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Hillslope scale effects of cropland abandonment on gully development: an example from Central Italy

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Abstract: This paper is focused on the quantification of the effects of cropland abandonment on gully development and denudation rates for a sample hillslope of Central Italy that underwent cropland abandonment, located within the Tevere River Basin. This goal is pursued by the integration of different erosion monitoring and estimation techniques: the application of DGPS surveys let us estimating the erosion rate since agricultural practices were interrupted (30 years ago) and the traditional erosion monitoring technique with pins was applied during two years in order to validate DGPS survey results and comprehend the dynamics of geomorphic processes affecting the considered denudation hot spot. The investigations proved that cropland abandonment provoked an intensification of erosion rate in the study area, as already observed in other sites of the Mediterranean region. Moreover this work contributes to the comprehension of the applicability of DGPS surveys to compute erosion rates for fairly large time-spans.

Keywords: badlands, soil erosion monitoring, DGPS survey, human impact, central Italy

Introduction

In the Mediterranean region, severe slope denudation is one of the most important environmental problems. Particularly, water erosion is pervasive in central Italy, due to extensive clayey outcrops, current climatic conditions and rapid uplift. Human impact significantly affects the development of denudational processes, since deforestation, grazing and farming are among the most important triggers for accelerated water erosion, tillage erosion and gravitational movements on slopes (Della Seta et al. 2009 and references therein). Ephemeral gullies (Foster 1986) are often recognizable in croplands, and grow rapidly as a consequence of concentrated rainfall. Moreover, the effects of farming may become stronger if land-use changes determine cropland abandonment (Romero-Díaz et al. 2007).

This work aimed at quantifying the effects of cropland abandonment on gully development and denudation rates for an experimental hillslope of Central Italy, through erosion pins and Differential GPS (DGPS) monitoring.

Study area

The experimental hillslope (Bargiano site, Fig. 1) is located within the Tevere River Basin, in Umbria (Central Italy). The morphostructures of the Apennine orogenic wedge (Oligocene to Tortonian) were cut by several NW-SE striking normal faults, which define a system of horst and graben affecting the Tyrrhenian margin of the Italian peninsula (Baldi et al. 1994; Carmignani et al. 1994). Most of the graben depressions were filled up by a Plio-Pleistocene sequence of marine deposits, successively uplifted up to several hundred of meters above the present sea level. These deposits consist of lithological units particularly prone to denudation (Fig. 1).

Mean rainfall (1,328 mm yr^{-1} over 84.5 rainy days) is above the national average (970 mm yr^{-1}) and seasonal distribution shows the maximum concentration in autumn (418 mm over 18.5 rainy days) with a secondary peak in the spring season. The minimum rainfall is recorded in July and the mean annual temperature is 14.3°C, with autumn season slightly warmer than spring (mean seasonal temperature is respectively 20°C and 17°C).

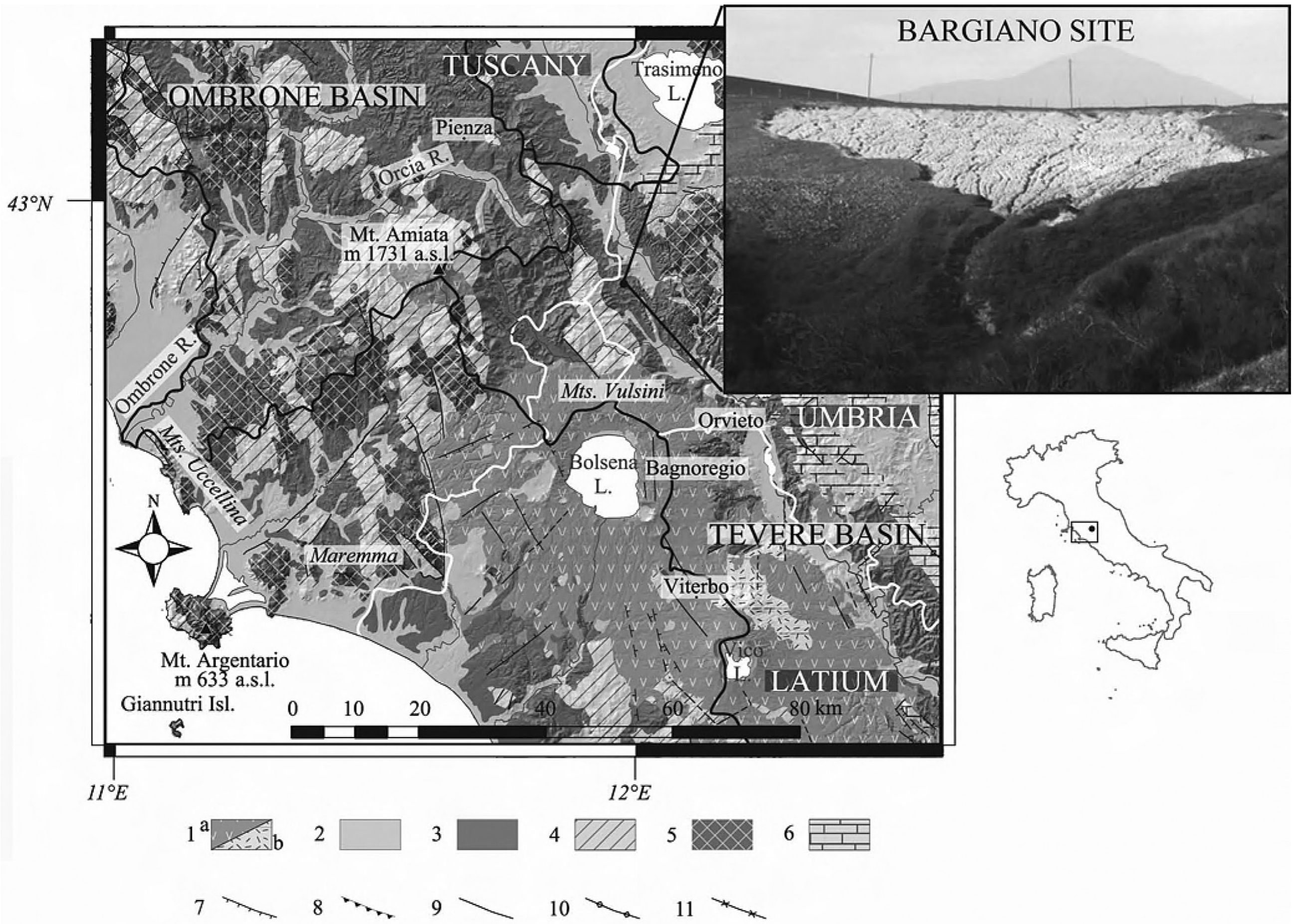


Fig 1. Geological sketch of the study area and location of the experimental hillslope (Bargiano site)
a – Quaternary silica undersaturated to intermediate volcanic rocks; 1b – Quaternary (and subordinate Pliocene) acid volcanic rocks; 2 – Quaternary undifferentiated continental deposits; 3 – Plio-Pleistocene terrigenous marine deposits and Messinian evaporites; 4 – sedimentary and metamorphic units of Ligurian and sub-Ligurian nappes (Trias to Lower Cretaceous); 5 – sedimentary and metamorphic units of Tuscan nappe (Paleozoic to Miocene); 6 – Umbria–Marche sedimentary sequence (Trias to Tortonian); 7 – normal fault; 8 – overthrust and reverse fault; 9 – undetermined fault; 10 – axis of anticline; 11 – axis of syncline

The experimental site of Bargiano consists of a gently dipping slope with an extent of about 4,300 m^2. Up to the ’60 it was part of a *calanchi* badlands slope, successively levelled for agricultural purposes (cereal crop). In 1980 the cropland was abandoned, with the consequence of a very rapid development of a close net of meandering rills and gullies, with a parallel geometry that follows the maximum slope direction (Fig. 1). The site appears as a miniature catchment where it is possible to study the dynamics of surface processes, such as splash erosion, runoff, rill and gully evolution, and landsliding. According to Romero-Díaz et al. (2007), piping generaly acts as dominating process since the cropland abandonment. In Bargiano, most of the observed channels show evidence of being collapsed tunnels. Gravitational movements work together with water erosion, especially on the steep slopes of the most incised gullies, determining continuous modifications of the dynamic equilibrium between erosion and deposition.

Methods

Two methods for direct monitoring of denudation at the hillslope scale have been applied at Bargiano site:

a) erosion pins for measuring uphill, downdale (Δy) and lateral (Δx) changes in the ground level at rill and inter-rill positions;
b) DGPS survey to sample the remnants of the 1980 cropland surface and the present (eroded) surface, in order to perform volumetric estimation of the eroded material.

Iron pins

24 iron pins were placed at different depths, in order to cross the weathered horizon (Del Monte 2003, Della Seta et al. 2007, 2009), most of them recording ground level changes since January 2008. They were placed along two rills and along the major gully the rills are flowing into (Fig. 2). Each monitoring point

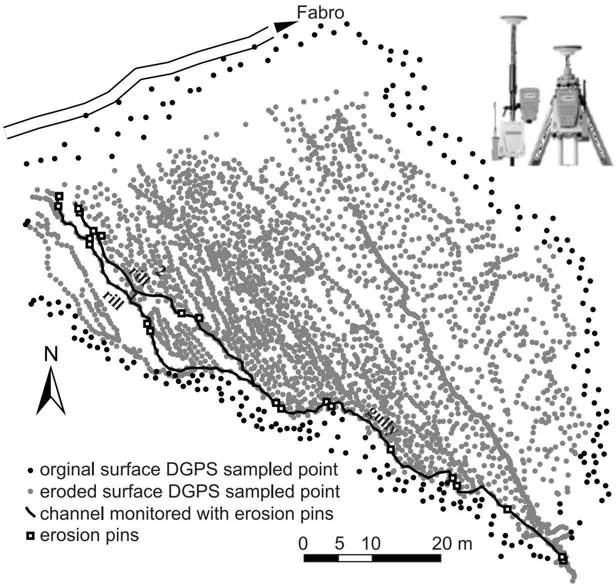


Fig. 2. Location of DGPS sampled points: on the remnant of the original surface (black) and on the eroded surface (gray). The channels monitored with erosion pins are evidenced with the black lines

consists of two pins, one placed in inter-rill position (pin type: A), the other one within the channel (pin type: B).

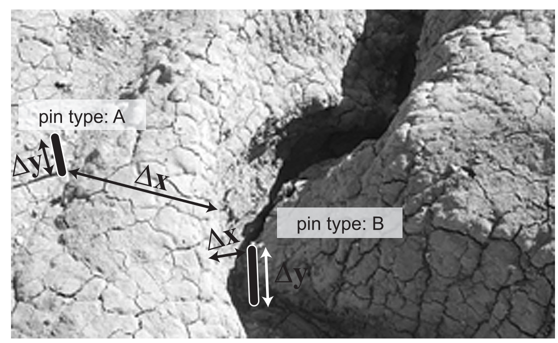
DGPS Survey

DGPS survey was performed using a Leica GPS 1200 instrument. We sampled point from the remnants of the original 1980 cropland surface and from the eroded surface using the right sampling density for recording the roughness of the surfaces (Fig. 2). Through geostatistical interpolation (Universal Kriging) performed in GIS environment we obtained the reconstruction of both the original and eroded surfaces. We chose the Kriging method since it is an exact interpolator. Moreover it takes into account both autocorrelation of the considered variable (elevation in this case) and spatial relationships between measured values around unknown point, when assigning weights to measured points (Cressie 1990 and references therein).

Once the DEMs of the original and eroded surfaces have been obtained, we performed the raster difference. Each pixel in the new output raster records the height difference between the original and eroded surfaces. As the pixel dimension is known (0.3 × 0.3 m), we derived the volume of eroded material in the considered 30 years time-span.

Results

During the period of erosion pin monitoring (21 months), a progressive removal of clayey material from the slope by surface running waters was recorded. In particular, a regular ground surface lowering at the inter-rill erosion pins (type A) as indicated in Figure 3 was observed. This is in agreement with the erosion/accumulation dynamics, giving a rise to progressive removal of material where the lonely surface running water is acting (inter-rill). Spring rainfall over water saturated clayey deposits favored the runoff power and caused accumulation just locally, even on the inter-rill surface, as indicated in Figure 3. Erosion pins placed within rills and gullies (type B) typically show positive and negative oscillation of ground level, as a consequence of the combination of strong incision and accumulation,



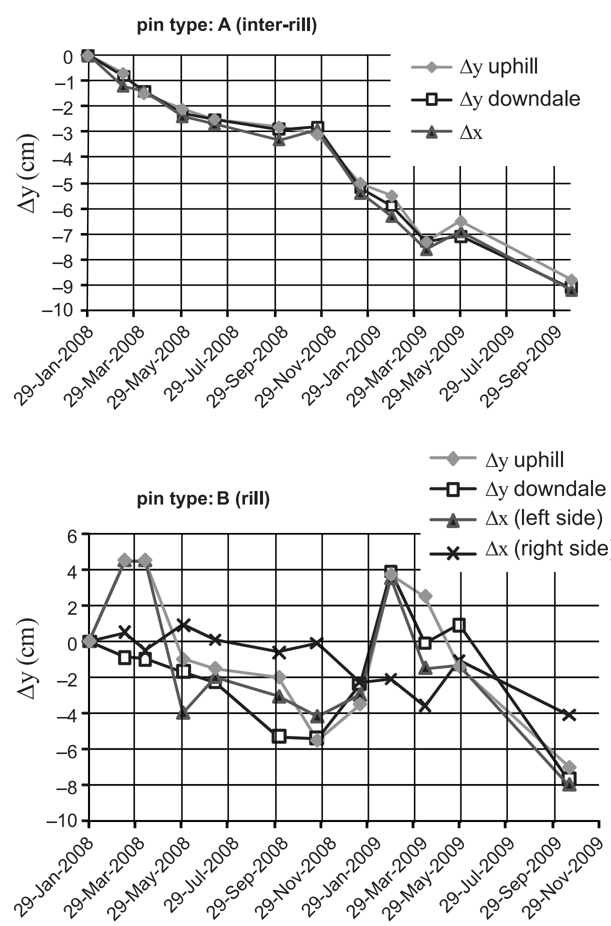


Fig. 3. Examples of inter-rill (type A) and rill (type B) pins and corresponding denudation graphs covering the monitoring time-span

Table 1. Mean annual denudation rates obtained from erosion pin record over the first 21 months of monitoring. Negative and positive rates indicate respectively net erosion and net accumulation

	Mean annual denudation rate [cm]		
	rill/gully	inter-rill	total
Rill 1	–1.57	–3.87	–2.72
Rill 2	–1.02	–4.26	–2.64
Gully	+5.06	–3.18	+1.63
Total	+2.13	–3.66	–0.52

the latter mainly ascribed to the collapsing of gully slopes or piping tunnels. Small falls or overturning of the channel sidewall frequently occurred within the deepest channels, mainly in conjunction with spring rainfall.

Table 1 summarizes the mean annual denudation rates of ground level changes for each of the two considered rills and for the gully they flow into. Upper slope area (RILL 1 and RILL 2) clearly underwent the maximum net erosion of 4.26 cm yr^{-1} (inter-rill) and net erosion was recorded even within rills. On the other hand, within the channel of the monitored gully, located down slope, the maximum net accumulation of 5.06 cm yr^{-1} was recorded, while the inter-rill areas underwent net erosion, even if slightly lower than in the upper slope inter-rill area. Thus total mean denudation rates indicate net accumulation within rills of 2.13 cm yr^{-1} and net erosion on inter-rills of 3.66 cm yr^{-1}, with a resulting general net erosion rate of 0.52 cm yr^{-1}.

Figure 4 shows the raster outputs of DGPS sampled points interpolations. The reconstructed 1980 cropland is, as expected, a smoothed, gently shelving surface (Fig. 4a). The present day eroded surface is, on the contrary, well represented with its close net of semi-parallel rills flowing into deep gullies located down slope (Fig. 4b).

The calculated volume of removed material over the 30 years time-span is 3,971.39 m^3. Considering the bulk density of clay (about 2 t m^{-3}) the removed materials amount to 7,942.78 t over 30 years. Thus the mean annual denudation rate is about 8,1015.91 t km^{-2} yr^{-1}. Taking into account the extent of the experimental hillslope, calculated erosion rate is about 121.5 cm over 30 years, that corresponds to a mean surface lowering rate of 4.05 cm yr^{-1}.

Conclusions

Mean annual erosion rate obtained through volumetric estimation from DGPS survey (81,015.91 t km^{-2} yr^{-1}) is a very high value that reflects the strongly accelerated erosion on the Bargiano experimental hillslope. The corresponding mean surface lowering rate of 4.05 cm yr^{-1} is not comparable to the total mean value obtained by erosion pin records. Nevertheless this discrepancy may be discussed as follows:

a) erosion pins were places, up to now, just on a limited portion of the hillslope, thus the obtained mean denudation rates could be not representative of the whole site, while DGPS survey was performed on the entire site surface;
b) the gully monitored with pins is located close to the major scarp delimiting the boundary between the original and the eroded surface. This scarp is particularly steep and high, thus experiencing frequent landsliding that on the whole contribute to strong net accumulation within the channel. This influences, obviously, the total mean denudation rate, with respect to the ones obtained separately for rill and inter-rill areas. Moreover, the inter-rill area (where net erosion systematically occurs) is, on the whole, more extended than the

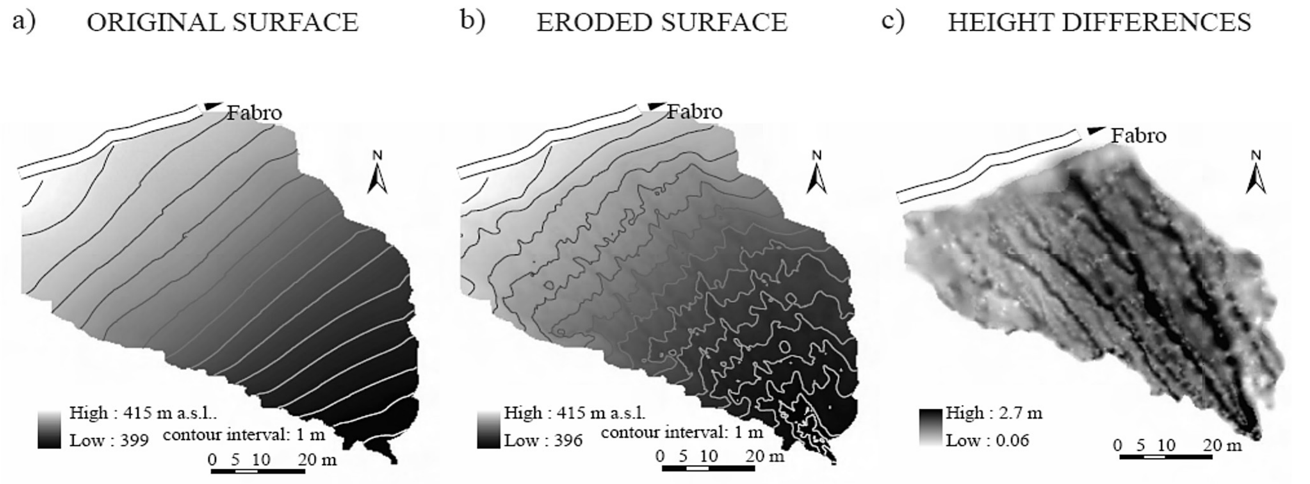


Fig. 4. Original (a) and eroded (b) surfaces of Bargiano experimental hillslope site, from the geostatistical interpolation of DGPS sampled points. Raster difference between these surfaces produced a new raster representing height differences (c)

rill area, even if in the averages we obtained they have the same weight since we placed the same number of rill and inter-rill pins;

c) the initial strong cutting rate might have progressively decreased, even as a consequence of increasing partial accumulation down slope of materials removed from uphill or as a consequence of the decrease of powerful rainfall events;
d) last but not least, the erosion pin monitoring was performed, up to now, over a considerably short time-span. Thus the observations at pins, even if providing detailed information about the acting processes, cannot be significant for the 30 years period over which the volumetric estimation of eroded material was performed.

Nevertheless, if we consider the inter-rill pin data, it must be outlined that the net erosion rates recorded over the 2008/2009 monitoring are not so far from the mean erosion rates over the last 30 years.

The mean annual erosion rate obtained through volumetric estimation is within the range of values estimated for many other catchments of central Italy, especially those widely affected by "erosion hot spots" (i.e. badlands; Ciccacci et al. 1992, 2003, 2008, Del Monte et al. 2002, Della Seta et al. 2007, 2009).

In this context, the extremely high erosion rate obtained for Bargiano experimental hillslope site indicates a very fast development of denudational landforms, as a consequence of cropland abandonment. This case provides an example of the quantification of the dangerous effects of human impact in terms of land degradation.

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