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Use of the 3-D scanner in mapping and monitoring the dynamic degradation of soils. Case study of the Cucuteni-Baiceni Gully on the Moldavian Plateau (Romania).

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Abstract

The 3-D Scanner, a rapid and precise means of monitoring the dynamics of erosive processes, was used, first of all nationally (Romania), as a new technique of cartography and monitoring the dynamics of soil degradation processes in the Moldavian Plateau. Three sets of measurements took place: in 2008, in 2009 and in 2010, at intervals of exactly one year for the first and six months for the second part. Qualitative and quantitative differences were highlighted. The data obtained were corroborated with precipitation in the area studied. The 3-D scanner has a measurement accuracy of 6 mm. The map highlights the dynamics of gullies developed and may form the basis for the prediction of soil degradation phenomena. The dynamics of the gully and the type of land use show that the phenomenon of erosion of the Moldova Plateau will continue to accelerate. In this case the gully attacked and destroyed an archaeological site of national importance. The rate of advance of the Cucuteni-Baiceni gully is extremely high (10 m/1.6 yr). There are no measures at all to reduce or fight the process of the gully advance. Maximum erosion occurred at the beginning of spring after a winter rich in rainfall, which made the terrain subject to the process of subsidence.

1 Introduction

To analyze the morphological and dynamic geomorphological slope process, a variety of modern methods have been used so far. They have not, however, been used frequently, and have not been very accurate. In most studies rough traditional methods have been used, based on wood or metal markers. In this study, for the first time in Romania, and also on a global scale, a 3-D scanner was used in the mapping of gullies. The dynamics of the geomorphological processes of soil erosion were followed in detail. Specialized institutions closely followed the geomorphological processes that actively show the whole of the Moldova Plateau but, unfortunately, inadequate instruments were used and the results were not satisfactory. By using a 3-D scanner many

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of the expected responses will provide accurate, dynamic geomorphology and a much-improved database.

It will develop a study on the dynamics of gullies of the Moldavian Plateau, and develop a specific methodology and 3-D scanner to obtain accurate data, in millimeters or centimeters, about the changes that may occur in very short periods of time. Correlation of 3-D scanner data with those obtained via traditional methods will certainly improve the methods of preventing and combating the risk of geomorphological phenomena. At the same time, it seeks to use the technique to be implemented in as many areas of investigation as possible: geomorphology, archeology, agronomy, protection of the environment, land management, etc.

The study of the gully is of particular importance because it is extremely active, and its development will affect the Cucuteni archaeological site from the Neolithic period, which is very important in the proof of an ancient habitation on the territory in the north-eastern part of Moldova. For a good correlation with data previously obtained and a full analysis of morphological traits (morphography and morphometry) in specific gullies, wide-ranging international and national sources have been consulted: Bacauanu, 1968; Barnoals et al., 2010; Blong et al., 1982; Böhler and Marbs, 2006; Bornaz and Rinaudo, 2004; Bradford et al., 1978; Bretar et al., 2009; Bull and Kirkby, 1997; Casas et al., 2010; De Oliveira, 1990; Ernst et al., 2010; Harvey, 1992; Heede, 1976; Ionita, 2006; James et al., 2007; Kern, 2002; Lane, 2008; Leica HDS3000 data sheet, 2006; Milan et al., 2007; Phillips, 2006; Radoane et al., 1995, 1999, 2009; Vandaele et al., 1996.

2 Regional setting

The Moldavian Plateau is the largest and most representative of Romania's plateaus. It occupies the eastern part of the country, ranging from Bukovina, the Moldavian Sub-Carpathians, the northeastern Romanian Plain, the Prut valley and the river Danube (Fig. 1).

A landscape including the Carpathians and the Danube characterizes part of the great stage of hilly lands (Romanescu et al., 2008). It has a total area of 25 000 km^2, over 10 % of the territory (Romanescu, 2009; Romanescu and Nistor, 2011; Romanescu et al., 2011a, b).

The gully scanned in 2008, 2009 and 2010 is located in the south western Plains of Moldavia, a subdivision of the Moldavian Plateau relief. It cuts off the right side of the Cucuteni brook (13 km^2 catchment area and 11 km long), left tributary of the Bahluiet (551 km^2 catchment area and 41 km long).

The Moldavian Plateau, or the Moldavian Plain default, is a large relief unit affected by land degradation processes, especially surface erosion, deep erosion and landslides. Across the Moldavian Plateau there are two important areas of expansion of gullies: Plain southern half of Moldavia Plateau (Jijia middle basin, the upper basin of Bahluiet) and the southern half of Barlad (Falciu Hills, Tutovei hills, Covurluiului) (Ionita, 2006). The lower density of the Central Moldavian gullies is due to the presence of sandstone and limestone plate and a high level of afforestation.

3 Materials and methods

For measurements of the morphometrical parameters of the Cucuteni-Baiceni gullies, the Leica 3-D scanner was used in the first place. Up to now, this device had been used in architecture, archeology, etc. As a result of its performance, it can be used successfully to assess the state of the environment, especially in land mapping and measuring the rate of erosion in some land surfaces with limited extension. A fixed satellite aimed at settling the mathematical coordinates of the 3-D scanner, because successive following measurements must cover the same points. For the scan to be extremely precise, nine locations must be chosen. In this case we were able to measure the entire surface of gullying, although morphological and hydro-geo-morphological conditions were extremely poor. For a better mapping of the contours of gullies, a Leica 1201 total station and GPS were used.

The Cucuteni-Baiceni gully was selected for the present research because it is very active. There is no forest vegetation on its surface that could prevent partial volumetric measurement parameters. Shrub vegetation, although rare, had to be removed using the techniques allowed by the software. The choice was due to the fact that erosion has affected a very interesting archaeological site dating back to 5000 BP, from the Cucuteni or the Precucuteni period. This makes it easier to assess the rate of erosion over a period of great extremes.

The 3-D scanner has a measurement accuracy of 6 mm. During a measurement with a laser scanner, thousands or millions of points are measured and saved.

Three consecutive measurements were performed at relatively equal intervals in 2008, 2009 and 2010. The last measurement was made in spring 2010 after a solid winter precipitation and high rainfall in spring.

For the historical evolution of gullies, topographic maps and military plans of the Romanian Army were consulted. During the Second World War the Army had placed a battery of guns in the area of the unit studied. Unfortunately, it has only been possible to make use of land-use maps since 1950. Those developed before this year are not accurate and they are often for orientation only, with a high degree of generalization.

Meteorological data on precipitation, daily and monthly, were provided by the Meteorological Centre, Iasi, Moldavia. They were focussed on Cotnari Meteorological Station, located near the Cucuteni-Baiceni gullies. The most important stations were rather uniformly distributed on Moldavian territory (Eastern Romania).

4 Results and discussions

Erosion gullies are deep, cut from loose rocks. They consist of a channel with steep banks and talweg thresholds (with a cross-section greater than 1000 cm^2), a threshold of spring water that often flows ephemerally and a longitudinal profile as a powerful curved parabol (De Oliveira, 1990). The Cucuteni-Baiceni gully is representative from a morphological and dynamic point of view. Selected for a prolonged monitoring from the beginning of 2008 it is located near the most important chalcolithic archaeological site on the territory of the Moldavian plateau, and affects its integrity. Citadel Hill remains of the Cucuteni culture were discovered, unique in Europe (Boghean, 2004; Ursulescu, 2006; Cotiuga and Cotoi, 2006).

From the geomorphological point of view it is found within the following typology: a longitudinal profile form: continuous, as the plan configuration (two points of origin) or front (the bank); after locating in the basin: the slope; by form of cross-section: the shape of "V"; after the development cycle: perennial (with banks).

On the territory of the Moldavian Plateau 9000 ravines have been inventoried. Microform relief leads to significant losses of soil and causes mal gravitational processes (Radoane et al., 1999). Gullying processes triggering causes are found primarily in the nature of the geological substratum of the landscape, climate change, pollution phenomena and anthropogenic interventions (Blong et al., 1982).

The gullies of the Moldavian Plateau made a strong debut whose date was determined to be 1828, when deforestation corresponded to the centre of these massive relief units. It seems that the afforestation rate in 1832 was across the entire plateau of over 47 %. In 1893 it amounted to 21.9 % (Poghirc, 1972).The development of forests in the nineteenth century was strongly influenced by land laws in the years 1828, 1842, 1864, 1877 and 1881. Stepping gullies in recent years has been due to poor road infrastructure and inadequate agricultural techniques. To these must be added the Land Law of 18/1991 which led to a strong fragmentation of arable land properties, and whose effect was almost entirely oriented towards the hill-valley direction.

Specific linear erosion of the gullies occurs when surface flow is concentrated in a context of increasing kinetic energy of liquid flow resistance and a decrease of the substrate or protective coating plant (Ionita, 2000). In the Moldovian Plateau the critical season for gullying was set for March 15 to 20 and July 15 to 20 (Ionita, 2000). This role took it to the cold season (57 %), while forming 43 % of the hot season. In fact, the material was prepared by the winter freeze-thaw phenomena. This case is due to the strong brittle substrate of the gully (loess, clay, sand, sandstone, etc.) slope

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and special hydroclimatic conditions (Bacauanu et al., 1980; Branzila, 1999). Recent years have seen increasingly more frequent and torrential spring rains, with amounts that sometimes exceed those of the summer. At the same time strong erosion of the spring coincides with a field devoid of vegetation, and at the same time ploughed, in preparation for sowing.

The Moldavian Plateau, with its extra-Carpathian position is temperate continental with some excessive nuances. For W and NW a moderate continental climate characteristic of western continental interferes (Pantazica, 1974). The most characteristic of the Eastern European influences are the imprinted predominance of cold air masses during the winters and hot and dry summers. Annual average temperatures have values of 7.5–10 °C, with variations increasing in the N-S direction. Rainfall is between 500–700 mm, with lower values in the lower, southern sectors.

Climatic nuances are caused by latitude and altitude of the mountain chain shelter. Suceava Plateau has a colder climate, rich in moisture in NW Europe due to cyclonic influences. On the Barlad plateau continental influences are felt to generate large thermal contrasts. Cold winters, dry summers and snow storms with torrential rain are characteristic of the invasion of continental air in the Moldavian Plain (Erhan, 2001).

Between 1 October 2008 and 31 October 2009, the first measurements were taken. The amount of precipitation which fell at Cotnari station was 569.4 mm. The maximum amount of precipitation which fell within the range observed is relatively low. For erosive phenomena in the gullies, torrential rains, always present in this area, are very important. The largest amounts of precipitation were recorded on 12 February 2009 (21.8 mm), 3 August 2009 (16.7 mm), 6 March 2009 (30.8 mm), 25 June 2009 (24.2 mm), 29 June 2009 (41.4 mm), 13 July 2009 (18.8 mm), 13 October 2009 (16.8 mm). Quantities exceeding 20 mm in 24 h occurred during the summer (June–July) when the vegetation is relatively dry and soil will be eroded easily. Under normal precipitation, with averages of about 600 mm year^{-1}, the gully shows reduced dynamics. In the first year of monitoring, rainfall was below the annual average of the location. In this case, the changes were minor. In the remaining six months of monitoring, the

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quantity of precipitation amounted to 263.9 mm (November 2009–April 2010). An important factor was that this amount of water was stored in its entirety as a layer of snow, favoured by very low winter temperatures. Melting of snow and the large amount of precipitation that fell in April 2010 (65.9 mm) made dynamic gullies react extremely rapidly. For this reason the measurement was made as number three, immediately after the collapse of the large central wall of gullies.

Deforestation and the felling of the forest led to important changes in the characteristics of the general climate in eastern Romania (Siret and Prut river basins), especially, increasing the tendency of torrential rains as well as growing aridity. Rainfall frequency values of more than 100 mm/24 h increased from 1.7 before 1900 to 47.9 in the period 1981–2000. After homogenization of the data (adjusted values as a result of the increased number of hydrometric posts) percentages have changed: by 7.7 before 1900 to 35.9 between 1981–2000 (Fig. 2). After 2000 there were common values of 200 mm/24 h, especially during the floods of 2004, 2005, 2006, 2008 and 2010 (Plesoianu and Olariu, 2010). However, deforestation was required and therefore the need for land suitable for grazing animals.

In the gullies, geomorphological processes are dominant in the vegetation (collapses, landslides, surface runoff, muddy surface run-off, bad-land-measures, etc.) as well as longitudinal transport. The peaks are the most dynamic sections of the entirety of the gullies. Typically, the ratio between the bank and the processes of longitudinal transport ranges from 0.1 to 10 (between 1–10 in excess of 50 %). Overall, the processes which contribute to shore erosion gullies are 1–5 times more than the processes of deepending. The average rate of advancement of gullies in the Moldavian Plateau, from the empirical data analyzed, indicates a value of 1.5 m yr^{-1} (Radoane et al., 1995). In the case of the Cucuteni-Baiceni ravines two empirical evaluations can be made. According to military plans made in the course of the Second World War, the central cornice, between the two branches of the ravines, was located about 40 m outside (Fig. 3). For a period of 65 yr, this resulted in an average rate of erosion of 0.61 m per year. If gullies relate to the main peak, the central cornice lay at a distance

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of about 200 m. In this case the average erosion rate was 3 m per year (with reference to the main active channel) or 6.48 m per year (with reference to the secondary channel). The second assessment related to a period of more than 5000 yr, when the settlement was located on the outskirts of the Cucuteni forested slope in the form of gullying. At this scale, the erosion rate was 0.07 m per year (340.15 m) or 0.11 m per year (561.80 m). This figure may not be relevant because we do not have the necessary data to indicate times of deforestation and the changing use of land. However, deforestation was required in view of the need for land suitable for grazing animals.

Eastern Romania (or the region of Moldavia as it is known), under the influence of a continental climate with excessive nuances, soil erosion has high values. Of the multiple causes, two are crucial: torrential rains and massive deforestation occurring in 1990 (the year which coincides with land disposal to former owners). For this reason linear erosion was not uniform or rhythmic, but created phenomena related to the production of high-risk disaster. Values of the erosion of 5–10 m per year were registered with the phenomena of powerful thunderstorms. In normal years in terms of rainfall, with rain falling throughout the year in a relatively uniform fashion, erosion is reduced.

Between 2008 and the measurements of the 2010 bank, radical changes occurred between the two branches of the gullies, the position of the riverbed and the length of the two branches (Figs. 4, 5).

Talweg gullies extended along the main route by about 7 m due to regressive erosion. The equilibrium profile was altered by drawing convex curves. Talweg gullies with 7.68 m sides were shortened by reducing the drifting index. The junction point is relatively stable because the material was deposited as a result of erosion occurring within gullies. In this case the talweg joint remained at a value of 78.61 m.

In the main gully, significant changes in the longitudinal profile took place through erosion or the deposit of brittle material (Figs. 6, 7). A strong reduction of thresholds and increased convexity can be observed. The phenomenon is due to erosion, given the prominence of the areas and the deposit of material on the gentle slope.

Altitude, gully, and outlet head remain, in principle, at the same rate.

The changes were produced in the longitudinal profile of the weaker side gullies for precedence, but were important for their relatively small size (Figs. 8, 9).

Altitude, head left-side gullies, took place, in principle, at the same rate. However, the outlet is located at a higher rate because the amount of material transported, following a pronounced slope, is high.

Obvious changes are seen in the transverse profiles, especially at the points threshold (Figs. 10, 11, 12, 13, 14). In areas upstream at the end of the two gullies (primary and secondary) there are relatively minor changes to the common outlet. The slight widening of the heads of gullies is noted, while the mouth shows minor lifting.

The strongest erosion occurs on the right bank of the main gullies at the junction with secondary gully, where the slope is steep. In this case the withdrawal is about 10 m. The average of 7.5 m per year is explained by the high friability of the rock, high slope and large amount of precipitation during the winter of 2009–2010. In 2008–2009, when precipitation was within the normal intervals, erosion gullies amounted to values below 1 m per year. As the average values were exceeded, especially during increased frequency and intensity of rainfall values over 20–50 mm/24 h, erosion increased exponentially. Therefore, the average represents a long reality with complex phenomena. Sequential, erosive situations are totally different.

In the bottom of the main gullies occurs due to a strong phenomenon an attractively high quantity of material moved, but not removed within gullies (Fig. 14). For secondary gullies significant changes are noted on the slopes, in the thalweg. Dislodged material is found, for the most part, within its own valley.

The Cucuteni-Baiceni sector outlet of gullies provide a relatively stable area, because of the loose material deposited inside the valley. It will be able to be freed when the threshold of accumulated material is diminished by the outlet of materials deposited behind it.

The three-dimensional model and maps are made using a highly accurate 3-D scanner (6 mm/6 mm fidelity) and can be executed at the desired scale, depending on the requirement. To implement equidistant contour maps at 1m, parasites also appear which represent vegetation or bodies placed there by Man. They can be removed by computer and data-processing. In this case, they may have a higher accuracy. The measurement carried out using the 3-D scanner is more accurate and faster than anything carried out using Total Station or other tools. The most important issue is related to the georeferenced points, which were surveyed in their dynamics, especially due to the intense activity of the gully. Measurements must be repeated frequently to monitor reality more closely.

It can be noticed that among the three measurements taken at an interval of exactly one year, and then six months, that the strongest erosion occurred at the end cornices between the side gullies (Fig. 15). Lateral erosion occurs predominantly on the "minor bed" sides of gullying on the slopes which are themselves very low, and now covered with herbaceous vegetation. The collapse occurred in the largest sector of the two branches of the gullies, where the bank is steep and lacking support. Fouling occurs directly in the bed of the gullying which therefore abruptly changed its position. The outlet of the gullies was practically alluvial and the loose material inside stagnated. Sedimentation of the riverbed is specific between the two side arms. Extending upstream in two arms different attractive outlets are visible, with values ranging between 20–25 cm and 1m. This is due to the heavy rains in the period analyzed. They were appropriately strong and fell during summer. This area is conducive to high erosion.

Withdrawal from the cornice by the stronger of the two branches of the gully was due to the collapse of the slopes. Accumulation of material was based on the bank, on the interfluve. The withdrawal amount was well above average and the forecast for the large gullies of the Moldavian Plateau indicates a permanent withdrawal on the same alignment.

The Cucuteni-Baiceni gullies show an increased degree of dynamism, due to a combination of factors, among which the high slope of the slope, brittle material that forms

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the substrate, the lack of forest and intensive agricultural use of the adjacent shelf, the torrential rainfall, etc., are prominent.

The volume of the Cucuteni-Baiceni gullies was calculated for each measurement period, but it remains constant as a result of the eroded materials deposited throughout the interior valley. In the period under review, the material was not set in motion by the enclosure gullies. Unfortunately, in this gully, like many others across the Moldavian Plateau, quick action will not bring about protection because they do not affect a human settlement, but an archaeological site. The history and culture of the Romanian people do not feature on the current agenda of the Romanian government.

5 Conclusions

Taking measurements is a new speciality in the Romanian literature and therefore some difficulties were encountered in accurately estimating the rate of erosion and its accumulation, in calculating the volume of displaced material, etc. Finally they were resolved. Using 3-D scanner is extremely easy, and accurate data obtained were very good.

From this point of view the geomorphology field will have basic support in using this tool. By using a 3-D scanner, morphometric measurements were made to prepare a topographical map as well as a detailed and accurate three-dimensional model (accuracy 6 mm), including dynamic gullies. This is a typical form of relief which contributes to soil degradation and the measures required to stabilize a process of this kind.

For a period of 1.6 yr the Cucuteni gully has moved quickly and experienced a degree of warping at an accelerated rate in its drainage. This is the case of strong gullies, given the specific eastern Europe hydroclimatic conditions, substrate and slope. The average regression of the Cucuteni-Baiceni gullies is a much higher (10 m/1.6 yr, that is 7.5 m yr^{-1}) average in the content of the Moldavian Plateau (1.5 m yr^{-1}). At a pace of this kind, in less than 20 yr the whole archaeological site near the gullies will be affected. On a historical scale, over a period for 5000 yr, the erosion rate is relatively

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reduced (0.07 or 0.11 m per year). From the end of the Second World War until the present date, the average rate of erosion of the Cucuteni-Biceni gullies was 0.61 m per year. An important reason for the acceleration of erosion in recent years has been the intensity of torrential rains. Their growth has been notable, especially in Eastern Romania, where the continental climate experiences significant nuances.

Urgent measures of protection are required to stop farming in the area and hence also the archaeological site of the gullies. There should be emergency afforestation in the related basin slopes, a grazing ban, etc. The 3-D scanner can be used in various fields of physical geography, especially geomorphology, hydrology, cartography, etc. For the moment, appropriate methodology is being developed using these tools for the entire range of processes that contribute to shaping the current landscape.

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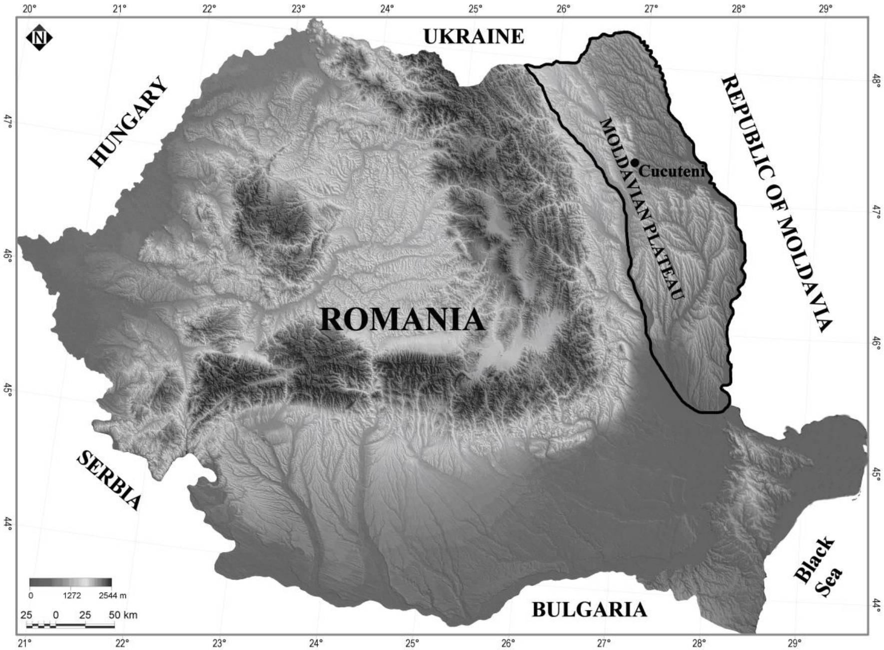

Fig. 1. The geographical location of the Cucuteni-Baiceni gullies and plateau in Romania and Moldova.

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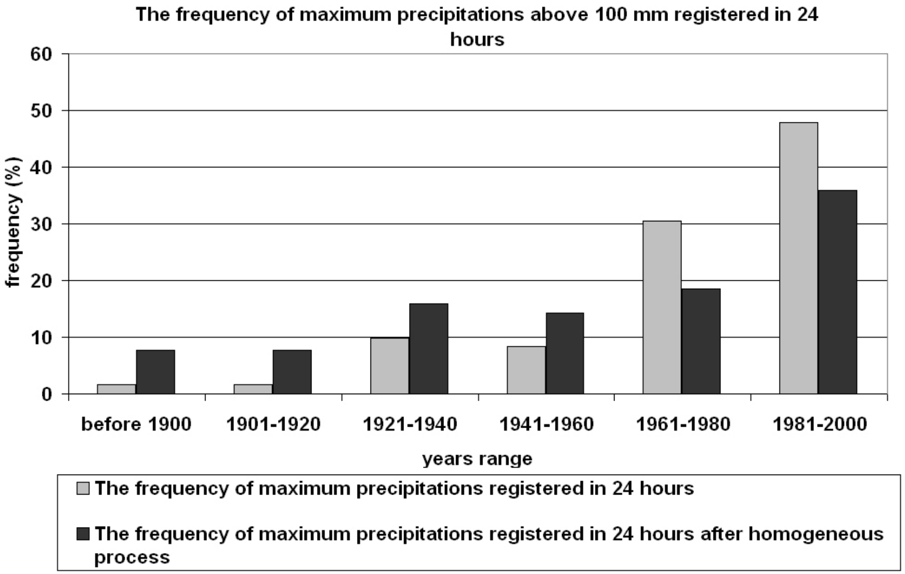

Fig. 2. The frequency of maximum precipitation above 100 mm registred in 24 h.

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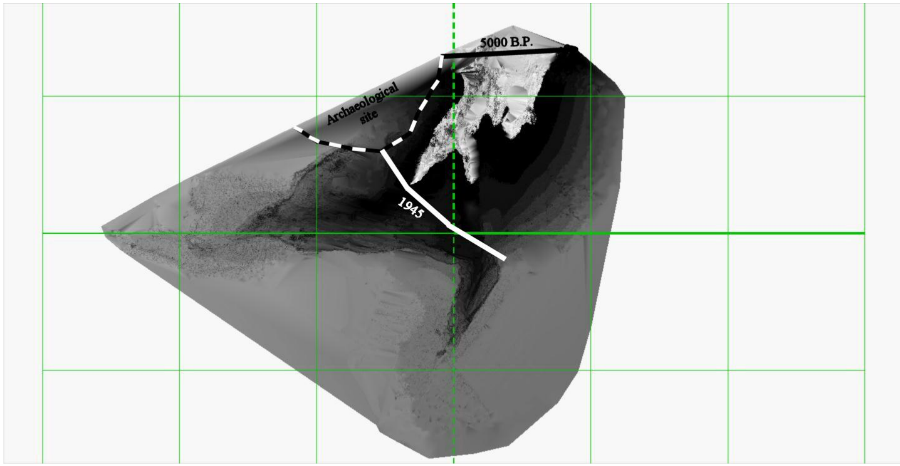

Fig. 3. Three-dimensional and mapping model of the Cucuteni-Baiceni gully in 2008. The position of the archaeological site and the limits of the gully 5000 BP and 1945 (main active channel).

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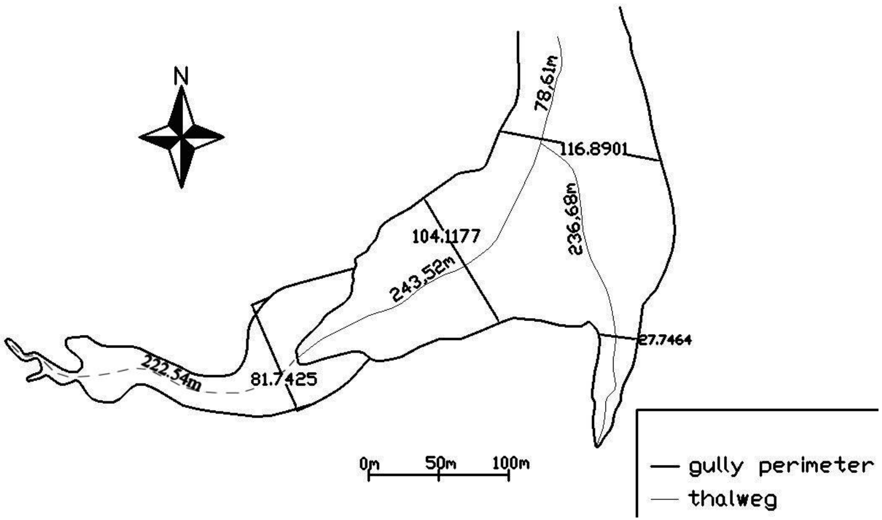

Fig. 4. Longitudinal profiles of surface and principal gullies on the Cucuteni-Baiceni side gullies in 2008.

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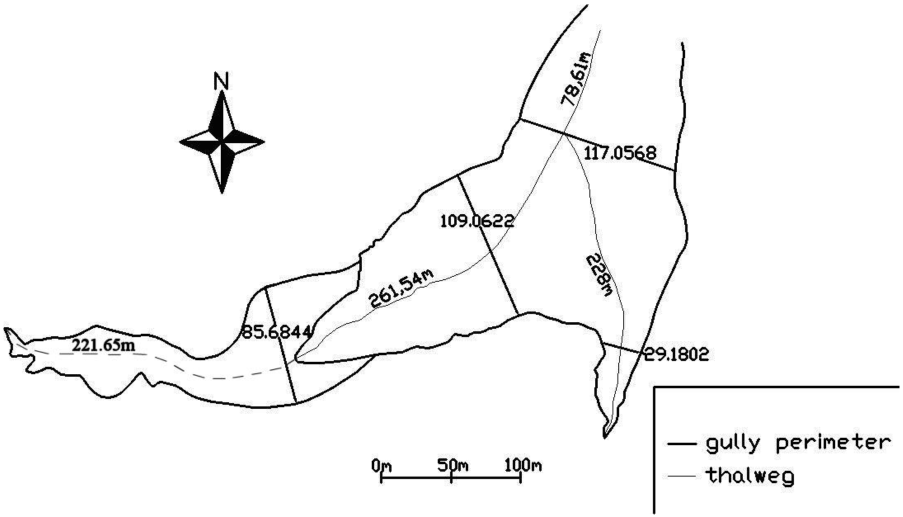

Fig. 5. Morphometry of the Cucuteni-Baiceni gullies in 2010.

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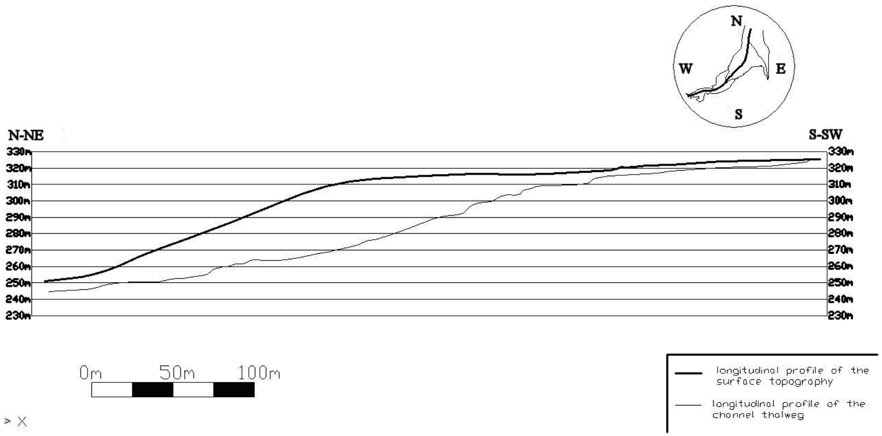

Fig. 6. Longitudinal profiles of all the surfaces and talwegs of the main Cucuteni-Băiceni gullies in 2008.

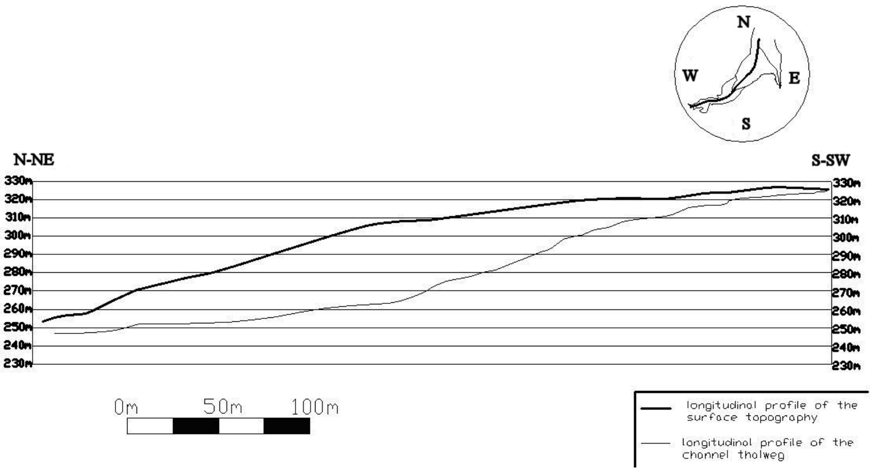

Fig. 7. Longitudinal profiles of surface and riverbed of the main Cucuteni-Baiceni gullies 2010.

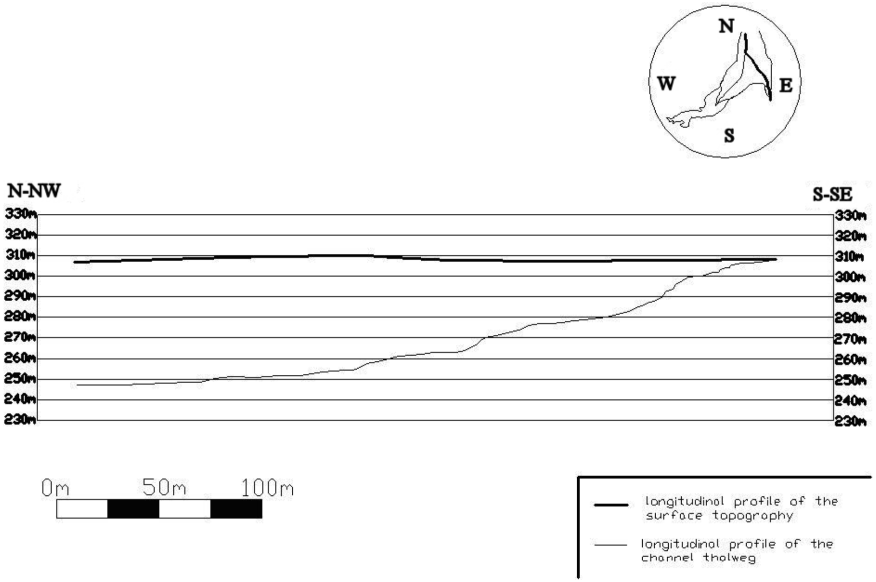

Fig. 8. Longitudinal profiles of surface and riverbed Cucuteni-Baiceni side gullies in 2008.

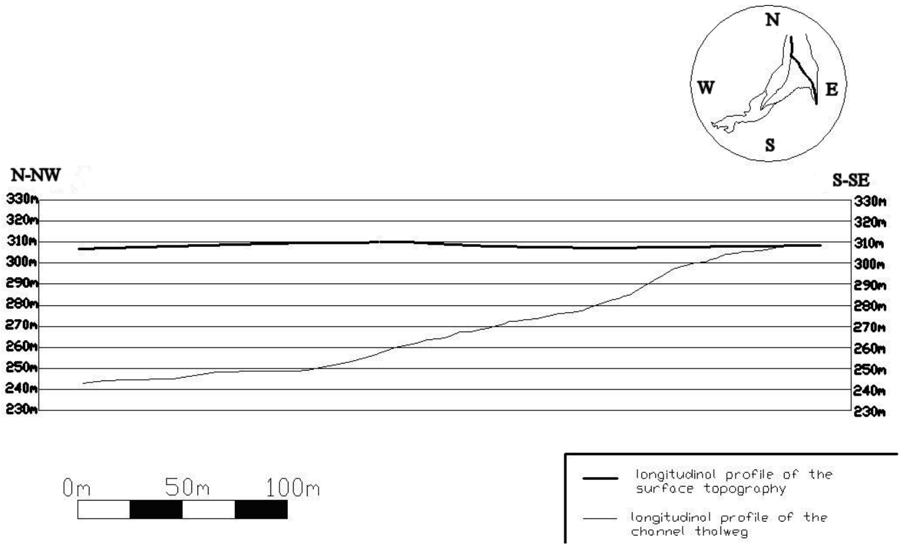

Fig. 9. Longitudinal profiles of the surface and riverbed Cucuteni-Baiceni side gullies in 2010.

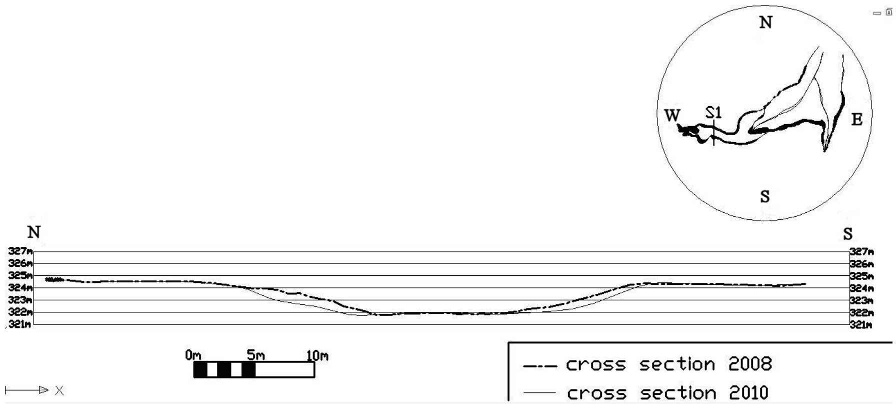

Fig. 10. Cross-section in the upstream of the main gullies.

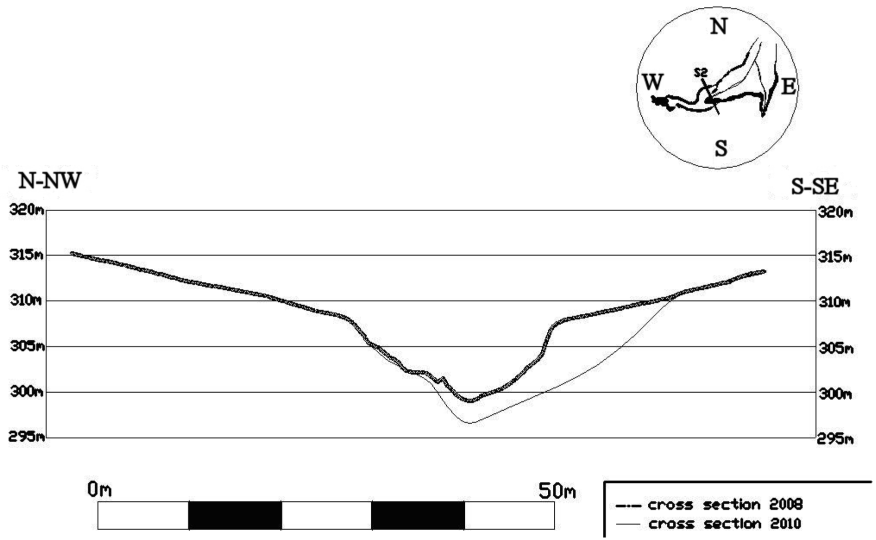

Fig. 11. Cross-section upstream of the gullies in the main high erosion activity.

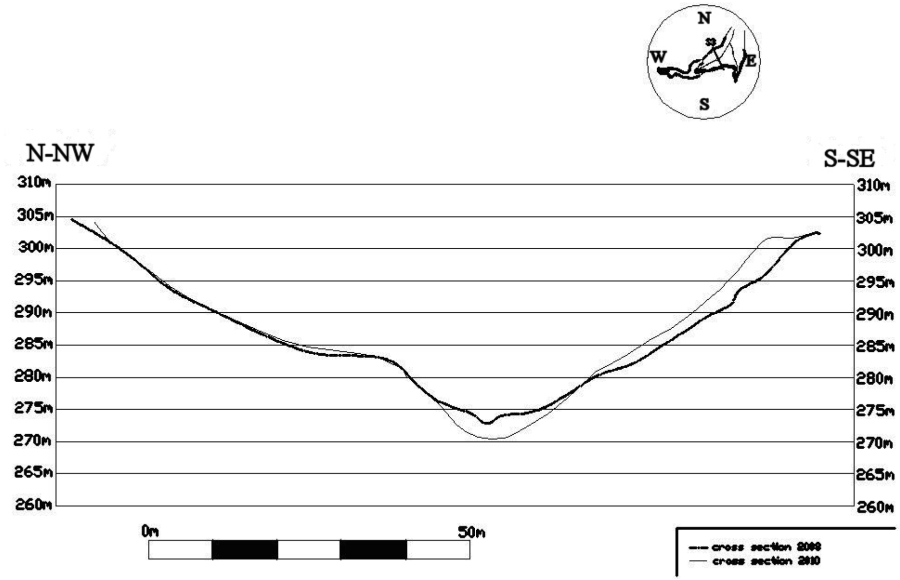

Fig. 12. Cross-section of the main gullies in the downstream.

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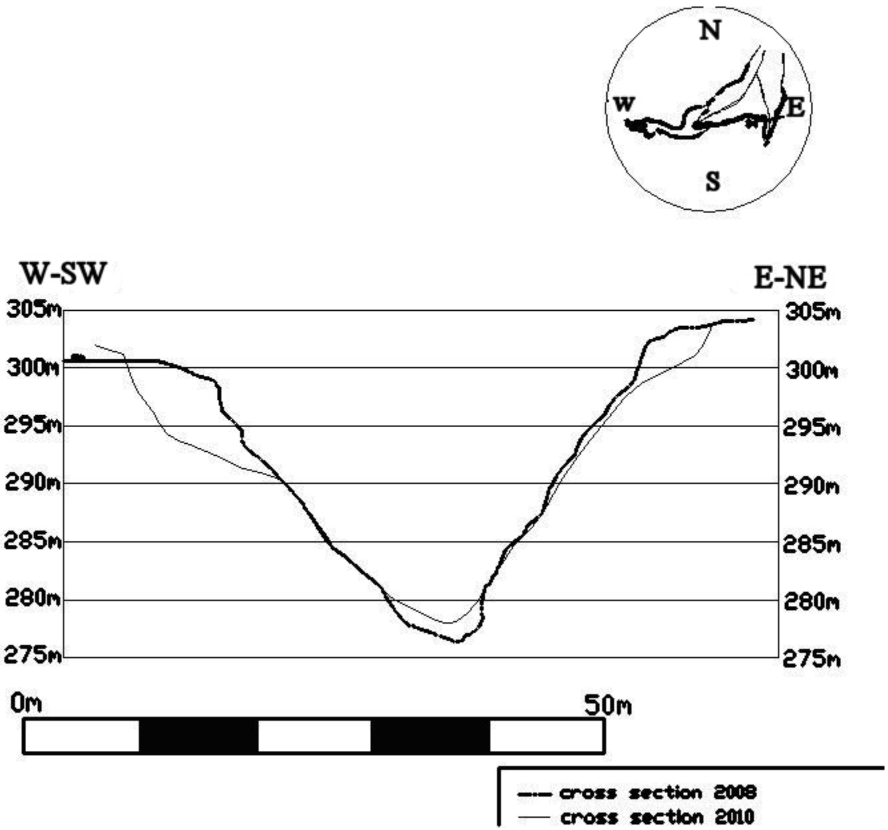

Fig. 13. Cross section of the main gullies in the downstream.

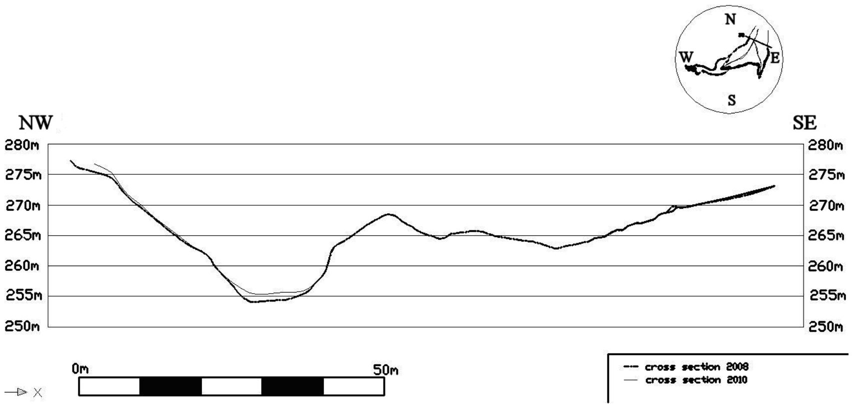

Fig. 14. Cross-section of the Cucuteni-Baiceni outlet gullies.

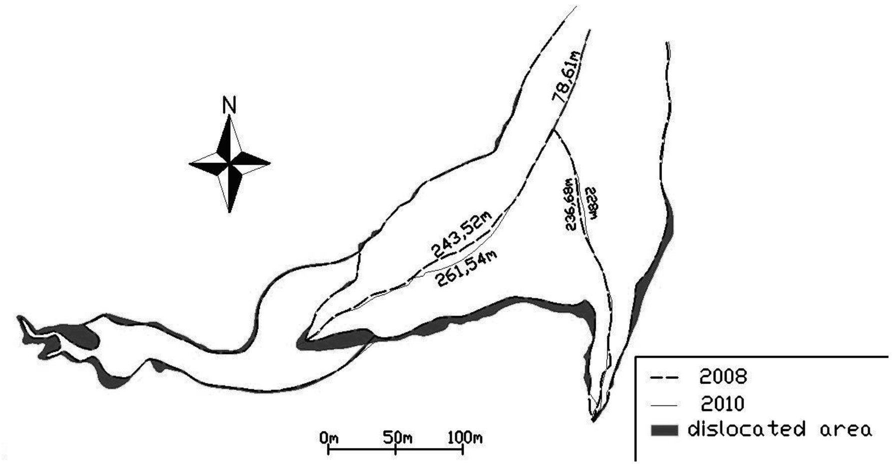

Fig. 15. The areas of separation and change in the Cucuteni-Băiceni riverbed in the gully (2008–2010).

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