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Sediment movement from small catchments within the Moldavian Plateau of eastern Romania

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Abstract Soil erosion, gullying, landslides, and reservoir sedimentation have been recognized as the most important environmental threat in the Moldavian Plateau of eastern Romania. A long-term field study of runoff and gully erosion rates under flash streamflow in small catchments, each less than about 3000 ha, showed much variability of sediment movement over time and among catchments. Two types of sediment delivery mode were identified. During the synchronous mode, erosion generation and sediment cleanout occur simultaneously, whereas during the more common asynchronous mode an eroding stage during late winter and early spring is followed by a channel debris cleanout stage with warm season rainstorms.

Key words runoff; soil erosion; gullying; sediment concentration; sediment movement

INTRODUCTION

At present, catchment sediment models and the design of conservation practices depend on adequate quantities of both runoff and sediment-yield data. This is a difficult goal, particularly in areas affected by short-term or *flash* streamflows and high erosion rates. For nearly 20 years, a sediment data collection project was carried out to improve the understanding of hydrological responses for small agricultural catchments in eastern Romania. The shapes of the sediment concentration curves and runoff hydrographs reflect the impact of the local conditions on catchment output. The research question to answer is: does relating sediment concentration to water discharge aid in solving the sediment movement problems in eastern Romania? Related problems include assessing the relative contribution of valley-bottom gullies compared to the upland sources of sediment. The purpose of this paper is to review what is known about sediment movement from small catchments with temporary runoff, and to define the main patterns of sediment delivery by applying field experience from monitored watersheds near the city of Barlad. Then, the possibility of interpreting discharge–sediment concentration curves for this purpose is explored.

THE STUDY AREA

The topography of the area is characterized by rolling hills of the Moldavian Plateau of eastern Romania. Several small catchments were chosen with areas of up to 3000 hectares. Most of the data were collected within the Chioara-Ghermanesti basin (2963 ha), that lies north-northeast of the city of Barlad (46°20′N 27°50′E). The maximum altitude is 321 m while the lowest elevation is 70 m along the flood plain of Barlad River. That area is underlain by loamy soils developed on deep sandy-clayey Pliocene layers. Cropland is the primary land use, followed by pasture, and 12.4% of the area is forested. Relatively hot summers and cold winters result in a temperate, continental climate with mean annual temperatures around 9°C. Rainfall distribution throughout the year is bimodal with peak monthly amounts during June and November. Most precipitation falls as rain and the mean annual amount is 500 mm. Given the high variability of snow in space and time, there is a low probability of snowmelt streamflow occurrence every year.

METHODS

Efforts have been deployed to get reliable flow sampling, and there were trials of both automatic and manual sampling. In many circumstances, under high suspended sediment concentration, the ISCO automatic pump sampler did not work. Therefore, during significant snowmelt runoff, manual operating was accomplished through the dual sampling of streamflow above gully headcuts and at catchment outlets. Nearly all samples were collected at 5 to 15 min intervals. During heavy rainfalls, the manual sampling was done only at the catchment outlet. Additional streamflow measurements included flow cross-section area, wetted perimeter, hydraulic radius, velocity of the flow and roughness coefficient. Gully erosion rates were estimated by topographic survey and by means of a *stake-grid* method in order to increase the accuracy of the data collected. These stationary, successive measurements of gully growth, have been deployed several times throughout the year.

RESULTS AND DISCUSSION

Based on data collected in the southern part of the Moldavian Plateau, two major types of sediment delivery scenario were identified, respectively synchronous and asynchronous.

Synchronous scenario type

The two subprocesses of debris production and debris cleanout take place almost simultaneously and may occur very seldom. For this synchronous scenario, two cases are considered, namely the cold season and warm season.

The cold season case is related to freeze–thaw weathering. Relatively marked runoff events result from snowmelt or mixed precipitation usually during a late or a gentle prolonged winter. The main feature is that gullying represents the major sediment source. Data collected within the Chioara basin during two series of representative snowmelt events illustrate this case. The first series is associated with runoff induced by a quick thaw between 19 and 23 March 1993 (Fig. 1). Active precipitation that brought changes in the gully configuration is estimated at 54.0 mm over the period 15 February–9 March 1993. Several conclusions can be drawn from data series for the five days of higher temperature levels and quick thawing:

- Peak water discharges of 5.01 and 4.02 $m^3 s^{-1}$ were recorded during the second and the third thawing day for daily maximum temperatures of 11.4 and 11.9°C, respectively (Fig. 1).
- Maximum values of the measured sediment concentration are very high, 279 and 312 $g L^{-1}$. During these two snowmelt flow events the suspended sediment concentration usually ranged between 100 and 300 $g L^{-1}$.
- Peak turbidity preceded the peak runoff by 60–90 min.
- The sediment concentration curve had a pulse shape but there was no debris-free period as suggested by Piest e*t al.* (1975).
- Sediment delivered by gullying is concurrent with the cleanout of the gully channel during these two days when the snowcap was exhausted. Although the turbidity remains as high as 195 $g L^{-1}$ during the last two days, the peak runoff drastically diminished and it did not exceed 1.15 $m^3 s^{-1}$.
- Measured maximum flow velocities were 2.70 and 2.53 $m s^{-1}$.
- During that five-day series of quick thaw, the headcut of Valcioaia and Tumba continuous gullies advanced by 10.1 m and 2.7 m, respectively.

The second series of runoff events in the Chioara basin resulted from a slow and prolonged thaw that took place 19–30 March 1996 when the maximum air temperature ranged from 2.8 to 8.1°C. These events occurred under lower temperature conditions and can be summarized as follows:

- Peak water discharge of 5.31 $m^3 s^{-1}$ and suspended sediment concentration of 237.0 $g L^{-1}$, as defined by 81 samples, were recorded during the fifth snowmelt event on 27 March 1996.
- Peak runoff and peak turbidity coincide.
- Measured stream velocity peaked at 2.77 $m s^{-1}$.

Field measurements of runoff above the gully headcut indicate that sediment concentrations range from 3 to 16 $g L^{-1}$ on the valley-bottom, to around 40 $g L^{-1}$ within rills on hillslopes. However, most of the sediments delivered by hillside rills were deposited on the valley-bottom and they did

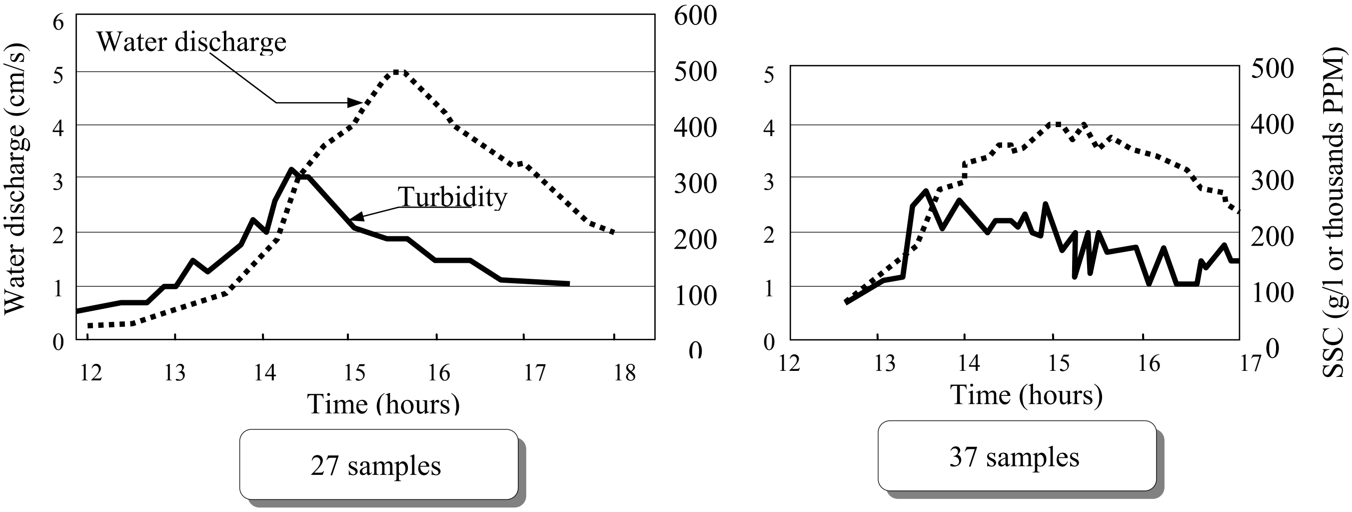

Fig. 1 Hydrograph and suspended sediment concentration (SSC) during two snowmelt events on 20–21 March 1993 for the Chioara-Ghermanesti basin, near Barlad, Romania.

not reach the main stream channels. If the flow induced by mixed precipitation on 15 April 1996 is taken into account, a linear advance by 13.0 m and an areal growth of 238.0 m^2 of the Valcioaia gully head was measured. These data reveal that during significant runoff events occurring over cold seasons, turbidity values are low in the upper catchment, above the gully headcut, and extremely high at the outlet. Therefore, under conditions that lack splash erosion, gullying remains the major sediment source.

The effectiveness of gullying processes is usually greater during late winter, as noted by Ionita (1998, 2000). These findings correspond to runoff events which occurred during an earlier and short thawing *window* on 20–22 February 1996, when the maximum air temperature went up to 6.6°C. The main streamflow was recorded on the second day of thaw. The peak water discharge increased sharply to 5.5 m^3 s^{-1}, and the shape of turbidity curve was flat ranging from 11.0 to 44.0 g L^{-1}. This rather low erosional response can be explained by the scarcity of gully soil debris. Even though the maximum stream velocity was 2.45 m s^{-1}, the shallow thawing depth limited the debris supply, and the main sediment delivery event took place one month later.

The warm season case is less frequent than the previous case. These few events of synchronism between debris detachment and debris cleanout are related to extremely heavy rainfalls and/or significant successive rains. At least two general conditions are necessary to induce such events: the gully headcut area must be free of soil debris and the soil must be wet enough. The features of this case are:

- Greater chance of occurrence from late May to mid July.
- Marked streamflows, associated with high peak water discharges ranging up to 69 m^3 s^{-1}.
- Measured stream velocity is greater than 3 m s^{-1}.
- Sediment concentration is very high across the whole watershed, usually 100–200 g L^{-1}.
- Measured downstream maximum suspended sediment concentration varied between 232 and 259 g L^{-1};
- Rill–interrill erosion and gullying are the main sediment sources.

Asynchronous scenario

This scenario represents the most frequent type of catchment behaviour over the Moldavian Plateau where detachment of waste soil debris does not occur simultaneously with the debris cleanout. Its typical form corresponds to the two-part cycle described by Piest *et al.* (1975) at Treynor, Iowa, USA. Two stages (subprocesses) have been identified. The preparatory stage (debris production subprocess) results from freeze–thaw cycles. Based on visual evidence and stationary measurements of gully development from the Barlad area, usually a great amount of gully-soil debris was observed to accumulate soon after the main snowmelt runoff. That means the maximum mass wasting occurs subsequent to the exhausting of almost the entire snowcap, and it occurs at a critical thermal level when the thawing gets deeper through gully heads. Therefore, this stage strongly depends on the magnitude, frequency and length of freeze–thaw cycles, especially during late winter. During the second stage of this scenario we witnessed the cleanout of the previously prepared debris. In many instances, a partial cleaning of the previous materials, combined with relatively slight new gullying, occurred. However, a fluctuating sediment concentration prevails as part of this scenario.

Three major runoff events can be recognized in the asynchronous scenario resulting from: (a) early spring rainstorms, (b) spring and summer rainstorms, and (c) long-term rainfall. The first type of runoff events occur during late May and June. Marked streamflows are defined by high water discharges resulting from heavy rainfalls. Sediment concentration is very high across the whole basin, ranging from 80–120 g L^{-1} on cultivated hillsides under row spaced crops, to 200–300 g L^{-1} in the channels. During such extreme rainstorms, high rates of soil and gully erosion have been recorded. Later on, the relative debris quantities moved are greatly reduced for each subsequent runoff event. The canopy protection of crops progressively increases through summer and causes decreasing erosion rates (Motoc &Ionita, 1983; Ionita & Ouatu, 1990). Fluctuating sediment concentrations are related to the land cover factor, pre-existing gully debris, or renewed sediment supply by soil erosion and gullying. Ionita (1998, 2000) stated that generally, by mid July, there was no significant gullying in the Moldavian Plateau. Finally, long-term rains on small watersheds induce streamflows with low turbidity values usually varying between 40 to 60 g L^{-1}.

For larger areas, features of the asynchronous scenario can be found in measurements from the Berheci basin, 49 100 ha catchment area, Tutova Rolling Hills. The shape of its mean suspended sediment discharge curve is depicted by two peaks. The minor one of 7.8 kg s^{-1} is related to gully debris delivered by snowmelt events during March. The major peak of 21.3 kg s^{-1} results from cleanout of the previous gully soil debris and both soil erosion and renewed gully erosion during June.

CONCLUSION

The synchronous scenario deals with the almost-simultaneous occurrence of debris production and debris cleanout in a catchment. Two synchronous types were identified: a cold season case was related to freeze–thaw cycles, usually developing during late winter; and a warm season case caused by extremely heavy rainfalls and significant successive rainfall events. This scenario seldom occurs but has produced very large values (100 to 310 g L^{-1} or thousands PPM) of suspended sediment concentration recorded at the catchment outlet. The asynchronous scenario occurs more commonly and consists of an eroding stage during late winter and early spring, and a channel debris cleanout stage with warm season rainstorms. The shape of the sediment concentration curve fluctuates, with high values during the first spring rainstorms and greatly reduced values for each subsequent runoff event throughout the year.

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