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Characteristics of July 2019 Cherna Mesta River flash flood

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ABSTRACT

One of the biggest rivers in the southern part of the Balkan peninsula – the Mesta River is well-known for frequent flash floods, especially in the upper river course. As a result of severe storms and related heavy rain in mid-July 2019, the Cherna Mesta River flooded, and this resulted in heavy damage to the road infrastructure and water-supply systems. All data indicate that this was not a usual water flood, instead at peak flow, the river carried a huge amount of gravel. Our mapping of erosional and depositional features related to the 2019 event, as well as geomorphological analysis, allows for distinguishing distinct sectors along the river valley. Most hazards are defined in the lower reaches of the Cherna Mesta River, where the processes of channel aggradation and lateral erosion are pronounced. The field analysis of the flood-related deposits indicates the operation of debris flood and hyperconcentrated and water flood processes.

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1. Introduction

A dense river system drains the highly elevated area formed by the Rila and West Rhodope Mountains. The 273 km long Mesta/Nestos is the largest river in this area (Zagorchev 2007). This river is formed by the confluence of the Cherna (Black) and Byala (White) Mesta Rivers. These rivers have their origins in the highest parts of Rila Mountain, a highland affected strongly by Pleistocene glaciations (Kuhlemann et al., 2013; Gachev, 2020). Both rivers have similar in size catchments and the main river channels are predominantly oriented in the N-S direction. The name Mesta has its origin in the verb "mestya", meaning to relocate, and is related with well-known for the local population behaviour of the river channels. Such rivers, that have several channels (active and inactive) are known as braided rivers. As (Kleinhans et al. 2013) commented: "'Braided' denotes the ever-changing channel pattern of gravel-bed or sand-bed river reaches with multiple channels that divide and recombine around bars, which are submerged sufficiently often that they have little or no vegetation cover". These are one of the most dynamic geomorphological systems (e.g. (Yang 2020)) and critical agent of geomorphological changes. Being situated in a mountainous environment with steep slope gradients, flood hazards and related phenomena can be highly damaging (Stoffel et al. 2016).

The upper course of the Mesta River is well-known for repeating occurrences of extreme flash floods as the latest event is from the summer of 2019 (Dotseva et al., 2019). Especially vulnerable are the surroundings of the Cherna Mesta main channel. Our post-event survey (summer 2019) documented severe infrastructure damage and features indicative of debris flows (Dotseva et al. 2019). In this paper, we are presenting the results of desktop study, GIS-analysis of satellite and orthophoto imagery and geological-geomorphological field studies of selected river segments. The new data allow us to document properly the damages caused by mid-2019 flash flood event and to characterize geological-geomorphological setting of Cherna Mesta watershed.

2. Materials and methods

The research follows two main lines of data collection and analysis. First, field surveys were conducted during several campaigns (August and September 2019, August 2021), as the first one was realized two weeks after the event. The positions of the site observations were recorded using a handheld GNSS (Global navigation satellite system) receiver with horizontal acuracy typically from 2 to 5 m. Methodologically, we followed recommendation of Gaume and Borga (2008) and Brenna et al (2020) for the conduct of post-flood field studies. An important part was an attempt to document geomorphological flood effects: changes in channel network, erosional and depositional processes. The investigations were carried out on reaches with minimal human influece, thus allowing to analyse the river response to the 2019 flood.

As second line of our research, along with the field inspections, a GIS-based system was set up to process all available spatial data: geological maps in 50 000 scale (Sarov et al., 2008; 2011), topographic maps, orthophoto images, etc. An attempt to map the dynamics of the deposits in the parts of the watershed was made, based on the different in time imagery from Google Earth Pro (May 2017, April 2019 and October 2020). The topographic analysis is based on the processing of 30 m DEM (ASTER GDEM, 2019) as well as topographic maps in a 1:5 000 scale (accessed from https://kade.si).

An essential step in our research was devision of the Cherna Mesta river into homogeneous reaches (Brierley and Fryirs 2005; Righini et al. 2017; Brenna et al. 2020). This analysis was realized using features like: tributary confluences, presence of important anthropic structures, character of the lateral confinement, dominant process (erosion vs. accumulation), valley slope and variations of the basement rocks. The classification of sediment-water flow types that occurred during the 2019 flood is based on the methodological approaches of Brenna et al. (2020) Church and Jakob (2020) and Matthews et al. (2020).

3. Characteristics of Cherna Mesta watershed: Geomorphological and Geological setting

Cherna Mesta watershed is a steep basin, which extends from 1 000 to 2 600 m a.s.l. The river is formed by the confluence of three main tributaries - Sofan dere, Leevshtitsa and Dautitsa Rivers. Due to the construction of the Belmeken Dam, the size of the Sofan dere catchment is reduced, yet this is the largest catchment in the Cherna Mesta basin (Fig. 1). The total length of the Cherna Mesta River, measured from headwaters in the Belmeken peak area to the confluence with the Byala Mesta River is 20.8 km. The geological

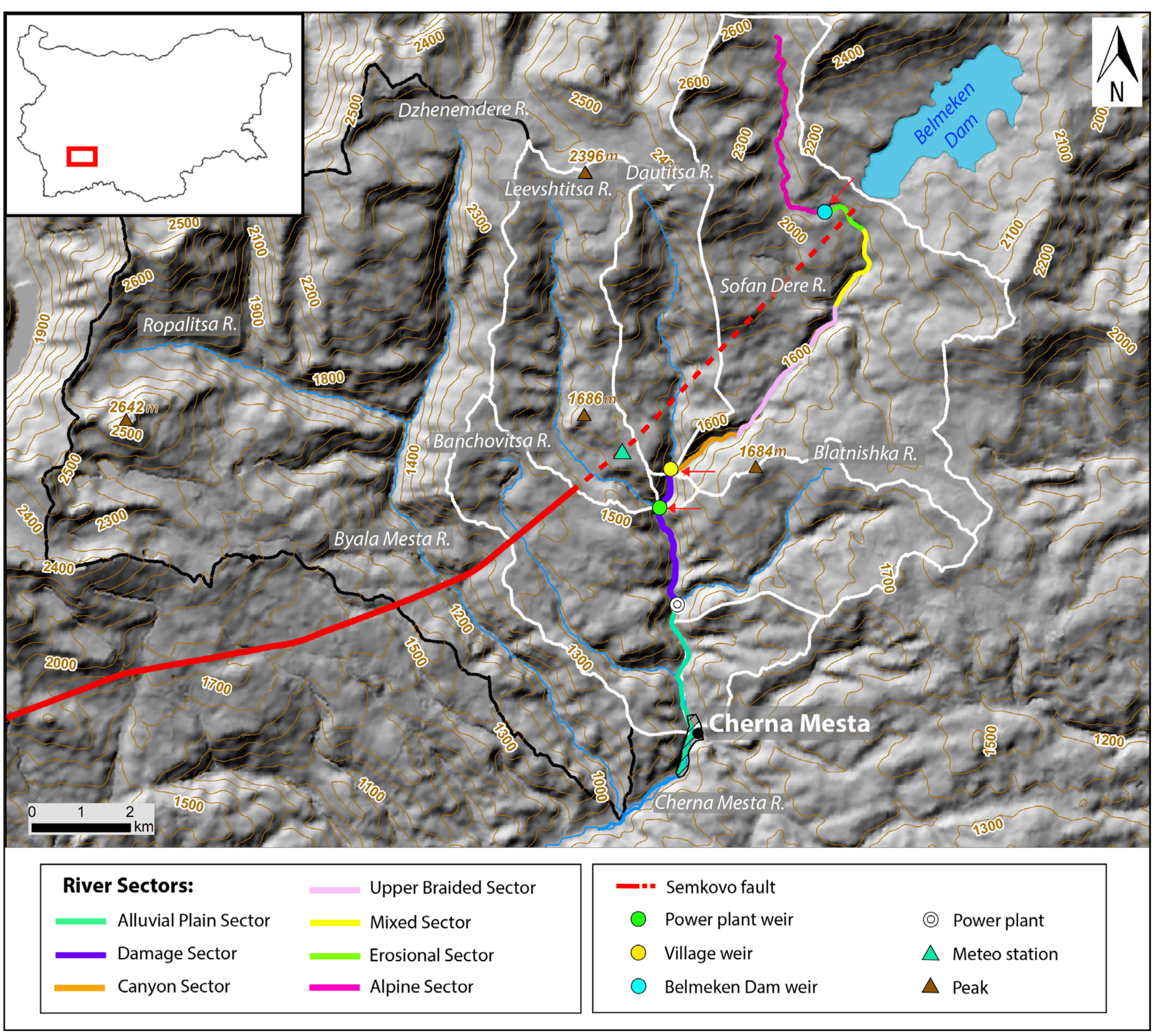

Figure 1. Cherna Mesta composite watershed and geomorphological sectors of the 2019 flash flood

substrate of the Cherna Mesta catchment is uniform, represented by the granitoids of the Rila-West Rhodope batholith (Sarov et al. 2008, 2011. Recently Radulov (2016) stress on the importance of the Semkovo fault as one of the main seismic zones in SW Bulgaria. Our analysis of the presented by Radulov map data, as well as our study of satellite imagery and digital elevation data, point to the possible continuation of the fault in the Cherna Mesta watershed (Fig. 1). A large part of the catchment is underlain by Quaternary deposits. Approximately above 1 800 m a.s.l. glacial (moraines) and post-glacial (talus accumulations, solifluction sheets and lobes) sediments are dominant. Below this elevation, these youngest deposits show significant genetic variations. The steep valley slopes are often covered by colluvium that can reach 2-3 m in thickness. In the shallow and short gullies, these sediments are mixed with debris flow deposits. Rockfall deposits are spatially limited to comparatively rare almost vertical rock cliffs. A well-defined valley floor is not everywhere present, but in lower reaches is more than 100 m wide. These areas are occupied by various alluvial deposits. Anthropic influence is often significant, as the largest impact has the structures related to the Belmeken Dam (Gerdjikov et al. 2022) (Fig. 1). Via the system of water catchments and channels, the Belmeken Dam receives waters from the southern slope of Rila Mountain. These water-intake structures (weirs), located at 2 000 - 1 900 m elevation, not only limit the water power but also act as sites of deposition of debris transported by streams. Another water catchment is located at the confluence of the three rivers that is supplying water to the power plant located at 1 080 m a.s.l. Between the power plant and the confluence, the area occupied by the river channels is artificially restricted due to the construction of the main access road for the southern slopes of Rila Mountain. The lowermost part of the Cherna Mesta Valley, where it crosses the urban area of the village, is channelized by the construction of concrete leeves. These bank protection measures restrict the area of the floodplain and increase water speed at times of flooding.

4. July 2019 event

Thunderstorms or convective storms are common and increasingly frequent events for the period of May-September (Simeonov et al. 2009). During the evening of 22nd July, a severe convective storm event struck part of eastern Rila Mountain. The distribution of the heavy rain was highly uneven. Most affected was the area of the Belmeken Dam as well as the watershed of the Dautitsa River. Local people from Cherna Mesta Village reported no significant rain for the area below 1 000 m a.s.l. The rain gauge, installed by the Forest Institute of the Bulgarian Academy of Sciences (Leeve station, 1 550 m a.s.l., Fig. 1), recorded 97.6 mm of precipitation on the morning of 23rd July. The rain continued, but with no such intensity and on the next day 21 mm of precipitation was recorded. These are the only quantitative data available for the event, there are no data about rainfall rates and water discharge. The intensive rainfall-induced large floods affected the catchments of the Cherna Mesta and its tributaries (Sofan dere, Dautitsa rivers). Our reconstruction of the event is based on news reports (https://nova.bg/news; https://btvnovinite.bg), talks with eyewitnesses, and data from Yakoruda Municipality and forest service. Flood and related extremely high water levels probably started after 21:00 and the first serious damage affected the road Youndula - Razlog, as one of the lines was undercut by the river. Importantly, it was no clear-water flood. The flood was related to the transportation of huge masses of various in size debris, as well as wood pieces and other organic materials. The locals reported extremely strong noise, caused by debris striking each other, the artificial banks as well as cracking of large wood pieces. Some houses, situated in the part with no artificial banks, were flooded.

To understand the nature of the flood, very relevant are the descriptions provided by the guard of the powerplant who witnessed the event. He reported very high water levels and extreme noise that lasted a few hours. At least 2-3 high waves (surges) were observed and during their passage, the artificial banks that protect the powerplant were at least partly overtopped by the water. The occurrence of more than one surge during a single flood event is well-known (e.g. Huebl et al. 2019) and is also confirmed by our field studies. Early in the morning on 23rd July, a state of emergency was declared in Yakoruda Municipality. The main damages are concentrated within the village and the Cherna Mesta Valley above the village. Strongly affected was the water supply system for the village. The water catchment was clogged with debris and was out of function, also 0.5 km of the water pipe was completely destroyed. Recovery from the disaster was severely impacted by damage to the main access road. Approximately 2.5 km of the road and two of the bridges were partially destroyed (Fig. 2A). Only the cost to restore this part of the road is estimated to be 100 000 Euro (personal communications from Forest service - Yakoruda).

During the flood, a depocenter formed at the river confluence, and as a result water catchment was severely clogged and it took one week of work for an excavator to remove the debris and to renew the operation of the powerplant. Hundreds of square meters of arable land and meadows, situated next to the main river channels, were flooded and covered by sand and organics (branches, bushes, etc.). In the immediate aftermath of the event on the news, there were some speculations that the devastations were caused by the discharge of waters from the Belmeken Dam. Our detailed field checks in the area below the dam do not find any evidence for high water levels in all visited streams. This is confirmed by locals that describe low water levels in the dam for the whole summer of 2019. Thus, it is clear that the flood was caused by the intensive rain associated with the severe summer convective storm.

5. Geomorphological / Hazard sectors

Our analysis of the field data, satellite imagery, DEM and its derivatives allows us to define seven sectors in Sofan Dere - Cherna Mesta (s.s) catchment (Fig. 1). They are defined based on several parameters (Table 1) and are related to some general valley features, e.g., valley morphology, major tributary confluences, river gradient, clast supply and flood-related hazards.

The Alpine sector was not a subject of our detailed studies, because we interpret the water catchments related to the Belmeken Dam as an important discontinuity that is breaking sediment and water connectivity in the Sofan Dere catchment. The water catchment at Sofan Dere Valley was visited two months after the July event and there was evidence that the basin behind the barrage have been filled with debris. Yet, there were no signs that a large amount of clasts managed to pass the barrage, and there was not any damage on the road below the barrage. Thus, we interpret the water catchment facilities at 1 900-2 000 m a.s.l. as barriers for sediment connectivity and having a role to reduce waterpower. Also, for Sofan Dere and Leevshtitsa catchments there is a clear change in valley morphology at that elevation: above the valleys are open, mainly U-shaped with no incised channels and valley floors occupied by Quaternary sediments, while below they are narrow, deeply incised, often in the bedrock.

The Erosional sector is characterized by the steepest slope (Table 1). In the upper part of this sector the river is a single channel, often cut into bedrock, and only in lower parts the valley floor is

Figure 2. Examples of the damages and geomorphological features related to the mid-July 2019 flood. **A** Damages on the bridge above the powerplant water catchment. In the foreground, a large concrete chunk is visible, part of reinforcements next to the bridge. The photo was taken in August 2019. **B** Broken logjam with fresh deposition around. The photo was taken in September 2019. **C** Active water erosion and slope collapse. The photo was taken in August 2021. **D** Flash flood wave attempted to straighten the river course and scoured a new channel in the meadow, part of the flood plain. The flood-related deposition is represented mainly by sand sheets, yet boulder-sized clasts are also present. The photo was taken in August 2019 to the west of the main channel, looking N, upstream.

few meters wide and there are two or three channels. Because of the limited transport capacity of the river, despite the dominance of the erosional processes, most probably this sector is not a major source of debris for the lower reaches of the Cherna Mesta River.

For the **Mixed sector** is typical the wider valley floor reaches up to 20-30 m in width. The braided nature of the river starts to be obvious, yet still not detectable from the detailed topographic maps and satellite imagery. Erosional processes seem to dominate, as the river channels are often incised in bedrock or older alluvium deposits. A typical feature for this part is dams/jams created by large wood trunks. Such logjams are blocking either the entire channel system or a single channel (Fig. 2B). The areas behind them act as sediment traps.

Due to the drastic reduction (>50%) in river slope, the depositional processes dominate in the **Upper braided sector**. Here the valley floor is flat-bottomed and across it streams flow in braided channels. Masses of fresh debris material cover parts of the valley floor and are well-visible on satellite imagery. The transportation capacity of the river here is significantly increased because the confluence with the two largest tributaries marks the uppermost part of this sector. Below 1 450 m a.s.l. Sofan Dere River eroded a deep, mainly bedrock canyon.

The **Canyon sector** is well defined by a higher river slope and strong confinement of river channel/s. Especially impressive are the lower parts of this sector, where the valley floor barely reaches 10 m in width, and it is surrounded by vertical rock cliffs. The riverbed is occupied by a high proportion of large (up to 3-4 m) angular to sub-rounded granitic fragments, deposited as a result of rockfalls or erosion of colluvial cones. Here the amount of finer sediments (sand, silt) is extremely limited if any. This sector can be described as a transport and erosion zone, with exposed fresh bedrock as a result of debris flows/floods erosion.

In the parts of the watershed above the **Damage zone sector**, the floods and mass-movement processes can only damage secondary forestry roads. While within this sector, the natural hazards impose a severe threat to the water supply system and road infrastructure. Here, the river is having again braided character and in cases of medium or low flow, there is only one active channel, while the other

Table 1. Characteristics of the defined geomorphological sectors

Sector	Elevation (m)	Slope %	Total drainage area (km²)	Confinement	Flow type	Max size of mobilized clast	Clast sources	Vegetation type
Alpine	> 1900-1950	15.53	9.75	no	Water flow/ rare DF		moraines, solifluction taluses	Alpine meadows, mountain pine
Erosional	1800-1900	10.36	12.05	strong	Water flow/ rare DF	up to 1 m	colluvium	Pine forest
Mixed	1610-1800	10.33	17.3	confined	Debris flood		colluvium, rock falls	Pine forest
Upper braided	1450-1610	4.49	36.4	partially confined	Debris flood		channel banks, colluvium	Pine forest
Canyon	1280-1450	11.33	38.03	strong	Water flow/ rare DF		rock falls	Pine forest
Damage zone	1280-1100	6.16	55.54	partially confined	Debris flood	up to 2 m	channel banks, colluvium	Pine forest
Alluvial plain	< 1100	3.08	73.28	no	Water flow/ HC flow	<1 m	channel banks, old alluvium	Meadows

parts of the valley floor are occupied by inactive channels, mid-channel bars (islands) and lateral leeves. Bedrock is exposed in the valley bottom only in a few cases. All main fluvial processes operate here. Erosion of riverbanks is one of the most hazardous processes in this sector. Due to the presence of the bedload during the flood events, the unstable banks, built by older alluvium are undercut and start to collapse. Channel bed scouring and banks erosion were particularly severe below the river confluence, and this led to the partial destruction of the main access road. Another important "within-sector" source of debris is the colluvial slope deposits and slopes built by the bedrock. In the upper part of the sector, especially above the powerplant water catchment, the side slopes expose strongly cataclastically reworked and weathered granite. The active river channel is eroding the toe of these slopes even in cases of low flow, thus causing instability and slope collapse (Fig. 2C). Sediment entrainment within this sector was an important contributor to flows with different sediment-to-water ratios that occurred down the river course. Importantly, increased sediment pulses into the river system strongly favour its widening, increase banks instability, and often lead to avulsion. All these features are documented in relation to the 2019 event in the lower parts of this sector and also in the Alluvial plain sector where huge amounts of sediments were

Figure 3. Formation of new river channels at the expence of the flood plain and newly formed cobble-boulder accumulations during mid 2019 flash flood event. Location: next to the Cherna Mesta powerplant (visible on the lower central part).

deposited into the river valley floor, thus resulting in significant channels aggradation. Using cloud-free satellite images from 2017 and 2020 (data from Google Earth) we mapped the extent of the valley floor that is occupied by fresh debris. The imagery from 2020 that document the extent of mid-2019 aggradation point to a 75% increase in the fresh sediment deposits (Fig. 3). Below the confluence, there are numerous examples of significant super-elevation that occurred when the water surges travelled around bends during its descent. The largest accumulations are at the curves and parts of the valley with lower river slope. They occupy the valley bottom and are represented by boulder-cobble dominated deposits, including debris levees, boulder bars (berms) and sheets. Often, the upper surfaces of the boulder sheets are covered by large woody debris. The most distal deposits are represented by sand sheets with thickness up to 0.3-0.5 m.

The Alluvial plain sector is defined below the 1 100 m a.s.l. where the valley widens significantly, channels are not laterally confined and there is a drastic reduction in the river slope. The width of the flood plain is increasing downstream from 100 m next to the powerplant to 150 m next to the village. There is no bedrock, and the valley floor is completely covered by alluvium. Typically, there are one active and 2 to 4 inactive channels. Here the erosional processes are of limited significance and only minor bank erosion, soil and alluvium erosion at the places of new channels are observed (Fig. 2D). Despite the lower slope, during flood events, the water flow is capable to transport even coarse sediments (up to small boulders), and this is evident from the studies of the recent alluvium below the village Cherna Mesta. In general, the river course is straight, yet at a decameter scale, the river channels are slightly sinuous. During the mid-2019 flash flood, there were numerous attempts to straighten the river course: new channels formed where floodwaters followed the most direct path downstream. In case when the water force was enough, the channel bends are cut across by a newly formed channel (chutes). In other cases, the river overtopped the banks at the bends, depositing sheets of cobbles and sand on the immediate floodplain (Fig. 2D).

6. Conclusions

We applied different methods to study the high-magnitude flood which took place in mid-July 2019 in Cherna Mesta Valley. This valley has all characteristics of a gravel-bed, braided river, a class of rivers well-known for their ability to transport huge amounts of debris downstream at the time of floods. Despite the lack of quantitative data, even simple calculations show that tens of tons of boulders and sand were transported downstream during the event. The flood was not at all clearwater one, and namely, the bedload was one of the reasons for the severe damage. And such a type of flood is one of the most effective processes that lead to geomorphological changes (Stoffel et al. 2016). The typical morphological responses to this event were channel aggradation and the formation of new channels at the expense of the pre-event floodplain. Initially, the observed landforms and phenomena were interpreted as a result of debris flows (Dotseva et al. 2019). Based on additional and more detailed fieldwork for most of the observed features, the mid-2019 event can be described as a debris flood and water flood. We are still far from a robust estimate of the hydrogeomorphic hazard and risk assessment of the Cherna Mesta catchment yet taking into account short recurrence intervals of the flash floods (2005, 2010) this area is one of the most vulnerable in this regard. As shown in numerous case studies, a careful geomorphological analysis can greatly contribute to defining the most critical river reaches.

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