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ORIGINAL PAPER

Gully development in eastern Romania: a case study from Falciu Hills

Ion Ionita[1] · Lilian Niacsu[1] · Gabriel Petrovici[2] · Ana Maria Blebea-Apostu[3]

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Abstract The gullied systems from the Falciu Hills within the Chioara catchment (2997 ha) consist of both main types of gullies, discontinuous and large continuous ones along valley bottoms, and lots of ephemeral gullies. Several methods have been used to measure and estimate gully characteristics. Then, the gully development stages, the effect of the natural conditions, and especially the impact of land management on gullying in the Falciu Hills over the last two centuries have been defined. In addition, the role of gully erosion in triggering landslides has also been studied. Two main periods have been distinguished (until 1960 and 1961–2012) for assessing major characteristics of land degradation. The results show that total gully area in the Chioara catchment is 66.4 ha excepting for the ephemeral gullies, and areas occupied by gullies from the five study sub-catchments (2334 ha) account for two-thirds. Total length of the main gully network in the entire catchment is 33.2 km from which the five sub-catchments account for 71 %. The mean gully density of 1.11 km km^{-2} supports the evidence that here gullying is the major environmental threat. Half of the gully areal growth and three-quarters of the new landslide area occurred over the 1961–2012 period. Delayed deforestation peaking during 1830–1930 and land conversion to arable use resulted in severe soil erosion, high aggradation along the non-gullied valley bottoms, and severe gullying. The average gully head retreat rate over the last two centuries from four trunk continuous gullies is 14 m year^{-1}, and the sediment yield from gullying only accounted for 54–69 % of the sediment mass produced by water erosion. The evolution of gullies is linked to major land-use changes in

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✉ Ion Ionita
ion.ionita72@yahoo.com

[1] Faculty of Geology and Geography, Department of Geography, "Al. I. Cuza" University of Iasi, Carol I Blvd. 24, 700505 Iasi, Romania

[2] Research and Development Centre for Soil Erosion Control Perieni, Bacau Road, km 7, P.O. Box 1, 731240 Barlad, Vaslui County, Romania

[3] "Horia Hulubei" National Institute for Physics and Nuclear Engineering, Reactorului Str. 30, P.O. Box MG-6, Bucharest – Magurele, Romania

the study area. Despite a decreasing tendency of gullying and catchment area over the last half century, gullying still remains problematically high in East Romania.

Keywords Gullying · Continuous gullies · Deforestation · Landslides · Sedimentation

1 Introduction

Land degradation has been recognized as a major environmental threat in the Moldavian Plateau, which occupies most of eastern Romania. Gully erosion is of particular concern, especially in the southern part of the Moldavian Plateau, besides soil erosion, landslides, aggradation via sedimentation of the floodplains, and reservoir siltation.

Investigation of gullies, in terms of evolution and control, has been a major research focus for the national community over recent decades, mainly after the period 1968–1973 that received more precipitation. The most significant contributions include identifying controlling factors, magnitude (distribution and density), estimating some rates of gullying, establishing critical periods for gullying, applying statistical models, and land improvement practices.

Two main gullying areas have been distinguished by Ichim et al. (1990) and Radoane et al. (1995) in the Moldavian Plateau of Romania. Firstly, the northern area covers the Jijia Rolling Plain, where small discontinuous gullies are usually located on valley sides. Secondly, the southern area extending around the town of Barlad is characterized by large and long, continuous, valley-bottom gullies. The relations between the texture of the soil and parent material, the morphology, and the gully dynamics have been discussed by Radoane et al. (1995, 1999), Ionita (2000), Hurjui (2008).

Ionita (2000, 2003, 2006, 2008, 2011) reported additional results obtained by studying gullies in the Barlad Plateau, and his main findings on continuous gullies can be summarized as follows:

- Gully erosion rates have decreased since 1960, but still remain problematic.
- The mean annual regime of gullying over the period 1981–1996 exhibited pulsatory activity.
- During this 16-year monitoring period, 57 % of total gullying occurred during the cold season (late winter–early spring), with the remainder occurring during the warm season.
- The critical period for gullying is during the 4 months between March 15–20 and July 15–20.
- The recorded sediment concentration values are very high at the catchment outlet (100–300 g L^{-1}), resulting from snowmelt, intense rainfalls, and heavy successive rainfall events.

Several types of statistical models have been applied to assess gully evolution in the Moldavian Plateau, such as the multiple regression model (Radoane et al. 1999) and the dynamic model series (Ionita 2000).

Across the entire Barlad Plateau, it is estimated that total erosion usually varies between 20 and 30 t ha^{-1} (Motoc 1983).

Despite the valuable research on gullies, there is also a need to accurately estimate the rates of gully erosion over the last two centuries, to distinguish between the primary drivers of severe gullying in the Falciu Hills, including climate (e.g., rainfall distribution), hydrology (e.g., organization of overland flow paths), lithology (e.g., duplex soils), and especially the human impact in terms of land management. This approach allows analysis of differences in gully growth with time. In addition, a second challenge refers to both the spatial distribution and the very recent development of landslides triggered by gullying. The case study from Chioara catchment, typical for this geomorphological unit of the Moldavian Plateau, allows to reach these goals.

2 Study area and methods

2.1 Study area

Extending over ca. 27,000 km^2, the Moldavian Plateau is the broadest and most typical plateau of Romania (Bacauanu et al. 1980; Ungureanu 1993; Fig. 1). Its major units are the Suceava Plateau, Jijia Rolling Plain in the northern part, and the Barlad Plateau and Covurlui High Plain in the central–southern area. The Barlad Plateau is the most extended high unit of the Moldavian Plateau and covers >8000 km^2. The Plateau comprises three major subunits: the Central Moldavian Plateau in the northern area; the Tutova Rolling Hills, west of Barlad Valley; and the Falciu Hills, east of Barlad Valley.

Three major geostructural units can be identified within the overall geological structure of the Moldavian Plateau. These are the East European Platform (its southwestern area is also called the Moldavian Platform), the Barlad Platform, and the Covurlui Platform. The

Fig. 1 Location of the Falciu Hills in the Moldavian Plateau of eastern Romania

geologic evolution of these units is characterized by the complicated and differentiated basement, which has been consolidated in successive phases.

From the stack of the Paleozoic, Mesozoic, and Tertiary sedimentary strata, Middle/Late Miocene (Upper Sarmatian, Meotian, and Pontian) and Pliocene (Dacian and Romanian) layers outcropped due to erosion in the Tutova Rolling Hills and the Falciu Hills. During the Upper Sarmatian (Kersonian), sedimentation changed in favor of two facies, namely: one of marine brine features (with clays, sands, and a few seams of lumachellic limestone) and the other, coastal–deltaic, consisting of cross-bedded sands and clays and sandstone concretions (Jeanrenand 1971).

The following three layers have been separated by Jeanrenand (1961, 1966, 1971) in the prevailing Meotian (Late Miocene) strata:

- The lower 8- to 100-m-thick layer, consisting of sands, clayey sands, and clays (later, this layer was attached to the Kersonian);
- The middle, cineritic layer (the "*Nutasca-Ruseni*" reference horizon) being 30–40 m thick in the middle area of the Tutova Rolling Hills. This layer consists of slabs of andesitic cinerites with sandstone concretions, which are separated by clayey and sandy–clayey seams (intercalations).
- The upper and thickest layer (150–180 m) comprises a succession of sands, clayey sands, clays, and shallow sandstone seams and are predominantly cross-bedded.

The Pontian, Dacian, and Romanian are associated with a pronounced marine regression toward the present basin of the Black Sea. Thus, most of the Tutova Rolling Hills and Falciu Hills became subaerial, since the Pontian and Dacian layers, represented by a prevailing sandy coastal facies (Macarovici 1960), occur along the main hilltops in the southern part. They are something more clayey if compared with the sandy–gravel matrix of the Romanian formations, where the sedimentation series is finished by the Balabanesti gravels (Sficlea 1960).

Neotectonic uplift during the Romanian can be correlated with the Valachian phase, and it affected the whole Moldavian Plateau, being more pronounced in the northwest and less in the southeast. In contrast to the subsidence during the Carpathian Orogeny, the layers that appear to date are slightly dipping (<1°), to the southeast, as shown Jeanrenand (1961, 1966, 1971) in relation to the general monocline structure.

East of the Barlad valley, in the Falciu Hills, geological formations are split by short subsequent, east–west-oriented tributaries of the Barlad River. They created typical asymmetrical valleys, where the left side is a north-facing cuesta front and the right side is a south-facing cuesta back slope. The Falciu Hills cover an area of ~57,100 ha, where from north to south, the following 12 catchments are included: Albesti (1267 ha), Idrici (7314 ha), Valeni (1344 ha), Chioara (2997 ha), Banca (1615 ha), Bujoreni (2209 ha), Zorleni (4946 ha), Trestiana (5101 ha), Jeravat (14,683 ha), Hobana (8317 ha), Vizureni (1048 ha), and Barzota (6242 ha).

Due to its geographical position, the Falciu Hills, along with the entire Moldavian Plateau, have a temperate–continental climate, a feature emphasized by the major inter-annual fluctuations of temperature and precipitation. These fluctuations are reflected in the oscillating character of the yields of the main crops (Bacauanu et al. 1980; Ungureanu Al 1993).

Summers are hot and winters cold, so that the absolute temperature amplitudes are ~70 °C (40 °C in July and −32 °C in January), and the annual mean temperature is 9 °C at Bârlad. The lowest mean monthly temperature is recorded in January (~−4 °C), while the highest increases to ~20 °C in July. Mean annual precipitation is 490–550 mm per year, and usually, ~65 % of precipitation falls during the warm season (April–September).

Drought is common, and the dry periods usually last about 2 weeks, but are sometimes longer, such as in 1945–1946, 1953, 1967, 1982–1983, 1985–1987, 1989–1990, 2000–2001, 2008–2009, and 2011.

In terms of sources, the semipermanent drainage net of the region shows a predominantly pluvial snowfall type with slight rainfall dominance. In terms of the water discharge regime, the flash floods triggered by snowmelt and overlapping with certain rains during late winter and early spring are distinguished. Floods induced by heavy rainfall during the warm season are more frequent in May and June, followed by shallow flows over autumn–winter.

By the start of the nineteenth century, the Falciu Hills were heavily forested, where the prevailing durmast (*Quercus petraea*) is frequently mixed in different proportions with both the beech (*Fagus silvatica*) in the greatest heights and the common maple (*Acer campestre*) and lime (*Tilia* sp.). The sylvo-steppe is advancing on the Barlad Couloir and is composed of quercine coppices and meadows consisting mainly of fescue grasses. Accordingly, most of the soil cover consists of loamy-textured Cernisols (especially Phaeozems) in the lower part and Entic Luvisols in the higher part of the area. However, the native vegetation, especially forest, has been drastically changed.

The impact of two significant milestones in modern Romanian history is evident. Firstly, the Treaty of Adrianople (also called the Treaty of Edirne) concluded the Russo-Turkish War of 1828–1829 and opened the Dardanelles to all commercial vessels, including the Principalities of Moldavia and Walachia, thus liberating commerce for cereals, livestock, and timber. Secondly, the Land Reform of 1864 sought to undo the feudal structure that had persisted after the unification of the Danubian Principalities in 1859. It aimed at the abolition of compulsory labor and the establishment of private small-holdings. Under these conditions, the collapse of the forest by deforestation in the neighboring western unit, the Tutova Rolling Hills, occurred during the nineteenth century. The marked land-use change by severe deforestation resulted in sharp decline of the extent of forest, from 47 % of the total area in 1832 to 22 % in 1893 (Poghirc 1972). A similar pattern is evident in the Falciu Hills. Concomitantly, the land was converted especially to arable use, and the proportion of cultivated land in Moldavia sharply increased from 6 % in 1832 to 19 % in 1862 and 36 % in 1893. The removal of forests in eastern Romania was later than in Central Europe. There, woodland coverage was drastically reduced to 15 % of the total in the early fourteenth century, as reported by Bork and Lang (2003), Dotterweich (2003), and Schmidtchen and Bork (2003).

Several key phases can be identified in the historical development of land management in Romania during the last 150 years, mainly since the Land Reform of 1921, which tried to resolve lingering peasant discontent and create social harmony after the upheaval of World War I. By 1960, the traditional up-and-down hill farming system under small plots averaged ~85 % of cropland on slopes. Tillage operations were commonly deployed by animal traction or manually, and there were few inputs of chemical fertilizers. Combined with additional impacts of local natural conditions, there was a high risk of erosion.

Since 1960, the awareness of soil erosion and conservation practises has gradually increased. The areas under small plots were turned into cooperative farms. About 15 % of agricultural land, which belonged to more successful farmers with larger fields, was changed to state farms. Nationwide, the first important objective was to implement soil conservation practises, such as contouring, strip-cropping, buffer strip-cropping, terracing, grassed waterways, improving the state of pastures, check dams within gullies, subsurface drainage, and land levelling. The conservation practises included the use of bench terraces, both in vineyards and orchards. By the end of 1989, some 2.2 million ha or ~30 % of agricultural land with erosion potential was adequately treated with conservation practices.

Since 1990, new land reforms have been implemented. The impact of implementing two major provisions of Act No. 18/1991 was marked on soil conservation and crop yields. One of these stipulates that land re-appropriation has *to be usually applied on the old locations.* In most cases, this means that the layout of plots is orientated up-and-down slope. The second provision refers to *successors* rights up to the fourth degree of kinship. Consequently, the rate of land division has sharply increased, and today, there are over 46 million small individual plots. An added Act (No. 1/2000) focuses on forest–land division for private ownership. The major effect of these Acts is the revival of traditional agricultural systems, especially up-and-down hill farming. Another major problem over recent decades is that the State ceased funding conservation practises, and such an investment is not a high priority for landowners.

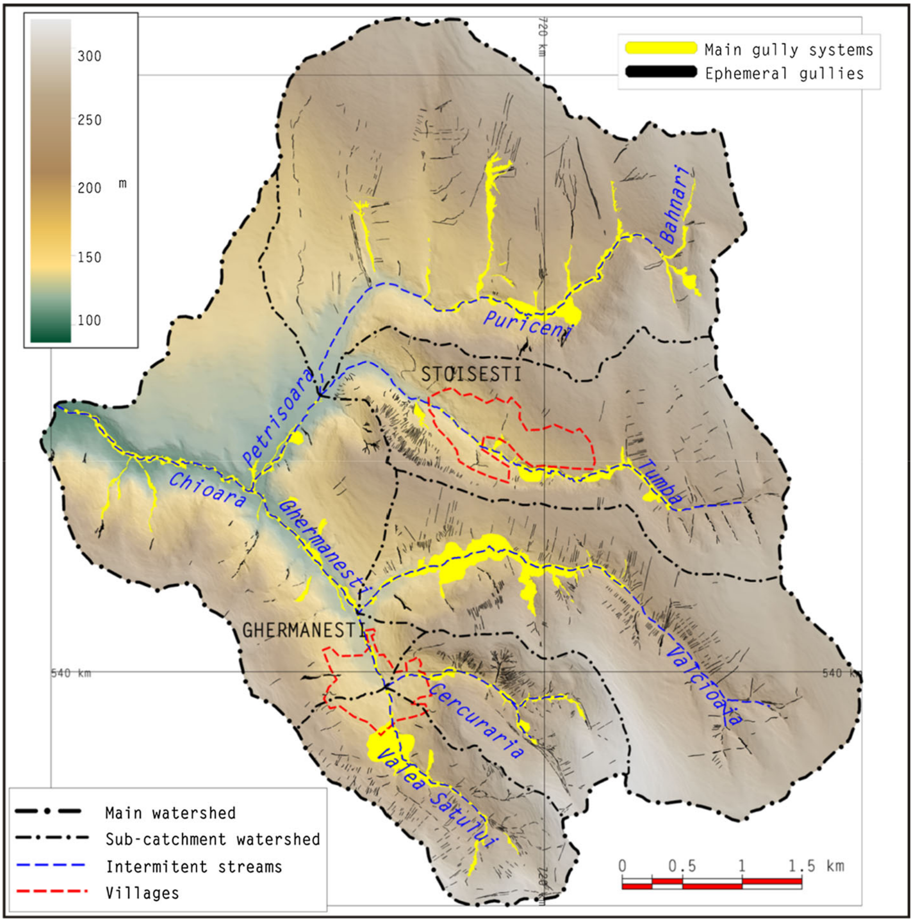

Fig. 2 Digital elevation model (DEM) of Chioara catchment and location of the two gully types

The main focus of this paper will be on the Chioara catchment almost 3000 ha in size and having an average of 15.6 % slope, in the central part of the Falciu Hills, located 100 km south of the City of Iaşi and 25 km NNE of the town of Barlad. Some additional discussion will refer to the adjoining Banca catchment, to the south. The minimum altitude of 76 m is on the Barlad floodplain, and the maximum (321 m) is the summit of Cercuraria Hill. About half of the catchment is covered by slopes that vary between 5–18 %, and a loess mantle (generally >5 m thick) overlies Late Miocene (Meotian and Pontian) formations.

The study area is highly susceptible and prone to rill and gully erosion, which damages the local landscape by depleting soil resources and decreasing agricultural productivity. Deep continuous gullies generally incise the valley bottoms. They represent the main erosional feature of the Falciu Hills, despite the obvious presence of smaller, discontinuous gullies usually located on valley sides and lots of ephemeral gullies (Figs. 2, 3).

Most continuous gullies are fed either by upper discontinuous gullies, developed several tens or hundreds of meters upstream from the main gully head cut (e.g., Tumba, Puriceni 1, Puriceni-Bahnari, Puriceni 3, Puriceni-Intre Tarlale, Banca-Chira, Banca-Loava) or by small channels located in the very recent alluvium along the valley bottom (e.g., Valcioaia, Banca-Recea). Ephemeral gullies or rills that developed on valley sides can feed some main gully heads, as in the Puriceni gully system, Podis Gully and Valea Adanca Gully. Since 1960, their gully heads have been severely dissected by multiple head cuts, although their drainage area was 48–22 ha, respectively, and the hillslope gradient is 6 % (Fig. 4). In places, rills feed new head cuts initiated on gully banks (e.g., Valcioaia, Puriceni 1, Valeni) as shown in Fig. 5.

Duplex soils are one of the main features of the valley bottoms in the Falciu Hills. Here, the gully banks show soils with contrasting texture between soil horizons (Table 1). The topsoil is a very recent alluvium blanket, commonly 2–3 m thick, sandy loam to loamy sand texture, and overlying a finer B_t horizon. The presence of this unusual thick B_t horizon along the former forested valley bottoms is believed to be associated with natural conditions, in particular the higher soil moisture. Thus, the largest thickness of the B_t horizon, of $\leq \sim 3.50$ m, occurs along the thalweg of the previous non-gullied main valley bottoms, and it arrives within no more 100 m from the thalweg.

Then follows the loam to sandy loam C horizon and usually loamy sand to sand D horizon, which in places ends as black and blue, when wet, silty clay.

Fig. 3 Tumba continuous gully in valley bottom (May 21, 2011)

Fig. 4 Valea Adanca gully head. Multiple head cuts fed by ephemeral gullies and rills developed on the gently sloping right side of the Puriceni Valley (May 12, 2012)

Fig. 5 New subsequent gully head cuts developed on the right bank of Valcioaia gully, located in valley bottom. These are fed by rill and ephemeral gullies (May 26, 2013)

Table 1 Characteristics of the duplex soils in the gully heads from Falciu Hills, Romania

No	Horizon	Texture	Thickness (m)	
			Valcioaia gully	Puriceni 1 gully
1	Very recent alluvium	Sandy loam–Loamy sand	2.25	2.70
2	B_t	Loam	3.35	3.60
3	C	Loam–sandy loam	3.10	2.60
4	D_1	Loamy sand–sand	1.90	3.10
5	D_2	Silty clay	1.70	–
Total			12.30	12.00

Further down valley in gullies, beyond the actively eroding reach, the continuous gullies are 10–30 m wide and 10–16 m (maximum 25 m) deep. The summit slopes and toe slopes within the study area are 0–5 %, the cuesta back slope is 6–14 %, and the cuesta front is >20 %. Water enters the gullies as both surface and subsurface flow. Surface runoff is the major contributor that shows pulses and enters the gullies primarily through the small channels (mainly discontinuous gullies) and incised rills at their head, where water flows over a 7 m (when sunk by debris) to 10/12 m high step (scarp) into a plunge pool at the base of the head cut. Water then flows down the gully axis through a slightly meandering channel. Groundwater seeps through the gully walls, and seepage presence is obvious along the gully bed, especially during snowmelt or after more rainy periods. Actually, the name Chioara means *blind,* but the local hydrological meaning refers to the scarcity of stream flows. In places, under prolonged wet conditions and/or gully bank undercutting by concentrated flow, active landslides occur. New deep-seated slides may significantly extend or widen gullies (Fig. 6). More commonly, gully banks are reshaped progressively by hillslope runoff initially resulting in hanging alcoves (alveoli) at the small fan heads, which overlay the former alluvial blanket, and troughs in the subjacent layers splitting a buttress (protrusion) grid (Fig. 7). Later, when crenelation (notching) of the gully bank turns extreme, the remnant area of previous valley bottoms (in the shape of lateral shoulders) is eroded, and some of those troughs enlarge and change into new lateral gully heads. This long-standing process is intermittently accompanied by pop-out failures, in which pyramidal (columnar) blocks slough and detach from near the bases of steep gully walls, resulting from undermining driven by stream flow and/or seepage.

2.2 Methods

Several methods have been deployed to accurately measure and estimate increments of gully growth, including

- Intensive monitoring between 1978 and 2003 using the “*stakes grid method*” within the active gully head area deployed several times throughout the year (start and end of winter, and after notable rainfall events) in order to increase the accuracy of data collected as maps at scale 1:100 (Fig. 8).

Fig. 6 Active landslides in the lower reach of Valea Adanca Gully, Puriceni Gully system (April 01, 2012)

Fig. 7 Crenellation/notching of the right bank of Valcioaia gully by sidewall erosion (October 14, 1997)

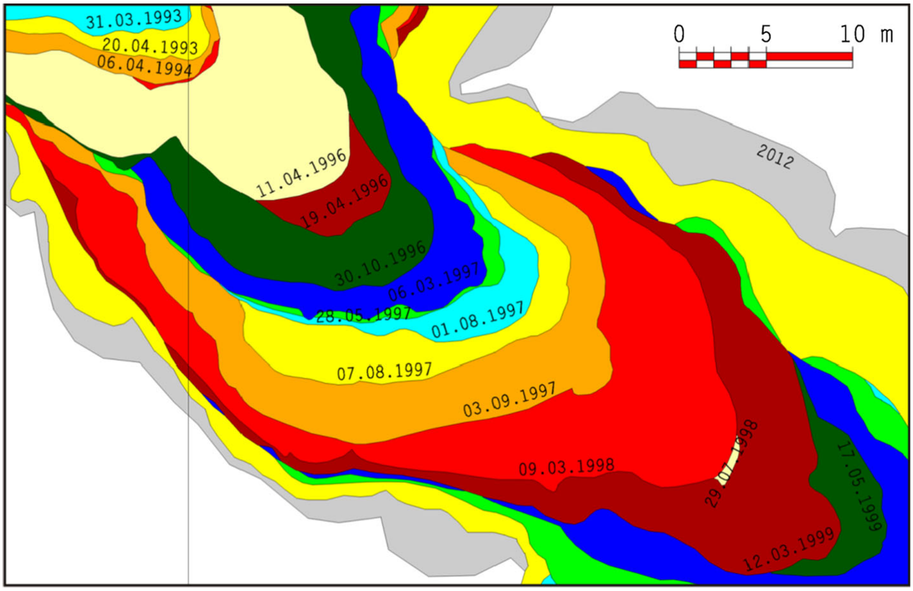

Fig. 8 Measured Valcioaia gully head retreat between March 31, 1993 and May 17, 1999 using the "*stakes grid method*." Labels refer to day, month, and year of survey

- Long-term stationary monitoring of gully growth using repeated levelling (topographic surveying usually with a Theo 020A, plus Leica 407 TCR, and GPS South 82 V-Trimble) to obtain maps at scale 1:500.
- Using aerial photographs (the ones taken in 1960, 1970, 2005, and 2009), topographical plans at 1:5000 scale and reliable local information to assess the chronological sequence of recent gully development.
- Useful information about the land use at the end of the nineteenth century was drawn from both the topographic map of Moldavia at scale 1:20,000, carried out by the

Romanian Military Topographic Service between 1873 and 1899, and the Atlas of Moldavia at scale 1:50,000 published in 1894.

- The Cesium-137 technique was effectively used in some areas of recent deposition of sediments to provide chronological measures of gully development.
- Cartographic material was obtained using TNT Mips version 7.1 software, and data processing was performed using Microsoft Office 2010.

Therefore, classical research methods (especially repeated field surveys and mapping, mathematical–statistical processing) and present-day methods based on the GIS software have been used effectively to measure and evaluate gully growth.

The main studied gully variables are gully length, areal gully growth, gully volume, eroded material (sediment yield), and the drainage area above gully heads. When making estimates of the volume and/or sediment yield of a continuous gully reach, the following steps were followed:

- Calculate *mean measured depth* based on data from gully perimeter and longitudinal profile or from field measurements with tapes, e.g., (10.2 + 10.4 + 11.1 + 11.2 + 10.5):5 = 10.7 m;
- Compute *mean depth* of levelled cross section as cross-sectional area divided by bankfull width (161.4:20.5 = 7.87 m) according to Heede (1974);
- Determine *depth ratio* by relating mean depth of cross section to mean measured depth (7.87:10.7 = 0.735). The depth ratio can be useful for faster calculation of the *adjusted mean depth* in gully reaches with similar shape, but without levelled cross sections, when only the gully perimeter was surveyed. For example, if the mean measured depth is 12.3 m and the mean depth ratio is 0.671, then the adjusted mean depth is 12.3 × 0.671 = 8.25 m;
- Enter plan area of the gully reach for a particular period of time, and by multiplying with the adjusted mean depth, the associated volume, total or mean annual, is obtained.
- An average bulk density of 1.45 $t\ m^{-3}$ has been frequently used in the study area to convert soil volumes to soil mass eroded (sediment yield) from gullies (Ionita 2000, 2006).

3 Results and discussion

Studies in Chioara catchment have been undertaken since April 1980 and primarily concern the development of the continuous, valley-bottom gullies. The head cuts of these studied gullies are mostly located in the upper part of five small sub-catchments (Table 2).

Table 2 Topographic characteristics of the studied sub-catchments in the Chioara–Ghermanesti basin

No.	Sub-catchment	Area (ha)	Mean slope (%)
1	Puriceni–Bahnari	867	12.8
2	Tumba	468	16.0
3	Valcioaia	598	15.8
4	Cercuraria	186	21.5
5	Valea Satului	215	19.5
Total		2334	15.5
6	Other area	663	15.9
Total Chioara Basin		2997	15.6

These gullies were intensively surveyed until 2003 using the "*stakes grid method*," plus intermittent levelling. For example, Valcioaia gully head was monitored 45 times over 16 years using this method. By 2010, this approach was replaced by topographic surveying with a total station and GPS. Detailed topographic survey of the whole gully systems was completed in spring of 2011, 2012, and 2013. Most of these were surveys of gully perimeter, length, width, depth, gully cross section, and longitudinal profile. Figures 9 and 10 depict the planimetric extension and growth of both the gullies and the triggered landslides within the Puriceni, Tumba, and Valcioaia sub-catchments. There are few gully heads (Puriceni 1, 2, and 3) without local names, and their designation is according to the field book numbering. The total gully area in Chioara catchment is 66.39 ha (2.2 % of the total area), and gullies from the five study sub-catchments account for two-thirds (66.7 %) of the gullied area.

Considering the 1960 aerial flight as a reference one, two periods have been distinguished (before 1960 and 1961–2012) for assessing some major land degradation characteristics. Data from Table 3 show that gullies cover 44.3 ha in those five sub-catchments, and the associated triggered new landslides extend over 39.9 ha. By far, the Puriceni sub-catchment is the main contributor to the gully area, some 41 % of the total. It is followed

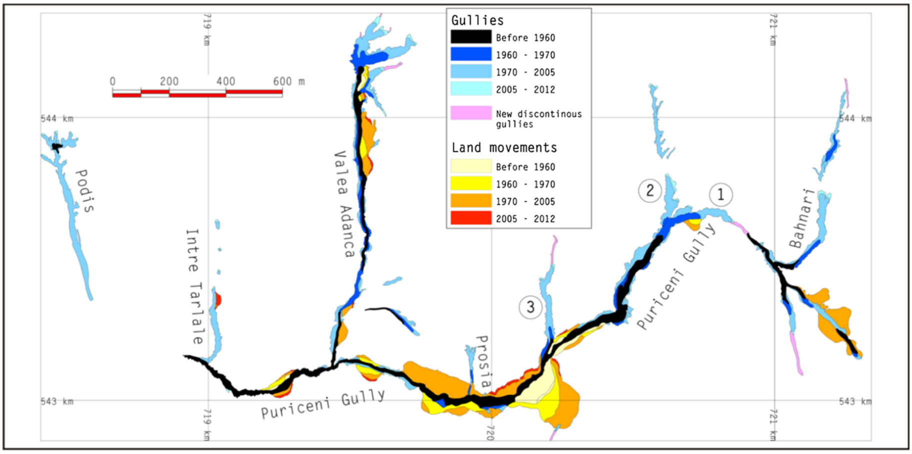

Fig. 9 Development of the gully system and triggered landslides in the Puriceni sub-catchment

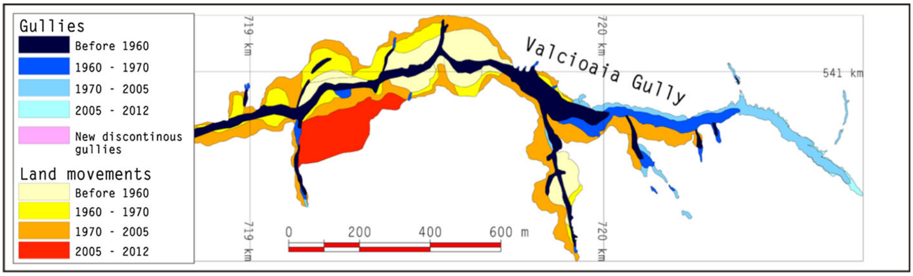

Fig. 10 Development of the gully system and triggered landslides in the Valcioaia sub-catchment

Table 3 Areal gully and active landslide growth within five sub-catchments of the Chioara basin, Falciu Hills, Moldavian Plateau of eastern Romania

No	Sub-catchment	Period	Areal gully growth		Areal growth of active landslides		Total areal growth	
			ha	%	ha	%	ha	%
1	Puriceni	Before 1960	6.532	14.75	1.422	3.56	7.954	9.45
		1961–2012	11.616	26.24	8.983	22.52	20.599	24.47
		Total	18.148	40.99	10.405	26.08	28.553	33.92
2	Tumba	Before 1960	5.811	13.12	1.491	3.74	7.302	8.67
		1961–2012	3.223	7.28	3.355	8.41	6.578	7.82
		Total	9.034	20.40	4.846	12.15	13.880	16.49
3	Valcioaia	Before 1960	6.005	13.56	4.288	10.75	10.293	12.23
		1961–2012	4.137	9.35	14.287	35.82	18.424	21.89
		Total	10.142	22.91	18.575	46.57	28.717	34.12
4	Cercuraria	Before 1960	1.755	3.96	0.655	1.64	2.410	2.86
		1961–2012	1.429	3.23	2.597	6.51	4.026	4.78
		Total	3.184	7.19	3.252	8.15	6.436	7.64
5	Valea Satului	Before 1960	2.840	6.41	1.105	2.77	3.945	4.69
		1961–2012	0.930	2.10	1.706	4.28	2.636	3.13
		Total	3.770	8.51	2.811	7.05	6.581	7.82
General		Before 1960	22.943	51.82	8.961	22.46	31.904	37.91
		1961–2012	21.335	48.18	30.928	77.54	52.263	62.09
		Total	44.278	100.00	39.889	100.00	84.167	100.00

by Tumba and Valcioaia accounting for 20–23 %, and Cercuraria and Valea Satului (7–8.5 % of the total).

Surprisingly, half of the gully areal growth occurred since 1961, although most of the gully systems exhibited higher increments before 1960. These fractions are due the gullying contribution along the right tributaries of Puriceni Valley, because 74 % of the areal growth of Puriceni trunk gully also occurred by 1960. As for the new landslides triggered by gullying, three-quarters of the total landslide area (77.5 %) occurred during the 1961–2012 period. Valcioaia sub-catchment accounts for almost half of the total and then follows Puriceni (26 %), Tumba (12 %), Valea Satului (7 %), and Cercuraria (8 % of the total). The high values in the first two catchments result from an increased clayeyer fraction within the incised substratum, especially in their middle basin.

Generally, by combining the areal growth of both gullying and landslides, it is noticeable that 62 % of the total recent land degradation (84.2 ha) occurred during the last 52 years, with the remainder pre-1960. This asymmetrical distribution reveals that usually a preparing time lag of tens of years is required for triggering landslides by gullying. The Valcioaia and Puriceni sub-catchments show equal and highest shares of 34 % each from the total land degradation, followed by Tumba (16.5 %) and Cercuraria and Valea Satului (7–8 % each of the total).

A strong linear correlation was found between mean annual areal gully growth and mean gully head retreat over the 52-year period that was broken down into five successive time spans, namely: 1961–1970, 1971–1980, 1981–1990, 1991–2000, and 2001–2012 (Fig. 11).

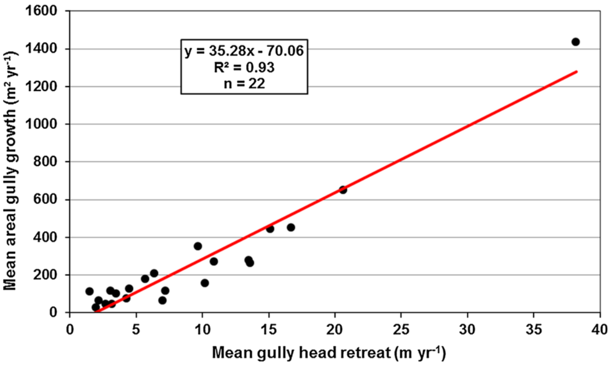

Fig. 11 Relation of mean annual areal gully growth to retreat of gully head in the Falciu Hills over the period 1961–2012

The total length of the gully systems (apart from the ephemeral gullies and many, more faintly visible, discontinuous gullies) within these five sub-catchments (2334 ha in size) is 23.60 km. The Puriceni gully system accounted for 40 % of the total length, followed by Tumba, Valcioaia (each with 18–20 %), and Cercuraria and Valea Satului with equal shares of 10–11 % of the total. Hence, mean gully density is 1.01 km km^{-2} and ranges from 0.82 km km^{-2} in Valcioaia to 1.17 km km^{-2} in Valea Satului sub-catchment. In addition, the total length of the gully network in Chioara catchment is 33.20 km from which the five sub-catchments account for 71 %. Consequently, the associated mean gully density of 1.11 km km^{-2} exceeds the mean value of 0.1–1.0 km km^{-2} estimated by Radoane et al. (1995) for the entire Moldavian Plateau of eastern Romania. If adding the ephemeral gullies network from Chioara catchment, its mean gully density would be at least double.

Previous results obtained by Ionita (2000, 2006) on the development of 13 continuous gullies located near the town of Barlad were quantified for three successive periods, i.e., (1) 1961–1970, (2) 1971–1980, and (3) 1981–1990. They indicate that gully erosion rates have decreased since 1960, but still remain at high levels. The mean gully rate advance ranged from 19.8 m year^{-1} during the 1960s and 12.6 m year^{-1} in the 1970s to 5.0 m year^{-1} during the 1980s. This gullying decline has been explained by a changing rainfall distribution, and the increased influence of soil erosion control such as contour farming, strip-cropping, and terraces progressively implemented since early 1970s.

These findings fit with data from the continuous gullies from the Falciu Hills area, even though the monitoring period is extended to a half century (1961–2012). For example, the mean gully rate retreat of three trunk gullies is 9.65 m year^{-1}, consisting of 5.6 m year^{-1} in Puriceni, 7.15 m year^{-1} in Tumba, and 16.2 m year^{-1} in Valcioaia gully. The highest rates occurred during the 1960s, namely: 16.7 m year^{-1} in Puriceni, 20.6 m year^{-1} in Tumba, and 38.2 m year^{-1} in Valcioaia. The mean annual increase in gully volume for the period 1961–2012 was 2490 m^3, corresponding to a mean of 3610 t of sediment removed from such a trunk gully annually.

Studies of gully erosion commonly consider many drainage basins, with the goal of linking various measures of gully growth rates with characteristics that govern runoff. These characteristics include catchment area (Graf 1977; Poesen et al. 2002, 2003; Vandekerckhove et al. 2003) and other factors that reflect climate, geology, and land use. Some authors have advocated that the decrease in gully growth rate results from the associated

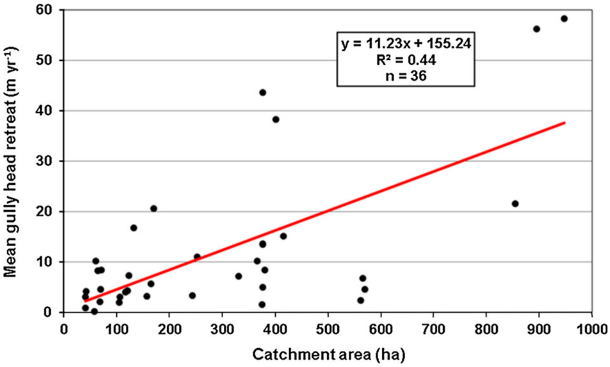

Fig. 12 Relationship between contributing catchment area and mean annual retreat of 12 gully heads over the periods 1961–1970, 1971–1980, and 1981–1990

decrease in gully catchment area and consequent runoff (Graf 1977; Nachtergaele et al. 2002). Important assumptions of these studies were that erosion rates were controlled dominantly by runoff, and that catchment area was the overriding influence on runoff magnitude.

Based on a long-term study of a valley-bottom gully in western Iowa, USA, Thomas et al. (2004) agreed with the assumption that decreasing runoff was, indeed, responsible for the decrease in growth rate with time. However, they concluded that despite correlation of growth rates to runoff "*decreasing growth rates did not result from a decrease in catchment area.*" The declining runoff that slowed growth resulted from the major change in the partitioning of runoff and base flow, namely the ratio of runoff to base flow decreased steadily in western Iowa.

Our data for the southern part of the Moldavian Plateau of eastern Romania are consistent with the study of Thomas et al. (2004). Although the correlation coefficient ($r = 0.66$) is statistically significant even for 0.01 significance level, the low value of the coefficient of determination ($R^2 = 0.44$) does not indicate a strong correlation between contributing drainage area and the mean annual gully head retreat from 12 catchments, each $\leq$1000 ha, around the town of Barlad, Vaslui County (Fig. 12). Due to gully growth, the catchment area contributing water to the trunk gully decreased by 1.5–51.0 % from 1961 to 1990 (2–254 ha). Within the Chioara catchment, that decrease varied between 10 and 33 % (18.3–52.0 ha) in the Tumba, Valcioaia, and Puriceni sub-catchments. In addition, Ionita (2000) noticed that the growth rate of the continuous gullies with wet bottom is as much as 3.4–4.5 faster than of those with dry bottom.

Under these conditions, beside precipitation distribution and soil conservation practises, several other factors influence results, but these are difficult to quantify. Nevertheless, the influences of such these factors have been slowly but surely observed during long-standing field measurements. We refer to the evolution of approaching discontinuous gullies above the trunk gully head during the process of gully fusion. These discontinuous gullies enlarge gradually to a maximum width of ~8 m (e.g., Tumba), and some of them can significantly incise the main head cut, as observed in the Puriceni 1, Puriceni 3, and Banca-Chira gullies (Fig. 13).

When the approaching discontinuous gullies develop mostly in recent alluvial/colluvial fill, they are usually 1.0–1.5 m deep and have 2–4 m^2 U-shaped cross-sectional area. Thus,

Fig. 13 Head cut of Puriceni Gully 3 is fed and significantly incised by a discontinuous gully (June 13, 2011)

the associated hydraulic radius (cross-sectional area/wetted perimeter) ranges from 0.600 to 0.700 m. As they progressively incise into the B_t horizon, their cross section turns into a V-shape and the value of hydraulic radius doubles. According to Poesen and Govers (1990) and Poesen (1993), the B_t material is as much as 3–4 times more resistant to erosion than the A and C soil horizons.

The higher the hydraulic radius is, the more efficient the channel is. That means, the higher degree in concentration of stream flow the water will have to increase velocity, unit discharge, rate of vertical erosion, and so gradient increases. The first effect of changing geometry of the approaching discontinuous gully consists in the reduction in waterfall height in the main gully head. This results in the decrease in continuous gully growth. After the incision passes through the C and D horizons, the cross section assumes a U-shape and enlarges. Now, the process of gully fusion is complete, and often it is difficult to distinguish the new location of the former main gully head scarp. For example, in May 1984, the total vertical height of Puriceni 1 gully head cut was 9.0 m, from which the head scarp height was 4.9 m and the remaining 4.1 m was depth of the approaching discontinuous gully. Eight years later, in June 1992, the depth of discontinuous gully increased to 5.4 m, its floor being this time being sculptured in C horizon material. At present, the incision evolves in the D horizon, and the former impressive gully head scarp has almost disappeared. In turn, the Puriceni 2 gully, associated with a right tributary, has developed since 1970 in a smaller catchment (46–40 ha) on the right side of its fan built upstream the junction with Puriceni 1. Its vertical gully head exceeds 11.0 m, and although it does not collect the entire volume of upstream runoff (partly it is diverted over the alluvial fan and can trigger changes in the right bank of Puriceni 1 gully), it grew slightly more than Puriceni trunk gully over 1971–2012 (Fig. 14).

The foregoing indicates that the sixfold decrease in headward retreat rate of Puriceni 1 trunk gully (16.7 m year^{-1} in 1961–1970; 2.9 m year^{-1} in 1971–2012) cannot be reasonably attributed to shrinkage of the catchment area by one-third (from 157 to 105 ha, mainly the area of Puriceni 2) over 1961–2012. Except for the larger annual precipitation depth during 1961–1970 (582 mm year^{-1} at Barlad), at that period, we assume the approaching discontinuous gully developed in the alluvial fill blanket, and the head scarp of the Puriceni 1 gully head was 7.5–8.0 m. Then, a threshold interferes with the deepening

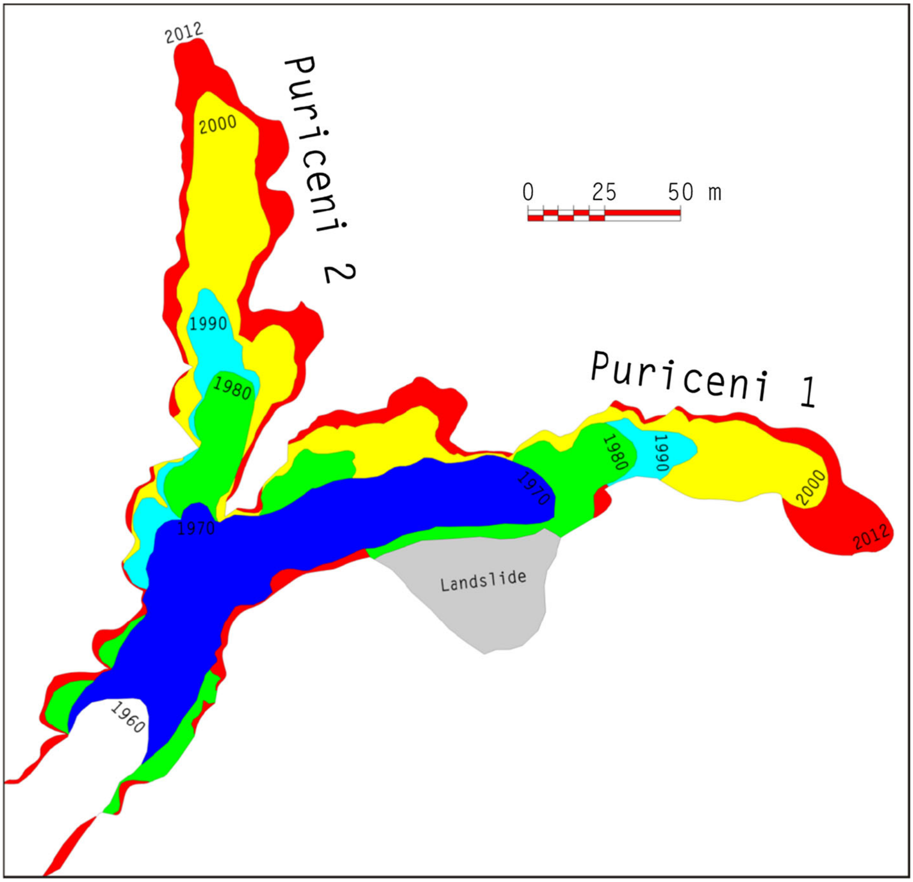

Fig. 14 Development of the Puriceni gully system between 1961 and 2012, assessed using aerial photographs and successive topographic levelling

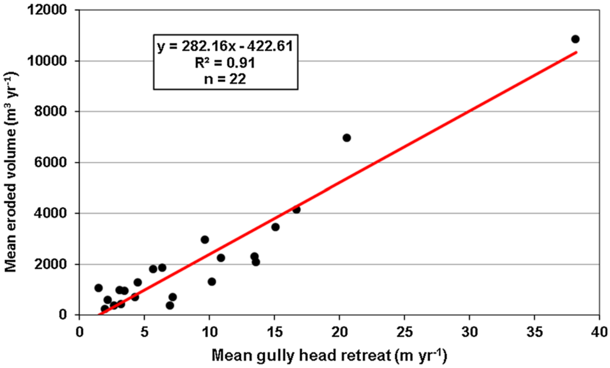

Fig. 15 Relation of mean annual eroded volume to retreat of gully head in the Falciu Hills over the decadal time span between 1961 and 2012

along the end reach of the discontinuous gully, and the decrease in the head scarp height (and thus the potential energy) of the main gully head has begun. The increased trenching of that reach may presumably be due to a geomorphic factor, specifically the changes in longitudinal slope with time. However, it still remains unclear what is the controlling factor responsible for that threshold.

A strong linearity has been estimated between the mean annual retreat of gully head and mean annual eroded volume by gullying in the Falciu Hills over the following five successive decadal time spans: 1961–1970, 1971–1980, 1981–1990, 1991–2000, and 2001–2012 (Fig. 15). Another similar linear relationship was found between annual sediment yield (SY) and mean annual retreat of gully head for the same 52-year period, 1961–2012, respectively:

$$\mathrm{SY} = 409.13x - 612.86 \quad R^2 = 0.91 \quad n = 22$$

Based on 65 gully cross sections levelled since 1981 around the town of Barlad, it was possible to test the validity of the linear relationship between gully width and gully cross section (Fig. 16). The high value of the coefficient of determination ($R^2 = 0.91$) allows us to use this relationship to calculate cross sections of gully reaches when only the gully perimeter was surveyed.

Despite a decreasing catchment area and tendency of gullying over the last half century, gully erosion still remains problematically high and hence the main question, what are the driving factors? Two of them will be further emphasized in our case study, namely the aggradation of valley floors and changes in land management.

The topsoil along the valley bottom consists of a very recent alluvial blanket, usually 2–3 m deep, but in places can attain $\leq$4.0 m (Fig. 17). This process of aggradation along the non-gullied valley bottoms has been significantly connected to severe soil erosion when land was converted to arable use after deforestation. Later, trenching of the valley floor, initially by discontinuous gullies, has been followed by gully fusion and an impressive net of continuous gullies developed. The accelerated aggradation of valley floors resulted in rises in the local elevation, increases in the potential energy of the head cut and, thus, promoting further gully erosion.

The Cesium-137 technique can be effectively used in these areas of deposition of former gully sediments to provide chronological measures of gully development (Ionita and

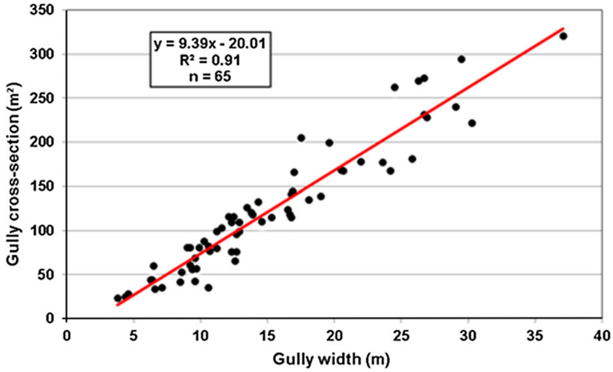

Fig. 16 Relation between gully cross section and gully width in the southern part of the Moldavian Plateau, eastern Romania

Fig. 17 Relevant alluvial blanket ≤370 cm thick mostly in the former fan of Puriceni 2 (April 21, 2012)

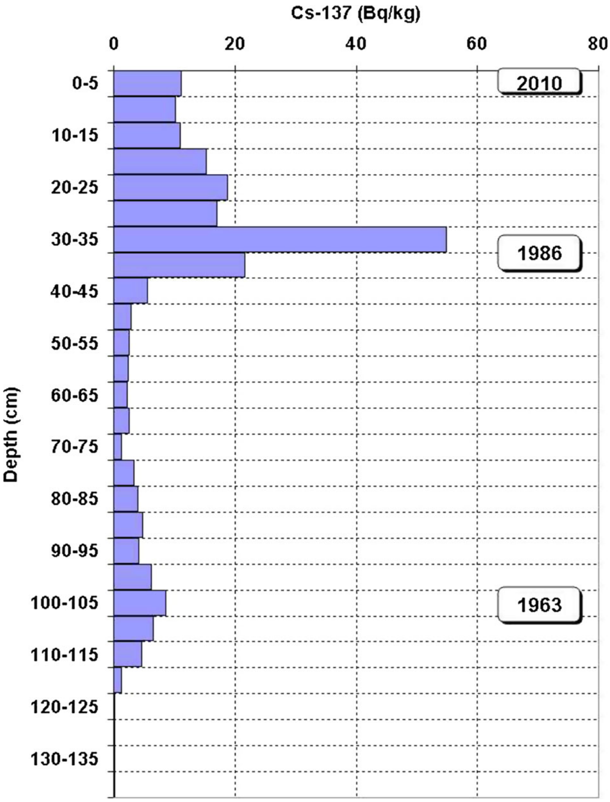

Fig. 18 Cesium-137 distribution in the fan head of Puriceni 2 Gully (July 09, 2010)

Margineanu 2000). The depth distribution of ^{137}Cesium in the alluvial blanket along the right bank of the Puriceni 1 gully, upstream of the junction with Puriceni 2 gully, exhibits two peaks (Fig. 18).

The first one, located at 35–40 cm depth, is derived from the Chernobyl accident in late April 1986, and the second one at 105 cm depth is associated with the radioactive fallout resulting from nuclear bomb testing during 1963. Consequently, the mean sedimentation rate varied from 1.67 cm year^{-1} over 1986–2010 to 2.83 cm year^{-1} between 1963 and 1986. The higher sedimentation rate from the last period is as much as 1.7 times larger than that from the 1986–2010 period and reflects the more intense land degradation in the study area in the 1960s. If the mean sedimentation rate of 2.23 cm year^{-1} for the 47-year period (1963–2010) could be considered relatively constant, then the age of the alluvial blanket of 340 cm is 150 years at the profile site. That means the sedimentation threshold in the upper Puriceni sub-catchment is connected with the aftermaths of the Land Reform of 1864. A similar mean sedimentation rate during the last half century was calculated for the depth profile of ^{137}Cesium compiled in the alluvial blanket of the Valcioaia valley bottom around the gully head area.

Considering the most important milestones in modern Romanian history (Treaty of Adrianople of 1828–1829 and Land Reforms of 1864 and 1921), the breakdown of the forest in the Falciu Hills area was quite similar to the pattern in the Tutova Rolling Hills, where the extent of forest sharply decreased from 47 % during the early nineteenth century to 22 % in 1893 and 19 % of the total area in 1970 (Poghirc 1972). Based on the 1893 topographic map of Moldavia at scale 1:20,000 and the aerial flight of 2009, it was possible to assess the evolution of native forest in Chioara catchment. Data from Table 4 show that at the end of the nineteenth century, forest accounted for 27.5 % of the total and decreased to 12.5 % in 2009 if the black locust (*Robinia pseudoacacia*) plantations, established during the 1970s and 1980s, are included. Since the Falciu Hills area enjoyed larger private properties, some of them >1000 ha, we suppose that the forest covered ~55–60 % of the study area at the start of the nineteenth century.

On the other hand, there are differences between the studied sub-catchments associated with demographic developments. There have been reported some traces of human habitation dating back millennia (Gherghe and Rotaru 2002; Apostol and Gherghe 2012). However, most of the initial documentary evidence of present-day settlements dates from during the fifteenth and sixteenth centuries, and these were recorded as dispersed hamlets. It was estimated that in the mid-eighteenth century, each of those small villages usually comprised up to 20 dwellings and a small number of inhabitants, usually ca. 100 persons. A sharp population increase occurred during the nineteenth century. According to the 1885 Census, there were 620 and 720 inhabitants in the Ghermanesti and Stoisesti villages, respectively. The population peak of 1020–1100 persons was registered around 1960 and a decline to 511–604 at present time (Poghirc 1972; Muntele 1998; Gherghe and Rotaru 2002; Apostol and Gherghe 2012).

The native vegetation cover was differentially but significantly changed. More precisely, until the nineteenth century, it was a period of quiescence and progressive but slowly clearing was practiced, mostly for livestock grazing. The sharp increase in population coupled with other particular socioeconomic factors favored rapid and drastic changes in land use during one century (1830–1930). Currently, deforestation has been focused on the conversion of forestland especially to cropland that gradually turned into small up-and-down hill plots. Concomitantly, the vast majority of local earth roads have been laid out along valley floors or across hills. Despite temporary implementation of conservation practises over 1970–1990, inappropriate land management has continued to the present.

By the end of the nineteenth century, the most important changes occurred in the lower Chioara catchment (designated above as other areas) and Tumba sub-catchment, where

Table 4 Evolution of the forest area in the Chioara catchment, Falciu Hills, Moldavian Plateau of eastern Romania over the period 1893–2009

No	Catchment	Year	Forest area			
			ha		% of total	
1	Puriceni	1893	269.52			**31.08**
		2009	195.37	142.34 (F)	16.41	**22.52**
				53.03 (BL)	6.11	
2	Tumba	1893	62.20			**13.29**
		2009	24.41	3.12 (F)	0.66	**5.20**
				21.29 (BL)	4.54	
3	Valcioaia	1893	256.69			**42.92**
		2009	44.50	23.15 (F)	3.87	**7.44**
				21.35 (BL)	3.57	
4	Cercuraria	1893	149.21			**80.20**
		2009	47.74	47.74 (F)	25.66	**25.66**
				– (BL)	–	
5	Valea Satului	1893	66.88			**31.10**
		2009	27.96	27.96 (F)	13.00	**13.00**
				– (BL)	–	
6	Other areas	1893	21.32			**3.21**
		2009	35.32	– (F)	–	**5.32**
				35.32 (BL)	5.32	
Chioara		**1893**	**825.89**			**27.55**
		2009	**375.25**	244.31 (F)	8.15	**12.52**
				130.98 (BL)	4.37	

F forest, *BL* black locust (*Robinia pseudoacacia*)

forest cover accounted for only 5 and 13 % of the total, respectively. In turn, due to the lower demographic stress, 80 % of the Cercuraria (Fundatura) and 43 % of Valcioaia sub-catchments were under forest. The Puriceni and Valea Satului sub-catchments follow in between with 31 % forest cover. At present, the forestland covers 5 % in Tumba, 7 % in Valcioaia, 13 % in Valea Satului, 22 % in Puriceni, and 26 % of the total in Cercuraria sub-catchments.

The topographic map at scale 1:20,000 of Moldavia depicts the presence of three trunk valley-bottom gullies in 1893 along the lower Chioara and Ghermanesti reach (3381 m in length as the major gully), lower Puriceni, and lower Valcioaia. Evidence of probable continuous gullies appears along Tumba and Valea Satului, but because of Stoiesesti and Ghermanesti villages, it is not possible to establish the gully head position. In addition, some more discontinuous gullies, both valley bottom and valley sides, have been noted in the study area.

Based on the foregoing, we assume that the initiation of the main trunk gullies was as follows: Puriceni Gully during early the nineteenth century, particularly after the Treaty of Adrianople of 1829; Valcioaia gully since the second half of the nineteenth century, especially after the Land Reform of 1864; and Cercuraria since the early twentieth century after the Land Reform of 1921. By combining the primary natural factors (substratum lithology, climate, duplex soils) and the tremendous impact of the land-use changes, it is possible to explain the exceptionally high erosion rates over the last two centuries within the Falciu Hills. For example, the estimated/calculated mean gully head retreat rate along valley bottoms varies as follows from north to south:

- 13.6 m year^{-1} in the Puriceni trunk gully over 180-year period, divided into 16.8 (1832–1893), 17.0 (1893–1960), and 5.6 m year^{-1} (1961–2012);
- 9.6 m year^{-1} in the Tumba gully for 72-year period, calculated as: 16.0 (1941–1960, based on local information and air photos) and 7.15 m year^{-1} (1961–2012);
- 17.6 m year^{-1} in the Valcioaia gully over 149-year period, calculated as: 11.7 (1864–1893), 21.3 (1893–1960), and 16.2 m year^{-1} (1961–2012);
- 13.8 m year^{-1} in the Cercuraria (Fundatura) gully for the 85-year period, calculated as: 15.2 (1921–1960) and 12.5 m year^{-1} (1961–2005, that is, before bifurcation). Although its drainage area is as much as five times smaller than Puriceni, the double value of average slope is likely to be responsible for the similar mean value of 13.8 m year^{-1} of gully head retreat.

The average gully head retreat along the main continuous gullies was estimated at 14 m year^{-1} during the nineteenth century, then increased to 17 m year^{-1} between 1893/1921/1940–1960, and decreased to 10 m year^{-1} over 1961–2012. That means, the gullying peak occurred during the first half of the twentieth century. Overall, it would result in an impressive average of 14 m year^{-1} of gully head retreat rate in the valley bottoms within the study area over the last two centuries.

As to the discontinuous gullies from the Barlad Plateau, results have indicated a slow erosion rate, namely the mean gully head advance was 0.92 m year^{-1} ranging from 0.42 to 1.83 m year^{-1}, and the mean areal gully growth was 17.0 m^2 year^{-1} varying between 3.2 and 34.3 m^2 year^{-1} (Ionita 2000, 2003).

More specifically, the soil losses from gully erosion only are exceptionally high. Specific sediment yield by gullying accounted for 54–69 % of the soil loss by water erosion from the above four sub-catchments over long periods of time (Table 5). These values are almost similar with those reported by Trimble in South California and Casali et al. in Spain as cited by Poesen et al. (2003). The mean annual soil erosion is 15–16 t ha^{-1} year^{-1} in the areas under severely eroded forest soils (Ionita 2007). These gully systems were indeed initiated by human activities in the catchments of the Barlad Plateau and represent one of the most important case scenarios of human impact on soil erosion in Europe (Vanmaercke 2013).

The estimated amount of soil and parent material removed from the gullies in the entire Chioara catchment is 8.3×10^6 t. Gullies from the five studied sub-catchments account for

Table 5 Sediment yield in the Chioara catchment, Falciu Hills, Moldavian Plateau of eastern Romania

No	Sub-catchment	Period (years)	Sediment yield (SY) by gullying		Specific SY by water erosion (t ha^{-1} year^{-1})	Weight of SY by gullying (%)
			(t year^{-1})	(t ha^{-1} year^{-1})		
1	Puriceni	1893–2012	8924	25.2	40.2	62.7
2	Tumba	1941–2012	5275	23.2	38.2	60.7
3	Valcioaia	1893–2012	10,184	17.6	32.6	54.0
4	Cercuraria	1921–2012	6723	36.1	52.1	69.3

two-thirds of the total sediment mass, namely: a quarter in Puriceni, which is followed by Tumba and Valcioaia (13–16 % each) and Valea Satului and Cercuraria with the lowest equal shares of 5–7 %.

Ionita (2000, 2006, 2008) reported very high sediment concentrations in stream flow during snowmelt, and this scenario is very similar for some heavy rainfalls or intense successive rainfalls. During such extreme events, high rates of soil and gully erosion have been recorded. The sediment concentration curve had a pulse shape, usually between 100 and 300 g L^{-1}, but there was no evident debris-free period. This is not consistent with the study of Piest et al. (1975), who measured sediment transport from the Treynor–Iowa gullies during severe storms. They found debris-free periods ("break") in gully sediment discharges that provide evidence of the cleanout of the gully channel and rapid decreasing sediment transport from the gully, despite sustained runoff and high stream power. Going further, Thomas et al. (2004) assumed that bedload transport was negligible in the studied gully in western Iowa. Figure 19 illustrates significant bedload transport (mud balls), triggered by a heavy rainfall of $\sim$45 mm in less than an hour, occurred on July 11, 2014 in the Ghermanesti reach upstream of a dam structure built in 1984. During some flash floods associated with such events, the peak flow discharge can reach up to 90–110 $m^3\ s^{-1}$ at the Chioara outlet.

Conceptually, the derived main stages of gully development over the last two centuries in the Chioara basin of the Falciu Hills are as follows:

- Aggradation of valley bottoms associated with severe soil erosion in those areas, where after deforestation the land was converted to arable use, generally as up-and-down hill farming (i.e., Puriceni, Valcioaia, Tumba valleys). Concomitantly, most of the local earth roads have been constructed along the valley floors.
- Discontinuous gully initiation by trenching on the localized steeper sections of alluvial fill along the non-gullied valley bottoms, as discussed by Schumm and Hadley (1957).
- Integration (coalescence) of the discontinuous gullies initiated at the basin outlet into a continuous gully (Schumm and Hadley 1957; Heede 1974).
- Further and faster upstream development of the new continuous gully at a rate that is seemingly a power law function of drainage area. Gully extension is accompanied and

Fig. 19 Significant bedload transport and channel aggradation in the Chioara catchment, Falciu Hills (July 13, 2014). Note the "mud balls" $\leq$75 cm in diameter in the foreground

accelerated by valley-floor aggradation upstream, which raises local elevation and increases the potential energy of the head cut.

- Continuation of the process of gully fusion, especially along the main valley bottom, and time lag migration of the continuous gully on tributary valleys (i.e., Puriceni sub-catchment) by attempting to keep pace with the lowering of the main trunk.
- Maintaining the discontinuous gullies mostly in the headwater part of each sub-catchment.
- Headward extension of the old continuous gullies (e.g., Lower Chioara and Ghermanesti reaches) and their integration with the younger gullies.
- Alluvial infilling along initial reaches of some continuous gullies and valley-floor aggradation, as in the lower sub-catchment of Puriceni and Tumba, due to high amounts of upstream sediment yield.
- Change in the initial shape of some gully cross sections by channel deepening and widening, mainly associated with homoclinal shifting that triggered new landslides.

4 Conclusions

The studied main gullied systems from a 2997-ha catchment consist of both discontinuous and continuous gullies. The headwater part of each system includes several discontinuous gullies, but the continuous ones are very typical and impressive along the valley bottoms. In addition, the role of gully erosion in triggering landslides has been considered. The aerial flight of 1960 has been used as a base reference, and two periods have been distinguished (until 1960 and 1961–2012) for assessing land degradation characteristics.

Total gully area in the Chioara catchment is 66.4 ha excepting for the ephemeral gullies, and gullies from the five study sub-catchments (2334 ha) account for two-thirds. Total length of the gully network in the entire catchment is 33.20 km, from which the five sub-catchments account for 71 %. Here, half of the gully areal growth and three-quarters of the new landslide area occurred over the 1961–2012 period.

Delayed collapse of forest cover, if compared with Central Europe, peaking during 1830–1930 and land conversion to mostly arable use, in the shape of up-and-down hill farming, resulted in severe soil erosion on slopes, high aggradation along the non-gullied valley bottoms, and severe gullying. By combining the primary natural factors (substratum lithology, climate, duplex soils) and the tremendous impact of the land-use changes, it is possible to explain the exceptionally high erosion rates over the last two centuries within the Falciu Hills. Assessing long-term gully head retreat in four trunk continuous gullies indicates a very high average value of 14 m year^{-1}, peaking at 17 m year^{-1} during 1893/1941–1960 and decreasing to 10 m year^{-1} over 1961–2012. Despite decreasing gullying and catchment area over the last half century, gullying still remains problematically high.

Useful relations of mean annual areal gully growth and mean annual sediment yield to mean retreat of gully head have been found. Furthermore, it was possible to test the validity of the linear relationship between gully width and gully cross section. Although the correlation coefficient ($r = 0.66$) is statistically significant even for 0.01 significance level, the low value of the coefficient of determination ($R^2 = 0.44$) does not indicate a strong correlation between contributing drainage area and mean annual retreat of gully head within 12 catchments, each not exceeding 1000 ha, around the town of Barlad, Romania. Besides the above-mentioned controlling factors, the high rate of aggradation

(2.23 cm year^{-1} for the period 1963–2010) along the valley floor of the non-gullied valley bottoms, connected with the aftermath of Land Reform of 1864, and the ratio of depth of approaching discontinuous gully to head scarp height of the main gully head are also responsible for the development of continuous gullies with time.

About 8.3×10^6 t of sediment was removed from the main gully systems within Chioara catchment, and gullies from the five studied sub-catchments account for two-thirds of the total sediment mass. The sediment yield by gullying accounted for 54–69 % of the sediment mass eroded by water during the last 72–119 years (1893/1941–2012).

Very high sediment concentrations of stream flow occur during snowmelt and some heavy rainfalls or intense successive rainfalls, when its curve had a pulse shape, usually between 100 and 300 g L^{-1}, but there was no evidence of a debris-free period, as reported in western Iowa.

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