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Risk maps for gully erosion processes affecting archaeological sites in Moldavia, Romania

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with 10 figures

Summary. Most of the archaeological sites in Moldavia are situated on hill borders, at the contact with lower landform units. This is why most archaeological sites are affected by the erosion of slopes, mostly the one caused by gully erosion. In order to realize the topographical measurements of the Cucuteni gully, LEICA TCR 1201 Total Station has been used. Together with LEICA GPS 1200, this station is part of SYSTEM 1200 LEICA. In order to start the measurements, the coordinates of the ground control points were obtained from ANCPI Iasi. For data adequacy assessment, we also used the 3D Scanner measurements (6 mm/6 mm resolution). The differences between the two measurements are insignificant, which proves that the Total Station can be used with success at any time. The only shortcoming is that it takes more time and, at the same time, it is very difficult to get on very steep slopes. The Cucuteni gully registers a very fast evolution, as there is an ever growing intensity of pouring rains. The measurements carried on during 2008–2010 have shown that, if there are precipitations under 580 mm, the gully has a slow evolution. If the precipitations exceed this value, there is a very fast evolution – by 5–10 m/year. Given this advancement, a part of the archaeological site, belonging to the Cucuteni culture (Chalcolithic), was destroyed and risks complete disappearance in a couple of years. This is the reason why protection measures ought to be taken with no delay.

Key words: archaeological sites, land degradation, gully erosion processes, Leica TCR 1201 Total Station

1 *Introduction*

Soil degradation processes are more and more active in the entire world. The last decades have demonstrated that the meteorological risk and hydrological processes have accentuated. The Moldavian Plateau, situated in eastern Romania, is highly affected by gully erosion, under the influence of excessive continental factors. The most important causes contributing to gully erosion are determined by deforestations, the existence of a friable layer (clayey, sandy, loamy, loessoid, etc.), the intensity of pouring rains, wrong application of land improvement works, etc.

The gully is a tight valley with steep slopes, formed by the erosion exerted by running waters. Even though gullies are rather small landforms, they have a high degree of erosion, thus contributing in a major way to land degradation (Zavoianu 1985).

The beginning of the gully erosion process, highly intense in the Moldavian Plateau, is thought to be the year 1828, moment corresponding to the intensification of deforestations. In 1832, the percentage of the forestation on the plateau was of over

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47 %, and in 1893 it lowered to 21.9 % (Poghirc 1972). The existence of forests until the 19th century was strongly influenced by the land laws from 1828, 1842, 1864, 1877, and 1881. The intensification of gully erosion during the past few years is due to a deficient road infrastructure, communication networks, and highly inadequate land improvement works. On top of these there is the Land Fund Law No. 18/1991 which lead to a strong fragmentation on the properties with arable lands, almost entirely oriented and worked on the hill-valley direction.

The causes for the beginning of gully erosion are to be found mainly in the nature of the geologic or landform substrate, in the climatic changes, pollution phenomena, and in the anthropic intervention (Romanescu 2009).

The Cucuteni gully is of great practical and scientific importance because it is extremely active and it affects the archaeological site of Cucuteni, settlement of the Cucuteni culture. The Cucuteni culture (4225/4500–3500/3450 CAL BC [Bem 2000]) had an important role in the genesis of the most representative civilisation of the European Chalcolithic – Cucuteni-Trypillia. Along the three main evolution phases, the Chalcolithic communities occupied a large territory: the south-east of Transylvania and the south inter-river Bug-Dnieper (on the W-E direction), as well as from the upper streams of the Prut, Dniester and Bug until the contact between the silvo-steppe and the steppe of the North West Pontic region (on the N-S direction). Thus was prefigured the main core of the future area belonging to the cultural complex Cucuteni-Ariușd-Trypillia (Ursulescu et al. 2002).

As consequence of the erosion intensifications in eastern Romania, it is mandatory to know the current evolution degree of the gullies. The present study has as purpose the permanent monitoring of the Cucuteni gully in order to prevent the total destruction of the archaeological site. We also have in view to determine certain measures to stabilize or stop the erosion. For a very precise monitoring, we chose to study the gullies through last generation devices: LEICA TCR 1201 Total Station and LEICA 3D Laser Scanner.

The international and Romanian literature in the field is extremely rich and relevant for the gully-driven erosion processes: Bocco 1991, Casali et al. 2006, Derose et al. 1998, Ionita 2006, Marzolff & Ries 2007, Poesen et al. 2003, Radoane et al. 1995, Sidorchuk et al. 2003.

2 *Regional settings*

The Cucuteni gully is situated in the south-eastern sector of the Suceava Plateau, at the contact with the south-western sector of the Moldavian Plain (parts of the Moldavian Plateau). It is part of the landform subunit known as Dealul Mare. It is situated on the territory of the Baiceni commune and it emerges in the Valea Oilor river. It was called Cucuteni as it affects the most important archaeological site of the culture bearing the same name (fig. 1).

The territory of the Baiceni commune is in the upper basin of the Bahluiet river (551 km^2 the surface of the catchment and 41 km length), left tributary of the Bahlui River.

As consequence of the clayey and loessoid substrate, the territory of the Moldavian Plateau is affected by numerous landfalls and by intense gully erosion processes. Gully erosion is present due to a favouring (friable) lithology, an elevated

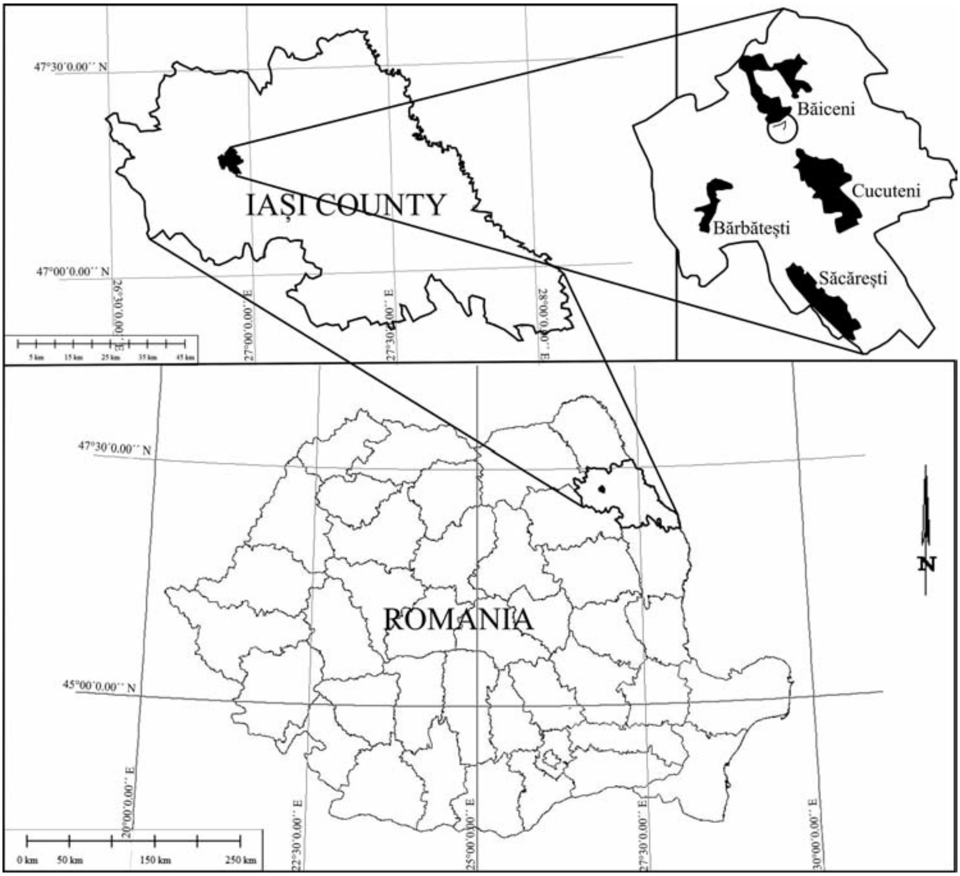

Fig. 1. Geographic location of the Cucuteni commune and the Chalcolithic archaeological site in Romania.

slope, no fixing vegetation, pouring rains, etc. The whole area once occupied by the Cucuteni settlements around the city of Târgu Frumos is affected today by intense land degradation processes. Permanent deforestation and the lands being taken over for agriculture will inevitably lead to an acceleration of these phenomena.

3 *Materials and methods*

The field measurements were executed with the help of LEICA TCR 1201 which, together with LEICA GPS 1200, is part of SYSTEM 1200 LEICA. The LEICA TCR 1201 Total Station is an optical device, a combination between the classic theodolite and a distance measuring electronic device. It may also include a small computer which, besides the storage capacity, may also provide very precise calculations. In principle, the Total Station is used to measure up the vertical and horizontal angles, according to the real North, as well as the distances towards the points to be measured.

In order to start the measurements, we made a request to ANCPI (National Agency for Cadastre and Land Registration) Iasi to get two sets of geographical coordinates (a set being used as fixed reference point, and the second as orientation point). Thus, we began the measurement from the second order ground control point Dealul lui Viteazul (X = 645029,943, Y = 644429,686, Z = 340,000 m), with the orientation on the third order geodesic point Movila Halmu (X = 648463,122, Y = 642161,474, Z = 256,000 m). We started the said measurement by targeting the prism with the Total Station. The distance between the points observed with the Total Station was of 5 m on the slopes with lower declivity, and of 1–2 m on the slopes with higher declivity, for a better emphasis of the slope and a better visualisation on the DEM. Where we measured the very gully, we targeted points on the upper edge and at its lower part, sometimes not being able to target point in the middle of the gully because of the very steep slope. We also targeted the points on the thalweg line, in longitudinal profile, to evaluate the degradation and aggradation of the thalweg.

The measurements were executed in the 1970 Stereographic Projection or STEREO 70 (the official Romanian cartographic projection, which replaced the Gauss-Krüger projection, after Decree no. 305 from September 1971).

In order to assess the data and the effectiveness of the Total Station, we also measured with the LEICA 3D Scanner. The differences between the two measurements are infinitesimal, which proves that the Total Station can be successfully used in measurements targeting gully dynamics. When using the Total Station, there may be problems in positioning the device on highly reclined slopes. The measurement time is relatively the same as that with the 3D Scanner. Using the Total Station is the right method to delimit the development area of the gully. There will be a punctual delimitation of the risk area. As regards the 3D Scanner, it makes it very difficult to trace the limit, thus losing precious centimetres. In reality, the two devices complete each other. The Total Station may be used to geographically delimit the gully, whilst the 3D Scanner may be used to actually scan the (dislocated) inside of the gully (Romanescu et al. 2012).

The measurements were carried on in 2008, 2009, and 2010, at relatively equal intervals. The measurements of 2010 were carried on during the spring, after a winter full of solid precipitations, stored in a thick, long lasting snow layer. At the same time, the spring rains were also rich, often pouring. The topographic maps published by the Romanian Army and the topographic plans of the Second World War were consulted. The Romanian Army cannons, defending the front line against the Russian invasion, were placed on the edge of the gully, at great distance from the current coast line. The measurements took into account the reference system represented by the Black Sea. After finishing the measurements and storing the data, we had in view the elaboration of our own database for the gully, in order to be able to compare future data with it.

4 *Results and discussions*

4.1 *The natural framework as factor of the gully erosion process*

The deposits of the middle (Bassarabian) Sarmatian are around 1,000 m thick and they are monocline, on the NW-SE direction. They are composed of alternant layers of loam, sands, clays, and also calcareous sandstones and oolithic limestones (Branzila 1999). The monocline and the fact that the rocks have different degrees of hardness makes the landform have a morphology specific to selective erosion, with steps on the hard rocks and under-digging niche on the softer ones. As consequence of the sandy substrate, the gullies in the Moldavian Plateau are strongly incrusted in the landform, with differences in height exceeding 20–30 m in certain cases (Romanescu et al. 2012).

The climate of the area is influenced by continentalism, with multi-annual temperature average values of 9 °C and precipitations of 600 mm. The monthly average values indicate increases in the precipitations from March to July, followed by a period of severe decrease (Erhan 2001, Pantazica 1974). Pouring rains are also characteristic, with local values often exceeding 200–300 mm a month, or 50–100 mm in 24 hours. It is the intensification of these elements which lead to a very fast evolution of the border gullies in the Moldavian Plateau.

Unfortunately, the broadleaf forest specific to this area was rapidly replaced by silvo-steppe and steppe. As a result of these events, there has been an increase in soil degradation (Poghirc 1972).

4.2 *The evolution of the gully in the context of the global climate changes*

The Cucuteni gully falls into the category of large gullies in the Moldavian Plateau according to the following criteria: cycle evolution – perennial (with banks); shape of the transversal section – "V"; shape of the longitudinal profile: continuous; configuration in the plan – dendritic (with two points of origin) or frontal (belonging to the bank); localisation in the hydrographical basin: of the slope.

We chose to monitor the Cucuteni gully evolution because of its fast dynamics and the fact that it affects one of the most important archaeological sites in Romania: the Chalcolithic settlement of Cucuteni, evidence of a long existence of the population on the Romania territory and eastern Europe (Boghian 2004). At the same time, the Cucuteni gully evolves rapidly because the old forest was eliminated, the slope is steep, the rock is highly friable, pouring rains have ideal conditions to occur, etc. (fig. 2).

The Chalcolithic culture used to place its settlements on the edge of slopes or on the inter-river promontories. Thus, they had a good view of the defended territory. In this case, the gully cannot be older than 5,000–5,500 years (fig. 3).

Around 2,000 years ago, the Moldavian Plateau was 70–80 % forested. In 1832, the percentage dropped to 47 %, and in 1893 to only 21.9 % (Poghirc 1972). The beginning of the intense gully erosion process occurred in 1928, when there have been massive deforestations in order to have new pastures. The land laws have strongly influenced the existence of the forest and the use of lands. The strong gully erosion within the last years is due to the wrong infrastructure and to the rudimentary agrotechnics. At the same time, the Land Fund Law of 1991 lead to a massive fragmentation of individual properties and to ploughing along the slope, on a hill-valley system (Romanescu & Nistor 2011).

The existence of the ditches in the back of the gully favoured the accelerated erosion since 1945 to the present day. The presence of the two banks left will make the gully continue its advancement. Water infiltrates rapidly through these ditches in the

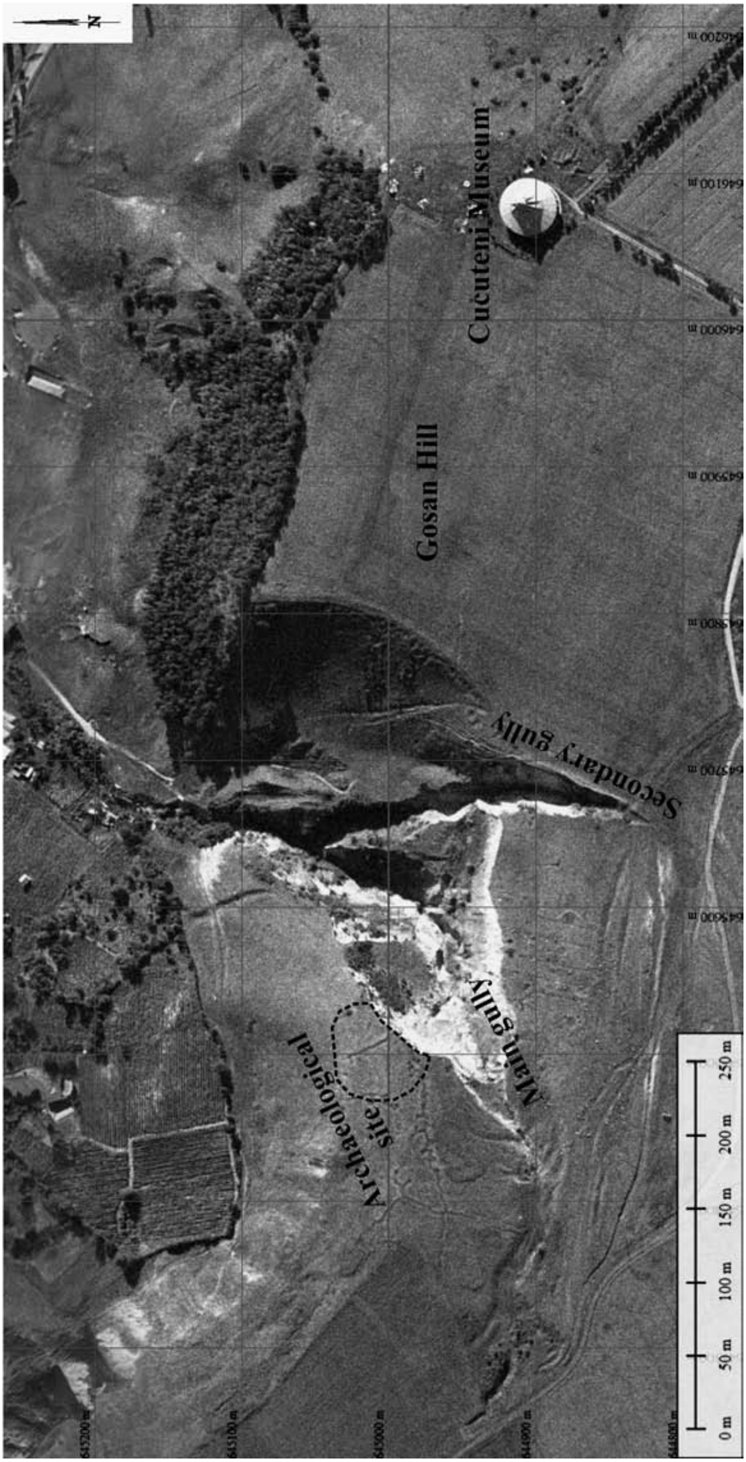

Fig. 2. The limit of the Cucuteni gully and of the archaeological site.

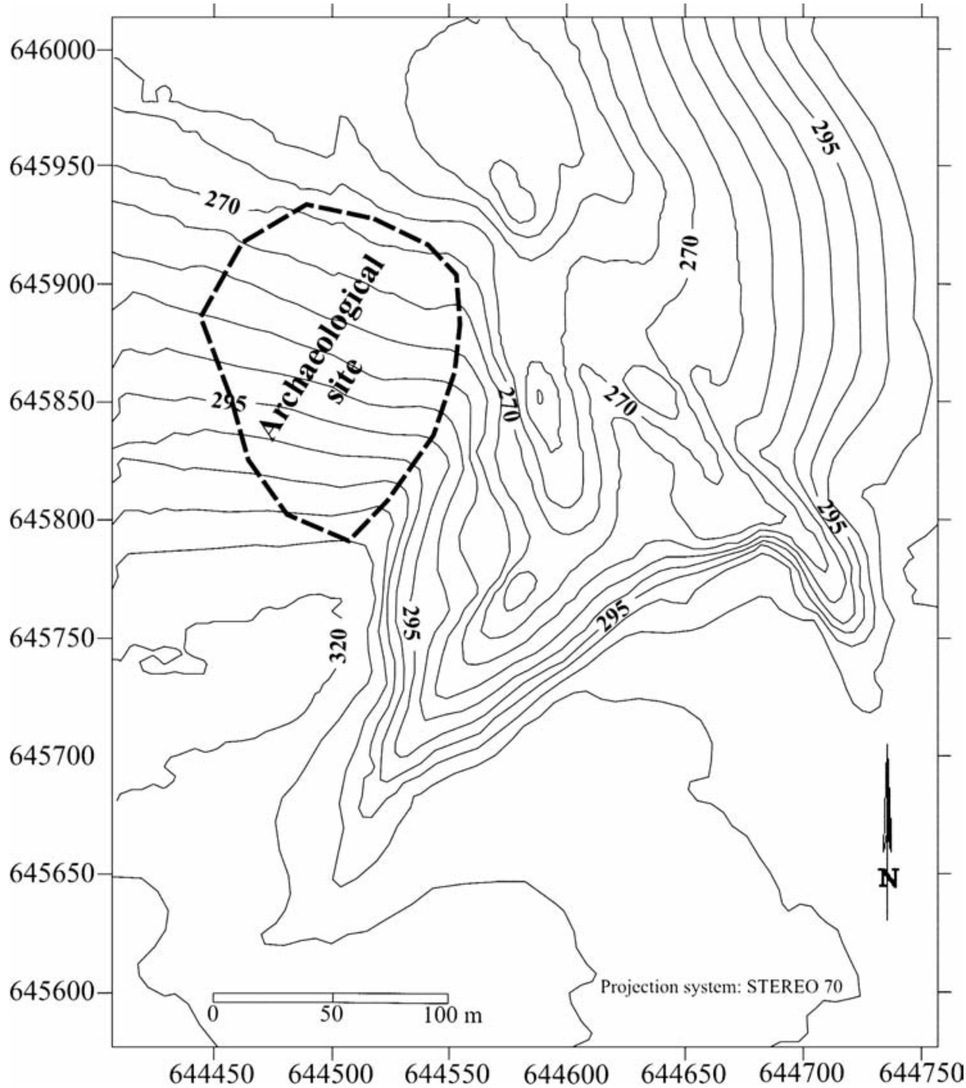

Fig. 3. The detailed DEM of the Cucuteni gully and of the archaeological site.

sandy-clayey deposits and it triggers the suffusion process. At the beginning, the finer, clayey particles are eliminated, and we can find them in the thalweg. In the gully wall the rougher, sandy particles remain, which start to move, a whole block of them, under the shape of large packs. The fact that these sandy blocks collapse favour the reduction of 5–10 m/year of the Cucuteni gully and the rapid destruction of the archaeological site, unless protection measures are taken with no delay.

Unfortunately, archaeological sites, even though they have a national or international importance, they are not protected by the State institutions as there are no projects or funds necessary to such an enterprise. As consequence, the Chalcolithic settlement from Băiceni risks complete disappearance in the near future, if the erosion degree maintains at the current average, of 7.5 m/year. If the erosion degree changes to that reported in 1945, it will be reduced only to 0.61 m/year. The reason the erosion degree has intensified is believed to be pouring rains and also deforestation.

After monitoring over 9,000 gullies in the Moldavian Plateau, we came to the conclusion that the critical season for gully erosion is the second half of March and the first half of June (Ionita 2006). A crucial role is played by winter, with 57 % (water accumulation because of the snow), and summer contributes with 43 % (pouring rains). The average erosion degree in the Moldavian Plateau is of 1.5 m/year (Ionita 2006, Radoane et al. 1999).

The precipitations of 2008 and 2009 were reduced in quantity (annual average values of 569–580 mm at the Cucuteni Station). At values under 580 mm per year, the gully is relatively stable. In 2008 and 2009 there have been pluvial average values under the normal ones. In the first part of 2010 there have been significant amounts of precipitations (November 2009 – April 2010 (269.9 mm). In this context, the melting of snow and the pouring rains of 2010 (65.9 mm) have determined a rapid evolution of the gully.

The first detailed DEM of the Cucuteni gully, in 2008, stressed the morphometric and morphographic characteristics of the landform created by pouring rains (fig. 4). It was done at a 1 : 200 m scale, with the contours equidistance of 5 m, in the projection system STEREO 70 (in relation to the Black Sea). The same measurements

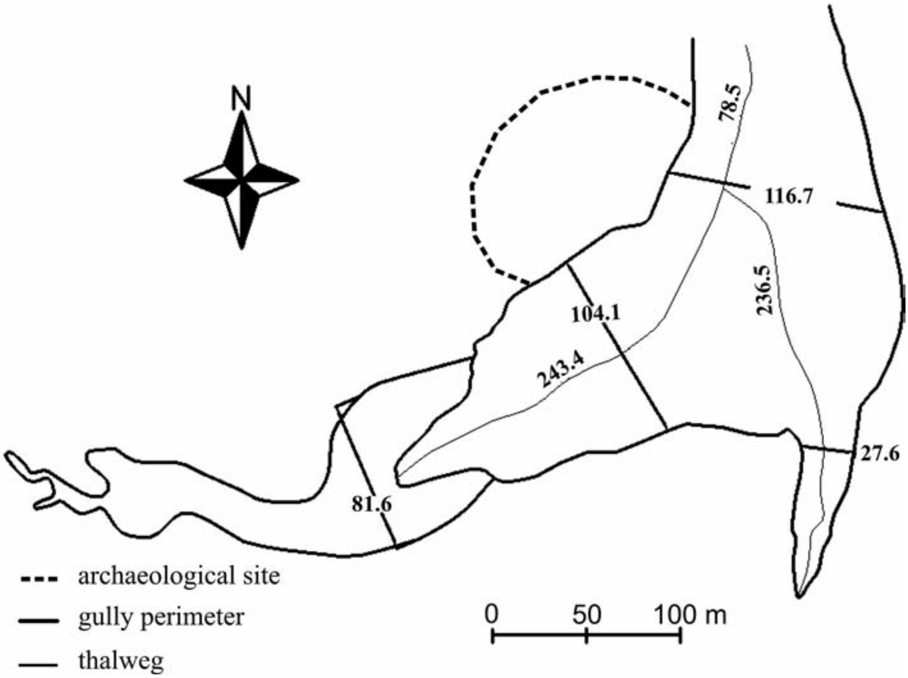

Fig. 4. Morphometric parameters of the Cucuteni gully in 2008.

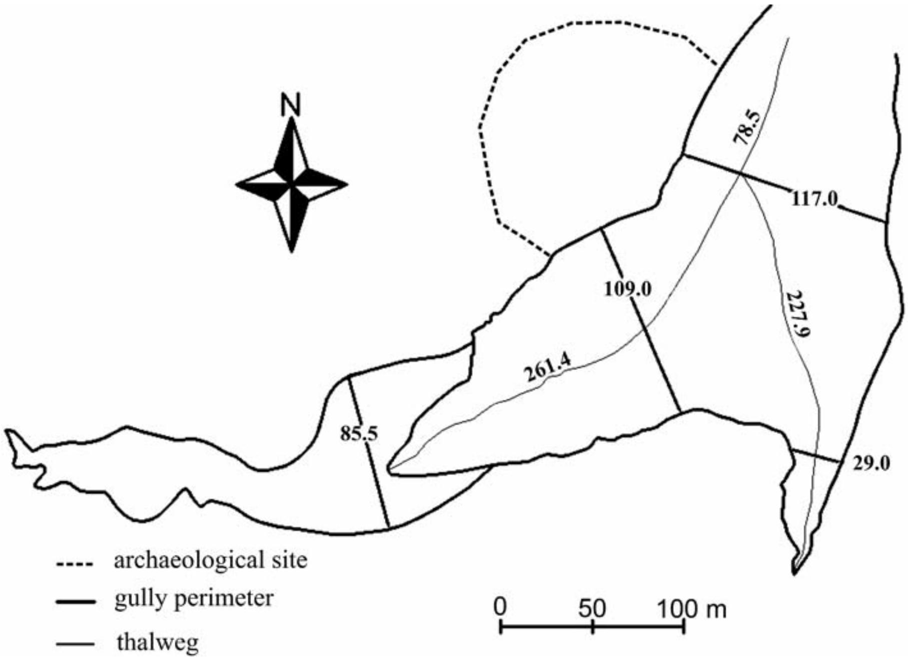

Fig. 5. Morphometric parameters of the Cucuteni gully in 2010.

have highlighted the limit of the active gully. This way, with the help of the points measured on the edge of the active gully, future measurements can be done in order to determine the evolution of the banks. After elaborating the two plans (2008 and 2010) we can quantify the data regarding the evolution of the Cucuteni gully in three years. Two years of pluviometric "calmness" and another one dominated by pouring rains, with high maximum values.

Between 2008 and 2010 there have been obvious changes in the length of the main and secondary thalweg of the two gully arteries. The alterations are due to both the edges of the gully and the downstream movement of the confluence of the two thalwegs (fig. 5).

The most obvious alteration characterizes the right bank of the main gully. The dislocated bank is 5.98 m thick. The material was deposited on the gully thalweg and participated to its violent aggradation. This way, the active surface of the gully modified from 26,475 m^2 in 2008 to 26,850 m^2 in 2010 (fig. 6).

The longitudinal profile of the main gully has suffered radical changes. During 2008 and 2010 the thalweg of the Cucuteni gully, at the level of the material dislocated from the right bank, was aggradated by 3.1 m (fig. 7). The thickness of the material is bigger in the lower sector and more reduced in the upper one. The only exception of the rule is represented by the gully apex, when the thalweg deepened by 0.5 m. the cause is the water jet from the abrupt slopes, falling violently on the bottom of the thalweg. The friable material is dislocated and transported downstream. At the gully mouth, the deposit gets tighter because of the dissemination process, on a larger sur-

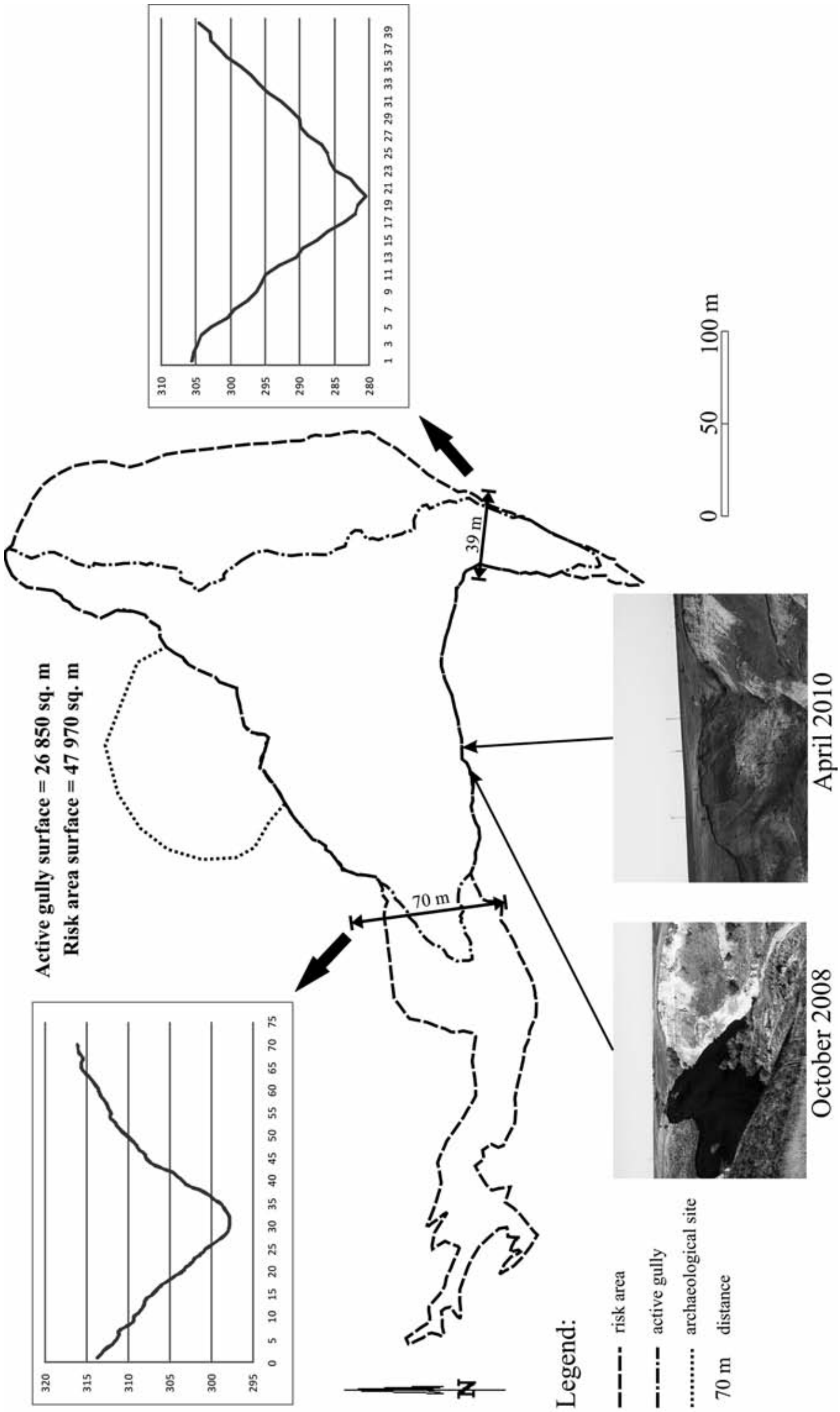

Fig. 6. Gully plan and cross sections in the risk area (April 2010).

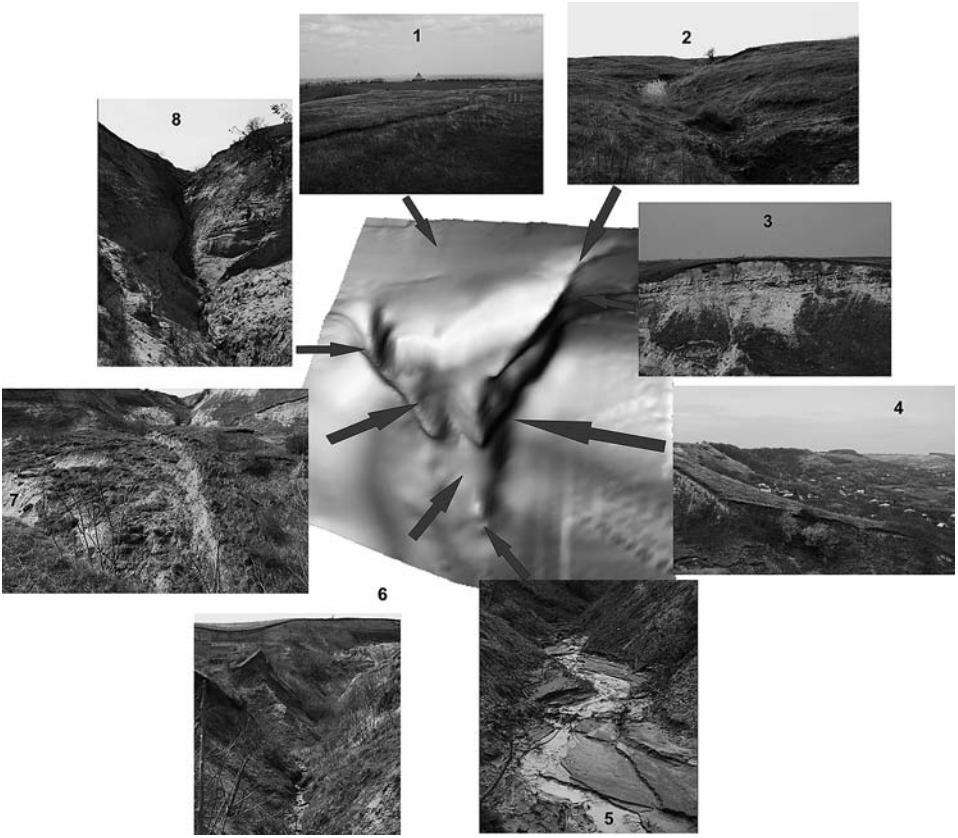

Fig. 7. Detailed geomorphological processes inside the gully (1. Upper area with water caption tubes; 2. Thresholds inside secondary gully; 3. Oolithic limestone plate; 4. Main gully left side sliding; 5. Alluvial cone; 6. Connection of the two thalwegs; 7. Small landslides inside the gully; 8. Thalweg of the secondary gully).

face. We have to mention that the dislocated material inside the gully is not eliminated in the main river valley, but remains inside it. For this very reason the aggradation index is very high.

The measurements of 2010 have indicated the following morphometric data: active gully surface 26,850 m^2, risk area surface 47,970 m^2, length of the active gully thalweg 563.02 m, maximum length of the main gully 113.997 m, minimum width of the main gully 14.588 m, maximum width of the secondary gully 30.380 m, minimum width of the secondary gully 5,191 m, maximum height of the active gully (quota) 314.920 m, minimum height of the active gully (quota) 243.854 m, maximum height of the risk area (quota) 325.337 m, minimum height of the risk area (quota) 243.854 m.

The active gully, with high erosion degree, has a reduced area in comparison to that with geomorphological risk, which comprises the entire area affected by minor dislocations, with differences of a few centimetres. The geomorphological risk area will affect the already shaped zone in the near future.

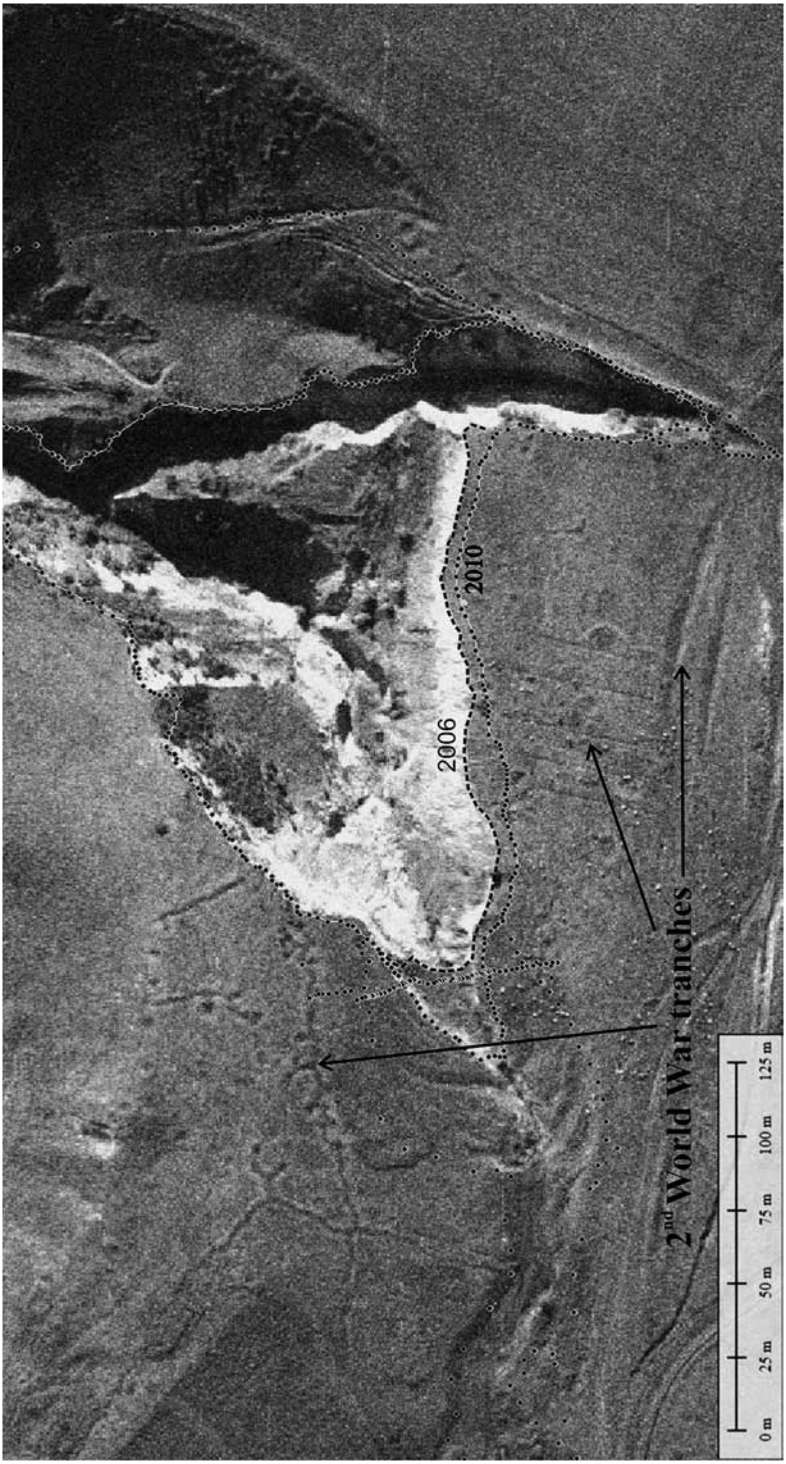

Fig. 8. Spatial distribution of the ditches during the Second World War around the Cucuteni gully.

Unfortunately, there is no prevention and protection plan for the gullies in the Moldavian Plateau. Thus, the evolution of these forms and their dynamics will register ample manifestation processes. In the given conditions, urgent protection measures must be taken because many gullies affect archaeological sites of national or international importance. This is why we propose a management plan for the Cucuteni gully, given that it has already destroyed half of the archaeological site dating from the Chalcolithic period of the Cucuteni culture.

The management plan proposition has as main purpose to reduce the advancement rate of the gully and to stabilize the slopes. The most important operation should ensure the rapid elimination of water from the system through channels.

By stabilizing the slope between the two gully edges, the ditches built by the Romanian Army during Second World War will be protected (fig. 8). Through their shape, the ditches take over a large amount of water that they carry afterwards through the friable deposits of the gully. In this case, there will be rapid land dislocations (fig. 9).

A very important measure of protection for the studied area aims to change the way the land is used (fig. 10). The area surrounding the archaeological site must be completely forested. Currently, it is mainly used for agriculture.

For the urgent vegetation of reclined slopes we recommend the stabilization with fascines and the plantation with draught-resistant greensward.

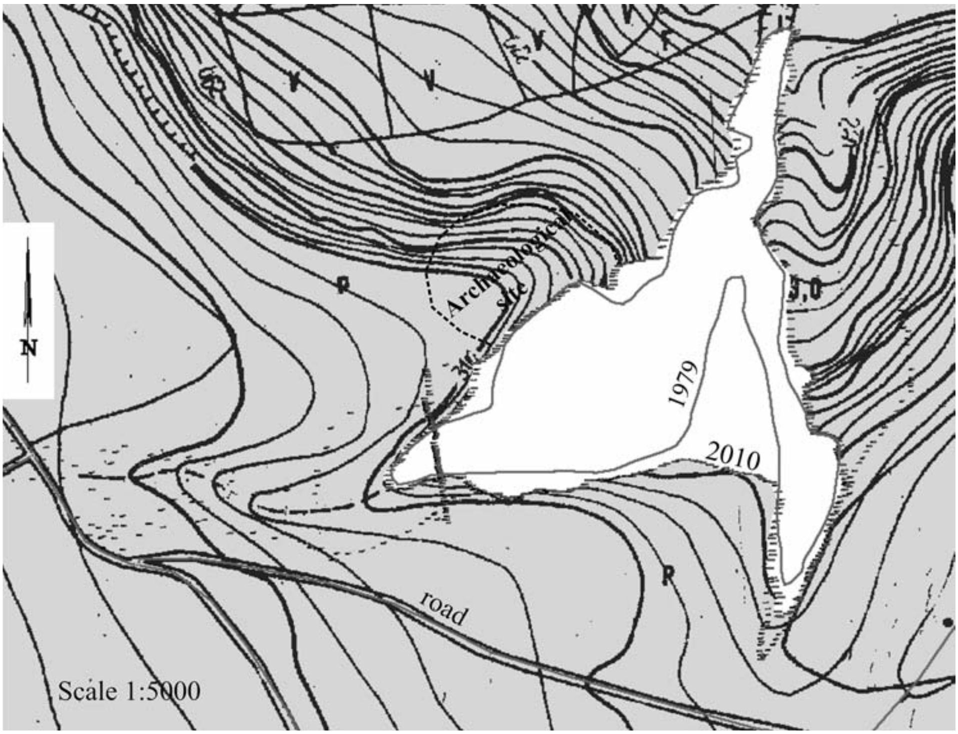

Fig. 9. Successive plans of the Cucuteni gully in the 1979–2010 period.

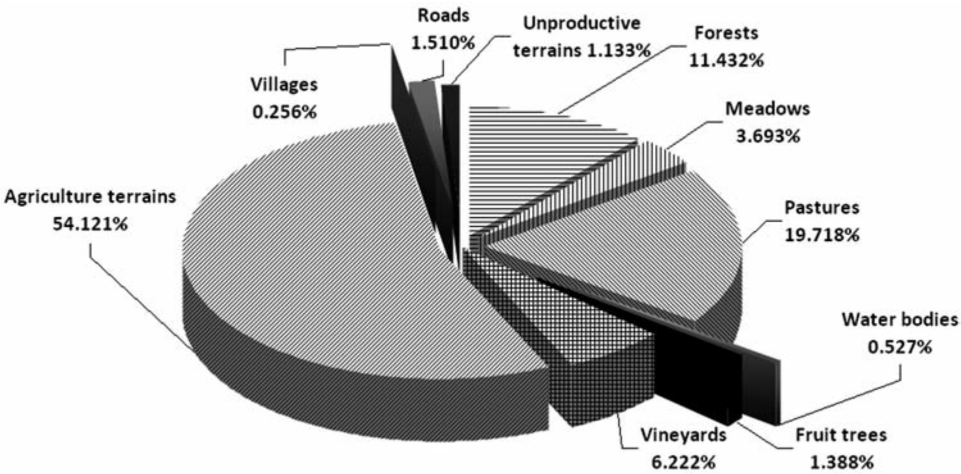

Fig. 10. Land use in the area of the Cucuteni gully.

5 *Conclusions*

The Cucuteni gully is representative for landforms dominated by friable rocks and steep slope. This is why the average advancement rate is high, in comparison to that of the whole plateau.

The settlements of the Chalcolithic period were placed on the edge of slopes or on the inter-river promontories. Around 5,000–6,000 years ago, the forestation degree was high, and there was no gully erosion. After the big deforestation periods and mostly after 1990, when the meteorological risk phenomena (pouring rains) intensified, there has been an intense gully erosion process and a higher degree of advancement concerning the old ones. This is why most archaeological sites situated on inter-river promontories or on the current banks of the Moldavian rivers are affected by gully erosion.

In order to preserve the archaeological site of national and international importance, we need management measures for the Cucuteni gully. Unfortunately, the decision-making factors delay these measures there are no projects or financial funds for it.

The most effective measure, with immediate applicability and maximum efficiency is to extend the forested areas. In this way, we can radically reduce the surface leaking.

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