention in the Kolubara river basin. J Mt Sci 2017; 14(11). https://doi.org/10.1007/s11629-017-4575-9
[23] Kostadinov S, Borisavljević A. Erosion Control and Soil and Water Conservation – Worldwide Review. Erosion 2012; 38 (4): 1–25.