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Land Degradation and Soil Conservation Measures in the Moldavian Plateau, Eastern Romania: A Case Study from the Racova Catchment

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Abstract: Land degradation by soil erosion, gullying and landslides and reservoir sedimentation is a major environmental threat in the Moldavian Plateau of eastern Romania. The widespread development of these processes in the last two centuries was favored mainly by traditional agriculture focused on 'up-and-down slope' farming on small plots. However, soil conservation measures were actively undertaken between 1970 and 1989. More recent legislation (No. 18/1991 Agricultural Real Estate Act) includes two provisions that discourage maintaining and extending soil conservation practices. Hence, the former contour farming system has been abandoned in favor of the traditional, inadequate farming methods. Thus, this paper reviews the impact of land degradation and soil conservation measures in a representative 32,908 ha catchment located in the Central Moldavian Plateau. Based on field measurements, the results show that the estimated mean long-term (1973–2017) sedimentation rate reaches 4.7 cm y^{-1} in the Puscasi Reservoir at the catchment outlet, resulting in an associated sediment delivery ratio of 0.28. The initial area of the Puscasi Reservoir at normal retention level has decreased by 32% and the water storage capacity has decreased by 39%. Consequently, land degradation remains a serious problem in the study area and effective soil conservation is urgently needed.

Keywords: soil erosion; gully erosion; landslides; conservation practices; reservoir sedimentation

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1. Introduction

Land degradation by soil erosion, gully erosion and mass movements is an important environmental threat throughout the world and poses major challenges to soil conservation measures. Over recent decades, significant progress has been made in understanding land degradation, its controlling factors and associated processes.

Soil erosion has been investigated in connection with its evolution over time, from past [1] to present [2] and even future scenarios [3]. The research scale varies largely, from planetary [4] to continental [5], regional [6], national [7] or local scales [8]. A lot of papers focus on quantitative assessment, using direct field measurements related to specific events [9], field plots [10] or modelling using GIS techniques [11]. Most frequently, research papers focus on specific issues regarding control factors such as climate change, land use, ecosystem pattern, [12,13] or the effects of erosion control measures [14–16]. Furthermore, a lot of research works developed in former communist countries from central-eastern Europe proves a direct impact of agriculture land use change and demographic change on sediment source and delivery over the last three post-communist decades [17–20].

Nevertheless, previous studies have focused on soil erosion in larger areas within the Moldavian Plateau, providing insufficient information at the smaller catchment scale. Many publications discuss environmental characteristics [21,22], whereas others focused on specific issues. Based on various sources, Motoc [23] estimated total erosion on agricultural lands in Romania, and suggested rates were especially high on the Barlad Plateau, with an average value of 20–30 t ha^{-1} y^{-1}.

In a similar way, investigations of gully erosion include identifying magnitude (distribution and density) at different scales all over the world [24–27], controlling factors [28–31], estimating some rates of gullying [32–34], applying modern GIS techniques and statistical models [35–37], and gully control practices [38–40].

Two main areas of gullying were distinguished in the Moldavian Plateau [41,42]. In order to obtain a clear overview of the development of continuous gullies, 13 gullies were first sampled near the town of Barlad. Linear gully head advance, areal gully growth and sediment quantities were measured for three timeframes (1961–70, 1971–80 and 1981–90). The results indicate that gully erosion rates have decreased since 1960, due to changes in rainfall distribution patterns and the increased influence of soil conservation measures [43–45]. The mean denudation rate by landslides was estimated at 36.0 mm yr1 between 1968–1992 within the Barlad Plateau [46,47]. The large extent of landslides within three catchments (Upper Barlad upstream of Bacesti, Sacovat and Crasna) on the Central Moldavian Plateau was emphasized by Ionita et al. [48].

Reservoir sedimentation is a serious problem worldwide, with studies focusing on the specific sedimentation rates in small reservoirs [49], sedimentation rates and factors at different research scales [50,51], or the mitigation measures to be implemented [52]. Referring to the central and southern Moldavian Plateau, Ionita et al. [53] conducted a preliminary study using the caesium-137 (137Cs) technique to estimate sedimentation rates at two sites on the floor of the Puscasi and Pungesti-Garceana reservoirs. The 137Cs technique was also effectively used in areas of recent deposition of gully sediments, to provide chronological measures of gully development around the town of Barlad [54,55].

About three-quarters of degraded agricultural land on the Moldavian Plateau were adequately treated during the short-lived period (1970–1989) of proper soil conservation measures. Then, the traditional 'up-and-down slope' farming under small plots became prevalent again. In this context, the aim of the present study is to present both the current state of land degradation and soil conservation and their impact on the reservoir sedimentation in the representative Racova Catchment in the Central Moldavian Plateau of eastern Romania.

2. Study Area

Extending over ~27,000 km^2, the Moldavian Plateau (MP) is the broadest and most typical plateau in Romania. Generally, it appears as an aggregate of plateaus, hills and rolling hills (collines) whose surface altitudes decrease towards the south–southeast.

The major units of the MP are the Suceava Plateau (SP), the Jijia Rolling Plain (JRP) in the northern part, and the Barlad Plateau (BP) and Covurlui High Plain (CHP) in the central–southern area. The BP is the most extensive high unit of the MP and covers > 8000 km^2. The plateau comprises three major subunits: the Central Moldavian Plateau (CMP) in the north, the Tutova Rolling Hills (TRH) west of the Barlad Valley, and the Falciu Hills (FH) east of the Barlad Valley.

The Racova Catchment is located in the southern frame of the CMP at the border with the TRH (Figure 1). The Racova Catchment covers 32,908 ha, is 49 km long and is orientated in a west–east direction.

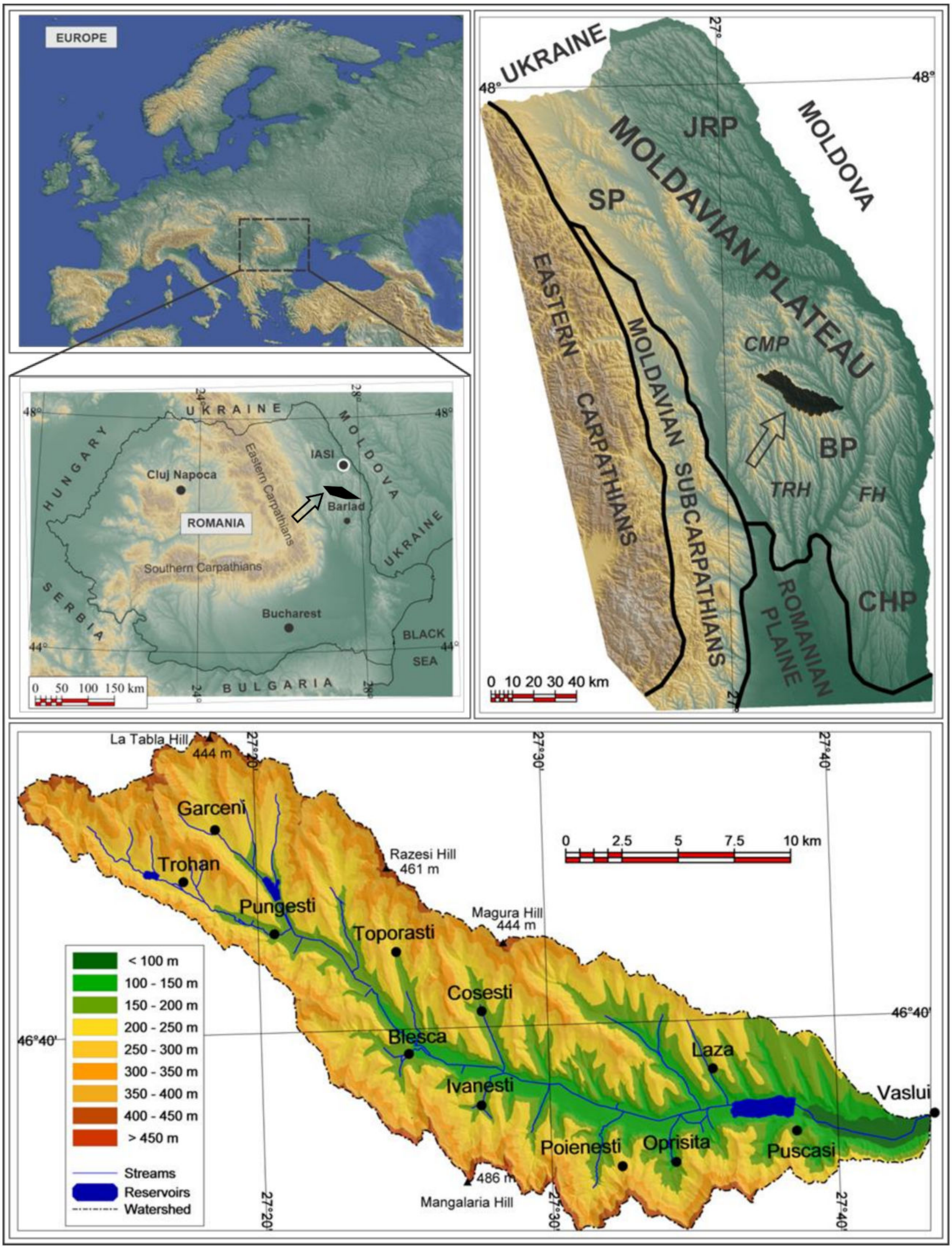

Figure 1. Location of the study area.

The Racova Catchment is made of clay-sandy and sandy-clay formations, almost exclusively deposited in deltaic facies. The sedimentary strata lie in a general homocline structure, with a gentle dip of 7–8 m km^{-1} towards the southeast [56,57].

The local relief is typically hilly, with altitudes varying from 485.5 m a.s.l. on the Mangalaria Hill in the southern watershed and 89 m a.s.l. on the Barlad floodplain.

Overall, the Racova valley shows a cross asymmetry. Generally, the left side of the Racova catchment covers 61% of the catchment, representing a broad cuesta back-slope. On the other side, the remaining 39% of the area represents a large north-facing cuesta.

The overall mean slope of the Racova Catchment is estimated to be 18.7%, which indicates that the study area has a high erosion potential (Figure 2) in most of the catchment (78.3%) [58].

Figure 2. Middle Racova catchment as seen next to an outcrop in lower Maeotian layers at 350 m on Poienesti Hill, towards Magura Hill (444 m) in the background.

The continental temperate climate is characterized by a mean annual temperature varying between 7.5 °C and 9.9 °C. The mean annual precipitation for the period 1963–2015 varied between 533 mm at 105 m a.s.l and ~700 mm in the area > 400 m a.s.l. Usually, two thirds of precipitation fall during the warm season, reaching a monthly maximum in June, with typical totals of 79–88 mm.

Bio-pedo-geographically, the higher areas are covered with deciduous forest. The sylvo-steppe is advancing in low areas. Accordingly, the zonal soils in the higher districts are Luvisols. Lower areas are predominantly Phaeozems and Chernozems. A large proportion of slopes is mantled by less productive soils such as Erodosols and Regosols, depending on the stage of land degradation processes.

Agricultural land covers 68% of the catchment area (Table A1). Some 35.4% is arable and 26% is pasture. The proportion of non-agricultural land is 32%, of which woodland covers 26.6%. This region was severely deforested during the 18th and especially the 19th century [59,60]. The area under the native forest in the Racova Catchment comprises only 17.8% of the area and has remained fairly constant since the late 19th Century. At present, woodland also includes the afforestation (silvic plantations) area, on 5.2% of the catchment area (1704 ha).

3. Methods

Several methods were deployed to estimate soil erosion losses, gully distribution, landslide inventory and reservoir sedimentation rates. Firstly, a digital elevation model (DEM) was created by digitizing the national 1:5000 topographic maps using TNT Mips version 7.1 software. The Revised Universal Soil Loss Equation (RUSLE) [61,62] based on the Universal Soil Loss Equation (USLE) was used to estimate long-term average annual soil loss from the Racova Catchment. The six factors [63,64], as adapted for Romanian conditions [65,66], are represented by: rainfall erosivity (R), soil erodibility (K), slope length & steepness (L&S), crop cover and management factors (C), and conservation practices (P).

Information for present-day land use was abstracted from the 2009 aerial orthophotos and 1:5000 topographic maps. These sources, together with the 2012 LiDAR images, have been successfully used to draw gully outlines and especially land covered by landslides. Useful information about land use and the gully network at the end of the 19th Century was drawn from both the topographic map of Moldavia (scale 1:20,000) and the 1894 Atlas of Moldavia (scale 1:50,000).

Levelling (topographic) surveys, using a Leica 407 TCR and GPS South 82V-Trimble, were conducted to obtain information about the behavior of the check-dams constructed during the early 1970s along gullies within the Ivanesti sub-catchment. The GPS South 82V-Trimble was used to obtain 2081 points on the former submerged floor of the Puscasi Reservoir, including the extensive but temporarily emerged area during spring 2017. Six bathymetrical cross-sections and a longitudinal profile were surveyed using the Midas Valeport Eco-sounder, type Bathy-500DF, in the permanently submerged area. A very detailed topographic map, consisting of a grid of 749 points covering the floor of the future Puscasi Reservoir, was completed in December 1969 by ISPIF (Institute for Land Treatments Studies and Designs), Bucharest [67]. We used the map to calculate the thickness and volume of deposited sediment in the reservoir over a 44-year period. A mean bulk density of 1.45 t m^{-3} has been frequently used in the study area to convert volumes to sediment yield (SY) and sediment delivery ratio (SDR) at the catchment outlet.

The 137Cs technique was used along gully floors in the Ivanesti sub-catchment to estimate the impact of soil conservation measures (check dams and afforestation). Gamma spectroscopy, associated with the Canberra MCA S100 system equipped with a Ge (Li) detector, was used to determine 137Cs concentrations in sediments. Soil surveys at a 1:10,000 scale were retrieved from OSPA Vaslui (Office for Pedological and Agrochemical Surveys) to distinguish the main soil classes and types [68]. Data processing was performed using Microsoft Office 2010 and particular attention was given to 'ground truthing' cartographic information.

In brief, the flowchart of the methodology starts from 1) the inventory of soil conservation measures carried out 44 years ago in a representative catchment located in the Central Moldavian Plateau and continues with 2) the assessment of their current state, being completed with 3) the analysis of the anti-erosional effect over time. By comparing the sedimentation volume within the Puscasi reservoir with the total gross erosion estimated for the entire tributary catchment, we try to demonstrate that land degradation remains a serious problem in the study area and extra soil conservation measures are urgently needed.

4. Results and Discussion

4.1. Land Degradation

Land degradation has been recognized as the major cause of environmental degradation worldwide [69,70] and, in particular, in the MP of eastern Romania. This area is highly susceptible to soil erosion [71], gullying [72] and landslides [73], which damage the local landscape by depleting soil resources and decreasing agricultural productivity.

4.1.1. Erosion

Soils in the study area are highly eroded (Figure 3A,B). A map of soil losses from agricultural land, with five erosion classes, was created by using the RUSLE as adapted to Romanian conditions (Figure 3C). The classes between 7–25 t ha^{-1} y^{-1} contributed an estimated 46% of the total, and one-third of soil loss was assigned to classes > 25 t ha^{-1} y^{-1}. The mean estimated soil loss by water erosion (rill and inter-rill) on agricultural land was 21.6 t ha^{-1} y^{-1} and this area delivered an estimated 455 103 t y^{-1}. Adjusting for the sediment contribution from woodlands, the mean specific sediment yield (SSY) decreased to 15.6 t ha^{-1} y^{-1}. Finally, by adding gully erosion input, the SSY mean was 22.7 t ha^{-1} y^{-1} at the catchment scale. Therefore, rill and inter-rill erosion from agricultural land accounted for an estimated 61 or 69% of gross erosion and therefore supplies most sediment.

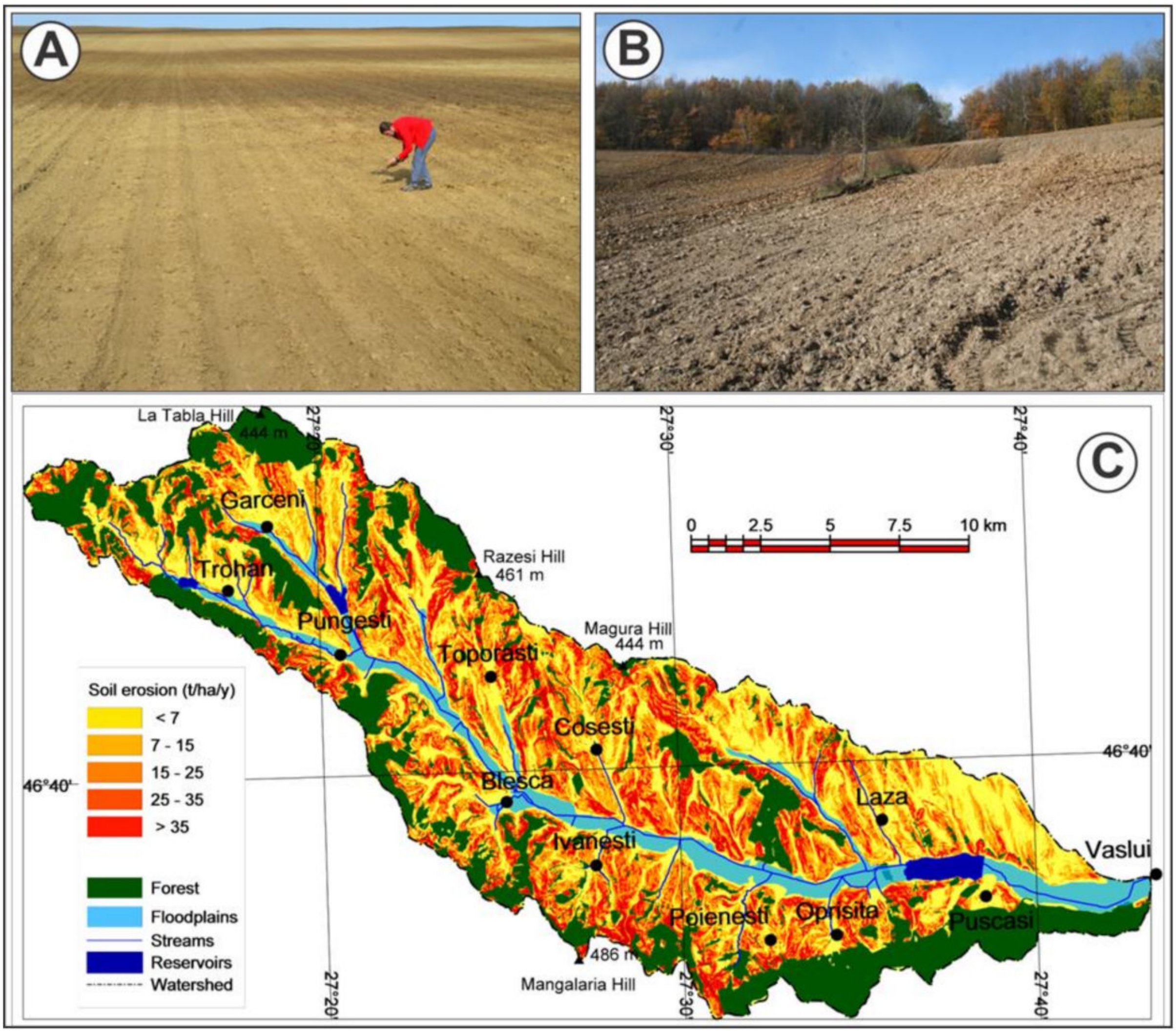

Figure 3. Excessive soil erosion under cambic Chernozems in the left side of Harsova valley on 4 April 2016 (**A**), severe erosion under Luvisols from upper Racovitza on 20 October 2013 (**B**), and map of annual soil losses on agricultural land in the Racova Catchment (**C**).

Gully erosion was much more limited on the CMP, due to more erosion-resistant substrata and forest cover, compared with other subunits on the BP. In the Racova Catchment, the present total gully length was 367 km, distributed in the tributary sub-catchments, and thus, gully density was 1.12 km km^{-2} (Figure 4A,B). These values are double those of the late 19th Century. However, at that time, the heads of the main gullies were located close to the watershed and today they enter as historical gullies [74,75]. That means former road gullies developed very rapidly after deforestation (Figure 4C). Although the area covered by gullies is small (2.7% of the total, 871 ha), they play important roles both in the triggering or reactivation of landslides and sediment detachment and transport. Using the relationships established by Ionita [44,45], based on medium-term field monitoring of some representative gullies on the BP, the SSY associated with gullying in the Racova Catchment was estimated at 7.1 t ha^{-1}y^{-1} and accounted for (31.2) 31% of the sediment mass eroded by water. This relative contribution was half that of the Falciu Hills (FH), where gullies have incised and developed in a blanket of loess and loamy sands [55].

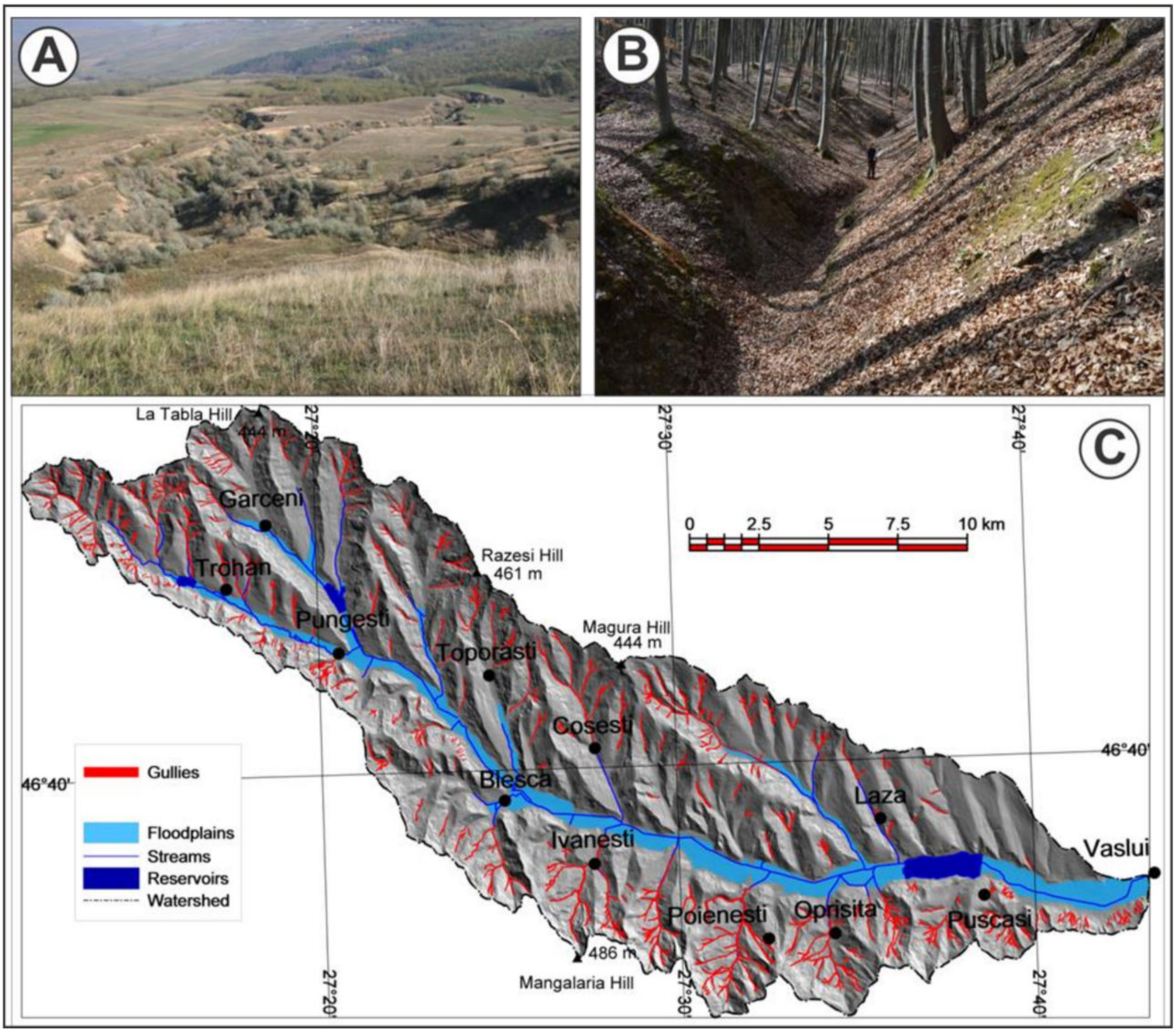

Figure 4. Continuous gullies incised in the upper Poienesti sub-catchment on 20 October 2013 (**A**), new discontinuous incisions in an old V-shaped gully from Oprisita forest on 4 April 2016 (**B**), and map of gully distribution in the Racova Catchment (**C**).

4.1.2. Landslides

Landslides are of particular concern on the Central Moldavian Plateau (CMP), both in terms of damage and affected areas. Despite the valuable research on landslides, there is a need to assess both their spatial distribution and the very recent temporal development of landslides (Figure 5A,B). The landslide inventory and map (Figure 5C) shows that landslides were highly variable in size, age, shape and form, and occurred on a total 56.2% (18,510.4 ha) of the catchment area. This was the highest identified proportion in the entire Moldavian Plateau (MP).

Based on sustained field campaigns, our landslide inventory shows that most landslides were stable (dormant) and the active ones formed only ~3% of the total landslide area (TLA), which is a representative value for the CMP. However, after the rainier 1973–1986 period, active landslides occupied 21.4% of the TLA [47]. The decline in landslide activity resulted from a decreasing tendency in precipitation totals since 1982. Most new landslides occurred by local reactivation of areas that had previously experienced landslide activity. Our conclusions are in accordance with those obtained by Pujină [47] based on field measurements or by Mărgărint et. al. [73] using modern GIS techniques.

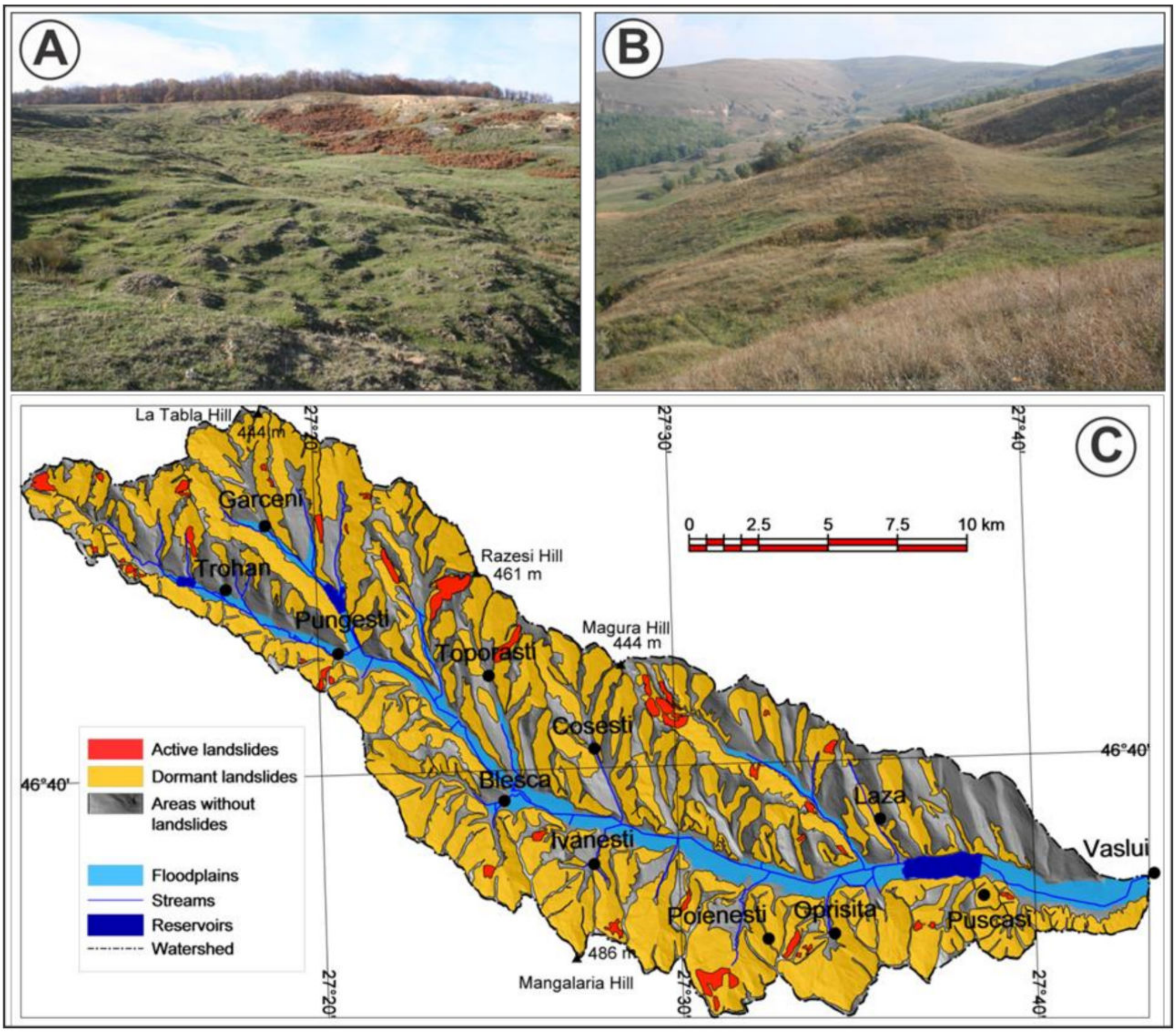

Figure 5. Reactivation of old landslides after deforestation in the upper catchment of the Racova upstream of Slobozia on 20 October 2013 (**A**), ample Canepa landslide amphitheatre (hartop), underlain mainly by Maeotian layers in the second step of the Racova cuesta front on 20 October 2013 (**B**), and landslide inventory map from the Racova Catchment, Moldavian Plateau, Romania (**C**).

The Landslide-Hypsometry Index (LHI) (i.e., the ratio of landslide area (LA) to total catchment area (CA) on hypsometric classes) showed a slightly asymmetrical distribution. The LHI peak value of 0.73 was typical of the 300–400 m contour interval. By cross-checking the landslide map with the slope map, it was evident that the three main slope classes (5–18, 18–27 and > 27%) amounted to one-third each of the LA. This finding underlines the even distribution of slope values within both sides of the Racova Catchment. Three-quarters of landslides developed on cuesta fronts with the remainder occurring on degraded cuesta back-slopes, especially in the upper sub-catchments. The deep-seated landslides were more frequently initiated in the Kersonian strata, because of weaknesses caused by the inter-bedding of sand and clay. These were one of the most characteristic landslide types, that is landslide amphitheatres, locally called "hartoape."

4.2. Evolution of Soil Conservation Measures

By 1960, the traditional agricultural system on the hills of the MP consisted of 'up-and-down-slope' farming, with ~90% of agricultural land divided into small (< 1 ha) plots. Except in local areas, there was no concern about soil erosion and little awareness of conservation practices. After 1960, these areas were turned into co-operative farms. The remaining larger plots (~10% of the area) were transferred from farmers to State farms.

After several decades of quiescence, many new, innovative research studies on soil erosion control were initiated [66,76]. The first priority consisted of implementing one or more conservation practices, starting with contour ploughing. By late 1989, 75% (0.9 × 106 ha) of agricultural land at risk of erosion on the MP was adequately treated with conservation measures.

The new legislation (No. 18/1991 of the Agricultural Real Estate Act) includes two provisions that discourage soil conservation measures [55,77]. One of these stipulates that land reallocation must conform to the old locations; that is, plots must be orientated up-and-down slopes. The second refers to the successors' land rights, which apply up to the fourth degree of kinship. Under these circumstances, land division increased and is now higher than before World War II. The major effect of the new law is the revival of the traditional agricultural system of 'up-and-down slope' farming. Another problem over recent decades is that the State ceased funding soil conservation, and investment in soil conservation has low priority among landowners.

Land changes within the Racova Catchment mirrored the general changes within the entire MP. During the 20-year period (1970–1989), much soil conservation work was accomplished, especially by IEELIF Vaslui (Enterprise for Performing and Exploiting the Land Improvement Works) [78], namely:

- The design and construction of dams and reservoirs, such as Puscasi in 1973 (lake area 257 ha at normal retention level/NRL) and Trohan in 1982 (21 ha at NRL) on the Racova floodplain, and Pungesti-Garceni on the Garceneanca floodplain in 1976 (61 ha at NRL).
- Design and construction of check-dams to control gully erosion in the tributaries of the River Racova.
- Design and implementation of soil conservation practices on slopes in large farms, namely: strip-cropping, buffer strip cropping and especially bench terraces.
- Design and building of drainage systems.
- Filling small gullies, land reshaping using topsoil, and improving pastures.
- Large-scale afforestation on 1704 ha on landslides and gullies, especially using black locust (Robinia pseudoacacia) and populus. Some 1001 ha of the afforested area were established by the Vaslui Silvic Enterprise and 703 ha by IEELIF Vaslui.

After implementing the provisions of Act No. 18/1991, the former short-lived contour farming system almost disappeared and the 'up-and-down slope' farming under small plots is prevalent again. The case of the 956 ha Ivanesti sub-catchment, located on the main Racova cuesta, illustrates this surprising evolution. Accordingly, a combination of contour strip cropping systems and bench terraces were implemented on 130.2 ha of arable land, especially northwest of the Ivanesti village. Here, on a field of 49.1 ha with an average slope of 13.6%, six 663–1024 m long bench terraces, spaced at 80–145 m intervals, were combined with six strip crops, each covering 4.3–11.5 ha (Figure 6).

Currently, the same field comprises 135 small individual plots, most of them orientated up-and-down slopes. About half of them are between two former bench terraces and their mean area is 0.37 ha. Others cross two, three, or four former strip crops and cover 0.6–1.6 ha each. Only nine plots are still on the contour, and these occupy 0.5–4.1 ha. Similar examples can be readily identified throughout the Racova Catchment (Figure 7A–F). Being one of the most important agricultural areas of Romania, during the 1990s and the first part of the 2000s, the Moldavian Plateau was characterized by the repopulation of rural areas, in the context of the collapse of the communist urban industry. This led to an increased pressure on agricultural land [79], having consequences in the further fragmentation of the agricultural land as well as in the continuous land degradation by erosion. In this part of Romania, compared to other central-eastern European regions [51], the most important land use changes related to the depopulation of rural areas and abandonment of agricultural land appear only in the second half of the 2000s, especially after 2007, the year of Romania's accession to the EU.

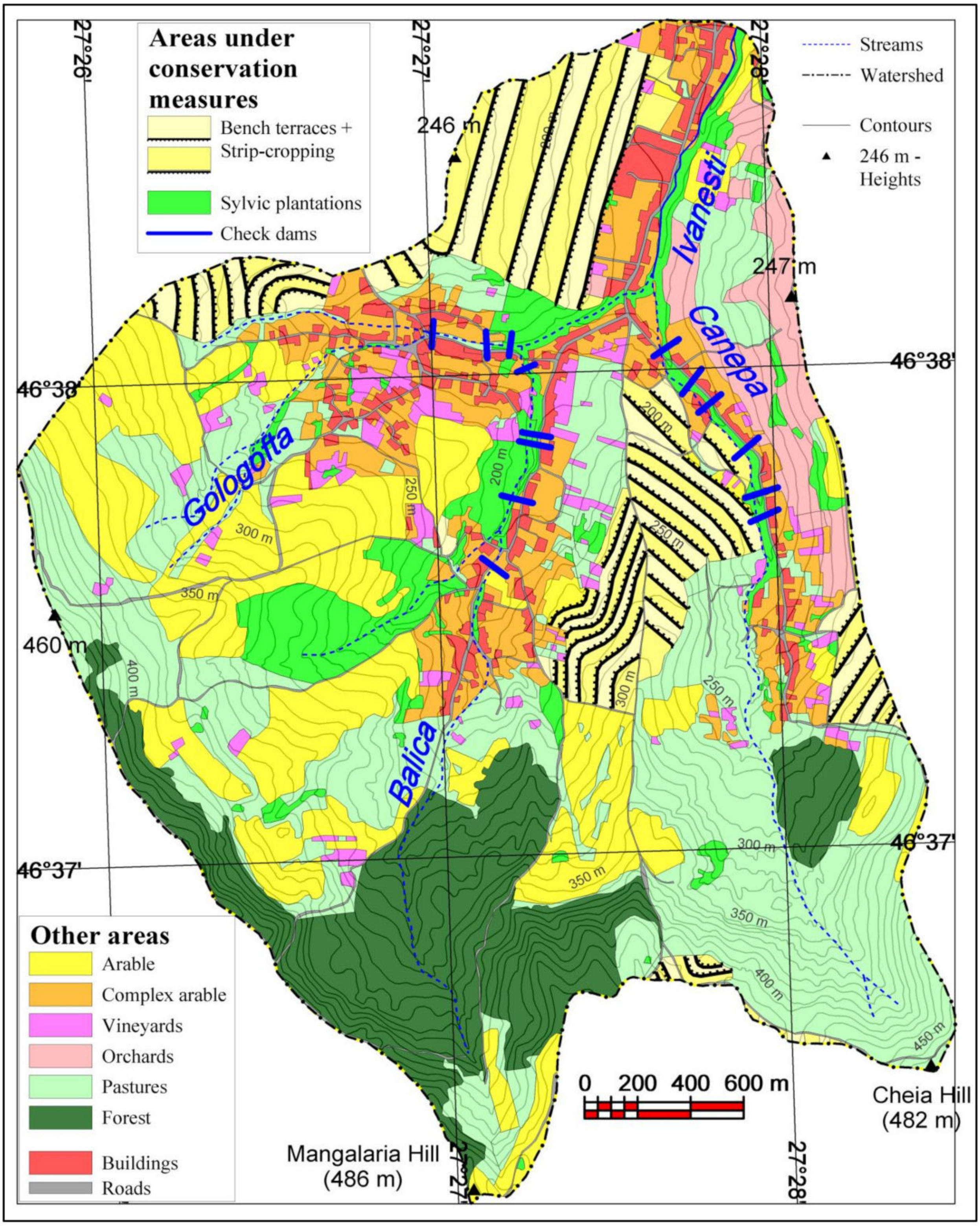

Figure 6. Map of the current land use & land cover in the Ivanesti sub-catchment. Among the conservation measures implemented during 1970–1989, those presented on the map are still functional.

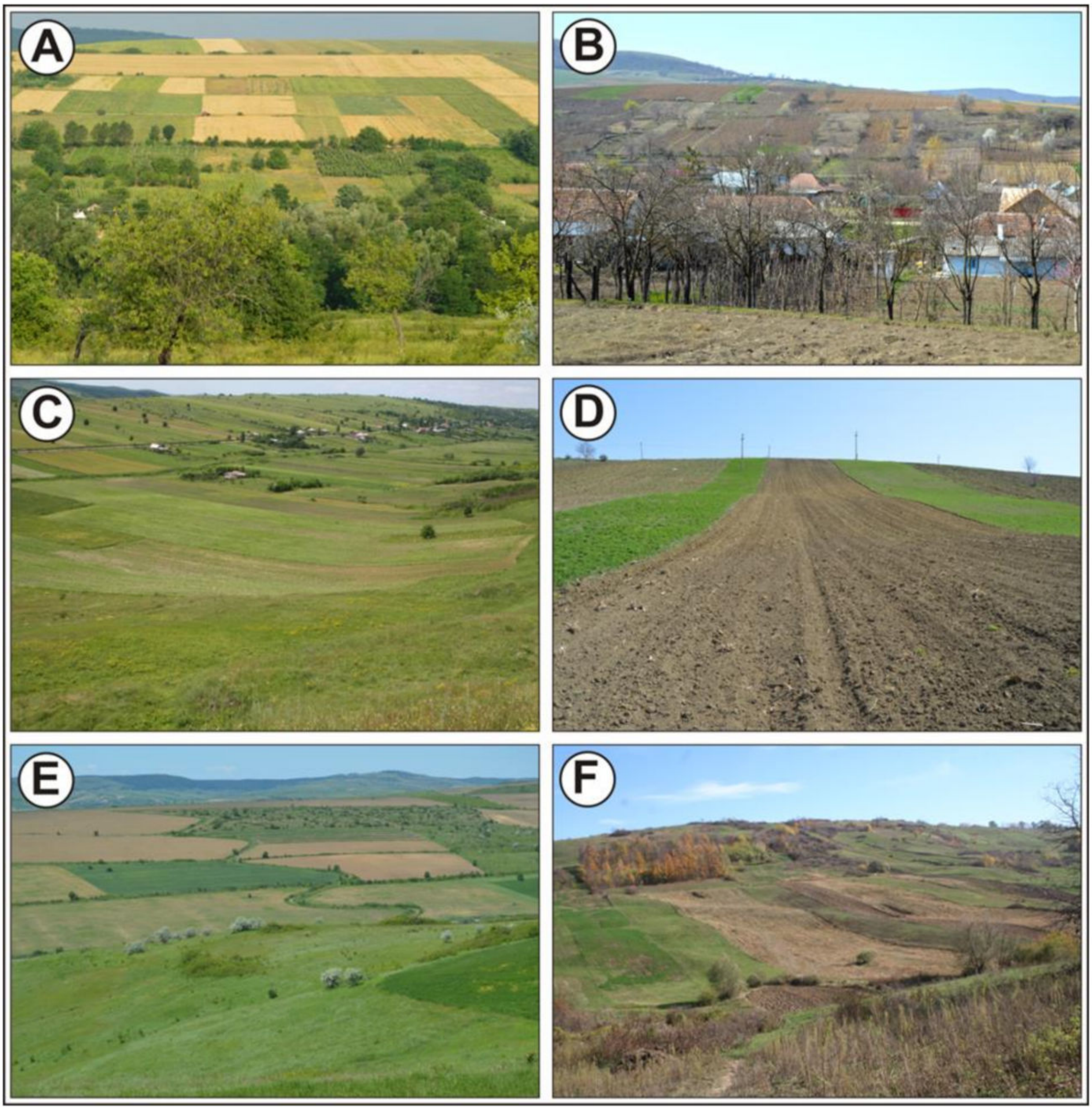

Figure 7. Shifting from contour conservation practices to up-and-down hill farming under small plots: (**A**) in the left side of the Ivanesti valley on 21 June 2017, (**B**) in the left side of the Oprisita valley on 4 April 2016, (**C**) in the middle Toporasti sub-catcment on 8 June 2016, (**D**) in the right side of the Poienesti valley on 4 April 2016, (**E**) in the Cosesti valley with remnants of former conservation practices on the right side (east looking cuesta back-slope) on 29 May 2017, and (**F**) in the left side (west facing cuesta front) of the Racovitza valley on 20 October 2013.

In 1974, 14 check-dams (CDs) were constructed along valley bottom gullies, namely: six in the Canepa gully, five in the Balica gully and three in the Gologofta gully. They were set apart on reaches with similar original slopes of 3.0–3.2% but with various lengths, namely: 805 m in the Canepa, 811 m in the Balica and 310 m in the Gologofta gully. The bottom width (b) of their trapezoidal spillway varied between 2.8–6.6 m and the vertical drop (the difference between spillway crest and stilling basin/energy dissipator) ranged from 1.2–4.2 m (Table A2). Simultaneously, afforestation on 15.1% of the total area (144.3 ha) has been deployed along the gully network and especially in areas with landslides.

Under these conditions, most streams are no longer competent to scour the bed or to undermine gully walls. The backwater effect of check-dams and the progressive impact of vegetation cover on stream flow decreased flow velocity and accelerate sediment deposition on the gully floor. In these cases, reducing bed gradient and the creation of trapezoidal cross-sections resulted in major changes in gully morphology (Figure 8).

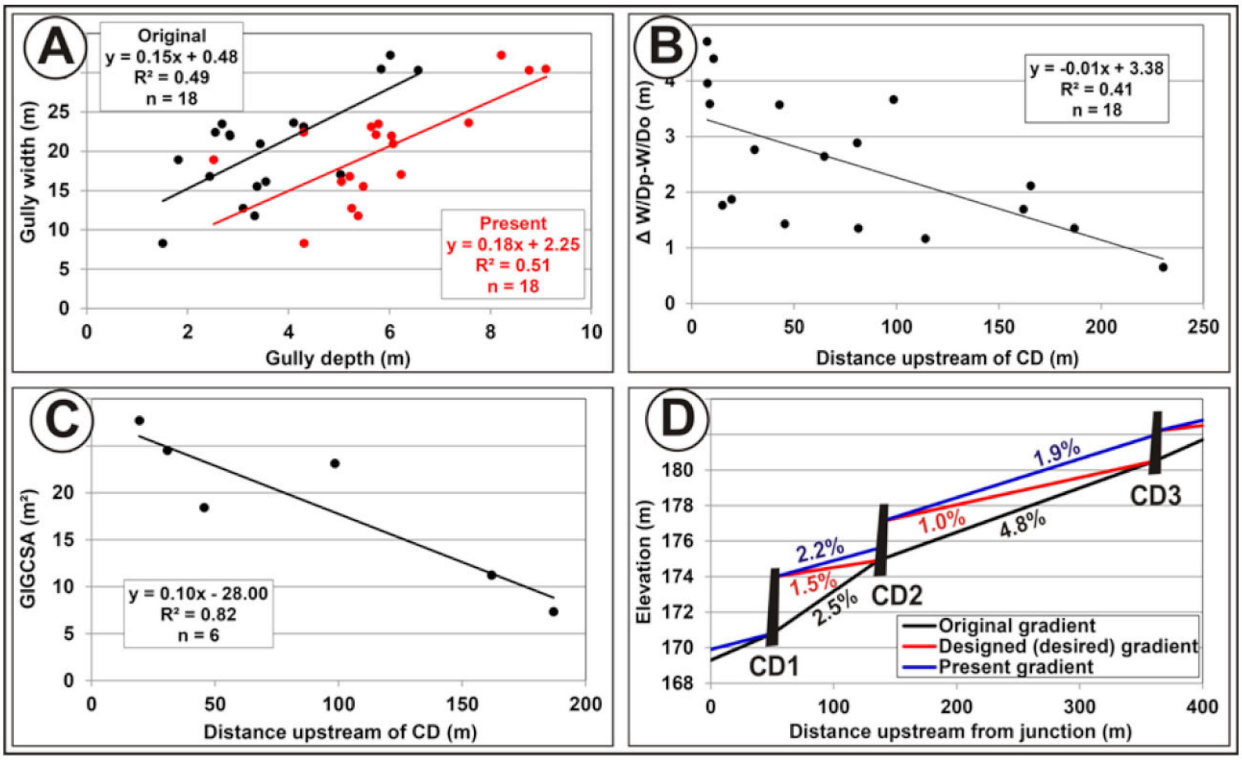

Figure 8. Changes in gully morphology after implementing conservation measures: (**A**) relationship between GD and GW at present and in 1974, (**B**) relationship of the difference between present and original W/D ratios versus the distance upstream of check dams, (**C**) rate of gully infilling expressed by growth of the infilled gully cross section area (GIGCSA) to distance upstream of check dams (CDs) in the Gologofta gully, (**D**) longitudinal profile along a reach of 361 m from the Gologofta gully, upstream of the junction with the Balica gully.

Overall, gully depth decreased by 0.7–3.5 m and gully bottom width increased between 3.1–11.1 m relative to the original (restored) situation in 1974. Based on values abstracted from 18 gully cross-sections in the Ivanesti sub-catchment, it was possible to identify strong associations between gully depth and gully width for time periods, underlining the present-day lower values of gully depth (Figure 8A). Consequently, the lower width/depth (W/D) ratios, between 1.93–7.50 for the original situation, versus the higher values ranging from 3.39–10.39 at present, exemplifies gully infilling over 42 years (1974–2016). Figure 8B illustrates the strong correlation (r = 0.64, $p < 0.01$, $n = 18$) of the difference between the present and original W/D ratios versus the distance upstream of CDs (Table A3). The difference between the original and present-day gully cross-section areas, ranging from 1.1–33.0 m^2, emphasizes the growth of the infilled gully cross-section area. Figure 8C shows the trend of decreasing gully infilling with distance upstream of CDs in the Gologofta gully. This gully was particularly suitable for survey, as it had a uniform and symmetric cross-section, in which the gully banks were not disturbed by landslides and the cross-section was largely intact. Figure 8D summarizes changes of the original, design (desired) and present-day gradients in the same reach in the Gologofta gully.

Eleven CDs had a blanket of sediment in their stilling basins (SBs) that ranges from 0.5–1.8 m depth (Figure 9A). The recommended design (desired) gradient in accordance with the particle-size distribution (PSD) was 0.5% for fine sediment (clay, silt) and 1.0% for middle and coarse sand [77]. However, the sandy PSD within the Ivanesti sub-catchment, along with the mature vegetation cover, can maintain higher gradients, usually of 1.8–2.4%.

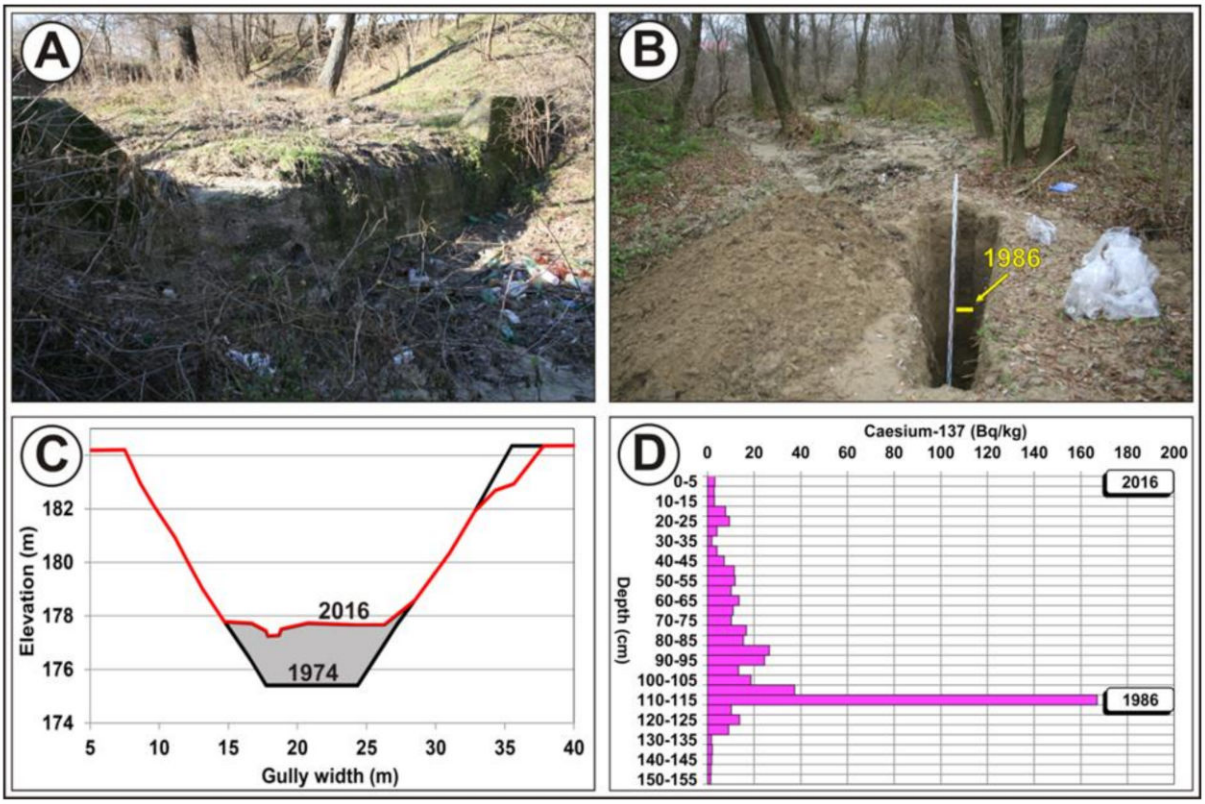

Figure 9. Gully infilling with recent alluvia after implementing conservation measures, (**A**) check dam no. 2 from the Gologofta gully on Nov. 29, 2016 (spillway bottom width = 6.6 m; vertical drop = 2.2 m from which 0.7 m is under sediments on stilling basin), (**B**) aggradation on the Balica gully floor mainly induced by afforestation on 23 November 2016, (**C**) cross section of the the Balica gully at the site of sediment profile, (**D**) depth distribution of 137Cs in the alluvia deposited on the Balica gully floor.

As a general conclusion related to the efficiency of these CDs, based on field measurements, all the data prove that the distance between those CDs was underestimated and their number overestimated. The SBs of two CDs were clean; consequently, those CDs were appropriately spaced. However, the SB of one CD was destroyed by stream scouring. The efficiency of these works is proven, but it could be obtained with a lower investment consisting of a smaller number of dams.

The progressively combined influence of conservation measures on sedimentation rates is emphasized by the depth distribution of 137Cs along the bottom of the Balica gully. Figure 9B,C shows the gully cross-section and the site of a 235 cm deep alluvial profile located 114 m upstream of CD1. The upper 220 cm consisted of recent sediments accumulated after 1974 as a result of the construction of the CD. The 137C peak value of 167 Bq kg^{-1}, associated with the Chernobil accident of April 1986, occurred at 110–115 cm (Figure 9D). This indicates a mean sedimentation rate of 3.8 cm y^{-1} over a drier 30-year timespan (1986–2016). That rate was double between 1963 (peak year of nuclear weapons tests) and 1986, due to more precipitation [53,55]. Therefore, almost the entire column of sediment in the gully bottom was deposited after implementing conservation measures, especially during the early 1970s. Thus, the mean sedimentation rate over 42 years (1974–2016) was estimated to be 5.2 cm y^{-1}.

4.3. Reservoir Sedimentation

Reservoir sedimentation data provides complementary information for evaluations of land degradation. As already mentioned, three dams were built in the study area, namely: Puscasi in the lower Racova Catchment, Pungesti-Garceni on the Garceneanca floodplain and Trohan in the upper Racova Catchment. They became operational in 1973, 1976, and 1982, respectively.

The Puscasi Reservoir is the most important and its initial area at the normal retention level (NRL) of 257 ha has decreased by 32.3% to its current area of 174 ha, while the water storage capacity has decreased by 38.6%, from 9.33 106 m^3 to 5.73 106 m^3. An accurate map of recent sediment deposition on the reservoir floor was created based on field measurements, using GPS (Figure 10). Deposition was assessed in eight classes and sediment thickness was uneven and adopted a deltaic shape.

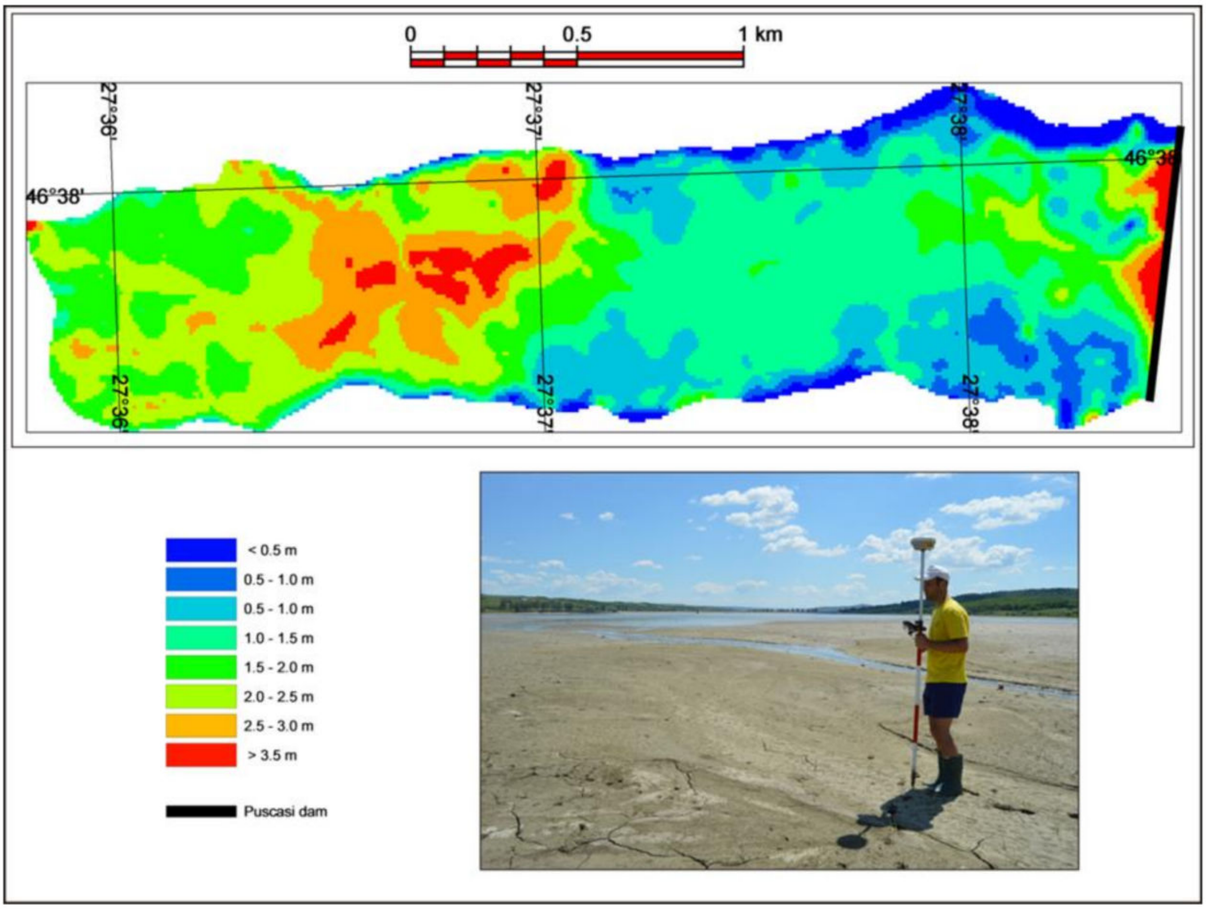

Figure 10. Map of sediment thickness within the Puscasi reservoir from the lower Racova catchment, Moldavian Plateau, Romania.

The mean sediment thickness (STH) deposited in the Puscasi Reservoir was 206 cm and the mean sedimentation rate was 4.7 cm y^{-1}. STH was greater in the upper-half of the reservoir and varied from 1.5–3.90 m, with a peak sedimentation rate of 9 cm y^{-1} over 44 years. A 137Cs profile in the area of high sedimentation showed a peak sedimentation rate of 11.5 cm y^{-1} during 1986–1998 [49]. The area exceeding 2.5 m STH highlighted the alluvial fan of the Racova River, which is the main contributor to siltation in the Puscasi Reservoir. However, the lateral input of close tributaries must be considered, since sediment discharge from upstream tributaries (such as the Tulbure, Ivanesti and Oprisita from the Racova cuesta front) also represents a major sediment source. An exception is the low alluvia input from densely forested sub-catchments, such as the Chelaru located upstream of the right shoulder of the dam, where forest covers 61% of the sub-catchment area.

The estimated volume of sediment within the Puscasi Reservoir was 5.3 × 10^6 m^3, which represents a SY of 7.7 × 10^6 t. Estimated gross erosion (GE) of 24.8 t $ha^{-1}y^{-1}$ was associated with the 25,056 ha catchment area (without 5461 ha of the Pungesti-Garceni and Trohan reservoir catchment areas). Over 44 years, this totaled 27.3 10^6 t, and thus, the estimated SDR was 0.28. Trapping efficiency was assumed to be 100%, since the proportion of river sediment load captured by dams approaches this value in large reservoirs [80].

The smaller reservoirs (Pungesti-Garceni and Trohan) showed an even distribution of deposited sediment, as they are temporarily drained every 2–3 years to facilitate fish harvesting. Here, the mean sedimentation rate was ~2.7 cm y^{-1}, as a consequence of the smaller catchment areas (3363 and 2098 ha, respectively) and the higher proportion of forest (32 and 44%, respectively).

5. Conclusions

The novelty of the current study resides in the application of an innovative and complex methodology using different field sampling and measurement methods applied in the field. Among others, the map of sediment thickness, the estimated volume of sediment within the Puscasi reservoir, as well as the estimated SDR of 0.28 are regarded as important issues in the present research. Other specific issues are:

(1) The 32,098 ha Racova Catchment on the Moldavian Plateau of eastern Romania is highly susceptible to land degradation, due to both natural conditions and human impacts.
(2) The mean value of soil losses by water erosion (rill and inter-rill) on agricultural land was estimated to be 21.6 t $ha^{-1}y^{-1}$. By adding the woodland contribution, this value decreased to 15.6 t $ha^{-1}y^{-1}$ and accounted for 68.7% of gross (total) erosion. The specific sediment yield by gully erosion was estimated at 7.1 t $ha^{-1}y^{-1}$ and averaged (31.2) 31.3% of the sediment mass eroded by water.
(3) The estimated mean long-term (1973–2017) sedimentation rate reached 4.7 cm y^{-1} in the Puscasi Reservoir at the catchment outlet and the estimated associated sediment delivery ratio (SDR) was 0.28. The initial area of the Puscasi Reservoir at normal retention level (NRL) had decreased by 32% and the water storage capacity had decreased by 39% over 44 years.
(4) Despite proper conservation measures that were designed and applied over a 20-year time-span from 1970–1990, after implementing the provisions of Act No. 18/1991, the contour farming system collapsed and returned to the traditional 'up-and-down slope' farming system on very small plots.

Furthermore, it is recommended that we intensify efforts to raise the awareness of citizens regarding the impact of land degradation and the societal importance of soil conservation. Farmers also need to revise their land use strategies, by focusing on better farming, improving pastures, and extending afforestation.

The need to conserve topsoil for future generations might be considered sufficient reason to justify establishing a Soil Conservation District covering the Racova Catchment. The recommended policy is that landowners and farmers must comply with soil control regulations provided by the District Commissioner. The Conservation District should be administered by a small board of directors, appointed by the County Council for five-year terms. The Board members should be local freeholders, residents of the Racova Catchment, and appointed on the basis of qualifications, without regard to political affiliation.

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Appendix A

Table A1. Land use in the Racova Catchment as abstracted from the 2009 aerial orthophotos.

Categories	Sub-Categories	Area	
		ha	% of Total
Arable	Total	13,203.95	40.13
	Proper arable	11,648.58	35.40
	Complex arable	1555.37	4.73
Pastures		8588.98	26.10
Vineyards		556.85	1.69
Orchards		47.33	0.14
Total agricultural land		22,397.11	68.06
Woodland	Total	7431.56	22.58
	Forest	*5727.98*	*17.40*
	Silvic plantations	*1703.58*	*5.18*
Bushes & thorn bushes		1181.91	3.59
Water land	Lakes	270.91	0.82
Roads		319.68	0.97
Land with buildings	Total	821.03	2.49
	Yards. buildings	*713.65*	*2.17*
	Buildings & industrial yards	*105.80*	*0.32*
	Dams	*1.58*	*0.003*
Wasteland		485.80	1.48
Total non-agricultural land		105,10.89	31.94
General total		32,908.00	100.00

Table A2. Check dams from the Ivanesti sub-catchment, Moldavian Plateau, Romania.

			Trapezoidal Spillway				Obs.
Gully	**Check Dam (CD)**	**Location Upstream of Junction with (UJW) or Upstream of Check Dam (UCD)**	**B (m)**	**b (m)**	**H (m)**	**Useful Height (Hu) as the Difference between Spillway Crest and Stilling Basin (m)**	**Sediment Thickness on Stilling Basin (SB) (m)**
Canepa	CD1	295.4 m UJW Ivanesti	5.7	3.2	1.1	4.2	1.8
	CD2	182.5 m UCD1	6.6	3.8	1.2	2.2	1.3
	CD3	100.1 m UCD2	6.8	4.1	1.0	2.0	1
	CD4	241.6 m UCD3	7.8	4.8	1.55	2.95	1
	CD5	193.0 m UCD4	5.95	4.8	0.5	1.2	0.95
	CD6	88.1 m UCD5	6.5	4.0	1.2	3.2	1.1
Balica	CD1	89.0 m UJW Gologofta	8	5.5	1.2	3.5	0.5
	CD2	277.3 m UCD1	4.0	3.2	0.75	2.1	0.7
	CD3	21.2 m UCD2	6.1	4.2	1.2	1.5	Destroyed SB
	CD4	228.9 m UCD3	5.45	2.8	1.0	2.8	SB without baffle piers
	CD5	283.8 m UCD4	5.4	3.0	1.1	2.7	1.30
Gologofta	CD1	50.4 m UJW Balica	5.90	2.95	1.3	3.2	Clean SB
	CD2	85.5 m UCD1	8.65	6.62	1.0	2.2	0.7
	CD3	225 m UCD2	6.72	4.25	1.0	1.7	1.5

Table A3. Some parameters of 18 gully cross-sections from the Ivanesti sub-catchment, Moldavian Plateau, Romania.

Gully	**Cross-Section No.**	**Location Upstream of Check Dam (UCD)**	**Ratio between the Present and Original Depth (Dp/Do)**	**Difference between the Present and Original W/D Ratios (Wp/Dp—Wo/Do)**	**Ratio between the Present and Original Area of Cross-Section (CSp/CSo)**
Gologofta	1	187 m UCD 2	0.62	1.35	0.80
	2	162 m UCD 2	0.59	1.69	0.71
	3	98.6 m UCD 2	0.47	3.66	0.59
	4	30.8 m UCD 2	0.57	2.76	0.70
	5	45.6 m UCD 3	0.73	1.43	0.88
	6	19.4 m UCD 3	0.64	1.87	0.80
Balica	1	80.7 m UCD 1	0.72	2.88	0.77
	2	7.6 m UCD 1	0.49	3.96	0.63
	3	7.5 m UCD 2	0.46	4.71	0.63
	4	114.0 m UCD 5	0.75	1.16	0.86
Canepa	1	8.8 m UCD 1	0.35	3.58	0.58
	2	42.9 m UCD 2	0.59	3.57	0.75
	3	10.6 m UCD 3	0.47	4.40	0.58
	4	230.4 m UCD 4	0.81	0.65	0.92
	5	15.0 m UCD 4	0.62	1.76	0.81
	6	81.3 m UCD 5	0.70	1.35	0.86
	7	165.6 m UCD 6	0.76	2.11	0.98
	8	64.8 m UCD 6	0.54	2.64	0.68

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