DE GRUYTER OPEN

SPATIUM
No. 34, December 2015, pp. 64-69

UDC 556.166(282.243.744)
Review paper
DOI: 10.2298/SPAT1534064P

SPATIOTEMPORAL REVIEW OF THE TORRENTIAL FLOOD PHENOMENON IN THE MORAVA RIVER BASIN

Ana M. Petrović[1], Geographical Institute "Jovan Cvijić" of the Serbian Academy of Sciences and Arts, Belgrade, Serbia
Ratko Ristić, Faculty of Forestry of the Belgrade University, Belgrade, Serbia

Phenomenon of torrential floods as the most destructive and the most frequent natural hazards in Serbia with serious socioeconomic, cultural and environmental consequences deserve special attention. In this paper, data collection strategy and data analysis with the aim of spatiotemporal characterization of the torrential flood phenomenon in the largest national, Morava river basin, are presented. A dataset (derived from the Inventory of torrential floods in Serbia) of 479 registered torrential flood events with over 84 casualties for the period 1926-2013 is presented. Monthly distribution of registered torrential floods indicates that the majority of events with the highest share of death toll occurred in the late spring, from May to the end of June. According to the annual distribution there is a linear increase of torrential flood occurrence in the course of 88 years, but decrease of death toll is found. The greatest number of torrential flood events and casualties is registered in the Južna Morava river basin (watersheds of Nišava, Toplica, Veternica, Jablanica). The results of this work can be of great value in the implementation of the Flood Directive of the European Commission on a river basin level as well as for the future natural hazards information system in Serbia.

***Key words*: torrential floods, spatiotemporal distribution, Zapadna Morava, Južna Morava, Velika Morava.**

INTRODUCTION

The frequency and magnitude of the torrential flood phenomenon have made many countries in the world suffer the large human and economic losses in the recent period (Hershy, 2005; Münchener Rückversicherungs-Gesellschaft, 2009; Marchi *et al.,* 2010; Gourley *et al.* 2010, Shao *et al.,* 2014; Wang *et al.*, 2015; Abbas *et al.*, 2015). Torrential floods are the frequently reccuring water-related natural hazard in Serbia that deserves a special attention (Ristić *et al.*, 2011a; Dragićević *et al.,* 2011; Dragićević *et al.*, 2013; Kostadinov *et al.*, 2014). This kind of natural hazard is related to the hilly-mountainous regions in Serbia, on the territory south of the Sava River and the Danube River, endangered by intensive soil erosion processes, having as a consequence specific hydrological and sediment transport regime in the torrential riverbeds (Petrović, 2014). Torrential flood wave occurs after a short-duration heavy rainfall as a sudden appearance of maximal discharge with a high concentration of erosion sediment lasting from one to several hours (Ristić *et al.*, 2012; Garambois *et al.*, 2014). Torrential flood wave discharge can be larger than 1000 times than mean discharge having destructive energy. However, these extremes are mostly ungauged despite the need of special kind of surveying (Borga *et al.*, 2008).

[1] Đure Jakšića 9, 11000 Belgrade, Serbia
a.petrovic@gi.sanu.ac.rs

Torrent network at the territory of Serbia numbers more than 12000 torrents (Kostadinov *et al.*, 2006), mostly situated in the Južna Morava, Zapadna Morava and Velika Morava river basins due to relief dissection as well as extent of area. The most striking torrential flood in the course of the 80ies occurred in Lještarska dolina (Južna Morava, July 1982), Sejanička (Južna Morava, July 1983), Lugomir (Velika Morava, February 1986) and Vlasina (Južna Morava, June 1988) watersheds. Recent large-scale torrential flood events in studied river basins happened in watersheds of Lugomir, Gruža, Jasenica and Lepenica in July 1999 (Velika Morava, eight fatalities), Resava in June 2002 (Južna Morava, one death), Vlasina in November 2007 (Južna Morava). Although the extreme flood events in April and May 2014 occurred mainly in north-western part of Serbia, flood events in Jagodina, Požega and Lučani in the Morava river basin left noticed material damages.

However, a small number of historical torrential flood events in Serbia were analysed, mostly they are poorly documented and mainly described with some photos and rare measured data. Although population and local economy is highly affected by torrential floods in the Morava river basin, there was no centralized and consistent collection of data on torrential floods. Databases on natural hazards in several developed countries which contribute to better understanding of torrential floods as extreme hydrological hazards, records this phenomenon for the past several centuries (Swiss database on natural hazards numbers over 20,000 events; Austrian database on natural hazards numbers about 28,000 events, of which torrent events share is over 20000; the first record is situated in the 6th century) (Petrović *et al.*, 2014). The purpose of this work is to present a phenomenon of torrential floods in the Morava river basin through spatiotemporal characterization of historical torrential flood events in order to give contribution to the improvement of the torrential flood policy which should be in accordance with the European Union Flood Directive.

METHODOLOGY

Study area

The research focus is on the greatest "national" river basin in Serbia (Figure 1), which is mostly hilly-mountainous area, with the confluence to the Danube River. It covers 41.5 % of the Serbian territory and homes of 53% of population are situated within. According to the Water Management Plan of the Republic of Serbia (2001), 38,890 ha in the Južna Morava river basin (A=15,465 km^2), 19,110 ha in the Zapadna Morava river basin (A=14,653 km^2) and 26,400 ha in the Velika Morava river basin (A=6,810 km^2) are potentially flooded area of a return period of 100 years. Beside meteorological extremes, geological and soil properties unfavourable for water infiltration, deforestation, land use changes and topography are the direct factors of torrential regimes of water discharges, i.e. disbalanced ratio between high and low waters in watersheds of torrential tributaries in the Morava river basin.

Figure 1. Study area – Morava river basin

Materials and methods

The dataset of torrential flood events in the Velika Morava river basin is derived from newspaper articles gathered for the period from 1926 to 1970 in the book by Gavrilović (1975), archival documentation of the newspaper "Politics" for the period from 1970 to 2013 and data from papers and studies with detailed analysis of past events. Absence of data and reports on torrential events in archives of public organizations on the state and local level mainly impeded them to contribute to this dataset. Method for building the dataset consists of five important steps: (1) defining spatial and time framework and needed parameters, after the insights into data availability, (2) data collection, (3) organizing data, (4) data analysis, (5) data publishing, distribution and use (Petrović *et al.*, 2015). Collection of minimum data (as shown in an example of river Koritnička, Table 1) facilitated analysis of spatial and temporal distribution of torrential flood events in the Morava river basin. The research question of data analysis consists in examining the trend changes of frequency of torrential flood occurrence as well as in exploring the most frequent localities with material damages and casualties.

Table 1. An example of minimum data for registering torrential flood event

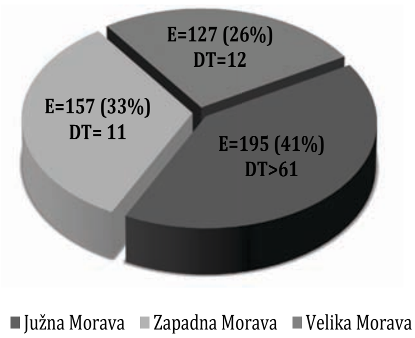
Torrent	•Koritnička river (Južna Morava)
Date of event	•27/10/1939
Affected locations and settlements	•Bela Palanka
Number of casualties	•17
Damage description	•20 houses were razed to the ground, 142 tended to decline, while 264 severely damaged, over 500 head of cattle disappeared in the torrents.
Event description	•After heavy rainstorm in the evening, ferocious torrent from the Suva Mountain made a local calamity. Disaster lasted 2 hours.
Source of informaton	•"Politika"

Rare torrential flood events were recorded with full meteorological (rainfall quantity and duration), hydrological (discharge and water level) and sediment transport data. Mainly they are modestly documented. For example, in the case of information about an affected location, but not the torrent, for identification of micro-torrential catchment as a subject of flood event, geo-referenced topographic maps in scale 1:25,000 (printed by Military Geographic Institute, 1980) for the whole area of the Morava river basin were used. Therefore, affected locations are given geographic coordinates in this database becoming geospatial data on natural hazards.

RESULTS

One of the oldest records of torrential flood events in studied river basin dates from the sixteenth century and refers to the flood of the Raška river (Zapadna Morava river basin) on 18th May in 1518 (Šakota, 1989). Some flood descriptions were found in monastery chronicles dating from XVIII and XIX century representing introductory historical information of this dataset. Dataset consists of data on the torrential floods during XX century up to date. The first data in the previous century we avail is the torrential flood of the Skrapež in May 1926. The following 20 torrential flood events were located in "torrential" 1929 in May, June and August.

Dataset on torrential floods in the Morava river basin records 479 events with over 84 casualties for the period 1926-2013. The largest number of torrential flood events and casualties took place in the Južna Morava river basin (Figure 2) which is a result of an inadequate soil management, extreme forest exploitation and destruction and intensive soil erosion processes (i.e. inadequate watershed management) having as a consequence severe economical damages in agriculture and traffic (for example, many times in history damaged international routes Belgrade - Atina and - Sofia). The greatest number of torrential floods in sub-basins is registered in watersheds of the Ibar (Z. Morava), the Nišava (J. Morava), the Jasenica (V. Morava) and the Veternica (J. Morava). Spatial distribution of the most destructive torrential flood events in terms of material damages and death tolls in the Morava river basin is given in Figure 3. According to distribution of locations, it can be concluded that material damages in the Južna and Zapadna Morava river basins are the greatest at the confluence of the torrents to greater rivers.



Watershed	E	DT
Ibar	49	10
Đetinja	16	-
Lepenica	21	4
Nišava	43	-
Veternica	26	-
Jablanica	17	3
Toplica	19	-
Lepenica	21	4
Jasenica	27	3

Figure 2. Number of torrential flood events (E) and death toll (DT) per river basin and selected watersheds

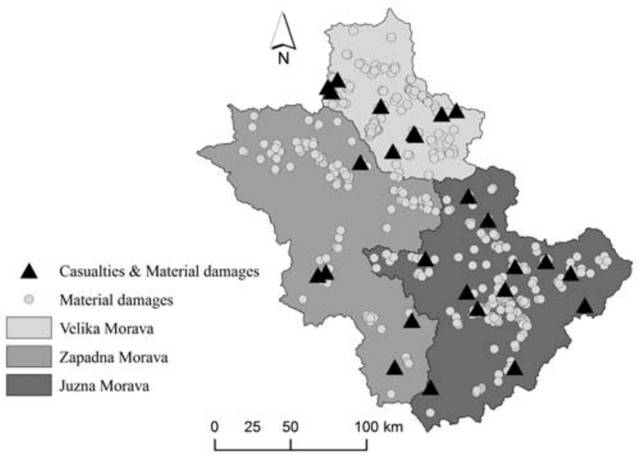


Figure 3. Locations with the most destructive torrential flood events recorded in the Morava river basin in the period 1926-2013

Hydrological statistical analysis according to the most fitted theoretical probability function is given in this work for some examples of extreme torrential flood events of selected watersheds in the Morava river basin (Table 2) which are naturally characterized by extreme discharges with high return period (T) and low probability of occurrence (P). The randomness of time series of maximum annual discharges is tested by methods of Newman and Wald-Wolfowitz. The homogeneity of average values is tested by Student test, dispersion homogeneity by Fisher test and distribution function by Wilcoxon test. Theoretical probability distribution functions: Normal, Log-Normal, Gumbel, Pearson III and Log-Pearson III are calculated. Kolmogorov-Smirnov and Kramer-Mizes tests are applied for concordance between empirical and theoretical distribution which decided on the most competent theoretical probability distribution.

Distribution of registered events within a year (Figure 4) indicates that the majority of floods occurred in June (E=159 or 33.2%) and May (96 or 20%), followed by July (57 or 11.9%), February (40 or 8.4%) and March (33 or 6.9%). Therefore, two peaks can be distinguished: the primary peak of torrential flood occurrence in warmer part of the year (June and May) and the secondary peak in the colder part of the year (February and March). Monthly distribution of registered torrential floods greatly corresponds to peaks of the rainfall regime in hilly-mountainous regions in Serbia as well as to the earlier domestic findings of research in the area of frequency of maximal discharges in torrential watersheds. Ristić *et al.* (2009) defined two critical periods of occurrence of the maximal discharges south of the Sava and the Danube - primary at the end of spring (May & first half of June) and secondary at the end of winter (February & first half of March). This result also corresponds to the findings of monthly distribution of recorded events at the level of the Inventory of torrential flood events in Serbia (Petrović *et al.*, 2014).

According to annual distribution (Figure 5) for an observed period of 88 years there is a trend of linear increase of number of torrential flood events. The peak years distinguished on the basis of number of events are 1969 (E=37), 2005 (34), 1992 (32) and 1975 (32). The annual mean of registered torrential flood events for the observed period is 5.4.

The changes in the frequency of torrential flood events is noticed in their distribution per periods: 1931-1960 and 1961-1990, which are recommended by the Republic Hydromethorological Service of Serbia to analyze the precipitation and air temperature trend changes, and

Table 2. The frequency of occurrence of maximal discharges of extreme torrential floods

Watershed: Profile	River basin	Year	Q_{max} (m^3/s)	Function	P (%)	T (yr)
Vlasina: Vlasotince	J. Morava	26.06.1988	780	Log-Pearson III	0.89	113
Visočica: V. Ržana		20.04.2000	202	Pearson III	0.79	126
Gruža: Guberevac	Z. Morava	12.07.1999	43	Pearson III	1.82	55
G. Moravica: Ivanjica		13.05.1965	362	Log-Pearson III	0.92	109
Crnica: Paraćin	V. Morava	11.06.2002	242	Log-Normal	0.51	195
Lepenica: Batočina		10.07.1999	193	Log-Pearson III	0.54	184

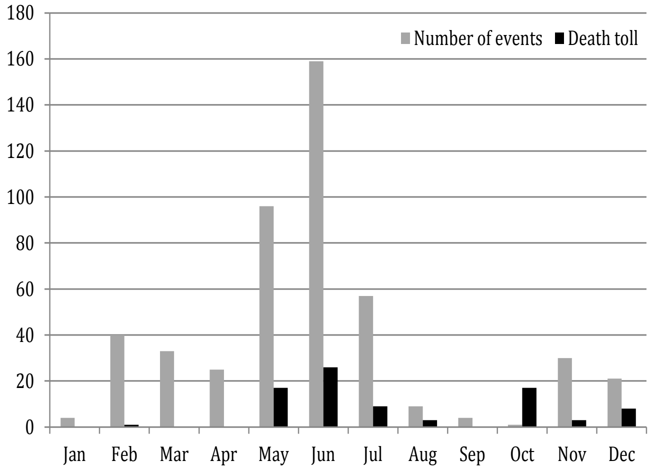


Figure 4. Monthly distribution of registered events and fatalities

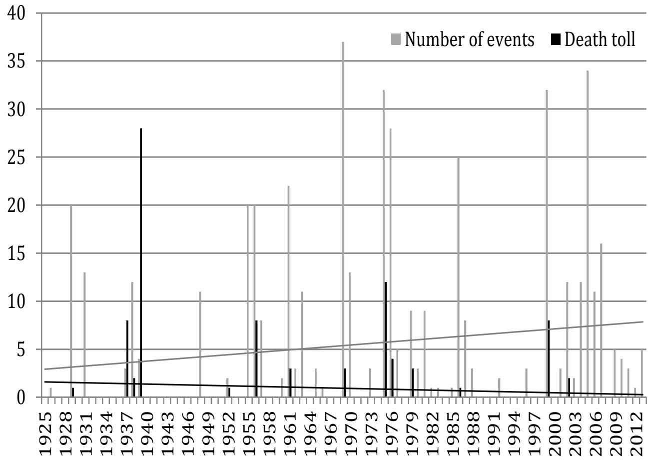


Figure 5. Annual distribution of registered events and casualties in the observed period with trend lines

remaining, the first period from 1915 to 1930 and the last period from 1990 to 2013. The increase of torrential flood frequency in the last two periods (averages of number torrential flood events per year for periods 1961-1990 and 1991-2013 are 7.3 and 6.3 respectively, in comparison with averages for the first period a=1.3 and the second one a=3.2) goes in line with the data from the literature about high increase in average annual hydrological natural hazards in the world per decade (Abbott, 2008; Munich Re, 2009; Ristić *et al.*, 2011; Llaset *et al.* 2014; Petrović *et al.*, 2014; Modrick *et al.*, 2015; Petrović, 2015a). Although there is a linear decrease of death toll per period (average for II period is 1.5 deaths, IIIa=0.9, IVa=0.7), there is still a need for risk education of affected local population. Flash floods with a high mortality rate account more than 5000 deaths annually on a global basis (Jonkman, 2005). Considering the number of fatalities and people affected, the torrential floods are top natural hazards in Serbia so that the following data should draw attention to the improvement in prevention and response of the torrential flood risk management cycle (Petrović, 2015b). In terms of death toll, the peak years are 1939 (28 deaths), 1975 (12), 1937 (eight), 1956 (eight) and 1999 (eight) and peak months are June (26 deaths), May (17) and October (17). Top torrential flood events in terms of fatalities took place in Koritnička river - October 1939 (17 deaths), Korbevačka river - May 1975 (12), Selska river - June 1939 (11).

In the Morava river basin, torrential flood events occurred in a wide range of intensity in sense of consequences and material damages which are inseparable part of the torrential flood phenomenon. Therefore, the idea is to show different stages of torrential flood event intensity (Table 3) according to the suggested categorization of the intensity of torrential flood events (Petrović *et al.*, 2014). The highest number of recorded historical events belongs to excessive (34%), high (23%) and very high intensity (21%), confirming the fact about catastrophic consequences of torrential flood on the local level.

Table 3. Categorization of torrential flood events in the Morava river basin

Category of flood event	Flooded area	E
I (excessive intensity)	>500 ha/>100 housing units	165
II (very high intensity)	101-500 ha/51-100 housing units	101
III (high intensity)	51-100 ha/21-50 housing units	110
IV (medium intensity)	21-50 ha/6-20 housing units	59
V (low intensity)	<20 ha/1-5 housing units	44

However, even when the ability to forecast events and warn population at risk in modern flood risk management systems increases, an increase in flash flood impact in the recent years is also noticed, which is a result of combination of a higher frequency of the extreme events and a higher exposure of the vulnerable population (Calliano *et al.*, 2013). Due to expected future changes in climate conditions, the adverse impacts of flash floods could unfortunately further increase (Ballesteros-Canovas *et al.*, 2015).

CONCLUSIONS

According to the analysis of dataset of torrential flood events in the Morava river basin, there are four main conclusions: 1) The greatest number of torrential flood events and casualties are registered in the Južna Morava river basin and belonging sub-basins of Nišava, Veternica, Toplica, Jablanica. 2) The primary maximum refers to summer months, June and May and the secondary maximum refers to winter months, February and March (which is triggered not only by strong showers but also coincidence of rain showers with sudden snow melting), according to intra-annual frequency analysis. 3) The highest death toll of registered torrential flood events follows the primary maximum of their occurrence, i.e. summer months June, May and July. 4) In terms of the extent of material damages, the excessive intensity or I category of torrential flood events is the most common.

Therefore, well-structured and systematic dataset of historical torrential flood events for each river basin enabling data analysis and leading to valuable findings can be of great importance for decision making in the torrential flood risk management and integrated river basin management. Although there was no centralized documentation of torrential flood phenomenon on the national level in previous period, this gap should be overcome in decades to come.

Acknowledgement

This work is supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia under Grant 47007 III.

REFERENCES

Abbas, A., Amjath-Babu, T. S., Kächele, H., Müller, K. (2015) Non-structural flood risk mitigation under developing country conditions: an analysis on the determinants of willingness to pay for flood insurance in rural Pakistan, *Natural Hazards,* Vol. 75, No. 3, pp. 2119-2135.

Abbott, P. L. (2008) *Natural Disaster.* New York: McGraw-Hill Science/Engineering/Math.

Ballesteros-Canovas, J. A., Czajka, B., Janecka, K., Lempa, M., Kaczka, R. J., Stoffel, M. (2015) Flash floods in the Tatra Mountain streams: Frequency and triggers, *Science of The Total Environment,* Vol. 511, pp. 639–648.

Borga, M., Gaume, E., Creutin, J. D., Marchi, L. (2008) Surveying flash floods: gauging the ungauged extremes, *Hydrological Processes,* Vol. 22, No.18, pp. 3883–3885.

Calianno, M., Ruin, I., Gourley, J. J. (2013) Supplementing flash flood reports with impact classifications, *Journal of Hydrology*, Vol. 477, pp. 1–16.

Dragicević, S., Filipović, D., Kostadinov, S., Ristić, R., Novković, I., Živković N., Andjelković, G., Abolmasov, B., Šećerov, V., Đurđić, S. (2011) Natural hazard assessment for land-use planning in Serbia. *Intternational Journal of Environmental Research*, Vol. 5, No. 2, pp. 371-380.

Dragićević, S., Ristić, R., Živković, N., Kostadinov, S., Tošić, R., Novković, I., Borisavljević, A., Radić, Z. (2013) Floods in Serbia in 2010 – Case Study: The Kolubara and Pcinja River Basins, in Loczy, D. (ed.) *Geomorphological impacts of extreme weather: Case studies from central and eastern Europe,* Heidelberg: Springer Geography, pp. 155-170.

Garambois, P. A., Larnier, K., Roux, H., Labat, D., Dartus, D. (2014) Analysis of flash flood-triggering rainfall for a process-oriented hydrological model, *Atmospheric Research*, Vol. 137, pp. 14–24.

Gavrilović, S. (1975) *Bujični tokovi u SR Srbiji.* Belgrade: Republički fond voda, Institut za vodoprivredu erozionih područja Šumarskog fakulteta. [Gavrilović, S. (1975) *Torrents in Serbia.* Belgrade: Republic Water Fund and Institute of erosion area management of the Faculty of Forestry].

Gourley, J. J., Erlingis, J. M., Smith, T. M., Ortega, K. L., Hong, Y. (2010) Remote collection and analysis of witness reports on flash floods, *Journal of Hydrology*, Vol. 394, No. 1–2, pp. 53-62.

Herschy, R. W., (2005) The world's maximum observed floods, *Flow Measurement and Instrumentation*, Vol. 13, pp. 231–235.

Institut za vodoprivredu „Jaroslav Černi" (2001) *Vodoprivredna osnova Republike Srbije.* Beograd: Ministarstvo za poljoprivredu, šumarstvo i vodoprivredu. [Jaroslav Černi Institute for the Development of Water Resources (2001) *Water Management Plan of the Republic of Serbia*. Belgrade: Ministry of agriculture, forestry and water management of the Republic of Serbia.]

Jonkman, S. N. (2005) Global perspectives on loss of human life caused by floods, *Natural Hazards*, Vol. 34, No. 2, pp. 151–175.

Kostadinov, S., Zlatić, M., Dragović, N., Gavrilović, Z. (2006) Serbia and Montenegro, in Boardman, J. and Poesen J. (eds.) *Soil Erosion in Europe*. Chichester: John Wiley & Sons, pp. 271–279.

Kostadinov, S., Borisavljević, A., Mlađan, D. (2014) Torrents and Torrential Floods in Serbia - Characteristics and Possibilities of its Control, in Zlatić, M. and Kostadinov, S. (eds.) *Advances in GeoEcology.* Reiskirchen: Catena Verlag, pp. 156-172.

Llasat, M. C., Marcos, R., Llasat-Botija, M., Gilabert, J., Turco, M., Quintana-Seguí, P. (2014) Flash flood evolution in North-Western Mediterranean, *Atmospheric Research*, Vol. 149, pp. 230–243.

Marchi, L., Borga, M., Preciso, E., Gaume, E. (2010) Characterisation of selected extreme flash floods in Europe and implications for flood risk management, *Journal of Hydrology,* Vol. 394, No. 1-2, pp. 118-133.

Modrick, T. M., Georgakakos, K. P. (2015) The character and causes of flash flood occurrence changes in mountainous small basins of Southern California under projected climatic change, *Journal of Hydrology: Regional Studies,* Vol. 3, pp. 312–336.

Münchener Rückversicherungs-Gesellschaft (2009) *Geo Natural Catastrophes 2008: Analyses, Assessments, Positions,* Munich.

Petrović, A. M. (2014) *Factors of torrential flood occurrence in Serbia.* Belgrade: Faculty of Forestry, University of Belgrade, Doctoral dissertation, 207 pp. [Petrović, A. M. (2014a) Faktori nastanka bujičnih poplava u Srbiji. Beograd: Šumarski fakultet, Univerzitet u Beogradu, Doktorska disertacija, 207 str.]

Petrović, A., Kostadinov, S., Dragićević, S. (2014) The Inventory and Characterization of Torrential Flood Phenomenon in Serbia, *Polish Journal of Environmental Studies*, Vol. 23, No. 3, pp. 823-830.

Petrović, A. M., Dragićević, D. S., Radić, B. P., Milanović Pešić, A. Z. (2015) Historical Torrential Flood Events in the Kolubara River Basin. *Natural Hazards,* Vol. 79, No. 1, pp. 537-547.

Petrović, A. M. (2015a). Torrential flood events in the Južna Morava River Basin, IInd International Conference „Natural Hazards – Links between Science and Practice", Saransk - Russia, Proceedings, pp. 356-362.

Petrović, A. M. (2015b). Challenge of torrential flood risk management, *Journal of Geographical Institute "Jovan Cvijić" of the Serbian Academy of Sciences and Arts*, Vol. 65, No. 2, pp. 131-143.

Ristić, R., Radić, B., Vasiljević, N. (2009) Characteristics of maximal discharges on torrential watersheds in Serbia. *Bulletin of Serbian Geographical Society,* Vol. 89, No. 4, pp. 161-189.

Ristić, R., Radić, B., Nikić, Z., Trivan, G., Vasiljević, N., Dragićević, S., Živković, N., Radosavljević, Z. (2011a) Erosion control and protection from torrential floods in Serbia - spatial aspects, *SPATIUM*, No. 25, pp. 1-6.

Ristić, R., Radić, B., Vasiljević, N., Nikić, Z. (2011b) Land use change for flood protection - a prospective study for the restoration of the river Jelašnica watershed, *Bulletin of the Faculty of Forestry*, No. 103, pp. 115-130.

Ristić, R., Kostadinov, S., Radić, B., Trivan, G., Nikić, Z. (2012) Torrential floods in Serbia – man made and natural hazards, 12th Congress Interprävent, Grenoble - France, Proceedings, pp. 771-779.

Šakota V. (1989): Tragom zapisa o poplavama prema srpskim pisanim izvorima od XIII do XIX veka, JUSOP, Kopaonik – Srbija. Zbornik radova, pp. 274-282. [Šakota, V. (1989) Track records of floods according to written sources from XIII to XIX century, the JUSOP Conference, Kopaonik: Serbia. Proceedings, pp. 274-282.]

Shao, M., Gong, Z., Xu, X. (2014) Risk assessment of rainstorm and flood disasters in China between 2004 and 2009 based on gray fixed weight cluster analysis, *Natural Hazards,* Vol. 71, No. 2, pp. 1025-1052.

Wang, Z., Lai, C., Chen, X., Yang, B., Zhao, S., Bai, X. (2015) Flood hazard risk assessment model based on random forest, *Journal of Hydrology*, Vol. 527, pp.1130-1141.

Received August 2015; accepted in revised form December 2015.