ASSESSMENT OF THE ANTHROPOGENIC IMPACT ON THE CHERNA MESTA RIVER SYSTEM DURING THE FLASH FLOOD OF MID-2019

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ABSTRACT. The lower parts of the Cherna Mesta river watershed are often affected by flash flood events. While anthropogenic structures have negligible size when compared to the length of the river, they significantly influence river behaviour at times of floods. Based on field data and analysis of satellite and aerial imagery, we have analysed how structures, such as water intakes and artificial banks, have affected river-related processes, such as erosion and sedimentation, at the time of the mid-2019 flash flood event. The highest artificial construction - the water intake for the Belmeken artificial lake - is situated at an elevation of 1,900 m. This structure not only limited the water power but also acted as a site of deposition of debris transported by the stream. Another water intake structure is located just below the confluence of the three main tributaries (the Sofan Dere, the Dautitsa, and the Leevshtitsa rivers) and supplies water to the power plant located at 1,080 m a.s.l. This facility is situated at a place where the river gradient is drastically reduced. As a result, like in the case of the Belmeken water intake, the water catchment acted as an important depocenter during the flash flood. Another common feature is the enhanced erosion in those parts of the river channels that are situated just below the water intake constructions. This erosion is related to the most destructive effects of the flood. The lowermost part of the Cherna Mesta valley, where it crosses the urban area of the village, is channelised by the construction of concrete leeves. These bank protection measures restrict the area of the floodplain and increase water speed during flooding. As a result, during the mid-2019 event, part of the main road Razlog-Velingrad collapsed due to the increased bank erosion.

Key words: the Cherna Mesta river, flash floods, anthropogenic impact, erosion

ОЦЕНКА НА АНТРОПОГЕННОТО ВЪЗДЕЙСТВИЕ ВЪРХУ ВОДОСБОРА НА РЕКА ЧЕРНА МЕСТА ПО ВРЕМЕ НА РЕЧНОТО ПРИИЖДАНЕ ОТ СРЕДАТА НА 2019 г.

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РЕЗЮМЕ. Долните части на водосбора на река Черна Места често са засегнати от внезапни наводнения. Докато антропогенните структури имат незначителен размер в сравнение с дължината на реката, те значително влияят върху поведението на реката по време на наводнения. Въз основа на полеви данни и анализ на сателитни и въздушни изображения, ние анализирахме как структури като водохващания и речни корекции са повлияли на процеси като ерозия и седиментация, на примера на наводнението от средата на 2019 г. На 1900 м надморска височина е разположена най-високата изкуствена конструкция - водохващането за яз. Белмекен. Тази структура не само ограничава силата на водният поток, но действа и като място за отлагане на кластичен материал. Друга водовземна структура се намира точно под сливането на трите основни притока (реките Софан дере, Даутица и Леевщица), която захранва с вода централата, разположена на 1 080 m н.в. Това съоръжение е разположено на място, в което речният градиент драстично намалява. В резултат на това, подобно на случая с водохващането за яз. Белмекен, водосборът е действал като важен депоцентър по време на внезапното наводнение. Друга обща характеристика е засилената ерозия в частите на речните канали, които се намират непосредствено под водовземните конструкции. С тази ерозия са свързани и най-разрушителните последици от наводнението. Най-долната част на долината на река Черна Места, където тя пресича урбанизираната зона на селото, е канализирана чрез изграждане на бетонови ограничителни диги. Тези брегозащитни мерки ограничават площта на заливната низина и увеличават скоростта на водата по време на наводнения. В резултат на събитието от средата на 2019 г. част от главния път Разлог-Велинград се срутва поради засилената ерозия на брега.

Ключови думи: Река Черна Места, внезапни наводнения, антропогенно въздействие, ерозия

Introduction

River floods and related damages are among the most destructive natural hazards. In the mountain environments, such events are important geological and geomorphological processes that transfer sediments from headwaters to valley floors. It is well-documented that natural processes, as well as anthropogenic impact (construction of flood-protection facilities, water intake facilities, etc.), can disturb sediment delivery to the downstream channel network (Ondráčková and Máčka 2019, Lucas-Borja et al. 2021). Traditional flood-mitigation measures aim to reduce river slope and decrease the amount of sediments transported as bed load (Eisbacher and Clague, 1984). Water intake structures have similar effects, and as a prime consequence reduced sediment supply from headwater areas results in changes in river behaviour: Areas of the most intensive river erosion (channel scouring) and aggradation (bed load sedimentation) are shifting their position. These processes often lead to channel avulsions, can pose an erosional risk to the road infrastructure, and can degrade arable land.

The Cherna Mesta watershed is well-known for the flash flood-related damages and most of them are related to the capacity of the river to transport a large amount of bed load at the time of increased water levels. Due to the relatively easy field access and well-defined satellite imagery (available via Google Earth Pro software) of depositional areas, this watershed provides the possibility to study the geological and geomorphological changes related to the recent flash flood events. The most recent such event occurred in mid-2019 and caused severe damage to forestry road infrastructure, degraded arable land, and compromised the function of several water intake systems, including the water supply system of the village of Cherna Mesta.

The objective of this study is to determine how human activities influenced the behaviour of the Cherna Mesta river at the time of the 2019 flood event. We have managed to identify the erosional-depositional effects related to the construction of water intake facilities, as well as recently-built artificial banks in the area of the village of Cherna Mesta. Other, probably important, anthropogenic impacts, such as narrowing the valley floor and the construction of a dense network of forestry roads, are not subjects of this study. The presented data and analyses are based on post-event fieldwork (August 2019 - October 2021), processing of satellite and aerial imagery, digital elevation models and change detection (comparison of imagery taken before and after the event) based on Google Earth imagery.

Geological and geomorphological setting. Mid-2019 event.

The Cherna Mesta watershed is situated on the south-eastern slopes of the Rila Mountain. The river is formed by the confluence of three tributaries – the Sofan Dere, the Leevshtitsa, and the Dautitsa rivers. All of them have their headwaters located in wide, formerly glaciated valleys (Fig. 1). The hydrological regime is typical of high water flow during spring snowmelt. During the period May-September, floods, including flash floods, are rather common because of convective storms.

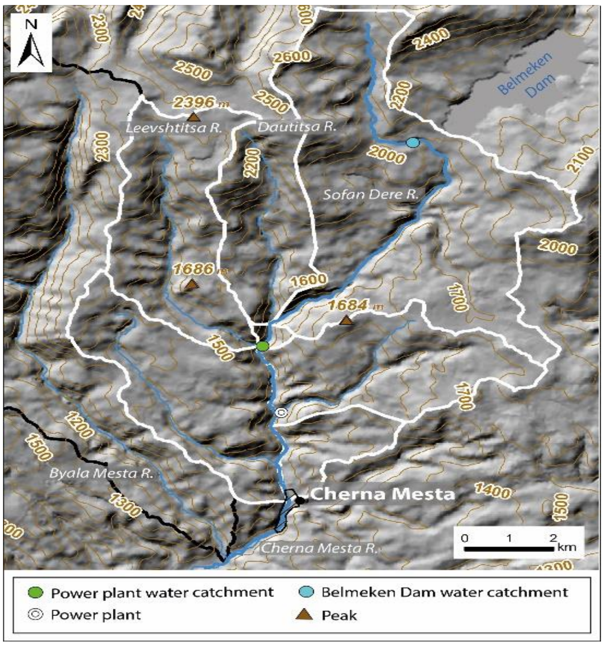

Fig. 1. Location map of the Cherna Mesta watershed and studied facilities.

The geological substrate is rather homogeneous, represented by the granitoids of the Rila - West Rhodope batholith (Dimitrova and Katzkov, 1990; Sarov et al., 2008; 2011). Various Quaternary deposits are also common, ~~as~~ and alluvial and colluvial sediments are the most important for the lower part of the catchment. The Leevshtitsa and the Dautitsa rivers have smaller catchments and there are no data for flood-related damages, except for the lower course of the Dautitsa river.

The description of the geomorphology is restricted to the Sofan Dere – the Cherna Mesta river system because they are the parts of the watershed that are affected by damages during flash floods. A more detailed description is provided by Gerdjikov et al. (submited to CR Acad. Sci. Bulg.). The valley morphology varies significantly and based on the number of active/inactive channels and valley cross-section geometry, several segments can be distinguished. Above 1,900 m a.s.l., the valley is open, most often weakly incised in glacial and post-glacial Quaternary cover. Between 1,900 and 1,610 m a.s.l., the valley is narrow and deeply incised, most often in bedrock. The uppermost larger alluvial accumulations are located in this segment. Between 1,450 and 1,610 m a.s.l., the river gradient is lower, the valley floor is wider and is occupied by more than one active/inactive channel. Below 1,450 m a.s.l., the Sofan Dere river forms a deep canyon where erosional and transportation processes dominate. Further downstream, below 1,280 m a.s.l., the valley has all features of a braided river, e.g. consists of a network of individual channels separated by small, often temporary, islands. The lowermost segment of the valley is dominated by an alluvial plain which is dozens of meters wide (up to 150 m). It is situated below 1,100 m a.s.l. and is characterised again by a braided pattern of active and inactive channels. The main approach to the river catchment is on a dirt road, which runs along the river between the village and the confluence of the three main tributaries. In the text below, we refer to it as the main access road. This road is of key importance for the sustainable human activity in the catchment and a part of it is strongly affected by the river floods.

Local people remember well the flash floods from 2005, 2010, and the last large one from 2019. On the night of the 22nd July 2019, heavy rain-induced severe flood affected mainly the catchments of the Sofan Dere and the Cherna Mesta (s.s.) rivers. Highly elevated water flow, coupled with bed load transport of a huge amount of clasts and sand, caused damage and subsequent closure of the road Razlog-Velingrad. The water supply system for the village of Cherna Mesta was strongly damaged, along with approximately 2.5 km of the unpaved road above the Cherna Mesta powerplant. It is important to note that the mid-2019 flood was not a clearwater flood event. Numerous field data indicate that the flood was related to intense bed load transport. Our post-flood fieldwork has provided arguments to describe the event as dominated by debris flood and hyper-concentrated flow (Brenna et al., 2020, Church and Jakob, 2020). The flood event of 22/23 July generated a plethora of erosional and depositional features, including channel widening and scouring and aggradation-related features, such as the formation of new depositional units, deposition on the floodplain, etc.

Results

Two types of anthropogenic structures affect the river-related processes in the Cherna Mesta watershed: water intake facilities and artificial banks.

The impact of water intake facilities

In both described cases, the water intake is represented by a dam (weir), constructed orthogonal to the main river channel. Upstream, above the weirs, there are artificially made flat surfaces (stonemasonry or concrete) that cover the whole channel. These places act as sediment traps.

The Belmeken dam water intake facility

The weir of this facility is located at 1,920 m a.s.l. (Fig. 1). The site was visited two months after the flood event of 22/23 July. There were clear signs that the space behind (upstream) from the weir has been recently filled with sediments. About 10 meters above the site, the river channel is filled with freshly-deposited clasts, and some of them are forming lateral levees (Fig. 2A). Considering the field criteria of (Brenna et al., 2020) and the low gradient of the river upstream of the weir, we interpret these sediments as a product of debris flood. Also, features such as sandy deposits at the level and above the crest of the weir, and yellow-rusty stains on the weir wall (Fig. 2B) testify to the long presence of wet debris and fresh cuts on the stonemasonry indicating a rather recent activity of the excavator. About 100 m below the facility, there is a bridge and below it, the river channel is starting to incise not only in Quaternary cover but also in the bedrock. Field data, such as fresh soil erosion and freshly polished bedrock, testify to the strong impact of the mid-2019 event in this part of the Cherna Mesta watershed.

Fig. 2. (A) Deposition related to mid-2019 flood event just above the water intake for the Belmeken dam. Photo taken in September 2019. (B) The water intake weir for the Belmeken dam. Stains related to the accumulation of wet sediments are marked with red arrows. (C) The main river channel side erosion. The main access road for the Cherna Mesta catchment, above the power plant. (D) Partial collapse of road II-84 (Velingrad – Razlog). Photos (C) and (D) were taken on 23 July 2019 and were provided by the Yakoruda manicipality.

The Cherna Mesta power plant water intake facility

This facility is located at 1,180 m a.s.l. and is situated at the confluence of the rivers that form the Cherna Mesta river. During the 22/23 July flash flood, the function of the structure was severely disturbed. The area behind the weir acted as a depocenter and the water intake system was completely clogged. According to the report from the guard of the power plant, it took one week of work of an excavator to clean the facility from the boulders, cobbles, and sand, deposited during the flash flood. This implies that at the time of the flood, the river deposited dozens of cubic metres of sediments.

The section between the water intake and the power plant is characterised by various processes and morphological forms related to the flood of 2019. Both erosion and sedimentation processes have been active, which has led to significant modifications of the geometry and morphology of the braided channel system that occupies the valley bottom. Undoubtedly, the segment of the river between the water intake facility and the power plant is the most strongly affected by the damages. Here, the main destructive agent was lateral stream erosion (Fig. 2C). According to the Yakoruda Forest Service, the main access road was destroyed at a distance of 2.5 km. Lateral river erosion has thus mobilised hundreds of cubic metres of clastic material subsequently deposited down the river valley.

Artificial banks at the village of Cherna Mesta

For the aims of flood prevention, the parts of the village situated to the east of the river are protected by artificial banks/ levees (Fig. 3). The 22/23 July flash flood nearly overtopped these banks: flood-related stains on the recently-built concrete walls were found to be just 20-30 cm below the upper wall surface. The lower part of the village is not protected, and houses situated next to the river were flooded. In this sector of the river, there is evidence both of erosion and deposition. Erosional processes are strictly localised in the area below the end of the artificial banks (Fig. 3). The II-84 national road (Velingrad - Razlog) was closed due to the collapse of one of the lines (Fig. 2D).

Fig. 3. Aerial imagery of the village of Cherna Mesta showing the position of the artificial banks (their beginning is marked with /1/; their end - with /2/); some areas affected by the mid-2019 flood event are also marked: (3) – location of photo 2D; (4) – location of the imagery on Fig. 4. Image from Agricultural State Fund.

Enhanced river erosion also causes partial removal of older alluvium further downstream. Two factors triggered this enhanced erosion capability of the river: the increased water speed due to the narrowing of the channel during the artificial banks construction, and the significant amount of bed load. Despite the low gradient of the river in the area of the village, the flash flood was able to carry a significant amount of sand and clasts. The deposits within the channelised part of the river are informative for the river capacity to carry bed load. Because during the recent construction of the artificial banks (2013-2017) all sediments on the riverbed were cleaned, it is easy to estimate of the volume and size of the clasts transported/deposited during the 22/23 July event. Field inspection conducted two weeks after the flood documented the presence of fresh deposits that were several dozens of meters long and up to 20 m wide, represented by coarse clasts reaching 0.5 m in diameter and abundant in sand sheets.

Conclusions

For centuries people have attempted to control river floods in mountainous catchments by constructing different facilities. The century-long experience in the case of the Alps (Eisbacher and Clague, 1984) is particularly impressive. Unlike the highly populated Alps, the studied watershed of the Cherna Mesta river is almost uninhabited and the aerial extent of the anthropogenic influence is rather limited.

Fig. 4. The newly-formed depocenter immediately before the channelised part of the river in the area just north of the village of Cherna Mesta. Satellite imagery from Google Earth Pro: A – before the event (from 2016), B – after the event (2020).

The results presented here indicate that both water intake facilities and artificial riverbanks influenced the river behaviour at the time of the mid-2019 flash flood. These anthropogenic structures affected the coarse sediment connectivity in the river system, created new sediment accumulation, and led to enhanced erosion. New depocenters formed and obstructed the work of the water intake structures. Also, new sediment accumulation formed immediately above the newly-constructed artificial banks protecting the northernmost part of the village. The position of this depocenter is not occasional - the case of the Glazne river alluvial fan is similar (Gerdjikov et al., 2021). Water intake structures play a role similar to the check dams and thus they are supposed to stabilise the river channel system (Lucas-Borja et al., 2021). In the studied case, an important effect of both such facilities is the increased erosion in the river reaches located downstream. In the case of the Cherna Mesta power plant, the effect of this erosion was particularly damaging for the main access road, other infrastructure, and arable land. Such intensive localised scouring of the river channels is known as the “hungry water effect” (Kondolf, 1997; Ondráčková and Máčka, 2019; Lucas-Borja et al., 2021). All these data are a reminder to forecast all possible consequences well in advance when planning any structure that will alter the normal river behaviour. As (Davies and McSaveney, 2006) stated, these structures “must be designed to maintain the pre-modification sediment transport capability of the river”. These days, there is a communal consensus that the management of mountain rivers has to pay special attention to upstream/downstream connections, thus allowing sediment connectivity (Wohl, 2006; Lucas-Borja et al., 2021).

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