Sediment dynamics and channel adjustments following a torrential flood in a small catchment: Gemenea, Eastern Carpathians

Florentina Livarciuc, Maria Rădoane

Ștefan cel Mare University of Suceava
Suceava, Romania

florentina_livarciuc@yahoo.com, radoane@usm.ro

Adrian Chelariu Moroșan

Water Management System
Suceava, Romania

chelariu.adriann@yahoo.com

Abstract— Our paper is aimed mainly to analyze temporal behavior of the succession of processes that occurred during the development of an exceptional rainfall in a small catchment. The ultimate purpose of our analysis was to understand the role of the factors that controlled the water and sediment fluxes along the drainage network and how the torrential channels responded in cross-section.

Keywords— small watershed; torrential flood; sediment dynamics; geomorphological processes

I. INTRODUCTION

Understanding the succession of hydrogeomorphic processes based on direct records at the level of small hydrographic basins still remains an understudied issue. The interest in studying small catchments, defined as fundamental erosional systems [1], was triggered starting with the research performed by [2, 3] and in Romania by [4, 5, 6]. To these authors, the contributions of the forestry or agronomy research must be added [7, 8]. Each of these authors has highlighted the need for a quantitative approach in the study of processes at the level of elementary catchments, i.e., the need for direct measurements of the processes responsible for landform dynamics. Our paper employs such an approach, and is aimed mainly to analyze temporal behavior of the succession of processes that occurred during the development of an exceptional rainfall in a small catchment. The ultimate purpose of our analysis was to understand the role of the factors that controlled the water and sediment fluxes along the drainage network and how the torrential channels responded in cross-section.

II. STUDY AREA AND THE DATABASE

The Gemenea drainage basin ($A = 77.7 \text{ km}^2$, order V of magnitude in the Strahler system), located in the northeastern part of the Eastern Carpathians, falls into the category of small catchments. It is characterized by a dense network of stations monitoring hydroclimatic processes, to which we added our measurements on sedimentology and

torrential channel dynamics (Fig. 1). There are five gauging stations on the main river and its tributaries, which recorded in detail the effects of the rainfall occurred on 27.06.2016 and the formation of a flash flood with all the geomorphological processes it involves.

Fig. 1. The Gemenea catchment and the network of gauging and pluviometric stations

The Gemenea River and its tributaries are part of the Moldova River hydrographic system and drain the eastern flank of Rarău Mountains, the northern flank of Stânișoara Mountains respectively. The characteristics of the geological substrate, of the landforms within the sub-drainage basins and the percentage of forest cover are presented in Tab. 1. These characteristics indicate that the five sub-drainage basins belong to the mountain area, the dominant geologic substrate being crystalline rocks or flysch. These are catchments with high potential energy that favors flow and rapid collection of water from precipitation. The configuration of these catchments tends to be of average to high circularity. Forest cover is generally high, except for the Gemenea 2 sub-drainage basin.

The available database consisted of: 1) daily data for year 2016 on precipitation and water discharges at all five pluviometric and gauging stations considered; 2) daily data on suspended sediment load at the gauging stations Gemenea 1, Slătioara and Gemenea 5 for year 2016; 3) detailed pluviographs and hydrographs on the rainfall and flash flood between 27. 06 and 4.07.2016; 4) data on the

dynamics of the cross-section of riverbeds at Gemenea 1 and Gemenea 2 gauging stations. Database processing consisted of statistical analysis (distribution of data sets, histograms, correlation and regression) and construction of synthetic graphs and maps on the spatial and temporal behavior of the analyzed parameters.

TABLE I. MORPHOMETRIC DATA ON THE STUDIED SMALL WATERSHEDS

Watershed Variable	Units	Gemenea 1	Gemenea 2	Valea lui Ion	Slătioara	Gemenea 5
Area (A)	km	13.88	30.28	6.59	6.45	19.14
Maximum elevation (Hmax)	m	1430.00	1430.00	1490.00	1600.00	1600.00
Minimum elevation (Hmin)	m	760.00	680.00	780.00	790.00	720.00
Average elevation (Hmed)	m	1095.00	1055.00	1135.00	1195.00	1160.00
Basin perimeter (P)	km	17.26	25.75	10.97	10.84	18.41
Basin energy (Emax)	m	670.00	750.00	710.00	810.00	880.00
Average slope (As)	%	41.40	36.87	39.37	36.75	36.61
Shape coefficient (Sc)	-	0.45	0.40	0.44	0.45	0.57
Basin circularity (C)	-	0.74	0.75	0.68	0.68	0.67
Relief raport (RR)	m/km	108.89	78.42	165.46	190.14	134.23
Integral hypsometric (IH)	%	0.55	0.55	0.55	0.55	0.55
Drainage network length (Ld)	km	36.05	76.65	14.34	12.96	41.52
Drainage density (Ld/A)	km/km ²	2.60	2.53	2.18	2.01	2.17
Forest cover (F)	%	87.85	68.84	92.30	79.36	75.80
Cristalline rocks	%	88.0	63.7	78.2	44	24.7
Flysch rocks	%	3.0	30.3	22.0	56	74.7
Quaternary rocks	%	9.0	6.1	0	0	0.6
Rainfall	mm	985	862	830	816	836
Water discharge	m ³ /s	0.204	0.574	0.0622	0.208	0.478
Suspended sediment load	Kg/s	0.728	NA	NA	0.0118	0.241

III. RESULTS AND DISCUSSIONS

Monitoring climatic, hydrological and geomorphological processes during the calendar year 2016 enabled the construction of a suite of diagrams showing how the water and sediment flows crossed the catchment until it reached the outlet of river network. We selected for presentation the data recorded for the Gemenea tributary (Sections 1 and 2) (Figs 2 and 3). Furthermore, detailed diagrams were constructed for all five sub-drainage basins.

In 2016, the five sub-drainage basins received rainfall ranging from 985 mm (Gemenea 1) and 816 mm (Slătioara). Their distribution during the year (Figs. 2A and 3A) shows a high degree of torrentiality given by the amount of rain fallen in a short period, such as during June. Over a single day (June 27th 2016), 67 mm of rainfall were received by Gemenea 1 catchment, and 37 mm by Gemenea 2. In the other sub-drainage basins, rainfall was less than 31 mm over the same day. The central area of the exceptional rainfall was located in the Gemenea 1 catchment. To assess the response in runoff we detailed the development of the two floods with peaks on the 2nd of June and the 27th of June respectively. The resulting changes in river discharge (gauging station Gemenea 1) did not occur rapidly, and the flash flood peak was delayed by 48 hours after the maximum rainfall peak. Conversely, on June 27th, these changes occurred at a much faster rate, as the flash flood peak (37.9 m³ / s) was recorded 50 minutes after the rainfall maximum.

The response in terms of suspended sediment discharges occurred rather synchronously with the daily water discharges (unfortunately, no hourly measurements

were performed on the suspended sediment load). For Gemenea 2, a rapid concentration of water in the two flash floods can be noted, as well as an increase in the duration of both floods.

The peak of the flash flood occurred on June 27th was 86.7 m³/s and was reached 20 minutes after it was recorded at Gemenea 1. The other three sub-drainage basins fitted the described pattern, except that the amplitude of variation was lower, due to the lower amount of water entered in these basins.

Fig. 2. The succession of hydrodynamic processes in the Gemenea 1 sub-drainage basin: The graphical representation of daily rainfall (A) and water discharge (C) for the year 2016 (in the inset, two flash floods selected for further discussion); (B) The map of the Gemenea 1 sub-drainage basin, with the distribution of slopes; (D) Morphometric characteristics of the catchment; (E) The distribution of precipitation between 1 June and 4 July 2016; (F) The hydrograph of drained water discharge; (G) The hydrograph of the suspended sediments discharge.

The differences we observed were related to the factors that delayed / accelerated the response of the water and sediment flows, such as the degree of water interception at the surface of the ground by vegetation and litter before June 2nd (higher) and prior to June 27th (lower); higher geodeclivity and circularity of the Gemenea 1 and 2 catchments, which contributed to the increase in propagation velocity of the flow; dominant crystalline rocks in these two catchments, with a thin layer of slope deposits, led to reduced suspended sediment load. Consequently, erosion capacity increased. This latter aspect is illustrated by changes observed for the Gemenea river channel in the two cross-sections shown (Fig. 4).

Fig. 3. The succession of hydrodynamic processes in the Gemenea 2 sub-drainage basin (the same explanation as in the caption above).

Fig. 4. Response of the Gemenea river channel to flow condition changes during the year 2016: Gemenea 1 (A) and Gemenea 2 (B) cross section dynamics; erosion-accumulation balance for the Gemenea 1 (C) and Gemenea 2 (D) channel cross sections.

In these valley sectors the channel is cut in the alluvial material of a less developed floodplain, consisting predominantly of gravel, boulders and even blocks. At low levels of discharge, channel processes are a quasi-balanced alternation between erosion and accumulation. This alternation was visible only at the channel bottom level. The flash floods from June 2016 oversized the cross section, particularly through lateral erosion. The river banks were the most affected, because the friable rocks (gravel and boulders in a sandy matrix) opposed lower resistance than the channel bottom. The balance between fluvial processes became strongly in favor of erosion that increased four times compared to accumulation. After the flood events, the cross-sections show a pattern of slight recovery with redistributed alluvial material.

IV. CONCLUSIONS

The final conclusion of this paper, summarized in Fig. 5, shows that one of the most sensitive controls in the distribution of water and sediment discharges is related to morphometry, namely the size of the catchment. As early as 1957, Anderson [9] described drainage basin area as 'the devils' own variable because of the strong control it exercises on the hydrological, morphometric and topologic attributes of streams. It has been widely used, therefore, as a surrogate for stream discharge where data on the latter are unavailable.

Fig. 5. Distribution of the daily rainfall, water discharge and suspended sediment load values for the five small catchments included in the Gemenea drainage system. The upper and lower limits of the boxes represent the interquartile ranges. The middle lines of the boxes represent the median value of the distribution and the dots show the mean. Whiskers represent one standard deviation, and the small horizontal lines represent all outliers. G1-Gemenea 1; G2 - Gemenea 2; VI - Valea lui Ion; S - Slătioara; G5 - Gemenea 5.

Monitoring water and sediment discharge in the five mountain sub-drainage basins, sized between 6.45 km² and 30.28 km², showed that the first factor distributing the water volume received from rainfall is catchment size.

Daily rainfall sum for the year 2016 shows a distribution of mean and median values with no large differences from one catchment to another (Fig. 5, Rainfall). The difference is seen in the outliers (maximum values) describing the nuclei of short duration precipitation, as recorded at Gemenea 1. On the other hand, the amount of water to be drained is reached in a short time depending on the size of the drainage basin. This in fact shows the efficiency in the pattern of water transport to the outlet point of the catchment. The two catchments (G1 and G2), with a dense drainage network, also have better efficiency in water transport (Fig. 5, Water discharges). Regarding the transport of sediments (data were available only for three sub-drainage basins), the highest efficiency characterizes the G1 catchment, despite that the sediment source is a hard rock (predominantly crystalline schists). In what concerns this latter issue, longer term investigations are needed to conclude whether a catchment mainly on crystalline schists provides a greater amount of suspended sediment. Yet this issue remains open in the present analysis.

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