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Abstract: To properly assess soil erosion in agricultural areas, it is necessary to determine precisely the volume of ephemeral gullies and rills in the field by using direct measurement procedures. However, little information is available on the accuracy of the different methods used. The main purpose of this paper is to provide information for a suitable assessment of rill and ephemeral gully erosion with such direct measurement methods. To achieve this objective: a) the measurement errors associated to three methods used for field assessment of channel cross sectional areas are explored; b) the influence of the number of cross sections used per unit channel length on the assessment accuracy, is analysed and; c) the effect of the channel size and shape on measurement errors is examined. The three methods considered to

determine the cross sectional areas were: micro-topographic profile meter (1); detailed measurement of section characteristic lengths with a tape (2); measurement of cross section width and depth with a tape (3). Five reaches of different ephemeral gully types 14.0 or 30.0 m long and a set of six 20.4 to 29.4 m long rill reaches were selected. On each gully reach, the cross sectional areas were measured using the three above mentioned methods, with a separation (s) between cross sections of 1 m. For rills, the cross sectional areas were measured with methods 1 and 3, with s= 2 m. Then, the corresponding total erosion volumes were computed. The volume calculated with method 1 with s= 1 m for gullies and s= 2 m for rills was taken as the reference method. For each channel, and for each one of the possible combinations of s and measurement method (m), the relative measurement error and the absolute value of the relative measurement error (Ersm and |Ersm|), defined with respect to the reference one, was calculated. |Ersm| much higher than 10% were obtained very easily, even for small s values and for apparently quasi prismatic channels. Channel size and shape had a great influence on measurement errors. In fact, the selection of the more suitable method for a certain gully shape and size seemed to be much more important than s, at least when s< 10 m. Method 1 always provided the most precise measurements, and its results were the less dependent on s. However, s must be <5 m to guarantee an error smaller than 10%. Method 2 is not recommended, because it is difficult, time consuming and can lead to large errors. Method 3 seems to be enough for small, wide and shallow gullies, and for small rills, but only if s is shorter than 5 m. Results obtained after the analysis of rill measurement errors were similar to those of gullies. The analysis of Ersm and |Ersm| when calculating channel volumes using a unique representative cross section highlighted the importance of correctly selecting the adequate cross section. Due to the high error values that this method can entail, it is not considered as advisable whenever accurate erosion measurements are pursued.

Figure 1

Figure 2

Figure 3

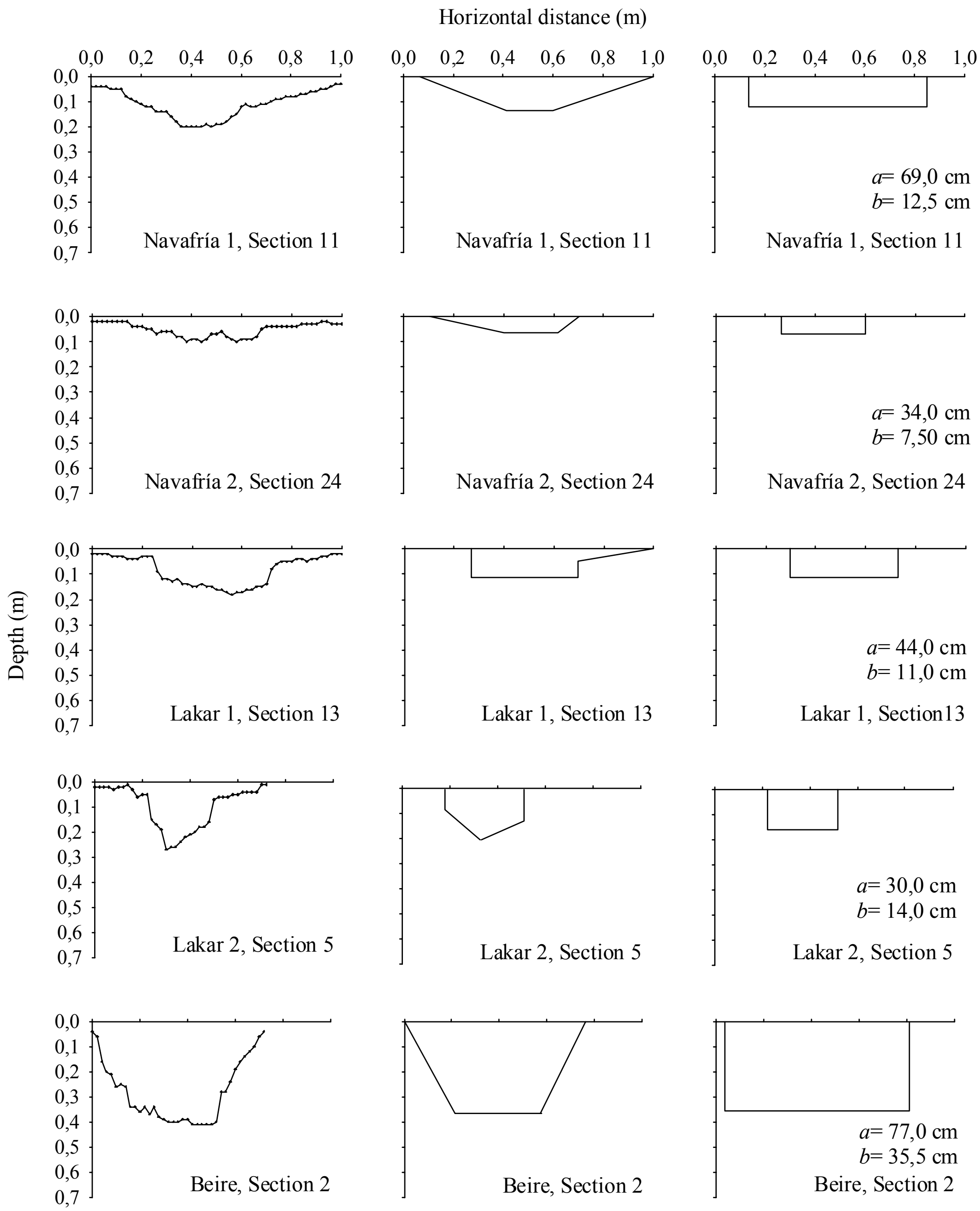

Horizontal distance (m)
Depth (m)
0,0 0,2 0,4 0,6 0,8 1,0
0,0 0,1 0,2 0,3 0,4 0,5 0,6 0,7
Navafría 1, Section 11
a= 69,0 cm
b= 12,5 cm
Navafría 2, Section 24
a= 34,0 cm
b= 7,50 cm
Lakar 1, Section 13
Lakar 1, Section13
a= 44,0 cm
b= 11,0 cm
Lakar 2, Section 5
a= 30,0 cm
b= 14,0 cm
Beire, Section 2
a= 77,0 cm
b= 35,5 cm

Figure 4

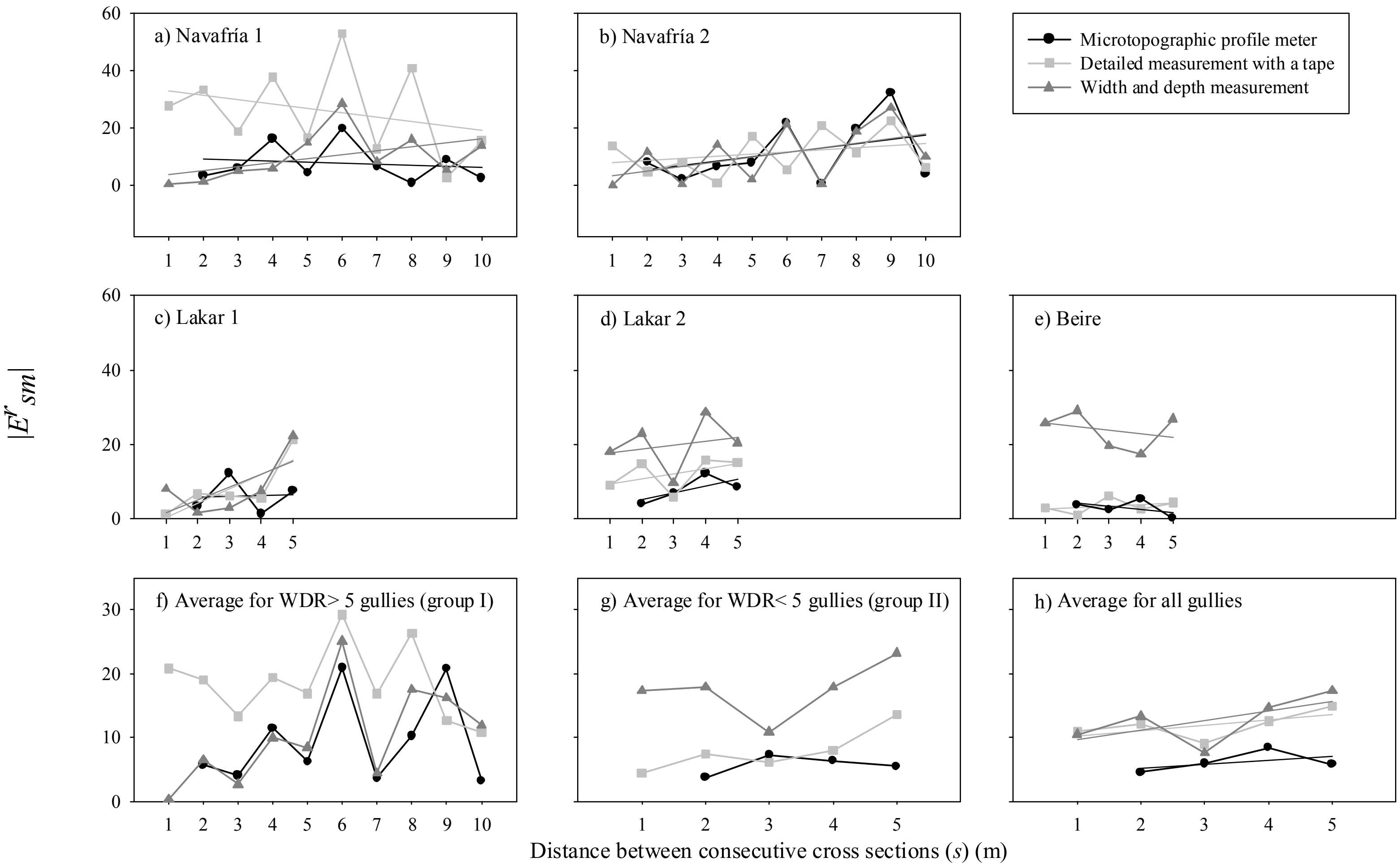
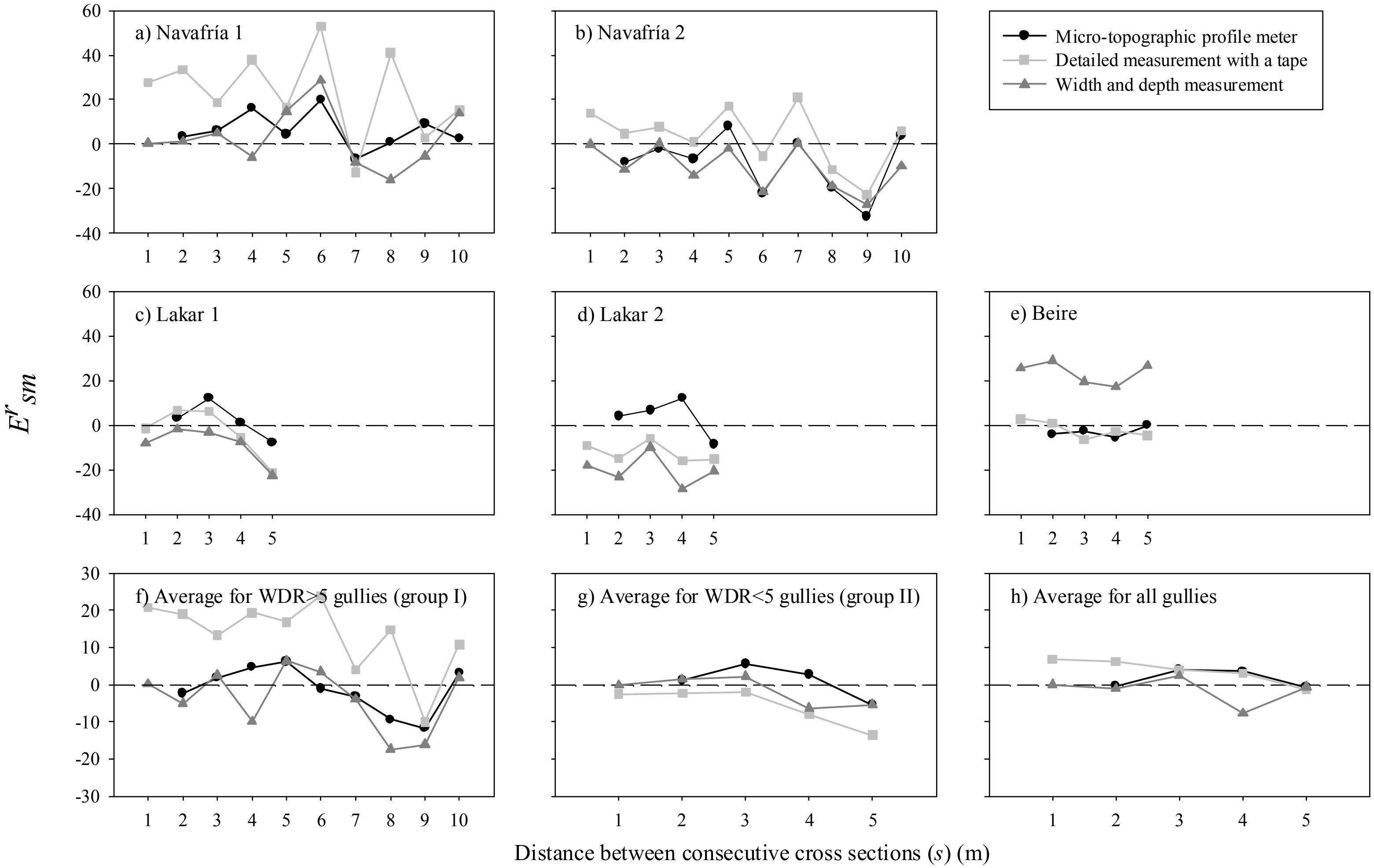
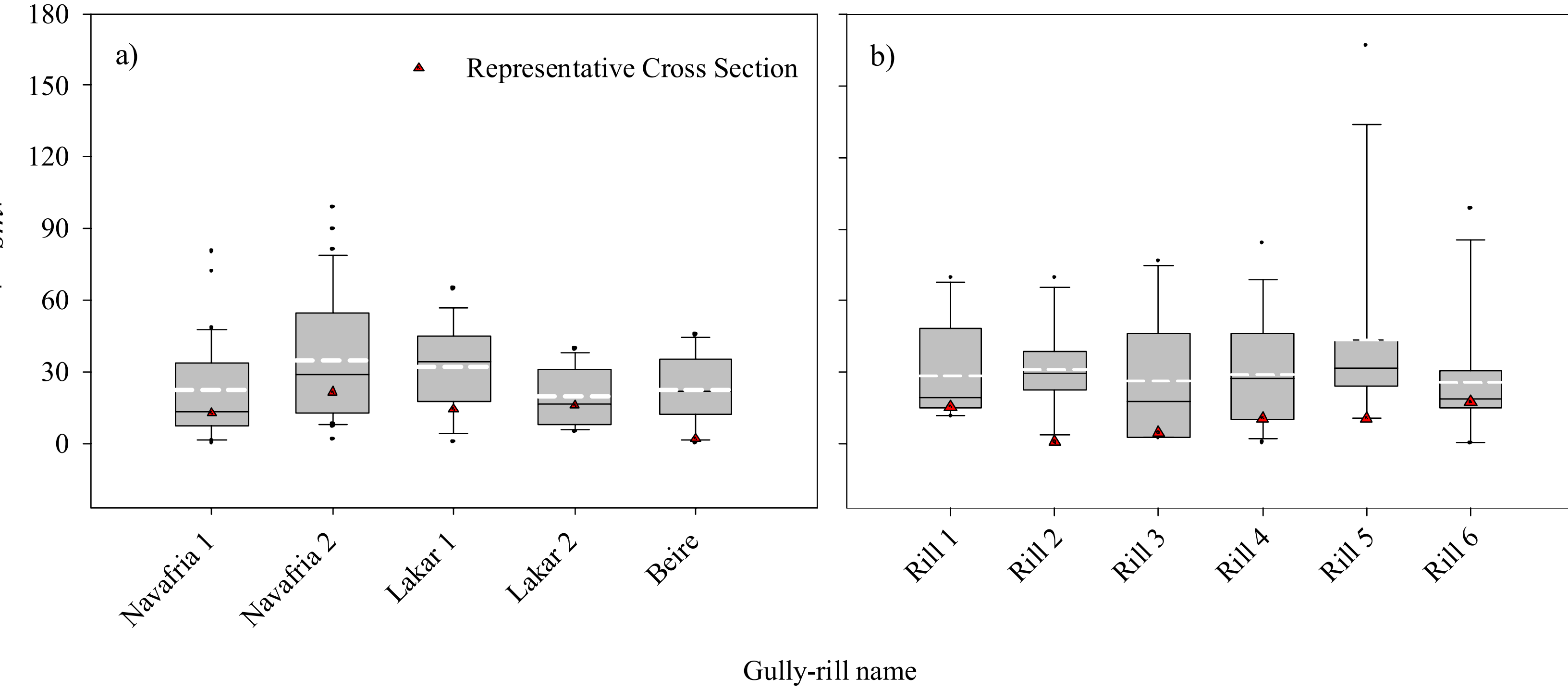

a) Navafría 1
b) Navafría 2
c) Lakar 1
d) Lakar 2
e) Beire
f) Average for WDR> 5 gullies (group I)
g) Average for WDR< 5 gullies (group II)
h) Average for all gullies
Microtopographic profile meter
Detailed measurement with a tape
Width and depth measurement
|E^r sm|
Distance between consecutive cross sections (s) (m)

Figure 5



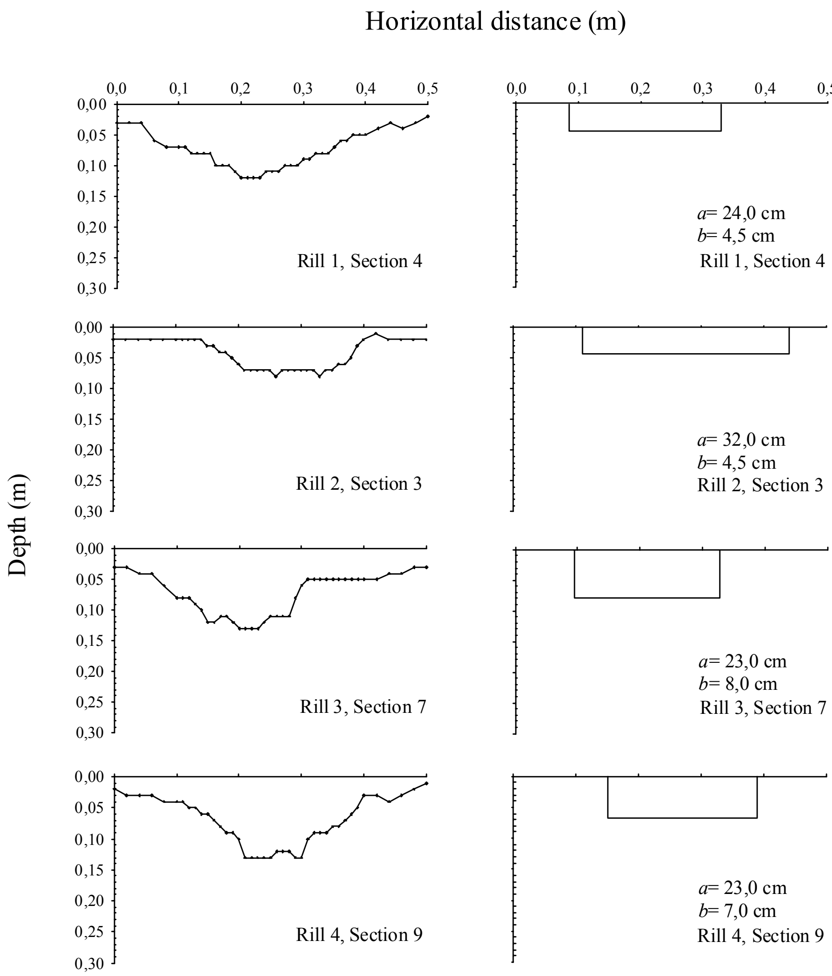
a) Navafría 1
b) Navafría 2
Micro-topographic profile meter
Detailed measurement with a tape
Width and depth measurement
c) Lakar 1
d) Lakar 2
e) Beire
f) Average for WDR>5 gullies (group I)
g) Average for WDR<5 gullies (group II)
h) Average for all gullies
E'sm
Distance between consecutive cross sections (s) (m)

Figure 6



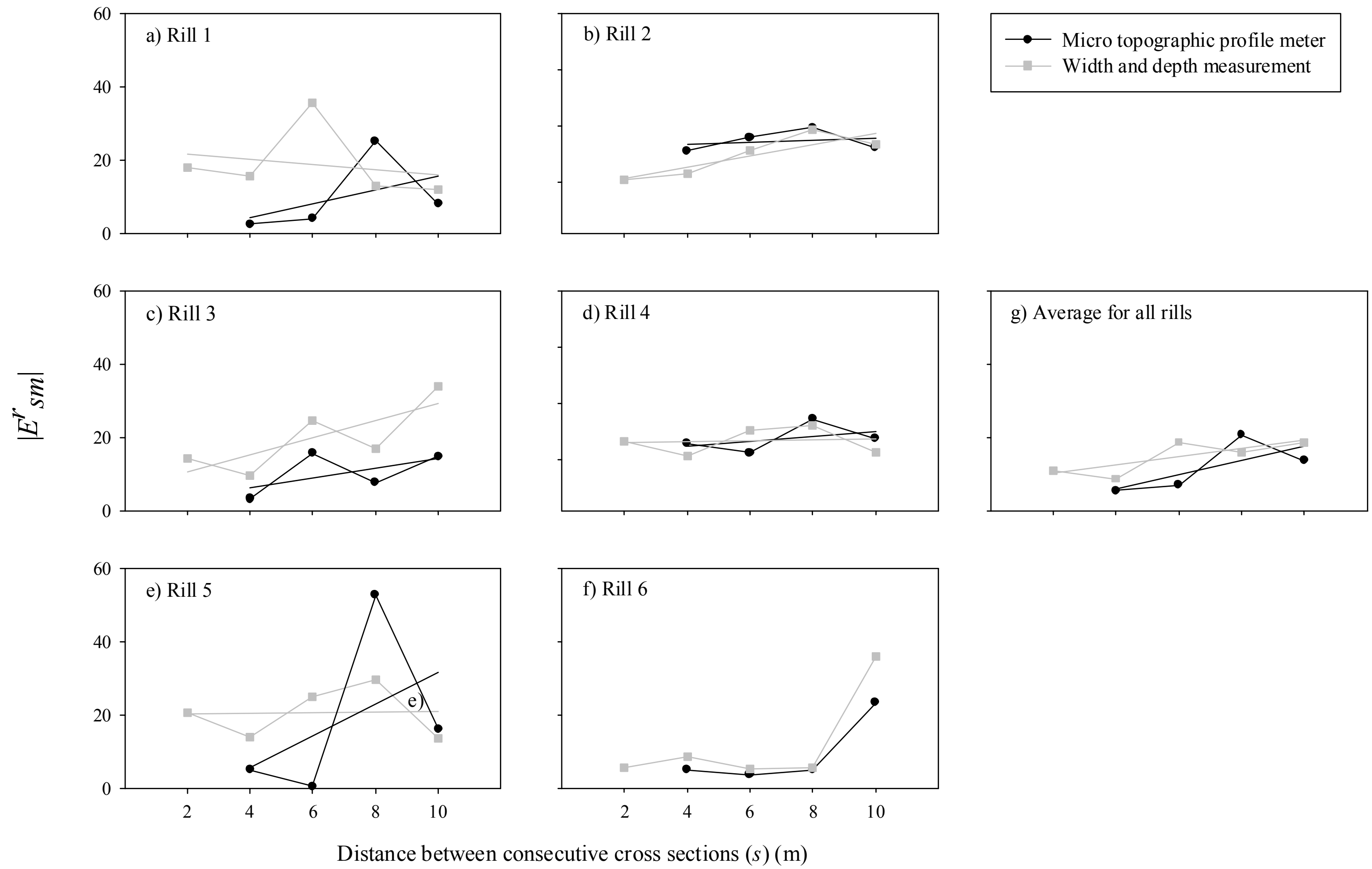
180
150
120
90
60
30
0
a)
Representative Cross Section
Navafria 1
Navafria 2
Lakar 1
Lakar 2
Beire
b)
Rill 1
Rill 2
Rill 3
Rill 4
Rill 5
Rill 6
Gully-rill name

Figure 7



Horizontal distance (m)
Depth (m)
0,0
0,1
0,2
0,3
0,4
0,5
0,00
0,05
0,10
0,15
0,20
0,25
0,30
Rill 1, Section 4
a= 24,0 cm
b= 4,5 cm
Rill 1, Section 4
Rill 2, Section 3
a= 32,0 cm
b= 4,5 cm
Rill 2, Section 3
Rill 3, Section 7
a= 23,0 cm
b= 8,0 cm
Rill 3, Section 7
Rill 4, Section 9
a= 23,0 cm
b= 7,0 cm
Rill 4, Section 9

Figure 8



a) Rill 1
b) Rill 2
c) Rill 3
d) Rill 4
e) Rill 5
f) Rill 6
g) Average for all rills
Micro topographic profile meter
Width and depth measurement
$|E^r sm|$
Distance between consecutive cross sections (*s*) (m)
0
20
40
60
2
4
6
8
10

Figure 9

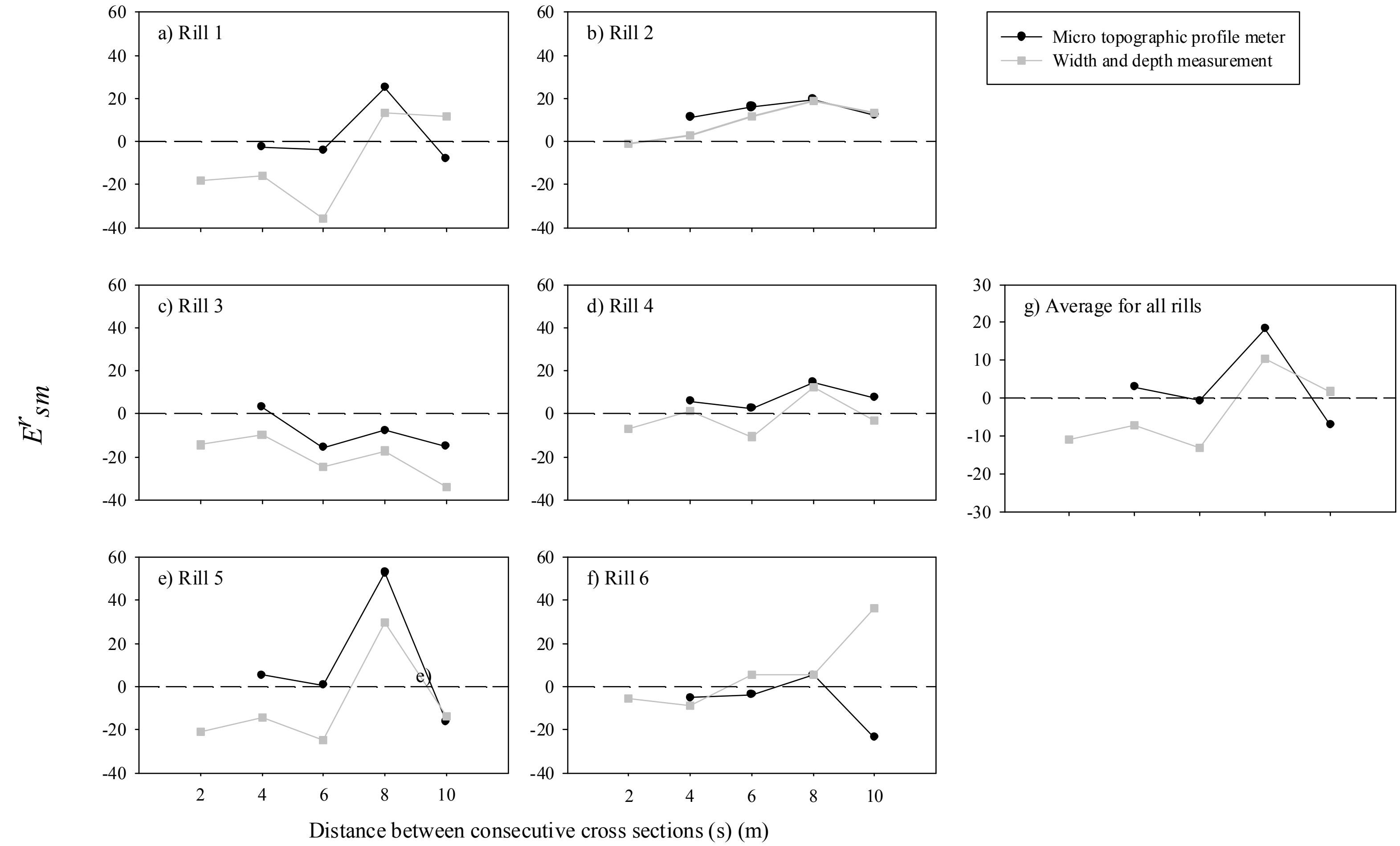
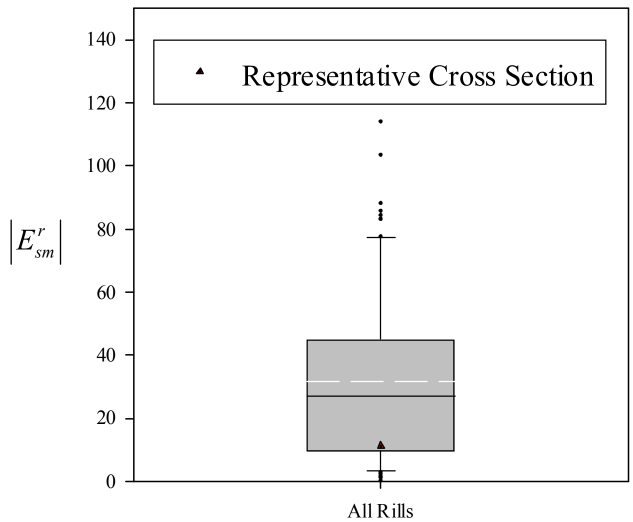

a) Rill 1
b) Rill 2
c) Rill 3
d) Rill 4
e) Rill 5
f) Rill 6
g) Average for all rills
Micro topographic profile meter
Width and depth measurement
$E^r sm$
Distance between consecutive cross sections (s) (m)
60
40
20
0
-20
-40
30
10
-10
-30
2
4
6
8
10

Figure 10



140
120
100
80
60
40
20
0
$\left|E_{sm}^{r}\right|$
Representative Cross Section
All Rills

Figure captions

Figure 1. Micro-topographic profiler measuring one of the gully cross sections.

Figure 2. View of Beire ephemeral gully. The selected cross sectional areas spaced 1 m apart are marked with plastic sticks.

Figure 3. Example of representative cross sections for each of the studied gullies, obtained by the three methods used for cross section characterization: (1) micro-topographic profiler (left hand side column); (2) detailed measurement with a tape (central column) and; (3) approximated measurement with a tape (right hand side column).

Figure 4. Absolute value of the relative measurement error ($|E^{r}_{sm}|$) as a function of gully type, distance between adjacent cross sections (s) and measurement method for each gully (a-e) and average absolute value of the relative measurement error for: WRD>5 gullies (f); WRD< 5 gullies (g); all gullies (h)

Figure 5. Relative measurement errors (E^{r}_{sm}) as a function of gully type, distance between adjacent cross sections (s) and measurement method for each gully (a-e) and average relative measurement errors for: WRD> 5 gullies (f); a for WRD< 5 gullies (g); all gullies (h),

Figure 6. Absolute value of the relative measurement error ($|E^r_{sm}|$) obtained by using a unique cross section for the calculation of channel volume in gullies (a) and in rills (b). Triangles indicate the error values obtained when the corresponding representative cross section is used. Box plots show errors obtained after randomly selecting one of the measured cross sections as representative. The dashed white line indicates the average error for each channel when the random procedure for selecting the representative cross section is applied.

Figure 7. Example of representative cross sections for each of the studied rills, obtained by method (1) (micro-topographic profiler, left hand side column) and (3) (approximated measurement with a tape, right hand side column).

Figure 8. Absolute value of the relative measurement error ($|E^r_{sm}|$) as a function of distance between adjacent cross sections (s) and measurement method: absolute error for each rill (a-f); average absolute value of the relative measurement errors for all rills (g),

Figure 9. Relative measurement errors (E^r_{sm}) as a function of distance between adjacent cross sections (s) and measurement method for each rill (a-f), and average relative measurement errors for all rills (g)

Figure 10. Absolute value of the relative ($|E^a_{sm}|$) measurement errors obtained using a unique representative cross section for the calculation of the volume of all rills. The triangle represents the error value obtained when the corresponding representative cross

section is used. The box plot show the error obtained after randomly selecting one of the measured cross sections as representative The dashed white line indicates the average error when the random procedure for selecting the representative cross section is applied.

Tables 1 and 2

Table 1. Some characteristics of the gully reaches

Gully name and group	L (m)	WDR_A	A_A (m^2)	W_A (m)	A_{cv}	Soil type and use
Navafría 2, I	30.0	12.39	0.0215	1.00	0.43	Loam, fallow after vineyards
Navafría 1, I	30.0	6.82	0.0584	0.70	0.30	Loam, fallow after vineyards
Lakar 1, II	14.0	4.49	0.0604	0.70	0.38	Loam, vineyards
Lakar 2, II	14.0	3.48	0.0477	0.40	0.23	Sandy loam, fallow after vineyards
Beire, II	14.0	2.21	0.1208	0.60	0.27	Not available, not cultivated

L: gully reach length; WDR_A: average width-depth ratio (Poesen and Govers, 1990) of each gully for a distance s between adjacent cross sections of 1 m; A_A: average cross sectional area of each gully for s= 1 m; W_A: average cross section upper width of each gully for s= 1 m; A_{cv}: cross section area variation coefficient of each gully for s= 1 m

Table 2. Some characteristics of the rill reaches

Rill Number	L(m)	WDR_A	A_A(m^2)	W_A(m)	A_{cv}	Soil type and use
1	20.4	5.67	0.0152	0.25	0.33	Loam, fallow after vineyards
2	21.3	5.43	0.0136	0.24	0.36	Loam, fallow after vineyards
3	23.0	3.93	0.0131	0.20	0.36	Loam, fallow after vineyards
4	29.4	5.03	0.0123	0.23	0.36	Loam, fallow after vineyards
5	29.4	6.21	0.0108	0.22	0.53	Loam, fallow after vineyards
6	22.3	4.93	0.0117	0.22	0.36	Loam, fallow after vineyards

L: rill reach length; WDR_A: average width-depth ratio (Poesen and Govers, 1990) of each rill for a distance s between adjacent cross sections of 2 m; A_A: average cross sectional area of each rill for $s = 2$ m; W_A: average cross section upper width of each rill for $s = 2$ m; A_{cv}: cross section area variation coefficient of each rill for $s = 2$ m

Accuracy of methods for field assessment of rill and ephemeral gully erosion

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Abstract

To properly assess soil erosion in agricultural areas, it is necessary to determine precisely the volume of ephemeral gullies and rills in the field by using direct measurement procedures. However, little information is available on the accuracy of the different methods used. The main purpose of this paper is to provide information for a suitable assessment of rill and ephemeral gully erosion with such direct measurement methods. To achieve this objective: a) the measurement errors associated to three methods used for field assessment of channel cross sectional areas are explored; b) the influence of the number of cross sections used per unit channel length on the assessment accuracy, is analysed and; c) the effect of the channel size and shape on measurement errors is examined. The three methods considered to determine the cross sectional areas were: micro-topographic profile meter (1); detailed measurement of section characteristic lengths with a tape (2); measurement of cross section width and depth with a tape (3). Five reaches of different ephemeral gully types 14.0 or 30.0 m long and a set of six 20.4 to 29.4 m long rill reaches were selected. On each gully reach, the cross sectional areas were measured using the three above mentioned methods, with a separation (s) between cross sections of 1 m. For rills, the cross sectional areas were measured with methods 1 and 3, with s= 2 m. Then, the corresponding total erosion volumes were computed. The volume calculated with method 1 with s= 1 m for gullies and s= 2 m for rills was taken as the reference method. For each channel, and for each one of the possible combinations of s and measurement method (m), the relative measurement error and the absolute value of the relative measurement error (E^{r}_{sm} and $|E^{r}_{sm}|$), defined with respect to the reference one, was calculated. $|E^{r}_{sm}|$ much higher than 10% were obtained very easily, even for small s values and for apparently *quasi* prismatic channels. Channel size and shape had a great influence on measurement errors. In fact, the selection of the more suitable method for a certain gully shape and size seemed to be much more important than *s*, at least when *s*< 10 m. Method 1 always provided the most precise measurements, and its results were the less dependent on *s*. However, *s* must be <5 m to guarantee an error smaller than 10%. Method 2 is not recommended, because it is difficult, time consuming and can lead to large errors. Method 3 seems to be enough for small, wide and shallow gullies, and for small rills, but only if *s* is shorter than 5 m. Results obtained after the analysis of rill measurement errors were similar to those of gullies. The analysis of E^{r}_{sm} and $|E^{r}_{sm}|$ when calculating channel volumes using a unique representative cross section highlighted the importance of correctly selecting the adequate cross section. Due to the high error values that this method can entail, it is not considered as advisable whenever accurate erosion measurements are pursued.

Keywords: Ephemeral gully erosion; rill erosion; field assessment; assessment methods; accuracy of methods

1. Introduction

Ephemeral gullies are channels of various sizes, formed by the scouring of concentrated surface runoff flowing on agricultural soils during rain events, refilled by the farmers usually shortly after the rains, but often reappearing in the next rainy season (Foster, 1986; Thorne *et al.*, 1986; Zheng and Huang, 2002). Rill erosion (Foster, 1986; Bryan, 1987; Flanagan, 2002) consists on the development of numerous minute closely spaced channels resulting from the uneven removal of surface soil by running water that is concentrated in streamlets of sufficient discharge and velocity to generate cutting power. It is an intermediate process between sheet erosion and gully erosion (Jackson, 1997). While the presence of rills is restricted to planar elements of watersheds, ephemeral gullies occur on valley bottoms, within swales. Ephemeral gullies and rills are common in cultivated soils in many areas around the world, and can cause large soil losses (Bryan, 1987; Govers and Poesen, 1988; Benito *et al*., 1992; Auzet *et al*., 1993; Bennett *et al*., 2000; De Alba and Benito, 2001; Zheng and Huang, 2002; Poesen *et al*., 2003; De Santisteban *et al*., 2004).

Considering the importance of this erosion types, measurement methods to precisely determine the volume of rills and ephemeral gullies are required. Methods based on the assessment of a number of cross sectional areas with microtopographic profilers, or with a tape or ruler along the channels, have been, and still are, widely used (Spomer and Hjelmfelt, 1986; Govers, 1987; Govers and Poesen, 1988; Govers, 1991; Auzet *et al*., 1993; Smith, 1993; Ludwig *et al.*, 1995; Vandaele and Poesen, 1995; Casalí *et al*., 1999; Bennett *et al*., 2000; Nachtergaele *et al*., 2001a,b; De Santisteban *et al*., 2004). In fact, direct assessment is often essential, because it can be very precise, simple and low-cost compared with other methods, which in turn require direct assessments for validation purposes. Accurate ground measurements are difficult, costly and time consuming. Therefore, authors have been forced to use approximated cross section and/or volume measurement methods. Authors very rarely provide information on probable errors that can be associated to each method.

The main purpose of this paper is to provide information and guidance for a suitable assessment of rill and ephemeral gully erosion with methods based on the direct assessment in the field of cross sectional areas with microtopographic profilers, or with a tape or ruler along the channels. Such information will be also of interest for a better application of other methods, like classical topographic surveys or photogrammetry. To achieve this objective: a) the measurement errors associated to three of the methods frequently used for direct assessment in the field of rill and ephemeral gully cross sectional areas are explored; b) the influence of the cross section density, i. e., the number of cross sections used per unit of channel length, on the assessment accuracy, is analysed and; c) the effect of the channel form (Imeson and Kwaad, 1980) on measurement errors is examined. The three methods considered to determine the cross sectional areas were: micro-topographic profile meter (1); detailed measurement, with a tape, of section characteristic lengths (bottom width, top width, heights, bank lengths and slopes, etc.), trying to take into account the complex cross section geometry (2); measurement with a tape of cross section width and depth (3).

2. Area descriptions, methods and materials

Five 14.0 or 30.0 m long reaches of different ephemeral gully types were selected for this study, trying to cover a wide range of channel forms (table 1). The study sites were located in the town councils of San Martín de Unx and Beire, in Central Navarre (Spain) (De Santisteban *et al*., 2004). On the other hand, a set of six 20.4 to 29.4 m long rill reaches was selected. Rills appeared quite uniformly distributed over a vineyard field located in the town council of Tafalla (Central Navarre). Rill affected area corresponded to a steep slope of approximately 2,000 m^2. The main characteristics of the selected rills are summarised in table 2.

The three methods used for cross section characterization and the procedure to calculate the volume of eroded soil are described below. In all cases, for upper cross section width definition, only points with evidence of recent water erosion were considered.

Micro-topographic profiler (1) (Sancho *et al*., 1991; Casalí *et al*., 1999; De Santisteban, 2003). Cross-section morphologies were characterized using a pin profiler that consisted of 50 stainless steel pins spaced 20 mm apart (figure 1), placed perpendicularly to the channel axis. The pin configuration and hence channel geometry was photographed, and pin heights were digitized directly from these pictures, finally obtaining the cross sectional area.

Detailed characterization of cross sections with a tape and ruler (2). Each cross section was assimilated to a simple geometric form, like a rectangle, a triangle or a trapezium, or a combination of some of those forms. Usually, a tape was used for directly measuring in the field horizontal distances, and a ruler was used for measuring the vertical distances (depths). For an accurate cross-section characterization, as many points as required were determined.

Approximated characterization of cross sections with a tape (3). This method consists in assuming that a rectangle is a good representation of all cross sections. One of its advantages is that a high number of cross sections can be measured very quickly. For characterizing the cross section representative depth, an average value was considered when required. It was also the case when the cross sections were complex and more than one gully bed could be identified.

After selecting the rill or gully reach, the cross sections were marked with plastic sticks (figure 2). On each gully reach, the cross sectional areas were measured using the three above mentioned methods, with a separation (s) between cross sections of 1 m. For rills, the cross sectional areas were measured with methods 1 and 3, with a separation (s) between cross sections of 2 m. Method 2 was considered too difficult to apply in rills due to the small size of most rill cross sections. Then, the corresponding total erosion volumes were computed. The effect on the resulting eroded volume of decreasing the cross section measurement density, by gradually increasing s, i. e., increasingly neglecting cross sections for calculations, was explored on each channel.

The volume of eroded soil was calculated for each sub-reach i, from its corresponding cross sectional areas A_{i-1} and A_i, spaced s meter apart. Thus, the volume of eroded soil in each complete channel reach is:

$$V = \sum_{i=1}^{n} V_i = \sum_{i=1}^{n} \frac{A_{i-1} + A_i}{2} \cdot s \qquad (1)$$

where:

V: Volume of eroded soil in the reach
n: Number of sub-reaches considered
V_i: Volume of eroded soil within the sub-reach i
A_{i-1}: Downstream cross sectional area of the sub-reach

A_i: Up stream cross sectional area of the sub-reach
s: Distance between adjacent cross sections

The volume calculated with micro-topographic profile meter (1), with s= 1 m for gullies and s= 2 m for rills, was considered as the most precise, and it was taken as the reference method. Elliot *et al.* (1997) also considered this method as the reference one, because of its high accuracy for estimating the hydraulic radius, an important variable for many water erosion models. For each channel, and for each one of the possible combinations of s and measurement method (m) previously described, the relative and absolute measurement error, defined with respect to the reference one, was calculated (equations 2 and 3):

$$E^r_{sm} = \frac{V_{sm} - V_{11}}{V_{11}} \cdot 100 \qquad (2)$$

where:

E^r_{sm} (%): Relative measurement error associated to s and to the cross section characterization method m
V_{sm}: Volume of eroded soil computed for a separation s and for the cross section characterization method m
V_{11}: Volume of eroded soil computed for the reference method, i. e, s= 1 and for the cross section characterization method 1 (micro-topographic profiler)

$$|E^r_{sm}| = \left| \frac{V_{sm} - V_{11}}{V_{11}} \right| \cdot 100 \qquad (3)$$

where:

$|E^{r}_{sm}|$ (%): Absolute value of the relative measurement error associated to s and to the cross section characterization method m

3. Results and discussion

3.1. Gullies

On figure 3, examples of representative cross sections for each of the studied gullies, obtained by the three methods, are shown. The different gully forms can be observed as well. The channel form was characterized according to the gully average cross sectional area and the average width-depth ratio (table 1).

$|E^{r}_{sm}|$ and E^{r}_{sm} associated to each cross section measuring method were calculated and the three methods compared. The relation between s and the obtained errors was investigated. Finally, gully volumes considering a unique representative cross section were also calculated and their errors assessed. That representative cross section was selected subjectively by the observer. It can be defined as the channel cross section whose cross sectional area multiplied by the reach length provides the best estimation of the channel reach volume.

Figures 4 and 5 show the main results. First, an individualized gully by gully analysis of $|E^{r}_{sm}|$ and E^{r}_{sm} was made (figure 4 and 5). Then, values for $|E^{r}_{sm}|$ and E^{r}_{sm} were grouped in sets that were homogenous with respect to the width-depth ratio (*WDR*) (Poesen and Govers, 1990) and the cross sectional area (*A*). It can be assumed that these two variables comprise a substantial part of the gully properties, as *WDR* is related to the gully shape and *A* is related to the gully size. The gullies were classified into two groups: gullies with $WDR > 5$ and $A < 0.06$ m^2 (I); gullies with $WDR < 5$ and $A > 0.06$ m^2 (II) (table 1). At Lakar 2 gully, $A < 0.06$ m^2, but it was included in group II, because *A* is not far from 0.06 m^2 and *WDR* is clearly less than 5. Group I correspond to small but wide and shallow gullies, and group II to large but narrow and deep gullies. Finally, the average $|E^{r}_{sm}|$ and E^{r}_{sm} for groups I and II and for all gullies were calculated (figures 4f, g, h and 5f, g, h).

Let us start the discussion with the average absolute value of the relative measurement error ($|E^{r}_{sm}|$) for all gullies (figure 4h). The smallest errors, on average, clearly occurred with method 1, with errors ranging from 4.0% (s= 2 m) to 8.5% (s= 4 m). For method 2, average errors ranged between 9.0% (s= 3 m) and 15.0% (s= 5 m). As expected, method 3 was on average the less precise, with errors ranging from 8.0 to 17.0% (s= 3 m and s= 5 m, respectively). Results from the linear regression between $|E^{r}_{sm}|$ and s (figure 4h) indicated that, when method 1 was used, the dependence of $|E^{r}_{sm}|$ on s was the smallest, and that when method 3 was used, such dependence was the largest.

For group I gullies (figure 4f), method 2 was leading the largest errors on both average and maximum errors. Curiously, methods 1 and 3 yielded almost the same results. On the other hand, any trend was found between $|E^{r}_{sm}|$ and s. Method 1 was the most precise and its errors were on average 10.1%. Average errors for methods 2 and 3 were 10.3 and 18.8% respectively. Maximum errors ranged between 22.0% for method 1 and 30.0% for method 2, meaning that, for that kind of gullies, large errors can occur with any measurement method. Besides, a great variability and dispersion of $|E^r_{sm}|$ was observed, mainly in Navafría 2 gully (figure 4b), with sudden and often alternating changes on its values. This variability may be bound to the high value of the cross section area variation coefficient A_{cv} (table 1) of that gully, meaning that, for irregular gullies (i. e., those with high A_c values) a small value of s is necessary to ensure small measurement errors. The dispersion of $|E^r_{sm}|$,tended to increase with s for the group I gullies: when s increases, the probability that the surface area of few representative cross sections plays an important role in the final value of the computed volume, and thus in the error. Explanations for some of these results can come from the analysis of the characteristics of the gullies, mainly Navafría 2 (figure 4b), the smallest and the one with the largest *WDR*. In small, shallow and relatively wide gullies like these, the assessment of the characteristic lengths required for method 2 can be especially difficult. Even the uncomfortable posture of who is measuring can have an influence on the results, because small lengths have to be accurately assessed with a tape and a ruler for quite a long time, also assimilating an often unclear gully form. It seems that a simpler assessment of gully width and depth can result in higher accuracy than a more complex, uncomfortable and time-consuming assessment of characteristic lengths. This can explain the better results obtained with method 3 compared with those with method 2 for Navafría 1 gully. On the other hand, is in Navafría 1 gully where the highest errors were found, reaching up to 50% with method 2 (s= 6 m), and 30% with method 3 (s= 6 m).

Thus, for assessing volumes of irregular (A_{cv}≈ 40% or higher), small (A_A< 0.03 m^2) and wide (WDR_A> 5) gullies, it seems to be necessary to use s values of 1-3 m with methods 1 and 3 to guarantee that errors remain below 10%.

For group II gullies (figure 4g), measurements with method 1 were also the most precise, with $|E^{r}_{sm}|$ values always below 10%, and frequently smaller (figure 4c, d, e). Errors with method 1 were almost non-dependent on s, and sudden changes on its values were not observed. Errors greatly increased for method 3, mainly in the case of Beire gully, which is the largest and the one with smallest WDR. The good results with method 2 could be explained now from the big size of Beire gully, what allows for a good definition, visually and manually, with the tape or ruler, of the cross section characteristic lengths. Errors with method 3 were similar to the values found for group I gullies, and around 20%.

Results on figure 5 show that the assessment errors can be a consequence of either overestimate or underestimate the eroded volumes. A clear tendency in this response is not observed.

The errors associated to gully volumes calculated from one unique representative cross section were calculated (figure 6a). In this case, results show a wide range of error values. Using the selected as most representative cross section (triangles in figure 6a), error values were quite low (below 20%) in all gullies. However, if the representative cross section was selected randomly (box plots on figure 6a) error values could be much higher. This fact is remarkable, considering that the studied gully reaches are quite uniform (figure 2, table 1). Logically, the error ranges on figure 6a are in complete agreement with A_{cv} values on table 1. So, the widest error range occurs in Navafría 2 gully (around 100%), which in turn shows the highest A_{cv} value (0.43). On the other hand, the narrowest range occurs in Lakar 2 gully (around 40%), with the lowest A_{cv} value (0.23). On average (white dashed lines on figure 6a), error values ranged from 20 to 40%. Thus, the selection of the adequate representative cross section, even in short reaches and in very uniform channels, seems to be very important. An inadequate cross section selection can entail high error values and, being a completely subjective selection, the experience of the observer seems to be a big issue.

From this study, we have found that, even for small *s* values, probably much smaller than the ones used in the majority of field surveys, large measurement errors occurred. In many cases, errors to be expected showed a high level of randomness and dispersion. The selection of the more suitable method for a certain gully shape and size, defined by *A*, *WDR* an A_{cv}, seemed to be much more important than the distance between cross sections *s*, at least when $s < 10$ m. For the same gully, errors when applying one method or another could differ in up to 6 times (figure 4e). The highest difficulties seemed to arise for small but wide gullies (group I) because large errors were obtained, even using method 1. On the contrary, with group II gullies (large but narrow) quite accurate assessments could be made with methods 1 and 2. The smallest probability of large errors always occurred with method 1. For this method, *s* did not influence the error values so, *s* could be as high as 5 m without errors greater that 10%. When the gullies were homogeneous (i. e., for example, for $A_{cv} < 40\%$), *s* could be even greater. Results with method 2 were similar to the ones from method 1, except for small and wide cross sections, where errors were not acceptable. For big gullies where method 1 cannot be used, method 2 must be always selected instead of 3. The use of profiler (method 1) is also recommended compared to method 2: the main possible supposed advantage was rapidity but, in fact, a lot of time was required for a suitable assessment of characteristic lengths in many cross sections. For group I gullies, method 3 should be used when a profiler was not available, since it was giving similar measurements for this gully type, but it was not valid for group II gullies.

3.2. Rills

In rills, methods 1 and 3 were used. As in the case of gullies both methods were compared, and it was also assessed whether the distance between cross sections influenced the obtained errors. Errors associated to rill volumes calculated from a unique representative cross section for each rill, previously defined, were calculated as well. Finally the errors obtained when assuming a constant cross section for a rill group were also evaluated. This approach is some times accepted by authors for assessing erosion in high density rill systems, trying to make the field survey a less time consuming process.

Figure 7 shows four representative cross sections of the six studied rills measured with both methods. In this case, the minimum distance between acquired cross sections was 2 m. Therefore, the assumed reference volume for error calculations was obtained measuring cross sections with method 1 (micro profiler) with a two meter interval.

First, an individualized rill by rill analysis of $|E^{r}_{sm}|$ and E^{r}_{sm} was made (figure 8, a-f; figure 9, a-f). All rills were very homogeneous with respect to WDR_A and A_A (table 2).

Consequently, groups like the ones considered for gullies could not be defined, and all rills were included within the same group.

The smallest $|E^{r}_{sm}|$ values (figure 8g) occurred on average again with method 1, despite in some particular rills, like rill 2 and rill 4, the error values for both methods were similar. r^2 values for the regression lines are 0.24 for method 1 and 0.37 for method 3. Los valores de r^2 para las correspondientes líneas de regresión son de 0.24 para el método 1 y de 0.37 para el método 3. Average errors with method 1 ranged from 5% (*s*= 4 m) to 21% (*s*= 8 m). For method 3, average errors ranged between 9% (*s*= 2 m) to 19% (*s*= 6 m). For this set of rills, the dependence of $|E^{r}_{sm}|$ on *s* for method 1 was slightly largest than for method 3. For *s*= 5 m, average $|E^{r}_{sm}|$ for gullies and rills could be compared (figures 4h and 8g). After this analysis, very similar errors values were observed for both channel classes.

Thus, for assessing volumes of this rill class, it seems to be necessary to use *s* values less than 4 m with methods 1 and 3 to guarantee that errors remain below 10%.

Results on figure 9 show that the assessment errors can be a consequence of either overestimating or underestimating the eroded volumes. A clear tendency in this response is not observed.

Considering a unique representative cross section for each rill reach, obtained results are very similar to the case of gullies (figure 6b). When the selected representative sections were used, error values were quite low (below 20%). But, if the representative cross sections were randomly defined, the range of errors obtained were quite high, ranging on average between 20 and 40%, and with very high peak values. Thus, the selection of the adequate representative cross section, even in short reaches and in very uniform channels, seems very important.

Finally, the error on the calculations of the total rill volume considering a unique representative section for all six rills was assessed (figure 10). The volume calculated with the cross section assumed as representative yielded a low error (11.35%), but randomly selecting other sections, an average error of approximately 30% was obtained.

Results obtained after the analysis of rill measurement errors are similar to those of gullies. In general, method 1 gave a higher accuracy than method 3. The influence of cross section distance (*s*) on the obtained errors was more prominent than in the case of gullies. The observed randomness in gully error values was not so evident in the case of rills, probably because cross sections tend to be more homogeneous in the latter case (see CV_A values in tables 1and 2).

Even for small *s* values, probably much smaller than the ones used in the majority of field surveys, large measurement errors occurred..

4. Conclusions

This paper intended to offer some first guidance for selecting the most suitable procedure when assessing rill and ephemeral gully erosion in the field by direct measurement methods. Error values much higher than 10% can be obtained very easily, even when a high number of cross sectional areas per unit length is considered, and for very uniform and apparently *quasi* prismatic channels. After classifying the studied gullies according with their size and shape, it was demonstrated that such parameters have a great influence on measurement errors. Consequently, it is necessary to identify the most suitable measurement method for each channel class. The microtopographic profiler always provided the most precise measurements, and its measurements were the less dependent on the distance between consecutive cross sections, s. Thus, its use, or the use of a similar apparatus, is strongly recommended. However, the distance between consecutive cross sections must be less than 5 m to guarantee an error value smaller than 10%. The detailed characterization of cross sections with a tape and ruler is not recommended, because it is difficult, time consuming, and can lead to large errors. The approximated characterization of cross sections with a tape can be enough for small wide and shallow gullies, and for small rills, but only if the distance between consecutive cross sections is shorter than 5 m. Results obtained after the analysis of rill measurement errors are similar to those of gullies. The analysis of obtained errors when calculating the channel volume using a representative cross section highlighted the importance of correctly selecting the adequate cross section. However, due to the high error values that this method can entail, we conclude that it is not advisable if accurate erosion measurements are pursued. For further studies, several points of interest can be explored: a) increase the data set with information from other gully forms, with A_A, WDR_A and A_{cv}, etc. values different from the ones used in this paper; b) consider longer reaches and assess the impact of s values higher than 10 m.

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Accuracy of methods for field assessment of rill and ephemeral gully erosion

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Abstract

To properly assess soil erosion in agricultural areas, it is necessary to determine precisely the volume of ephemeral gullies and rills in the field by using direct measurement procedures. However, little information is available on the accuracy of the different methods used. The main purpose of this paper is to provide information for a suitable assessment of rill and ephemeral gully erosion with such direct measurement methods. To achieve this objective: a) the measurement errors associated to three methods used for field assessment of channel cross sectional areas are explored; b) the influence of the number of cross sections used per unit channel length on the assessment accuracy, is analysed and; c) the effect of the channel size and shape on measurement errors is examined. The three methods considered to determine the cross sectional areas were: micro-topographic profile meter (1); detailed measurement of section characteristic lengths with a tape (2); measurement of cross section width and depth with a tape (3). Five reaches of different ephemeral gully types 14.0 or 30.0 m long and a set of six 20.4 to 29.4 m long rill reaches were selected. On each gully reach, the cross sectional areas were measured using the three above mentioned methods, with a separation (s) between cross sections of 1 m. For rills, the cross sectional areas were measured with methods 1 and 3, with s= 2 m. Then, the corresponding total erosion volumes were computed. The volume calculated with method 1 with s= 1 m for gullies and s= 2 m for rills was taken as the reference method. For each channel, and for each one of the possible combinations of s and measurement method (m), the relative measurement error and the absolute value of the relative measurement error (E^{r}_{sm} and $|E^{r}_{sm}|$), defined with respect to the reference one, was calculated. $|E^{r}_{sm}|$ much higher than 10% were obtained very easily, even for small s values and for apparently *quasi* prismatic channels. Channel size and shape had a great influence on measurement errors. In fact, the selection of the more suitable method for a certain gully shape and size seemed to be much more important than *s*, at least when $s < 10$ m. Method 1 always provided the most precise measurements, and its results were the less dependent on *s*. However, *s* must be <5 m to guarantee an error smaller than 10%. Method 2 is not recommended, because it is difficult, time consuming and can lead to large errors. Method 3 seems to be enough for small, wide and shallow gullies, and for small rills, but only if *s* is shorter than 5 m. Results obtained after the analysis of rill measurement errors were similar to those of gullies. The analysis of E^{r}_{sm} and $|E^{r}_{sm}|$ when calculating channel volumes using a unique representative cross section highlighted the importance of correctly selecting the adequate cross section. Due to the high error values that this method can entail, it is not considered as advisable whenever accurate erosion measurements are pursued.

Keywords: Ephemeral gully erosion; rill erosion; field assessment; assessment methods; accuracy of methods

1. Introduction

Ephemeral gullies are channels of various sizes, formed by the scouring of concentrated surface runoff flowing on agricultural soils during rain events, refilled by the farmers usually shortly after the rains, but often reappearing in the next rainy season (Foster, 1986; Thorne *et al.*, 1986; Zheng and Huang, 2002). Rill erosion (Foster, 1986; Bryan, 1987; Flanagan, 2002) consists on the development of numerous minute closely spaced channels resulting from the uneven removal of surface soil by running water that is concentrated in streamlets of sufficient discharge and velocity to generate cutting power. It is an intermediate process between sheet erosion and gully erosion (Jackson, 1997). While the presence of rills is restricted to planar elements of watersheds, ephemeral gullies occur on valley bottoms, within swales. Ephemeral gullies and rills are common in cultivated soils in many areas around the world, and can cause large soil losses (Bryan, 1987; Govers and Poesen, 1988; Benito *et al.*, 1992; Auzet *et al.*, 1993; Bennett *et al.*, 2000; De Alba and Benito, 2001; Zheng and Huang, 2002; Poesen *et al.*, 2003; De Santisteban *et al.*, 2004).

Considering the importance of this erosion types, measurement methods to precisely determine the volume of rills and ephemeral gullies are required. Methods based on the assessment of a number of cross sectional areas with microtopographic profilers, or with a tape or ruler along the channels, have been, and still are, widely used (Spomer and Hjelmfelt, 1986; Govers, 1987; Govers and Poesen, 1988; Govers, 1991; Auzet *et al.*, 1993; Smith, 1993; Ludwig *et al.*, 1995; Vandaele and Poesen, 1995; Casalí *et al.*, 1999; Bennett *et al.*, 2000; Nachtergaele *et al.*, 2001a,b; De Santisteban *et al.*, 2004). In fact, direct assessment is often essential, because it can be very precise, simple and low-cost compared with other methods, which in turn require direct assessments for validation purposes. Accurate ground measurements are difficult, costly and time consuming. Therefore, authors have been forced to use approximated cross section and/or volume measurement methods. Authors very rarely provide information on probable errors that can be associated to each method.

The main purpose of this paper is to provide information and guidance for a suitable assessment of rill and ephemeral gully erosion with methods based on the direct assessment in the field of cross sectional areas with microtopographic profilers, or with a tape or ruler along the channels. Such information will be also of interest for a better application of other methods, like classical topographic surveys or photogrammetry. To achieve this objective: a) the measurement errors associated to three of the methods frequently used for direct assessment in the field of rill and ephemeral gully cross sectional areas are explored; b) the influence of the cross section density, i. e., the number of cross sections used per unit of channel length, on the assessment accuracy, is analysed and; c) the effect of the channel form (Imeson and Kwaad, 1980) on measurement errors is examined. The three methods considered to determine the cross sectional areas were: micro-topographic profile meter (1); detailed measurement, with a tape, of section characteristic lengths (bottom width, top width, heights, bank lengths and slopes, etc.), trying to take into account the complex cross section geometry (2); measurement with a tape of cross section width and depth (3).

2. Area descriptions, methods and materials

Five 14.0 or 30.0 m long reaches of different ephemeral gully types were selected for this study, trying to cover a wide range of channel forms (table 1). The study sites were located in the town councils of San Martín de Unx and Beire, in Central Navarre (Spain) (De Santisteban *et al.*, 2004). On the other hand, a set of six 20.4 to 29.4 m long rill reaches was selected. Rills appeared quite uniformly distributed over a vineyard field located in the town council of Tafalla (Central Navarre). Rill affected area corresponded to a steep slope of approximately 2,000 m^2. The main characteristics of the selected rills are summarised in table 2.

The three methods used for cross section characterization and the procedure to calculate the volume of eroded soil are described below. In all cases, for upper cross section width definition, only points with evidence of recent water erosion were considered.

Micro-topographic profiler (1) (Sancho *et al*., 1991; Casalí *et al*., 1999; De Santisteban, 2003). Cross-section morphologies were characterized using a pin profiler that consisted of 50 stainless steel pins spaced 20 mm apart (figure 1), placed perpendicularly to the channel axis. The pin configuration and hence channel geometry was photographed, and pin heights were digitized directly from these pictures, finally obtaining the cross sectional area.

Detailed characterization of cross sections with a tape and ruler (2). Each cross section was assimilated to a simple geometric form, like a rectangle, a triangle or a trapezium, or a combination of some of those forms. Usually, a tape was used for directly measuring in the field horizontal distances, and a ruler was used for measuring the vertical distances (depths). For an accurate cross-section characterization, as many points as required were determined.

Approximated characterization of cross sections with a tape (3). This method consists in assuming that a rectangle is a good representation of all cross sections. One of its advantages is that a high number of cross sections can be measured very quickly. For characterizing the cross section representative depth, an average value was considered when required. It was also the case when the cross sections were complex and more than one gully bed could be identified.

After selecting the rill or gully reach, the cross sections were marked with plastic sticks (figure 2). On each gully reach, the cross sectional areas were measured using the three above mentioned methods, with a separation (*s*) between cross sections of 1 m. For rills, the cross sectional areas were measured with methods 1 and 3, with a separation (*s*) between cross sections of 2 m. Method 2 was considered too difficult to apply in rills due to the small size of most rill cross sections. Then, the corresponding total erosion volumes were computed. The effect on the resulting eroded volume of decreasing the cross section measurement density, by gradually increasing *s*, i. e., increasingly neglecting cross sections for calculations, was explored on each channel.

The volume of eroded soil was calculated for each sub-reach *i*, from its corresponding cross sectional areas A_{i-1} and A_i, spaced *s* meter apart. Thus, the volume of eroded soil in each complete channel reach is:

$$V = \sum_{i=1}^{n} V_i = \sum_{i=1}^{n} \frac{A_{i-1} + A_i}{2} \cdot s \qquad (1)$$

where:

V: Volume of eroded soil in the reach

n: Number of sub-reaches considered

V_i: Volume of eroded soil within the sub-reach i

A_{i-1}: Downstream cross sectional area of the sub-reach

A_i: Up stream cross sectional area of the sub-reach

s: Distance between adjacent cross sections

The volume calculated with micro-topographic profile meter (1), with s= 1 m for gullies and s= 2 m for rills, was considered as the most precise, and it was taken as the reference method. Elliot *et al.* (1997) also considered this method as the reference one, because of its high accuracy for estimating the hydraulic radius, an important variable for many water erosion models. For each channel, and for each one of the possible combinations of s and measurement method (m) previously described, the relative and absolute measurement error, defined with respect to the reference one, was calculated (equations 2 and 3):

$$E_{sm}^{r} = \frac{V_{sm} - V_{11}}{V_{11}} \cdot 100 \qquad (2)$$

where:

E^{r}_{sm} (%): Relative measurement error associated to s and to the cross section characterization method m

V_{sm}: Volume of eroded soil computed for a separation s and for the cross section characterization method m

V_{11}: Volume of eroded soil computed for the reference method, i. e, s= 1 and for the cross section characterization method 1 (micro-topographic profiler)

$$| E_{sm}^{r} | = \left| \frac{V_{sm} - V_{11}}{V_{11}} \right| \cdot 100 \qquad (3)$$

where:

$|E^{r}_{sm}|$ (%): Absolute value of the relative measurement error associated to s and to the cross section characterization method m

3. Results and discussion

3.1. Gullies

On figure 3, examples of representative cross sections for each of the studied gullies, obtained by the three methods, are shown. The different gully forms can be observed as well. The channel form was characterized according to the gully average cross sectional area and the average width-depth ratio (table 1).

$|E^{r}_{sm}|$ and E^{r}_{sm} associated to each cross section measuring method were calculated and the three methods compared. The relation between s and the obtained errors was investigated. Finally, gully volumes considering a unique representative cross section were also calculated and their errors assessed. That representative cross section was selected subjectively by the observer. It can be defined as the channel cross section whose cross sectional area multiplied by the reach length provides the best estimation of the channel reach volume.

Figures 4 and 5 show the main results. First, an individualized gully by gully analysis of $|E^r_{sm}|$ and E^r_{sm} was made (figure 4 and 5). Then, values for $|E^r_{sm}|$ and E^r_{sm} were grouped in sets that were homogenous with respect to the width-depth ratio (*WDR*) (Poesen and Govers, 1990) and the cross sectional area (*A*). It can be assumed that these two variables comprise a substantial part of the gully properties, as *WDR* is related to the gully shape and *A* is related to the gully size. The gullies were classified into two groups: gullies with $WDR > 5$ and $A < 0.06$ m^2 (I); gullies with $WDR < 5$ and $A > 0.06$ m^2 (II) (table 1). At Lakar 2 gully, $A < 0.06$ m^2, but it was included in group II, because *A* is not far from 0.06 m^2 and *WDR* is clearly less than 5. Group I correspond to small but wide and shallow gullies, and group II to large but narrow and deep gullies. Finally, the average $|E^r_{sm}|$ and E^r_{sm} for groups I and II and for all gullies were calculated (figures 4f, g, h and 5f, g, h).

Let us start the discussion with the average absolute value of the relative measurement error ($|E^r_{sm}|$) for all gullies (figure 4h). The smallest errors, on average, clearly occurred with method 1, with errors ranging from 4.0% (s= 2 m) to 8.5% (s= 4 m). For method 2, average errors ranged between 9.0% (s= 3 m) and 15.0% (s= 5 m). As expected, method 3 was on average the less precise, with errors ranging from 8.0 to 17.0% (s= 3 m and s= 5 m, respectively). Results from the linear regression between $|E^r_{sm}|$ and s (figure 4h) indicated that, when method 1 was used, the dependence of $|E^r_{sm}|$ on s was the smallest, and that when method 3 was used, such dependence was the largest.

For group I gullies (figure 4f), method 2 was leading the largest errors on both average and maximum errors. Curiously, methods 1 and 3 yielded almost the same results. On the other hand, any trend was found between $|E^r_{sm}|$ and s. Method 1 was the most precise and its errors were on average 10.1%. Average errors for methods 2 and 3 were 10.3 and 18.8% respectively. Maximum errors ranged between 22.0% for method 1 and 30.0% for method 2, meaning that, for that kind of gullies, large errors can occur with any measurement method. Besides, a great variability and dispersion of $|E^{r}_{sm}|$ was observed, mainly in Navafría 2 gully (figure 4b), with sudden and often alternating changes on its values. This variability may be bound to the high value of the cross section area variation coefficient A_{cv} (table 1) of that gully, meaning that, for irregular gullies (i. e., those with high A_c values) a small value of s is necessary to ensure small measurement errors. The dispersion of $|E^{r}_{sm}|$,tended to increase with s for the group I gullies: when s increases, the probability that the surface area of few representative cross sections plays an important role in the final value of the computed volume, and thus in the error. Explanations for some of these results can come from the analysis of the characteristics of the gullies, mainly Navafría 2 (figure 4b), the smallest and the one with the largest *WDR*. In small, shallow and relatively wide gullies like these, the assessment of the characteristic lengths required for method 2 can be especially difficult. Even the uncomfortable posture of who is measuring can have an influence on the results, because small lengths have to be accurately assessed with a tape and a ruler for quite a long time, also assimilating an often unclear gully form. It seems that a simpler assessment of gully width and depth can result in higher accuracy than a more complex, uncomfortable and time-consuming assessment of characteristic lengths. This can explain the better results obtained with method 3 compared with those with method 2 for Navafría 1 gully. On the other hand, is in Navafría 1 gully where the highest errors were found, reaching up to 50% with method 2 (s= 6 m), and 30% with method 3 (s= 6 m).

Thus, for assessing volumes of irregular (A_{cv}≈ 40% or higher), small (A_A< 0.03 m^2) and wide (WDR_A> 5) gullies, it seems to be necessary to use s values of 1-3 m with methods 1 and 3 to guarantee that errors remain below 10%.

For group II gullies (figure 4g), measurements with method 1 were also the most precise, with $|E^{r}_{sm}|$ values always below 10%, and frequently smaller (figure 4c, d, e). Errors with method 1 were almost non-dependent on s, and sudden changes on its values were not observed. Errors greatly increased for method 3, mainly in the case of Beire gully, which is the largest and the one with smallest WDR. The good results with method 2 could be explained now from the big size of Beire gully, what allows for a good definition, visually and manually, with the tape or ruler, of the cross section characteristic lengths. Errors with method 3 were similar to the values found for group I gullies, and around 20%.

Results on figure 5 show that the assessment errors can be a consequence of either overestimate or underestimate the eroded volumes. A clear tendency in this response is not observed.

The errors associated to gully volumes calculated from one unique representative cross section were calculated (figure 6a). In this case, results show a wide range of error values. Using the selected as most representative cross section (triangles in figure 6a), error values were quite low (below 20%) in all gullies. However, if the representative cross section was selected randomly (box plots on figure 6a) error values could be much higher. This fact is remarkable, considering that the studied gully reaches are quite uniform (figure 2, table 1). Logically, the error ranges on figure 6a are in complete agreement with A_{cv} values on table 1. So, the widest error range occurs in Navafría 2 gully (around 100%), which in turn shows the highest A_{cv} value (0.43). On the other hand, the narrowest range occurs in Lakar 2 gully (around 40%), with the lowest A_{cv} value (0.23). On average (white dashed lines on figure 6a), error values ranged from 20 to 40%. Thus, the selection of the adequate representative cross section, even in short reaches and in very uniform channels, seems to be very important. An inadequate cross section selection can entail high error values and, being a completely subjective selection, the experience of the observer seems to be a big issue.

From this study, we have found that, even for small *s* values, probably much smaller than the ones used in the majority of field surveys, large measurement errors occurred. In many cases, errors to be expected showed a high level of randomness and dispersion. The selection of the more suitable method for a certain gully shape and size, defined by *A*, *WDR* an A_{cv}, seemed to be much more important than the distance between cross sections *s*, at least when $s < 10$ m. For the same gully, errors when applying one method or another could differ in up to 6 times (figure 4e). The highest difficulties seemed to arise for small but wide gullies (group I) because large errors were obtained, even using method 1. On the contrary, with group II gullies (large but narrow) quite accurate assessments could be made with methods 1 and 2. The smallest probability of large errors always occurred with method 1. For this method, *s* did not influence the error values so, *s* could be as high as 5 m without errors greater that 10%. When the gullies were homogeneous (i. e., for example, for $A_{cv} < 40\%$), *s* could be even greater. Results with method 2 were similar to the ones from method 1, except for small and wide cross sections, where errors were not acceptable. For big gullies where method 1 cannot be used, method 2 must be always selected instead of 3. The use of profiler (method 1) is also recommended compared to method 2: the main possible supposed advantage was rapidity but, in fact, a lot of time was required for a suitable assessment of characteristic lengths in many cross sections. For group I gullies, method 3 should be used when a profiler was not available, since it was giving similar measurements for this gully type, but it was not valid for group II gullies.

3.2. Rills

In rills, methods 1 and 3 were used. As in the case of gullies both methods were compared, and it was also assessed whether the distance between cross sections influenced the obtained errors. Errors associated to rill volumes calculated from a unique representative cross section for each rill, previously defined, were calculated as well. Finally the errors obtained when assuming a constant cross section for a rill group were also evaluated. This approach is some times accepted by authors for assessing erosion in high density rill systems, trying to make the field survey a less time consuming process.

Figure 7 shows four representative cross sections of the six studied rills measured with both methods. In this case, the minimum distance between acquired cross sections was 2 m. Therefore, the assumed reference volume for error calculations was obtained measuring cross sections with method 1 (micro profiler) with a two meter interval.

First, an individualized rill by rill analysis of $|E^{r}_{sm}|$ and E^{r}_{sm} was made (figure 8, a-f; figure 9, a-f). All rills were very homogeneous with respect to WDR_A and A_A (table 2).

Consequently, groups like the ones considered for gullies could not be defined, and all rills were included within the same group.

The smallest $|E^{r}_{sm}|$ values (figure 8g) occurred on average again with method 1, despite in some particular rills, like rill 2 and rill 4, the error values for both methods were similar. r^2 values for the regression lines are 0.24 for method 1 and 0.37 for method 3. Los valores de r^2 para las correspondientes líneas de regresión son de 0.24 para el método 1 y de 0.37 para el método 3. Average errors with method 1 ranged from 5% (*s*= 4 m) to 21% (*s*= 8 m). For method 3, average errors ranged between 9% (*s*= 2 m) to 19% (*s*= 6 m). For this set of rills, the dependence of $|E^{r}_{sm}|$ on *s* for method 1 was slightly largest than for method 3. For *s*= 5 m, average $|E^{r}_{sm}|$ for gullies and rills could be compared (figures 4h and 8g). After this analysis, very similar errors values were observed for both channel classes.

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Thus, for assessing volumes of this rill class, it seems to be necessary to use *s* values less than 4 m with methods 1 and 3 to guarantee that errors remain below 10%.

Results on figure 9 show that the assessment errors can be a consequence of either overestimating or underestimating the eroded volumes. A clear tendency in this response is not observed.

Considering a unique representative cross section for each rill reach, obtained results are very similar to the case of gullies (figure 6b). When the selected representative sections were used, error values were quite low (below 20%). But, if the representative cross sections were randomly defined, the range of errors obtained were quite high, ranging on average between 20 and 40%, and with very high peak values. Thus, the selection of the adequate representative cross section, even in short reaches and in very uniform channels, seems very important.

Finally, the error on the calculations of the total rill volume considering a unique representative section for all six rills was assessed (figure 10). The volume calculated with the cross section assumed as representative yielded a low error (11.35%), but randomly selecting other sections, an average error of approximately 30% was obtained.

Results obtained after the analysis of rill measurement errors are similar to those of gullies. In general, method 1 gave a higher accuracy than method 3. The influence of cross section distance (*s*) on the obtained errors was more prominent than in the case of gullies. The observed randomness in gully error values was not so evident in the case of rills, probably because cross sections tend to be more homogeneous in the latter case (see CV_A values in tables 1 and 2).

Even for small *s* values, probably much smaller than the ones used in the majority of field surveys, large measurement errors occurred..

4. Conclusions

This paper intended to offer some first guidance for selecting the most suitable procedure when assessing rill and ephemeral gully erosion in the field by direct measurement methods. Error values much higher than 10% can be obtained very easily, even when a high number of cross sectional areas per unit length is considered, and for very uniform and apparently *quasi* prismatic channels. After classifying the studied gullies according with their size and shape, it was demonstrated that such parameters have a great influence on measurement errors. Consequently, it is necessary to identify the most suitable measurement method for each channel class. The microtopographic profiler always provided the most precise measurements, and its measurements were the less dependent on the distance between consecutive cross sections, *s*. Thus, its use, or the use of a similar apparatus, is strongly recommended. However, the distance between consecutive cross sections must be less than 5 m to guarantee an error value smaller than 10%. The detailed characterization of cross sections with a tape and ruler is not recommended, because it is difficult, time consuming, and can lead to large errors. The approximated characterization of cross sections with a tape can be enough for small wide and shallow gullies, and for small rills, but only if the distance between consecutive cross sections is shorter than 5 m. Results obtained after the analysis of rill measurement errors are similar to those of gullies. The analysis of obtained errors when calculating the channel volume using a representative cross section highlighted the importance of correctly selecting the adequate cross section. However, due to the high error values that this method can entail, we conclude that it is not advisable if accurate erosion measurements are pursued. For further studies, several points of interest can be explored: a) increase the data set with information from other gully forms, with A_A, WDR_A and A_{cv}, etc. values different from the ones used in this paper; b) consider longer reaches and assess the impact of *s* values higher than 10 m.

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Authors' answer to editors and reviewers

The sentence written by mistake in Spanish on page 15 has been translated to English.