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Gully geometry: what are we measuring?

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Abstract

Many of the researches on (ephemeral) gully erosion comprise the determination of the geometry of these eroded channels specially width and depth. This is not a simple task due to uncertainty generated by the wide range of variability of gully cross-section shape found in the field. However in the literature this uncertainty is not recognized and then no criteria in the measurement procedure is indicated. The aim of this work is to make the researchers aware of the ambiguity that arises when characterizing the geometry of an ephemeral gully and similar eroded channels. Besides, a measurement protocol is proposed with the ultimate goal of pooling criteria in future works. It is suggested to characterize the geometry of a gully through its effective width and effective depth, which, together with its length, define an "equivalent prismatic gully" (EPG). The latter would facilitate the comparison between each other of different gullies.

1 Introduction

The classic forms of water erosion are caused by non-concentrated or laminar flow and concentrated flow; in the latter, rill and gully erosion has been recognized (Hutchinson and Pritchard, 1976). Also, permanent gullies are distinguished from ephemeral ones (Foster, 1986; Thorne et al., 1986; Casalí et al., 1999). Rill erosion is produced in the form of numerous channels of a few centimeters in depth, distributed uniformly and randomly over sloping lands (Soil Science Society of America, 2015) and which can easily be obliterated by conventional tillage (Hutchinson and Pritchard, 1976). Permanent gullies are erosion channels which are too large to be eliminated by conventional tillage (Soil Science Society of America, 2015). Ephemeral gullies – present in agricultural soils – are, like rills, small enough for it to be possible to eliminate them by traditional tillage (Soil Science Society of America, 2015), hence their being qualified as ephemeral. However, when they form again, and contrary to what is observed in rills, they tend to appear in the same places. This is explained by the fact that the

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ephemeral gullies are formed in the thalweg which configures the confluence of two opposing slopes, a fact which conditions the trajectory of the runoff. Rills, however, occur entirely on one single slope (Casalí et al., 1999). Their formation is, therefore, mainly subjected to the high spatial variability of intrinsic factors of the soil (structural stability, hydraulic conductivity, etc.) and of its tillage.

The objectives of a large number of works on gully erosion have been the estimation of the spatial and/or temporal evolution of a gully or a network of them under different conditions (i.e. climate, land use, etc.) (e.g., Casalí et al., 2006; Gabet and Bookter, 2008; Campo-Bescós et al., 2013). For that purpose, as a first step, a morphological characterization is made of these channels. The most frequent way to do so is by the measurement of their width and depth – and the quotient between both parameters – (e.g., Giménez et al., 2009); and their typology is also studied (for example, whether their cross section presents a general shape like a U or a V). If the measurement of the length of the gully is added to this, it might be possible to arrive at determining their volume (eroded soil).

It is in this way that, for a precise description of the geometry of a gully, the correct determination of its width is a key factor. This is not always an easy task, especially when faced with cross sections with intricate shapes and diffuse limits. However, in the numerous scientific works existing on the subject, no uncertainty whatever is expressed on this measurement, and neither are the criteria followed in the procedure specified. We believe that, as a general rule, it is usually assumed that the width is defined by the imaginary line whose ends are located at both points of the two banks, where an abrupt change in slope is manifested. This criterion would be followed both in direct measurements in situ, and in indirect ones taken from digital elevation models and mathematic algorithms ad hoc (e.g., Evans and Lindsay, 2010; Parker et al., 2012; Castillo et al., 2014). This procedure, at first sight reasonable and unquestionable, has, however, two objections. First, the presence of more than one point of slope inflection in one or both banks. Second, although only one visible inflection point is presented in the slope of each bank – with the width of the channel thus being clearly defined – this

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poses a question. Do the limits of this channel, defined in this way, really correspond to the transversal limits of the erosive process which gave rise to the gully? Only by knowing the topography of the land at moments before the formation of the gully would that question be answered with any certainty.

On the other hand, the width of a gully defines the upper limit of its cross section, therefore conditioning the subsequent determination of the depth of that channel. Furthermore, in this latter measurement (depth of the gully), another important ambiguity is added, i.e. the determination of the lower limit of the cross section (channel bed). This latter limit is usually located – in our belief – at the lowest point of the cross section, which is questionable in beds with a highly irregular cross sectional profile. Even so, nor is the difficulty inherent in measuring a gully depth usually emphasized in the literature.

In short, the lack of any protocol or universal criterion in determining the geometry of gullies would then raise a certain uncertainty at the moment of comparing between each other the experimental results obtained by different researchers; for example, erosion rate values.

In this work it is sought to make the scientific community aware of the – precisely, inadvertent doubts – which are triggered when characterizing the geometry of an ephemeral gully, and for this purpose some examples of real cases will be shown. Also, a measurement protocol is proposed with the ultimate aim of pooling criteria in future works and experimentation. Although they are proposed for ephemeral gullies, these same criteria would equally apply for similar erosion channels.

2 Uncertainties in measuring the width and depth of a gully

Researchers, especially newcomers, when confronted with the measurement of gully geometry, assume that the limits of the erosion channel will present themselves in the field as being clearly defined, and, in fact, this is often true (see Fig. 1.1–1.3). However, on many occasions this is not the case (Fig. 1.4–1.6). It is therefore possible that a clear break in the slope of one of the banks (Fig. 1.6) or in both of them (Fig. 1.5) may not be noticed. Another possible ambiguity – independent or added to the previous one – is that which arises when both banks of the channel are uneven (Fig. 1.4, 1.6). This means that determining a single height value to trace an imaginary horizontal line between both banks is highly subjective. It is understood that the length of this line would be defining the width of the cross section that is being measured.

In another sense, when defining the depth of a gully, the lower limit of the cross section is usually well defined by the lowest point of the bed (see Fig. 1.2). However, what usually happens is that the location of this limit is also controversial as can be seen in the cross sections in Figs. 1.1 and 1.3, where it is precisely not clear if this limit would really be represented by the lower height of the bed.

An incorrect determination of the width and/or depth of a certain gully may cause (important) errors in the determination of its volume; i.e. in the estimation of the eroded soil (Figs. 2 and 3). The magnitude of this potential experimental error would be less obvious, and even underestimated, if we analyze the cross sections individually (Fig. 2). However, an overall review of all the sections conforming the gully being studied would give a better assessment of this measurement error (Fig. 3; see the remarkable difference in volume estimated, almost 100 %, depending on the width determination).

3 Topographic definition of gully width, equivalent prismatic gully (EPG)

Let‘s suppose that we have a detailed digital elevation model (DEM) of a gully whose geometry we wish to determine (Fig. 4a). Similarly, we would also have a DEM, not more than one year old, of the same area, but before the gully in question would have been formed. Remember that the cycle of the formation and obliteration of an ephemeral gully is conditioned by the periodicity (usually one year) of the agricultural tillage responsible for it. We shall call the DEM prior to the appearance of the gully $\text{DEM}_{\text{year}\,n}$, whereas that of the following year – that is, with the gully now present – $\text{DEM}_{\text{year}\,n+1}$ (Fig. 4a).

Let's imagine now that, at any point x along the longitudinal axis of length L of the gully, we draw a vertical plane P_x, perpendicular to that axis (Fig. 4b). If in this plane P_x we substract the $\text{DEM}_{\text{year}\,n+1}$ from the $\text{DEM}_{\text{year}\,n}$, we should obtain the eroded area or cross section of the gully (Fig. 4b). Now, the imaginary line which arises from joining the two points of the intersection of both DEMs would define, in turn, the width of the gully in that section (P_x) (Fig. 4b). In case both points are uneven, a horizontal projection of the line should be considered. This same operation could be repeated in a multitude of other points x_i along the channel, thus obtaining the two width values of each new section (W_i). Finally, the average of the values W_i would define the effective width of the whole gully, W_e. Those widths, determined thus, would undoubtedly be the true transversal limit of the erosion process which caused the gully in question.

If we now carry out the subtraction of both DEMs but on their entire surface, we should obtain the volume V of the gully (Fig. 4a).

Also, knowing V and W_e, we could, in turn, determine an effective depth D_e expressed as:

$$D_\text{e} = V/(W_\text{e} L). \tag{1}$$

This depth value would be more representative of the whole gully than that resulting from considering the minimum height of the bed as the lower limit of the cross section (see above).

Finally, the gully could be represented as a rectangular-based prism ($W_\text{e} D_\text{e}$) of a length L, which we would call "equivalent prismatic gully" (EPG) (Figs. 4c and 5). This sort of normalization of the complex geometry of a certain gully –by means of its respective EPG– would permit, for example, a quick visual comparison of the individuals of a varied population(s) of gullies (Fig. 5). It would thus be an interesting tool for incorporating into simulation models (e.g., AnnAGNPS, Gordon et al., 2007).

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4 Conclusions

Gully erosion, especially ephemeral gullies, has been studied with increasing interest for the past few decades. However, there is currently no general consensus on such basic aspects as the correct determination of the geometry (width and depth) of these erosion channels. Furthermore, and curiously, the uncertainty or conflict of criteria when taking measurements is not even usually recognized, when in fact this operation is at least dubious. This present work seeks to show up this inadvertent uncertainty. It is proposed to characterize the geometry of a gully through its effective width and effective depth, which, together with its length, would permit the definition of an equivalent prismatic gully (EPG). The latter would facilitate the comparison between each other of different gullies, aside from their complex and varied real geometry.

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References

Campo, M. A., Flores-Cervantes, J. H., Bras, R. L., Casalí, J., and Giráldez, J. V.: Evaluation of a gully headcut retreat model using multitemporal aerial photographs and digital elevation models, J. Geophys. Res.-Earth, 118, 1–15, 2013.

Casalí, J., López, J. J., and Giráldez, J. V.: Ephemeral gully erosion in southern Navarra (Spain), Catena, 36, 65–84, 1999.

Casalí, J., Loizu, J., Campo, M. A., De Santisteban, L. M., and Álvarez-Mozos, J.: Accuracy of methods for field assessment of rill and ephemeral gully erosion, Catena, 67, 128–138, 2006.

Castillo, C., Taguas, E. V., Zarco-Tejada, P., James, M. R., and Gómez, J. A.: The normalized topographic method: An automated procedure for gully mapping using GIS, Earth Surf. Proc. Land., 39, 2002–2015, 2014.

Evans, M. and Lindsay, J.: High resolution quantification of gully erosion in upland peatlands at the landscape scale, Earth Surf. Proc. Land., 35, 876–886, 2010.

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Foster, G. R.: Understanding ephemeral gully erosion, in: Soil Conservation, Assessing the National Resources Inventory 2. Committee on Conservation Needs and Opportunities, Board of Agriculture, National Research Council, National Academy Press, Washington: 90–125, 1986.
Gabet, E. J. and Bookter, A.: A morphometric analysis of gullies scoured by post-fire progressively bulked debris flows in southwest Montana, USA, Geomorphology, 96, 298–309, 2008.
Giménez, R., Marzolff, I., Campo, M. A., Seeger, M., Ries, J. B., Casalí, J., and Álvarez-Mozos, J.: Accuracy of high-resolution photogrammetric measurements of gullies with contrasting morphology, Earth Surf. Proc. Land., 34, 1915–1926, 2009.
Gordon, L. M., Bennett, S. J., Bingner, R. L., Theurer, F. D., and Alonso, C. V.: Simulating ephemeral gully erosion in AnnAGNPS, Transactions of the American Society of Agricultural and Biological Engineers, 50, 857–866, 2007.
Hutchinson, D. E. and Pritchard, H. W.: Resource conservation glossary, J. Soil Water Conserv., 31, 1–63, 1976.
Parker, C., Clifford, N. J., and Thorne, C. R.: Automatic delineation of functional river reach boundaries for river research and applications, River Res. Appl., 28, 1708–1725, 2012.
Soil Science Society of America: Glossary of Soil Science Terms, Soils Science Society of America, Madison, WI, available at: https://www.soils.org/publications/soils-glossary# (last access: 24 March 2015), 2015.
Thorne C. R., Zevenbergen, L. W., Grissinger, E. H., and Murphey, J. B.: Ephemeral gullies as sources of sediment, Proceedings of the Fourth Federal Interagency Sedimentation Conference, 1, 3.152–3.161, 1986.

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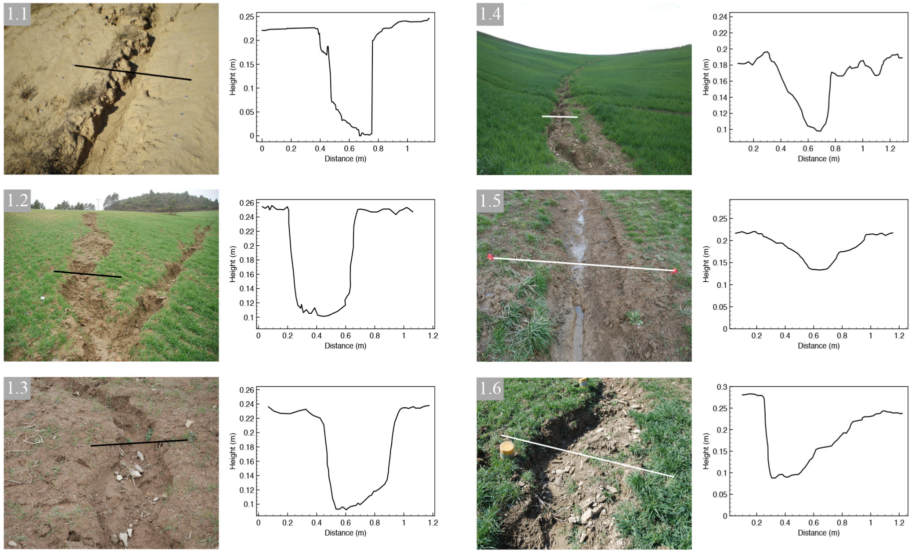

Figure 1. Examples of cross-sections of typical ephemeral gullies (Navarre, Spain).

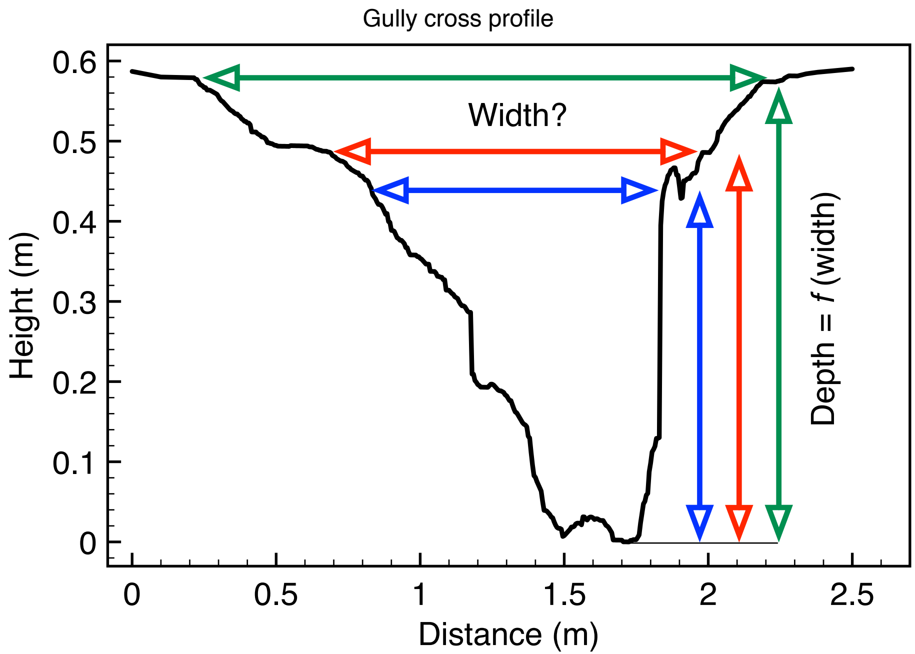

Figure 2. Uncertainty in the determination of a width in a cross-section of a gully (real example).

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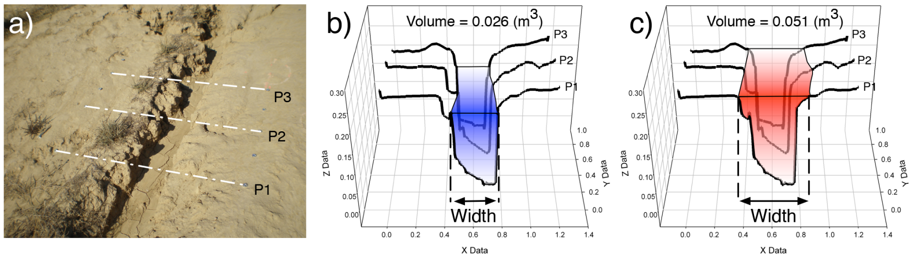

Figure 3. Determination of the volume of one ephemeral gully reach from three selected cross sections. Notice the difference in results depending on where the upper limit of the cross section (channel width) was located. See also Fig. 2.

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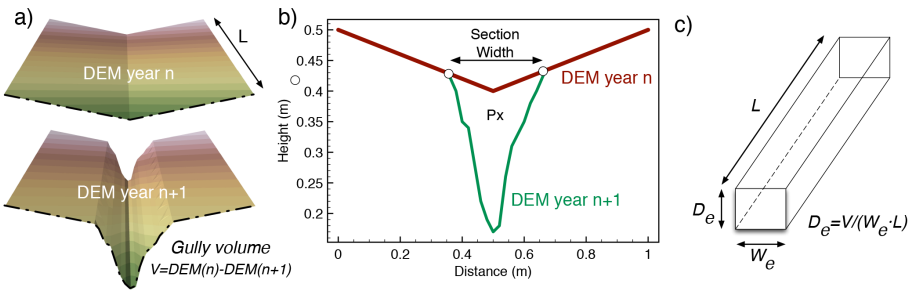

Figure 4. (a) Sketch of two separated digital elevation models of a fictitious plot before ($DEM_{year\ n}$) and after ($DEM_{year\ n+1}$) a gully has been formed in the plot thalweg; **(b)** sketch cross section area depicted at any point *x* along the longitudinal axis of the gully; **(c)** equivalent prismatic gully (EPG). See text for details.

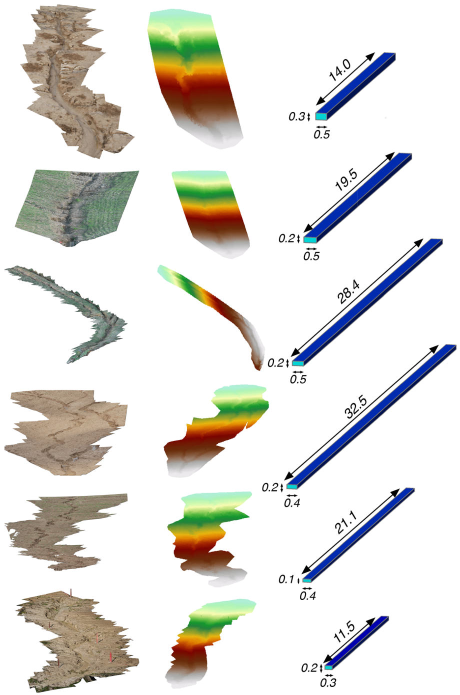

Figure 5. (Left) Pictures of ephemeral gullies of dierent shapes (Navarre, Spain); (center) digital elevation model ($DEM_{year\,n+1}$, see Fig. 4) of each gully; (right) equivalent prism of the gullies (since there was not available a DEM prior to the gully formation ($DEM_{year\,n}$, see Fig. 4) the width was arbitrary defined from abrupt changes at both gully banks (see text for more explanation). It should be made clear that the geometry of the equivalent prisms could have (dramatically) changed if we had counted also with the corresponding $DEM_{year\,n}$. (Lengths in m)

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