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Original Research

The Inventory and Characterization of Torrential Flood Phenomenon in Serbia

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Abstract

Torrential floods are the most destructive and most frequent natural disasters in Serbia with severe social, economic, cultural, and environmental consequences that deserve special attention. This paper presents a data-collection strategy and data analysis in terms of spatial and temporal characterization of the torrential flood phenomenon in Serbia for the last 99 years. Based on the available information obtained from various reliable sources, we registered 848 torrential flood events for 1915-2013. The registered number of deaths from torrential floods is over 133, including 24 people from 1991 to 2010. Monthly distribution of registered torrential floods indicates that the majority of floods occurred in Serbian territory in late spring (from May to the end of June) and the greatest number of torrential floods is registered in Southern Morava basin. This work resulted in creating a first inventory of torrential floods in Serbia and its analysis for the purpose of the spatial and temporal distribution and characterization of this phenomenon. The inventory on torrential floods will be integrated in future in a unique multi-user database on natural hazards in Serbia, and it should become a part of the European database of natural hazards.

Keywords: inventory, torrential flood, event distributions, damage, fatalities, Serbia

Introduction

Torrential floods, as specific types of floods, are the most frequent, water-related natural disasters in Serbia, with severe social, economic, cultural, and environmental consequences that deserve a special attention [1-6]. Specific characteristics of climate and relief, soil type, and vegetation cover, as well as changes of social-economical conditions such as population migration and land use, perform a wide range of factors for frequent occurrence of torrential floods in Serbia [2]. This kind of flood occurs in the hilly-mountainous regions in Serbia that are endangered by intensive water erosion processes.

In domestic literature it is accepted that torrential floods appear suddenly in small catchments after short duration rains (<24 h) with strong intensity (i>0.5 mm/min) [3]. Surface runoff and soil erosion are directly and nearly simultaneously manifested processes whose products, water and sediment, enter the hydrographic network and continue their movement as a two-phase fluid [7, 8]. According to previous research for Serbian territory, a flood is considered torrential if 30 kg of erosion sediment in 1 m^3 of water occurs and the flood wave duration is shorter than 7 hours [2]. Therefore, this phenomenon is related to the torrents whose main characteristic is a specific hydrologic and sediment regime.

More than 12,000 torrents are situated in Serbia, especially in the Southern Morava, Western Morava, and Great Morava river basins [8]. According to the data from former Department of Torrent Control at the Ministry of Forestry and Mining in Former Yugoslavia, excessive torrential floods in the Southern and Western Morava, Mlava, Timok,

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and Drina rivers occurred approximately every three years (1921, 1924, 1929, 1932, 1937, 1940). After World War II, pretty harmful torrential floods occurred in almost all regions in Serbia in 1947, 1948, 1951, 1953, 1957, 1961, 1963, 1965, 1967, 1969, 1970, and 1972 [9]. The most striking torrential flood occurred in the 1980s in the Lještarka dolina (1982), Sejanička (1983), and Vlasina (1988) watersheds. Large-scale torrential flood events happened in the torrential network in recent years: Topčiderska river, 1994 (1 fatality); Topčiderska river, Lugomir, Gruža Jasenica, and Lepenica, 1999 (18 fatalities); Southern Morava and Resava, 2002 (2); Vlasina, 2007, Jablanica, 2009 (1); and Timok and Pčinja, 2010 (2).

It is widely recognized that information and database are the cornerstone for solving the given problem. Databases on natural hazards in several developed countries' have recorded these phenomena for the past several centuries. Reviewing the international subject experience, we distinguished from others the Swiss database on natural hazards, which numbers over 20,000 events, and especially Austrian database on natural hazards which numbers about 28,000 events (including 20,000 torrent events; the first record is in the 6^{th} century) [10, 11].

Recent studies on various forms of floods in Europe have not encompassed the territory of Serbia, so this territory has been previously neglected for the most part [12-16]. This work resulted in the first inventory of torrential floods in Serbia and its analysis for the purpose of spatial and temporal distribution and characterization of this phenomenon. This study represents an important step in completing the European database of the torrential floods by providing data from Serbia, a territory that was a blank area in previous torrential flood hazard maps.

The results are essential for improving the system of preventive, organizational, and other measures [17], and instruments for mitigation of torrential flood consequences to an acceptable level. During the last few decades, however, increased attention has been paid to the consequences of torrential floods and measurements that could be developed to reduce the effects of a torrential flood.

Method

Study Area

Since torrential floods are related to the hilly-mountainous part of Serbian territory, our research focus is on the area south of the Danube and Sava rivers (Fig. 1). However, floods of torrents of Fruška Gora and Vrsačka Brda in Vojvodina were recorded as well. The most important torrential events in Serbia occur in the Southern and Western Morava river basins, where the proportion of high, medium, and small water shows greater unbalance, indicating the intensive erosion processes in watersheds [8]. The area of torrential watersheds in Serbia is in the scope of from 0.2 km^2 (in Grdelička george) to more than 1000 km^2.

Materials and Methods

The challenge of storing meteorological, hydrological, hydraulic, and socioeconomic data related to torrential flood events and its analysis was met in this work and depended on the availability of data. Initially, the inventory of torrential floods in Serbia was derived from previous research by Gavrilovic [9] and archival documentation of the newspaper *Politics* for the period from 1970 to 2012. Moreover, all expert reports and particular explanations of torrential flood events were reviewed and included. To complete historical data series on torrential flood events, we sent questionnaires to the authorities of local municipalities located in the watersheds affected by torrential floods. In addition, all institutions in the state (such as the Ministry of Agriculture, Forestry and Water Management, Water Directorate, the public water management company Serbia Water, Republic Hydrometeorological Service, Jaroslav Cerni Institute for Water Management, and municipalities, etc.) able to participate in generating the inventory on torrential floods were invited to give a contribution with reports. However, the response from both national and local levels was unfortunately slight due to the fact there were no systematic records and reports on torrential floods with continuity. Recording of floods by civil protection services started recently, but without recognizing torrential floods as a specific flood type.

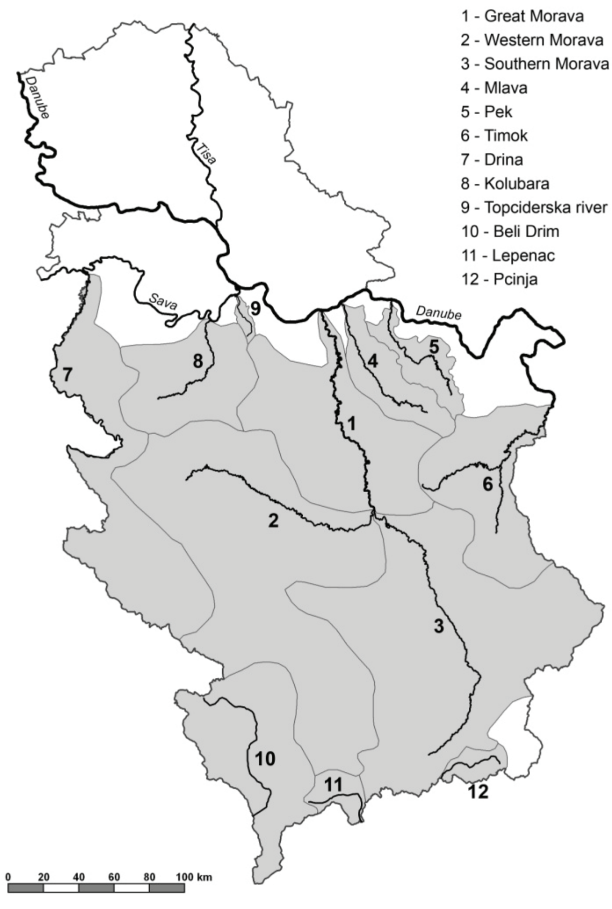

Fig. 1. Studied river basins in Serbia.

At first our data collection strategy was defined by the need for which data, the method of data collection, the manner of data processing and analysis, and possibilities of further data usage [10, 11]. Since the problem with lack and limited or incomplete information was envisaged, the database structure was based on the principle of collection of minimum data needed for further analysis:

- Name of torrent with flood event and macro watershed to whom it belongs
- Affected locations and settlements
- Date of event in format 2000/01/01
- Event description
- Number of casualties
- Damage description
- Source of information (in order to provide information quality)

Therefore, the two important types of information in the inventory are event and risk.

Several torrential flood events were recorded with only the year and month of event and the name of the torrent. On the other side, some of them were recorded with rainfall duration and depth, discharge, name of gauges, watershed area, water level, and trigger of the torrential flood occurrence, making inventory more detailed. Newspapers had many articles describing the serious torrential flood event, giving only names of affected settlements and villages and description of material damages in housing, industry, and traffic infrastructure. For identification of torrent as a subject of flood event, geo-referenced topographic maps in scale 1:25,000 were used (issued by Military Geographic Institute, 1980). Geo-referencing the map mosaic and assignment of geographic coordinates to affected locations for visualization of spatial distribution were conducted in the Global Mapper 11 GIS program. It should be borne in mind that some torrential floods may happen in small, ungauged and non-populated watersheds, with no societal consequences, which therefore have not been recorded. It can also be assumed that not all torrential flood events that really happened in the observed time period are recorded in this database. Therefore, it must be mentioned that data gaps in the time period, with respect to real situations, are expected.

Well-structured and systematic reports of torrential flood events should be designed for their optimum use in further future and when filled-in to be gathered to a central database. Table 2. shows a report proposal for the further systematic gathering of information after a torrential flood occurs.

Results and Discussion

The oldest record of torrential flooding in Serbia leads us to the bygone December in 1282, during the reign of King Stephen II Milutin and his war against Byzantium, when the Tartar army sank in the swollen Beli Drim. The next known record dates from the 16th century and refers to the flood of the Raska river on 18 May 1518 [18]. There are many flood descriptions afterward in monastery chronicles dating from 17th, 18th, and 19th centuries, representing introductory historical information [2].

Our inventory consists of data on torrential floods from the 20th century to today. The first data in the previous century we avail is on the torrential flood in the Timok river basin in May 1915 with 25 casualties.

Based on the available information obtained from various reliable sources, we registered 848 torrential flood events in our database for the period 1915-2013 in Serbia. It must be noted that most of them occurred in mountainous areas south of the Sava and Danube rivers, while floods that occurred in the Autonomous Province of Vojvodina were mainly caused by the large alluvial rivers Danube, Sava, Tisa, and Tamiš (Fig. 2).

Monthly distribution of registered torrential floods (Fig. 3) indicates that the majority of floods occurred in June (233 or 27.5%) and May (178 or 21%), followed by July (88 or 10.4%), March (71 or 8.4%) and February (67 or 7.9%). These results are logical, bearing in mind the rainfall regime in mountainous areas of Serbia, where the major and the highest intensity rainfalls occur in May and June [6, 19]. Strong floods occur during the summer months of July and August, after drought periods when high intensity rainfalls occur, as was the Kalimanska River flood on 4 August 1929, Lještarska Valley on 25 July 1982, Sejanička River on 2 July 1983, and floods during summer 1999 throughout Serbia. In such cases, due to the long drought, the soil structure is disturbed and easily erodes, and such high flows transport large amounts of sediment with the bed-load usu-

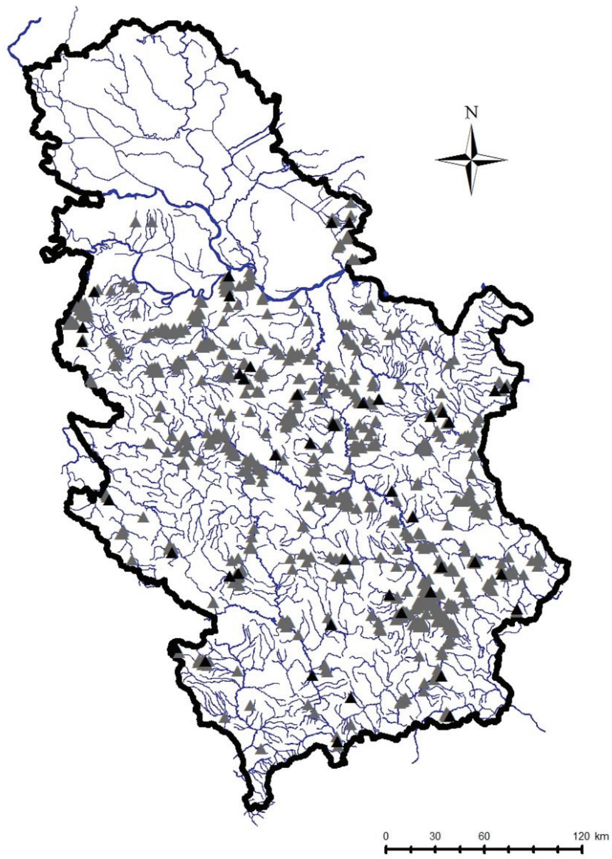

Fig. 2. Locations of the most destructive torrential flood events in Serbia in the period 1915-2013
▲ – casualties and material damage, Δ – material damage

Table 1. Proposal of report for the further collection of data on torrential flood events.

Report No.	Date of torrential flood event:
WATERSHED NAME	
Macro watershed	
A	km^2
Short description of watershed natural conditions	
TORRENT CONTROL	
Bioengineering works	ha
Technical works	m^3
Retention basin	□ yes, __ m^2 □ no □ for flood water □ for sediment
State of the structures and new established cultures (ECW)	
Proposal of measures	□ new construction □ sanitation □ upgrading □ no proposal
TORRENTIAL FLOOD EVENT	
Event description	
Rainfall depth/duration	mm/min*
Rainfall area	□ entire watershed □ part of watershed area
Earlier precipitation	hyetograph
Gauge	name: X/Y:
Discharge	m^3/s*
Additional factors of flood occurrence	(e.g. sudden snow melting, soil saturation)
Dominant process	□ flooding □ mud flow □ debris flow
Erosion processes	□ surface □ riverbed □ landslide
Sediment transport	m^3/s*
Other material picked by flood water	□ log, __ m^3 □ waste, __ m^3
Log/waste/sediment jam	□ yes, __ m^3 □ no
DAMAGE	
Scope of event impact (flooded area)	**EVENT INTENSITY**
□ >500 ha/>100 housing units →	□ I (excessive intensity)
□ 100-500 ha/50-100 h. u. →	□ II (very high intensity)
□ 50-100 ha/20-50 h. u. →	□ III (high intensity)
□ 20-50 ha/5-20 h. u. →	□ IV (medium intensity)
□ <20 ha/1-5 h. u. →	□ V (low intensity)
Damage assessment	€
Damage description	
Number of casualties	
Number of injured	
Influence on animals	
Damage on nature&ecosystem	
Recovery costs	
Warning unit	
Documentation attached	□ photo □ graph □ map
Report author:	
Organization:	Position:

*to collect data from RHMS

ally above 60% of total sediment [20]. The second maximum refers to winter months, March and February, which is triggered not only by strong showers but also sudden snow melting. This temporal distribution of registered torrential floods greatly corresponds to the outputs of ealier research in the area of frequency of maximal discharges in torrential watersheds. Two critical periods were defined: primary at the end of spring (May to the first half of June) and secondary at the end of winter (February to the first half of March) [19].

According to annual distribution for the observed period of the last 99 years, the peak years which are distinguished on the basis of a number of events are 1969 (54), 1999 (51), 2005 (47), 1956 (47), and 1986 (43). The annual mean of registered torrential flood events is 8.57. The trend line (Fig. 4) clearly shows an exponential increase of torrential flood events that is in line with the distribution of registered torrential floods for the periods 1931-60 and 1961-90, which are recommended by the Republic Hydromethorological Service of Serbia in order to perform detailed comparative analysis on precipitation and air temperature changes. This increase of events (Table 2) can be explained as a consequence of global climate change, which is also in accordance with data from the literature about high increase in average annual natural hazards in the world per decades [12, 21]. Nowadays, scientists all over the world agree that discharges with recurrence interval of 100 years become events with recurrence intervals of 20 years, which increases the importance of studies on torrential floods [3, 22]. Even though precipitation height on the annual level is unfavorable, the circumstances are such that they occur mainly in the form of heavy rainfalls, which results in sudden water concentration having torrential floods as a consequence.

Table 2. Distribution of registered torrential floods in the periods.

Time period	Number of torrential flood events	Average number of torrential flood events per period	Number of casualties per period
1915-30	33	2.06	>22
1931-60	175	5.83	>51
1961-90	384	12.80	36
1991-2013	256	19.69	24
Total	848		>133

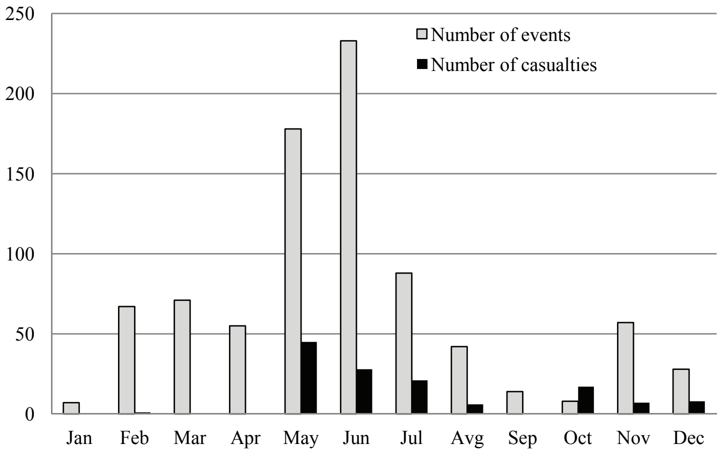

Fig. 3. Monthly distribution of torrential flood events and fatalities.

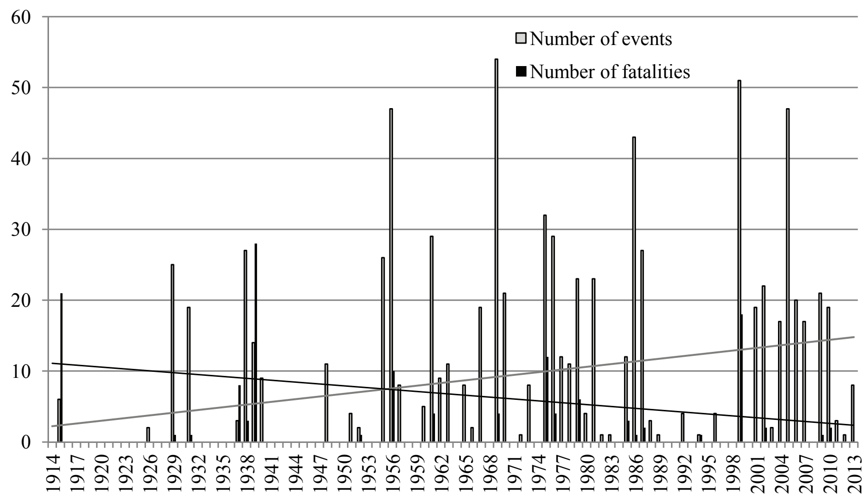

Fig. 4. Annual distribution of torrential flood events and casualties in the observed period, with trend lines.

Table 3. Torrential flood events per watershed.

River basins in Serbia	Number of torrential flood events	Number of casualties
Southern Morava	195	61
Western Morava	157	11
Great Morava	127	12
Kolubara	121	1
Drina	62	7
Timok	40	>21
Topciderska river	34	11
Dunav	32	>1
Mlava	24	3
Beli Drim	20	>1
Sava	14	>1
Lepenac	9	1
Pčinja	7	2
Pek	6	0
Total	848	>133

In the terms of the number of people affected and fatalities, the occurrence of flash floods is among the top natural disasters and thus of great concern in natural hazard science [14, 23]. The following data on casualties in Serbia should draw attention to the phenomenon of torrential floods. In terms of death toll, the peak years are 1939 (28 deaths), 1915 (>21), 1975 (12), 1999 (18), and 1956 (10), and peak months are May (45 deaths), June (28), and July (21). The top torrential flood events in terms of casualties took place in Koritnička river – October 1939 (17 deaths), the Korbevačka River – May 1975 (12), Selska River – June 1939 (11), Brestovačka River – May 1915 (11), Sikolska River – May 1915 (>10), and Topčiderska River – July 1999 (10). Data on injured people as a consequence of torrential floods are rare.

Table 4. Categorization of torrential flood events in Serbia.

Category of torrential flood event	Flooded area
I (excessive intensity)	>500 ha/>100 housing units
II (very high intensity)	100-500 ha/50-100 housing units
III (high intensity)	50-100 ha/20-50 housing units
IV (medium intensity)	20-50 ha/5-20 housing units
V (low intensity)	<20 ha/1-5 housing units

It is understandable that the greatest number of torrential floods is registered in the Southern Morava basin (15.000 km^2), since the most intensive soil erosion processes are present here (Table 3). Natural conditions but also an extreme forest exploitation and destruction in Grdelica gorge and Vranje Valley have resulted in extremely intensive erosion processes and frequent striking torrential floods, causing disastrous damage, including casualties [24]. Two major international routes, the railway and motorway Belgrade–Skopje–Athens, situated in the Southern Morava Valley, were often interrupted by torrential floods, which escalated after World War II, when those interruptions lasted up to 15 days. Grdelica Gorge of the Southern Morava is particularly important since 137 torrential streams, direct tributaries to Southern Morava, were registered in the small area from Grdelica to Vladičin Han at a length of 28 km [25]. Grdelica Gorge turns into Vranje Valley from Vladičin Han to the border with Macedonia, where 80 torrential streams were registered.

The registered number of deaths from torrential floods is over 133 and the average of 2.96 casualties per torrential flood event considers only those events with human fatalities (Table 3). We have also the information such as "several casualties" for certain events that are not summarized but shown as such. Accurate data on how deaths happened – due to drowning in the river or car, home, crossing a bridge – are sporadically available [26]. The number of deaths from torrential floods is significantly larger than in the case of floods of alluvial rivers that can be announced and predicted several days before a flood event.

Fig. 5. Torrential flood in Novi Pazar, May 2011 (left) and in Čačak, July 2013 (right) (Source: www.rts.rs)

Although the trend line (Fig. 4) shows a decrease in the number of casualties, it is important to develop a modern warning system. In that sense, the threshold of torrential flood occurrence for each torrential watershed should be defined. When warning and monitoring system are adequate, not a single life is lost [26, 27]. However, it is a question if politicians, citizens, farmers, and planners to learn from past disastrous torrential flood events.

Torrential floods of a wide range of intensity may occur in the same torrential watershed depending on a number of current circumstances. After review of available damage data (scope of flood impact, i.e. flooded area), criteria for categorization of torrential flood events were defined (Table 4). On the basis of determined thresholds, in further work each registered torrential flood event should be given its event category and intensity, which is certainly contribution to the torrential flood risk assessment on the basin scale.

Conclusions

Torrential flood control (technical and bioengineering works) should have a higher place in water management in Serbia and should be continuously improved in accordance with contemporary scientific and technological achievements in the subject field. Furthermore, recognizing the torrential flood as a specific issue in river basins of Western and Southern Morava, this phenomenon should be a significant part in integrated river basin management of the Great Morava River basin, according to Water Directive 2000/60/EC [28,29]. Although Serbia still is not a member of the European Union, authorities are committed to the implementation of Flood Directive 2007/60/EC. Preliminary flood risk assessment takes into account only large and smaller alluvial rivers, while the preliminary assessment of torrential (flash) flood risk will be made later, as planned by 2017.

Based on data collection and data mining techniques, we established a comprehensive torrential flood inventory for 1915-2013 using information from multiple sources, and analyzed the characteristics of torrential flood hazards and losses in Serbia. The presented inventory of torrential flood events in Serbia is made to support the torrential flood risk management approach at the basin scale. Well-structured historical data on torrential floods and its analysis are a pertinent moment in an expert and public communication on torrential flood risks, which is afterwards of high importance for success of integrated torrential flood management. Insurance companies have significant information and inputs from inventory for the purpose of defining insurance rates.

Harmonization of data on torrential flood events for the territory of Serbia is of high importance for the successful implementation of the INSPIRE Directive 2007/2/EC, data theme – natural risk zones in Serbia. Inventory on torrential floods should be integrated in the future in a unique multi-user database on natural hazards in Serbia. Furthermore, in the next step it should become a part of the European databases of natural hazards. These results can be a great contribution to international databases on natural hazards such as EMDAT and ESWD.

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