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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_{rsm} and $|E_{rsm}|$), defined with respect to the reference one, was calculated. $|E_{rsm}|$ 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_{rsm} and $|E_{rsm}|$ 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

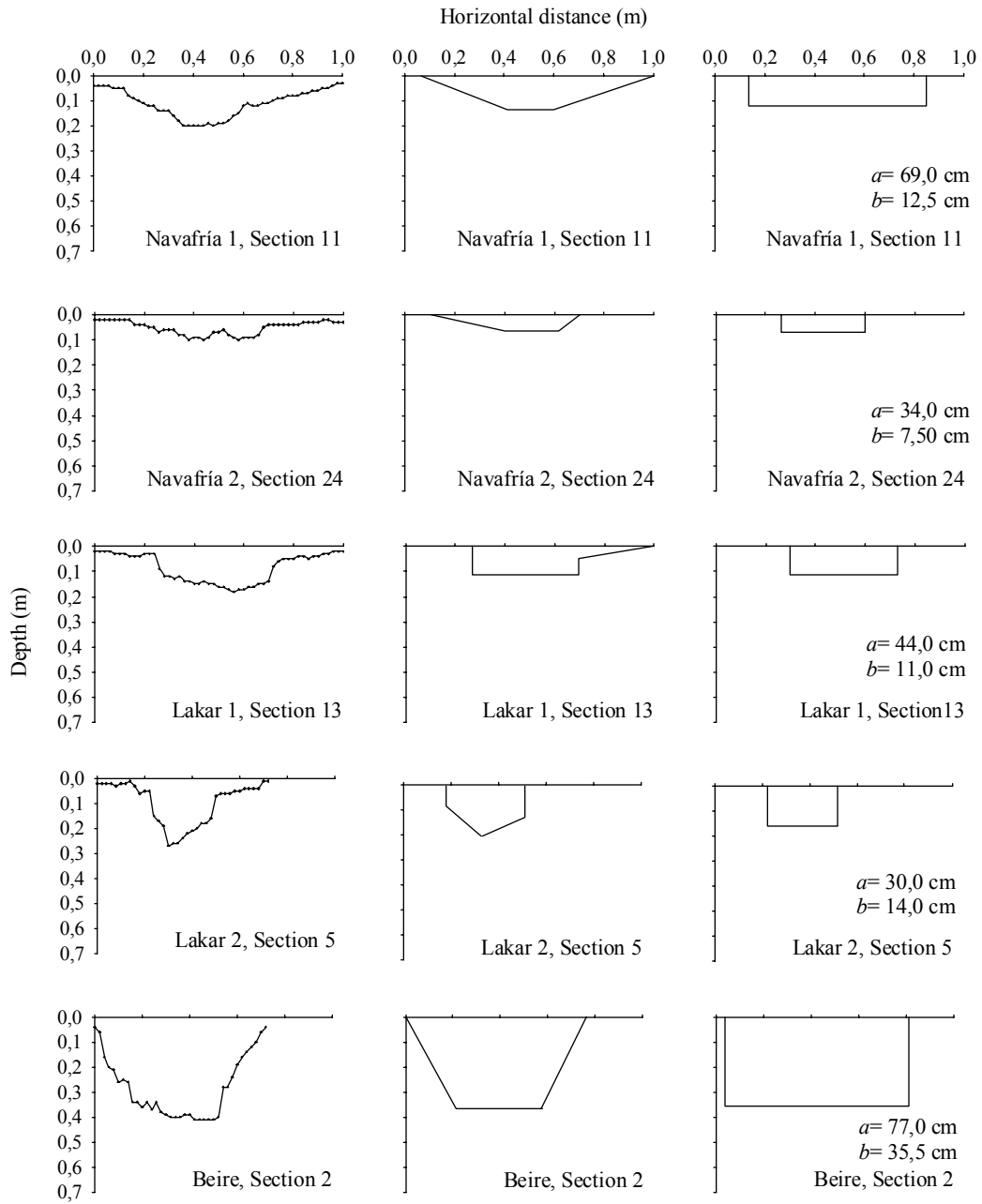


Figure 4

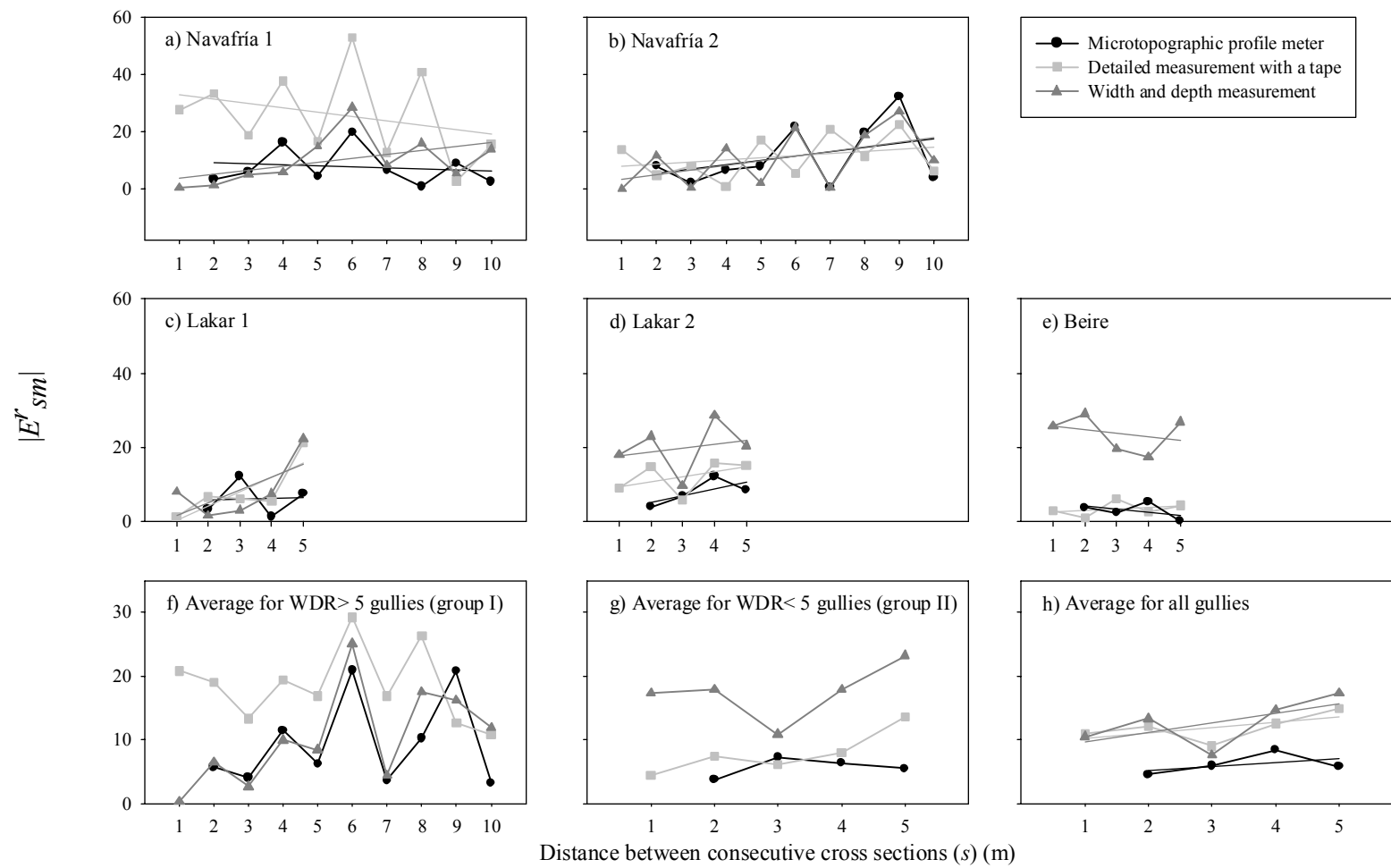


Figure 5

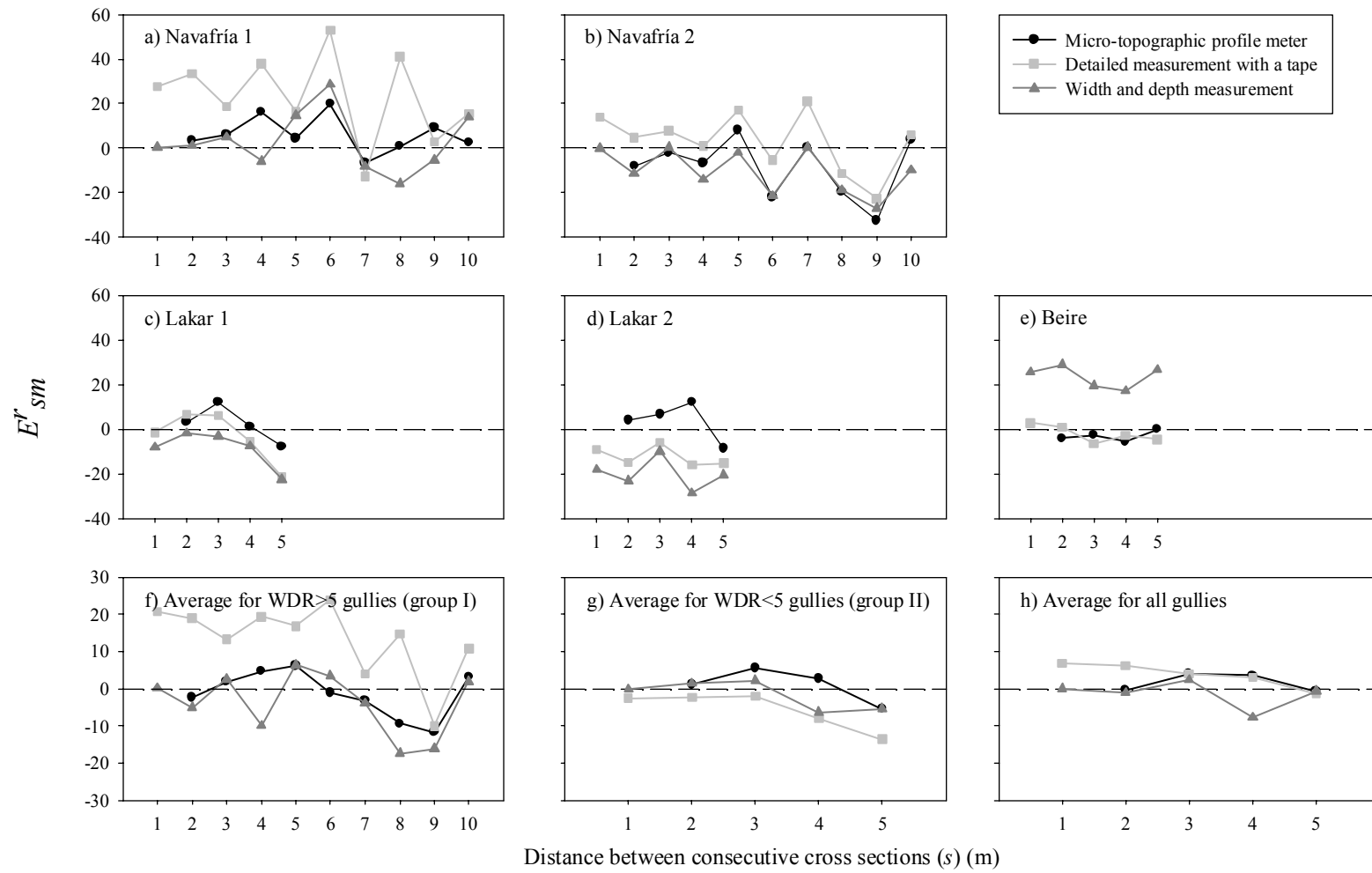


Figure 6

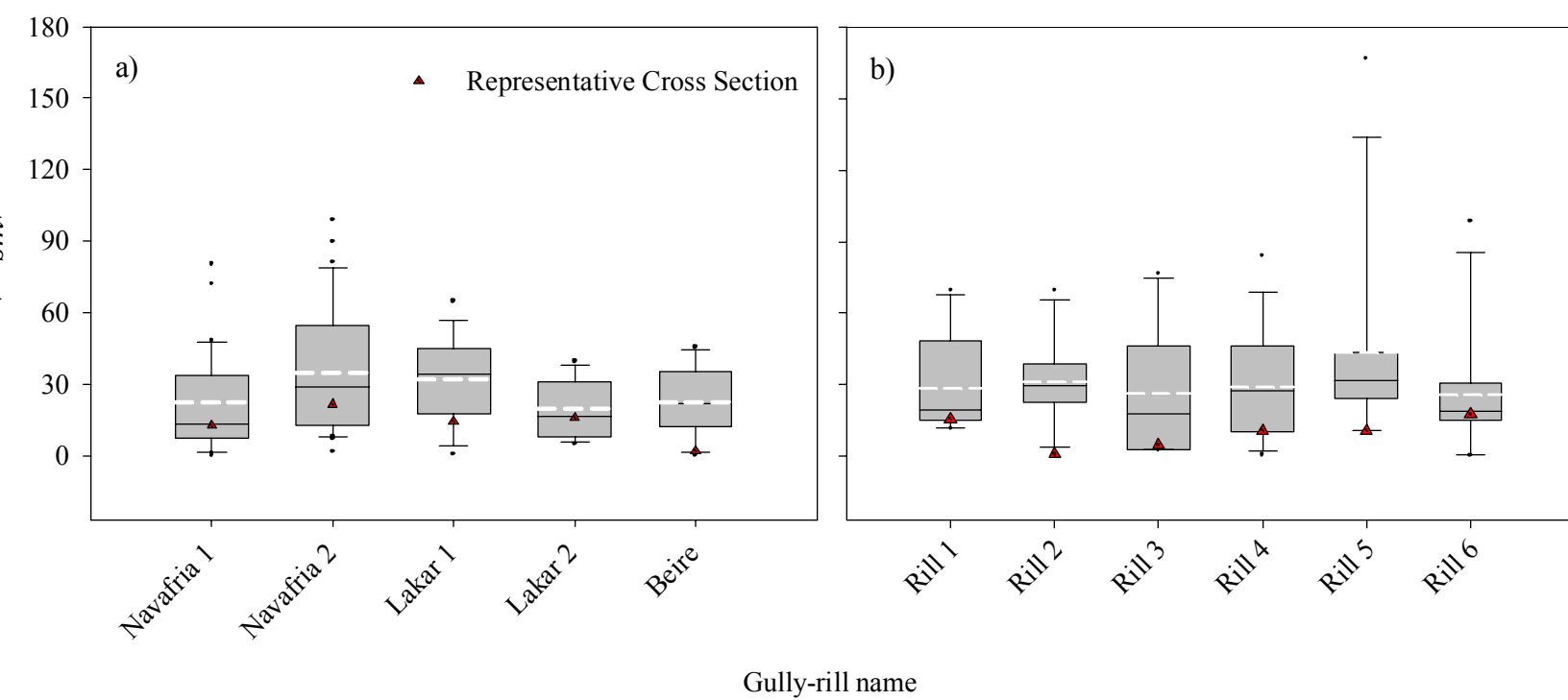


Figure 7

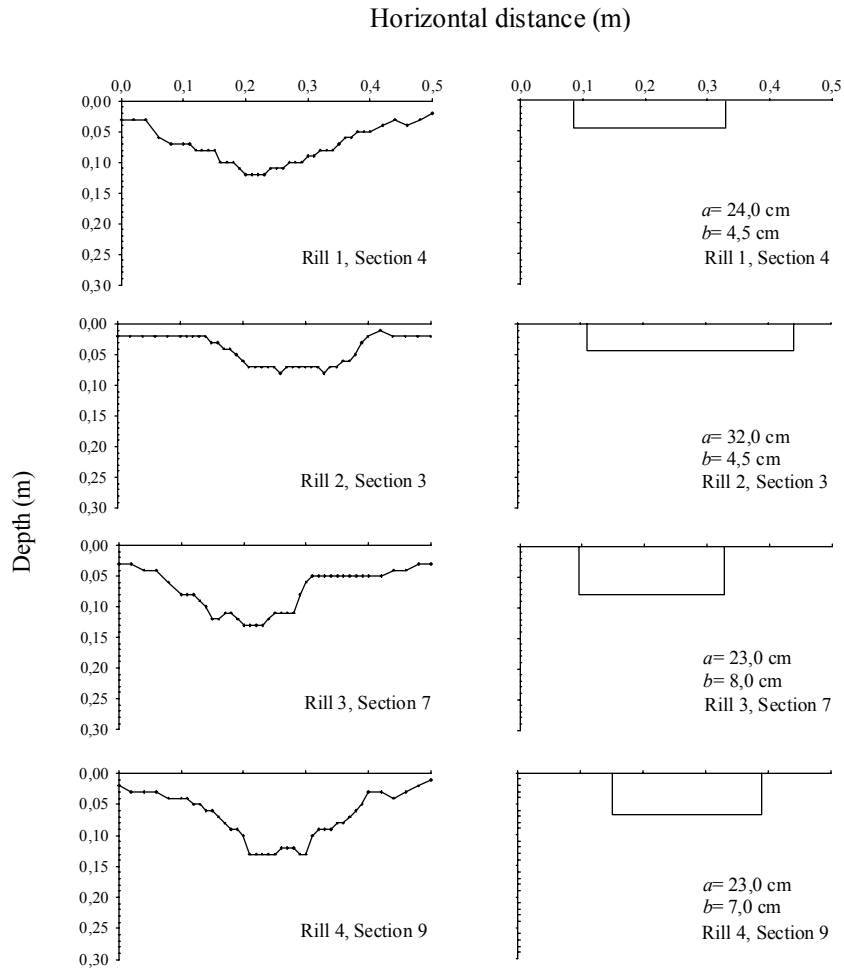


Figure 8

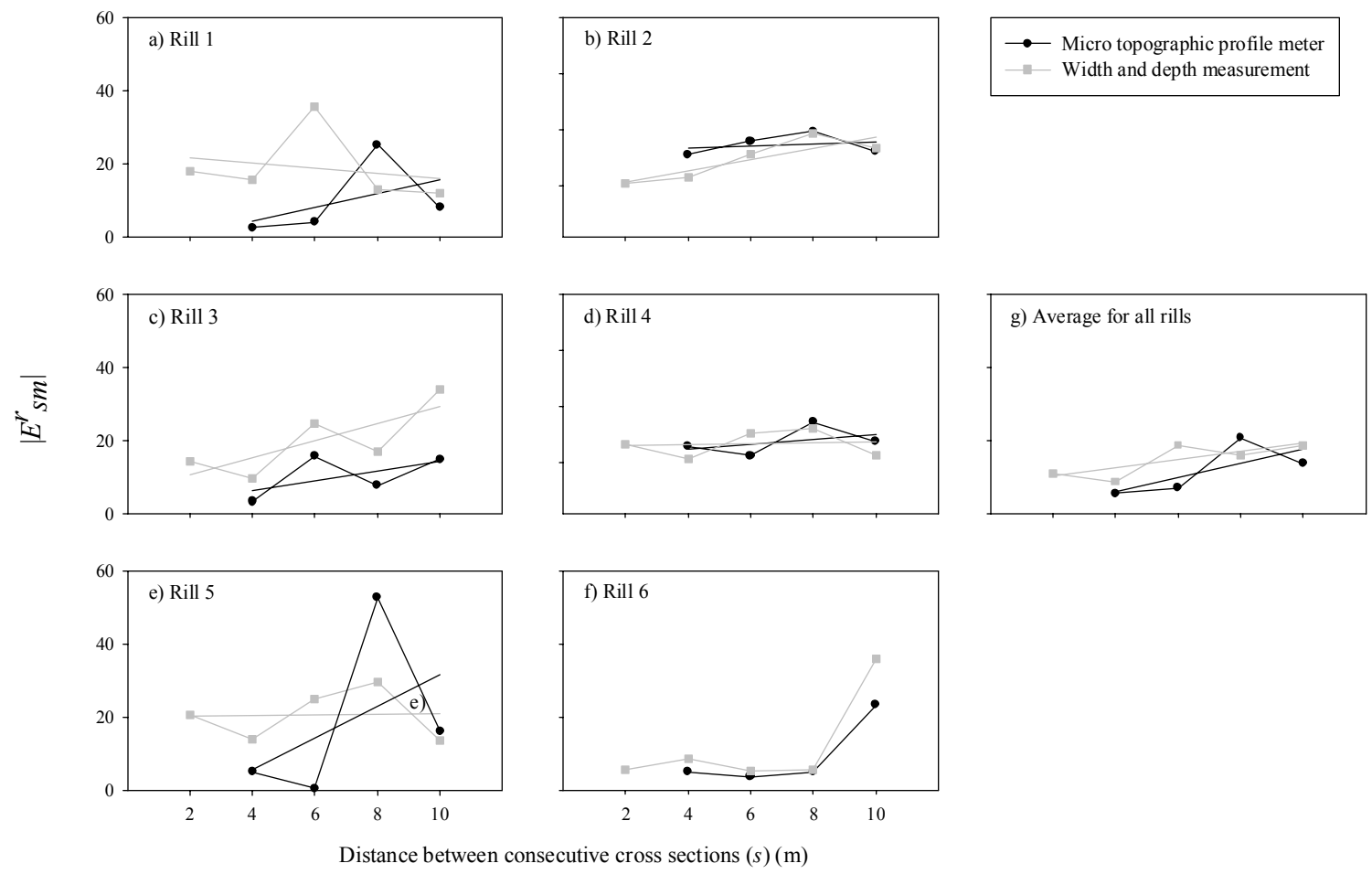


Figure 9

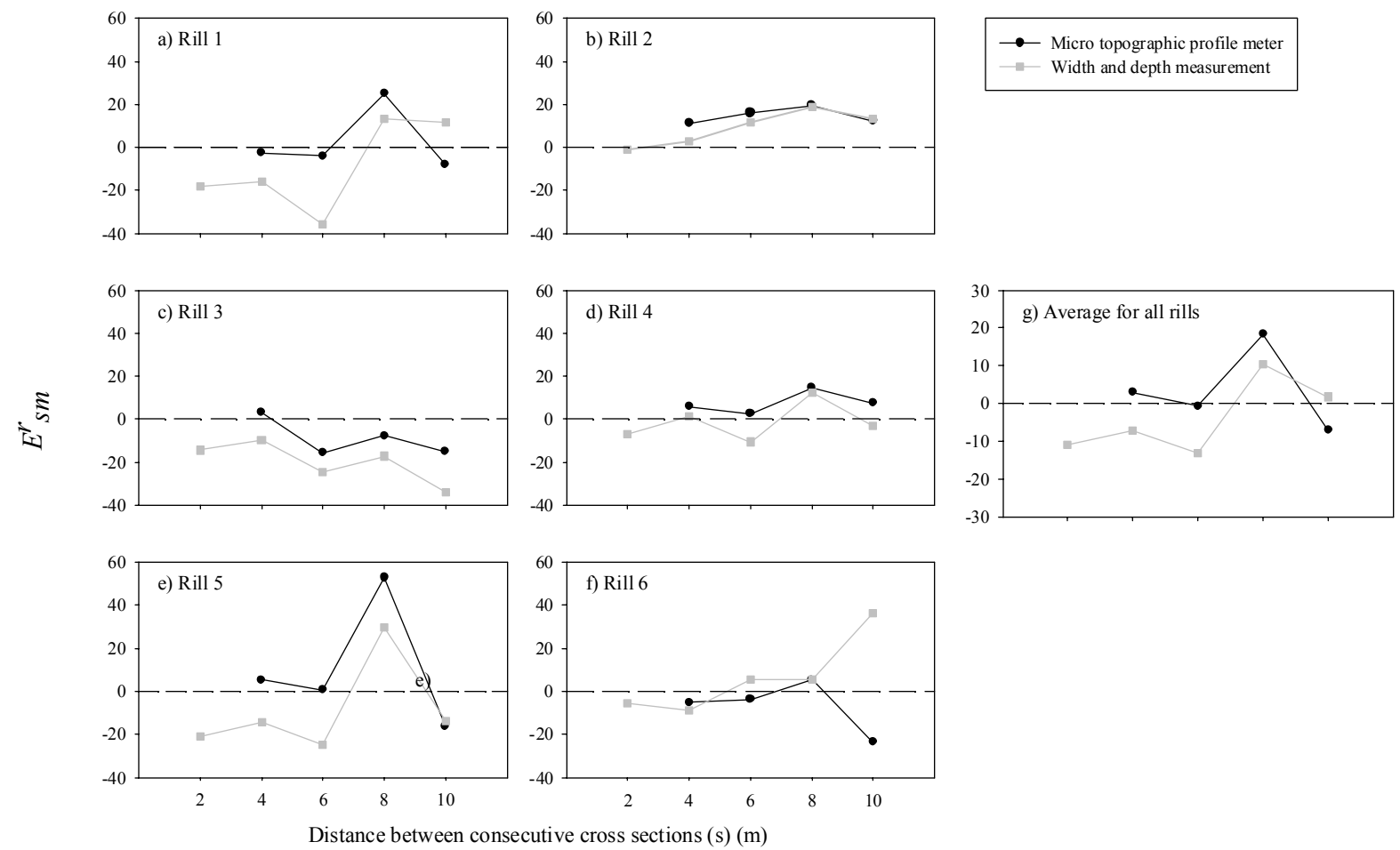
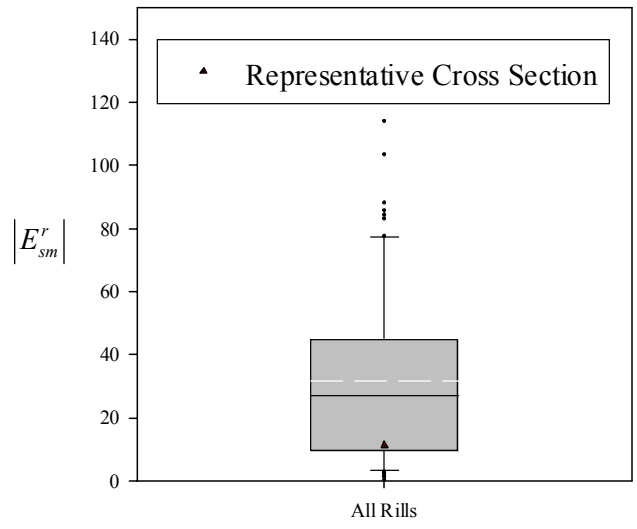


Figure 10



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

2

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

5

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

11

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

16

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

21

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

8

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

12

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

17

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

21

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

1 section is used. The box plot show the error obtained after randomly selecting one of the
2 measured cross sections as representative The dashed white line indicates the average
3 error when the random procedure for selecting the representative cross section is
4 applied.
5

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

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

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1 **Abstract**

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3 To properly assess soil erosion in agricultural areas, it is necessary to determine
4 precisely the volume of ephemeral gullies and rills in the field by using direct
5 measurement procedures. However, little information is available on the accuracy of the
6 different methods used. The main purpose of this paper is to provide information for a
7 suitable assessment of rill and ephemeral gully erosion with such direct measurement
8 methods. To achieve this objective: a) the measurement errors associated to three
9 methods used for field assessment of channel cross sectional areas are explored; b) the
10 influence of the number of cross sections used per unit channel length on the assessment
11 accuracy, is analysed and; c) the effect of the channel size and shape on measurement
12 errors is examined. The three methods considered to determine the cross sectional areas
13 were: micro-topographic profile meter (1); detailed measurement of section
14 characteristic lengths with a tape (2); measurement of cross section width and depth
15 with a tape (3). Five reaches of different ephemeral gully types 14.0 or 30.0 m long and
16 a set of six 20.4 to 29.4 m long rill reaches were selected. On each gully reach, the cross
17 sectional areas were measured using the three above mentioned methods, with a
18 separation (s) between cross sections of 1 m. For rills, the cross sectional areas were
19 measured with methods 1 and 3, with $s=2$ m. Then, the corresponding total erosion
20 volumes were computed. The volume calculated with method 1 with $s=1$ m for gullies
21 and $s=2$ m for rills was taken as the reference method. For each channel, and for each
22 one of the possible combinations of s and measurement method (m), the relative
23 measurement error and the absolute value of the relative measurement error (E'_{sm} and
24 $|E'_{sm}|$), defined with respect to the reference one, was calculated. $|E'_{sm}|$ much higher
25 than 10% were obtained very easily, even for small s values and for apparently *quasi*

1 prismatic channels. Channel size and shape had a great influence on measurement
2 errors. In fact, the selection of the more suitable method for a certain gully shape and
3 size seemed to be much more important than s , at least when $s < 10$ m. Method 1 always
4 provided the most precise measurements, and its results were the less dependent on s .
5 However, s must be < 5 m to guarantee an error smaller than 10%. Method 2 is not
6 recommended, because it is difficult, time consuming and can lead to large errors.
7 Method 3 seems to be enough for small, wide and shallow gullies, and for small rills,
8 but only if s is shorter than 5 m. Results obtained after the analysis of rill measurement
9 errors were similar to those of gullies. The analysis of E'_{sm} and $|E'_{sm}|$ when calculating
10 channel volumes using a unique representative cross section highlighted the importance
11 of correctly selecting the adequate cross section. Due to the high error values that this
12 method can entail, it is not considered as advisable whenever accurate erosion
13 measurements are pursued.

14

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

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19 **1. Introduction**

20

21 Ephemeral gullies are channels of various sizes, formed by the scouring of concentrated
22 surface runoff flowing on agricultural soils during rain events, refilled by the farmers
23 usually shortly after the rains, but often reappearing in the next rainy season (Foster,
24 1986; Thorne *et al.*, 1986; Zheng and Huang, 2002). Rill erosion (Foster, 1986; Bryan,
25 1987; Flanagan, 2002) consists on the development of numerous minute closely spaced

1 channels resulting from the uneven removal of surface soil by running water that is
2 concentrated in streamlets of sufficient discharge and velocity to generate cutting
3 power. It is an intermediate process between sheet erosion and gully erosion (Jackson,
4 1997). While the presence of rills is restricted to planar elements of watersheds,
5 ephemeral gullies occur on valley bottoms, within swales. Ephemeral gullies and rills
6 are common in cultivated soils in many areas around the world, and can cause large soil
7 losses (Bryan, 1987; Govers and Poesen, 1988; Benito *et al.*, 1992; Auzet *et al.*, 1993;
8 Bennett *et al.*, 2000; De Alba and Benito, 2001; Zheng and Huang, 2002; Poesen *et al.*,
9 2003; De Santisteban *et al.*, 2004).

10

11 Considering the importance of this erosion types, measurement methods to precisely
12 determine the volume of rills and ephemeral gullies are required. Methods based on the
13 assessment of a number of cross sectional areas with microtopographic profilers, or with
14 a tape or ruler along the channels, have been, and still are, widely used (Spomer and
15 Hjelmfelt, 1986; Govers, 1987; Govers and Poesen, 1988; Govers, 1991; Auzet *et al.*,
16 1993; Smith, 1993; Ludwig *et al.*, 1995; Vandaele and Poesen, 1995; Casali *et al.*,
17 1999; Bennett *et al.*, 2000; Nachtergaele *et al.*, 2001a,b; De Santisteban *et al.*, 2004). In
18 fact, direct assessment is often essential, because it can be very precise, simple and low-
19 cost compared with other methods, which in turn require direct assessments for
20 validation purposes. Accurate ground measurements are difficult, costly and time
21 consuming. Therefore, authors have been forced to use approximated cross section
22 and/or volume measurement methods. Authors very rarely provide information on
23 probable errors that can be associated to each method.

24

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

16

17

18 **2. Area descriptions, methods and materials**

19

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

1 corresponded to a steep slope of approximately 2,000 m². The main characteristics of
2 the selected rills are summarised in table 2.

3

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

7

8 Micro-topographic profiler (1) (Sancho *et al.*, 1991; Casali *et al.*, 1999; De Santisteban,
9 2003). Cross-section morphologies were characterized using a pin profiler that consisted
10 of 50 stainless steel pins spaced 20 mm apart (figure 1), placed perpendicularly to the
11 channel axis. The pin configuration and hence channel geometry was photographed, and
12 pin heights were digitized directly from these pictures, finally obtaining the cross
13 sectional area.

14

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

21

22 Approximated characterization of cross sections with a tape (3). This method consists in
23 assuming that a rectangle is a good representation of all cross sections. One of its
24 advantages is that a high number of cross sections can be measured very quickly. For
25 characterizing the cross section representative depth, an average value was considered

1 when required. It was also the case when the cross sections were complex and more
2 than one gully bed could be identified.

3

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

13

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

17

$$18 \quad V = \sum_{i=1}^n V_i = \sum_{i=1}^n \frac{A_{i-1} + A_i}{2} \cdot s \quad (1)$$

19

20 where:

21

22 V : Volume of eroded soil in the reach

23 n : Number of sub-reaches considered

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

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

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

2 s : Distance between adjacent cross sections

3

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

12

13
$$E_{sm}^r = \frac{V_{sm} - V_{11}}{V_{11}} \cdot 100 \quad (2)$$

14

15 where:

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

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

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

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

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where:

$|E'_{sm}|$ (%): 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).

$|E'_{sm}|$ and E'_{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.

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

13

14 Let us start the discussion with the average absolute value of the relative measurement
15 error ($|E'_{sm}|$) for all gullies (figure 4h). The smallest errors, on average, clearly occurred
16 with method 1, with errors ranging from 4.0% ($s = 2 \text{ m}$) to 8.5% ($s = 4 \text{ m}$). For method 2,
17 average errors ranged between 9.0% ($s = 3 \text{ m}$) and 15.0% ($s = 5 \text{ m}$). As expected, method
18 3 was on average the less precise, with errors ranging from 8.0 to 17.0% ($s = 3 \text{ m}$ and $s =$
19 5 m , respectively). Results from the linear regression between $|E'_{sm}|$ and s (figure 4h)
20 indicated that, when method 1 was used, the dependence of $|E'_{sm}|$ on s was the smallest,
21 and that when method 3 was used, such dependence was the largest.

22

23 For group I gullies (figure 4f), method 2 was leading the largest errors on both average
24 and maximum errors. Curiously, methods 1 and 3 yielded almost the same results. On
25 the other hand, any trend was found between $|E'_{sm}|$ and s . Method 1 was the most

1 precise and its errors were on average 10.1%. Average errors for methods 2 and 3 were
2 10.3 and 18.8% respectively. Maximum errors ranged between 22.0% for method 1 and
3 30.0% for method 2, meaning that, for that kind of gullies, large errors can occur with
4 any measurement method. Besides, a great variability and dispersion of $|E'_{sm}|$ was
5 observed, mainly in Navafría 2 gully (figure 4b), with sudden and often alternating
6 changes on its values. This variability may be bound to the high value of the cross
7 section area variation coefficient A_{cv} (table 1) of that gully, meaning that, for irregular
8 gullies (i. e., those with high A_c values) a small value of s is necessary to ensure small
9 measurement errors. The dispersion of $|E'_{sm}|$, tended to increase with s for the group I
10 gullies: when s increases, the probability that the surface area of few representative
11 cross sections plays an important role in the final value of the computed volume, and
12 thus in the error. Explanations for some of these results can come from the analysis of
13 the characteristics of the gullies, mainly Navafría 2 (figure 4b), the smallest and the one
14 with the largest WDR . In small, shallow and relatively wide gullies like these, the
15 assessment of the characteristic lengths required for method 2 can be especially
16 difficult. Even the uncomfortable posture of who is measuring can have an influence on
17 the results, because small lengths have to be accurately assessed with a tape and a ruler
18 for quite a long time, also assimilating an often unclear gully form. It seems that a
19 simpler assessment of gully width and depth can result in higher accuracy than a more
20 complex, uncomfortable and time-consuming assessment of characteristic lengths. This
21 can explain the better results obtained with method 3 compared with those with method
22 2 for Navafría 1 gully. On the other hand, is in Navafría 1 gully where the highest errors
23 were found, reaching up to 50% with method 2 ($s= 6$ m), and 30% with method 3 ($s= 6$
24 m).

25

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

4

5 For group II gullies (figure 4g), measurements with method 1 were also the most
6 precise, with $|E'_{sm}|$ values always below 10%, and frequently smaller (figure 4c, d, e).

7 Errors with method 1 were almost non-dependent on s , and sudden changes on its
8 values were not observed. Errors greatly increased for method 3, mainly in the case of
9 Beire gully, which is the largest and the one with smallest WDR . The good results with
10 method 2 could be explained now from the big size of Beire gully, what allows for a
11 good definition, visually and manually, with the tape or ruler, of the cross section
12 characteristic lengths. Errors with method 3 were similar to the values found for group I
13 gullies, and around 20%.

14

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

18

19 The errors associated to gully volumes calculated from one unique representative cross
20 section were calculated (figure 6a). In this case, results show a wide range of error
21 values. Using the selected as most representative cross section (triangles in figure 6a),
22 error values were quite low (below 20%) in all gullies. However, if the representative
23 cross section was selected randomly (box plots on figure 6a) error values could be much
24 higher. This fact is remarkable, considering that the studied gully reaches are quite
25 uniform (figure 2, table 1). Logically, the error ranges on figure 6a are in complete

1 agreement with A_{cv} values on table 1. So, the widest error range occurs in Navafría 2
2 gully (around 100%), which in turn shows the highest A_{cv} value (0.43). On the other
3 hand, the narrowest range occurs in Lakar 2 gully (around 40%), with the lowest A_{cv}
4 value (0.23). On average (white dashed lines on figure 6a), error values ranged from 20
5 to 40%. Thus, the selection of the adequate representative cross section, even in short
6 reaches and in very uniform channels, seems to be very important. An inadequate cross
7 section selection can entail high error values and, being a completely subjective
8 selection, the experience of the observer seems to be a big issue.

9

10 From this study, we have found that, even for small s values, probably much smaller
11 than the ones used in the majority of field surveys, large measurement errors occurred.
12 In many cases, errors to be expected showed a high level of randomness and dispersion.
13 The selection of the more suitable method for a certain gully shape and size, defined by
14 A , WDR and A_{cv} , seemed to be much more important than the distance between cross
15 sections s , at least when $s < 10$ m. For the same gully, errors when applying one method
16 or another could differ in up to 6 times (figure 4e). The highest difficulties seemed to
17 arise for small but wide gullies (group I) because large errors were obtained, even using
18 method 1. On the contrary, with group II gullies (large but narrow) quite accurate
19 assessments could be made with methods 1 and 2. The smallest probability of large
20 errors always occurred with method 1. For this method, s did not influence the error
21 values so, s could be as high as 5 m without errors greater than 10%. When the gullies
22 were homogeneous (i. e., for example, for $A_{cv} < 40\%$), s could be even greater. Results
23 with method 2 were similar to the ones from method 1, except for small and wide cross
24 sections, where errors were not acceptable. For big gullies where method 1 cannot be
25 used, method 2 must be always selected instead of 3. The use of profiler (method 1) is

1 also recommended compared to method 2: the main possible supposed advantage was
2 rapidity but, in fact, a lot of time was required for a suitable assessment of characteristic
3 lengths in many cross sections. For group I gullies, method 3 should be used when a
4 profiler was not available, since it was giving similar measurements for this gully type,
5 but it was not valid for group II gullies.

6

7

8 3.2. Rills

9

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

18

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

23

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

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

3

4 The smallest $|E'_{sm}|$ values (figure 8g) occurred on average again with method 1, despite
5 in some particular rills, like rill 2 and rill 4, the error values for both methods were
6 similar. r^2 values for the regression lines are 0.24 for method 1 and 0.37 for method 3.

7 Los valores de r^2 para las correspondientes líneas de regresión son de 0.24 para el
8 método 1 y de 0.37 para el método 3. Average errors with method 1 ranged from 5% ($s=$
9 4 m) to 21% ($s= 8$ m). For method 3, average errors ranged between 9% ($s= 2$ m) to
10 19% ($s= 6$ m). For this set of rills, the dependence of $|E'_{sm}|$ on s for method 1 was
11 slightly largest than for method 3. For $s= 5$ m, average $|E'_{sm}|$ for gullies and rills could
12 be compared (figures 4h and 8g). After this analysis, very similar errors values were
13 observed for both channel classes.

14

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

17

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

21

22 Considering a unique representative cross section for each rill reach, obtained results are
23 very similar to the case of gullies (figure 6b). When the selected representative sections
24 were used, error values were quite low (below 20%). But, if the representative cross
25 sections were randomly defined, the range of errors obtained were quite high, ranging

1 on average between 20 and 40%, and with very high peak values. Thus, the selection of
2 the adequate representative cross section, even in short reaches and in very uniform
3 channels, seems very important.

4

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

9

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

16

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

19

20

21 **4. Conclusions**

22

23 This paper intended to offer some first guidance for selecting the most suitable
24 procedure when assessing rill and ephemeral gully erosion in the field by direct
25 measurement methods. Error values much higher than 10% can be obtained very easily,

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

23

24

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2

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15 **REFERENCES**

16

17 Auzet, A.V., Boiffin, J., Papy, F., Ludwig, B., Maucorps, J., 1993. Rill erosion as a
18 function of the characteristics of cultivated catchments in the North of France. *Catena*
19 20, 41-62.

20

21 Benito, G., Gutiérrez, M., Sancho, C., 1992. Erosion Rates in Badland Areas of the
22 Central Ebro Basin (NE-Spain). *Catena* 19, 269-286.

23

1 Bennett, S.J., Casalí, J., Robinson, K.M., Kadavy, K.C., 2000. Characteristics of
2 actively eroding ephemeral gullies in an experimental channel. Trans. ASAE 43(3),
3 641-649.
4

5 Bryan RB (Ed.), 1987. Rill erosion. Processes and Significance. Catena Supplement 8.
6 Catena Verlag, Cremlingen.
7

8 Casalí, J., López, J., Giráldez, J.V., 1999. Ephemeral gully erosion in Southern Navarra
9 (Spain). Catena 36, 65-84.
10

11 De Alba, S., Benito, G., 2001. Effects of soil surface management on erosion during
12 extreme rainfall events in semiarid agricultural lands (Central Spain). Final Proceedings
13 Int. Symposium: The significance of soil surface characteristics in soil erosion,
14 Strasburg, France.
15

16 De Santisteban, L.M., 2003. Análisis de factores topográficos para predecir la erosión
17 por cárcavas efímeras. PhD diss. Department of Projects and Rural Engineering, Public
18 University of Navarre, Pamplona, Spain.
19

20 De Santisteban, L.M., Casalí, J., López, J.J., 2004. Evaluation of rill and ephemeral
21 gully erosion in cultivated areas of Navarre (Spain). Final Proceedings 3rd Int.
22 Symposium on Gully Erosion, Oxford (Mississippi), USA.
23

1 Elliot, W.J., Laflen, J.M., Thomas, A.W., Kohl, K.D., 1997. Photogrammetric and
2 rillmeter techniques for hydraulic measurement in soil erosion studies. *Trans. ASAE*
3 40(1), 157-165.
4
5 Flanagan, D., 2002. Erosion. In: Lal, R. (Ed.), *Encyclopedia of Soil Science*. Marcel
6 Dekker, New York, pp. 395-398.
7
8 Foster, G. R., 1986. Understanding ephemeral gully erosion. In: Committee on
9 Conservation Needs and Opportunities, Board on Agriculture, National Research
10 Council Soil Conservation. (Eds.), *Assesing the National Resources Inventory, 2.*
11 National Academy Press, Washington, pp. 90-125.
12
13 Govers, G., 1987. Spatial and temporal variability in rill development processes at the
14 Huldenberg experimental site. In: Bryan, R. B. (Ed.), *Rill erosion, processes and*
15 *significance. Catena Supplement 8, Cremlingen*, pp. 17-34
16
17 Govers, G., 1991. Rill erosion on arable land in Central Belgium: rates, controls and
18 predictability. *Catena* 18, 133-155.
19
20 Govers, G., Poesen, J., 1988. Assessment of the interrill and rill contributions to total
21 soil loss from an upland field plot. *Geomorphology* 1, 343-354.
22
23 Imeson, A.C., Kwaad, F.J.P.M., 1980. Gully types and gully prediction. *K.N.A.G.*
24 *Geografisch Tijdschrift* XIV 5, 430-441.
25

1 Jackson, J.A., 1997. Glossary of Geology. American Geological Institute, Alexandria.
2

3 Ludwig, B., Boiffin, J., Chadoeuf, J., Auzet, A. V., 1995. Hydrological structure and
4 erosion damage caused by concentrated flow in cultivated catchments. *Catena* 25, 227-
5 252.
6

7 Nachtergaele, J., Poesen, J., Steegen, A., Takken, I., Beuselinck, L., Vandekerckove, L.,
8 Govers, G., 2001a. The value of a physically based model versus an empirical approach
9 in the prediction of ephemeral gully erosion for loess-derived soils. *Geomorphology*
10 1007, 1-16.
11

12 Nachtergaele, J., Poesen, J., Vandekerckove, L., Oostwoud, D., Roxo, M., 2001b.
13 Testing the ephemeral gully erosion model (EGEM) for two Mediterranean
14 environments. *Earth Surf. Proc. Landforms* 26, 17-30.
15

16 Poesen, J., Govers G., 1990. Gully erosion in the Loam Belt of Belgium: Typology and
17 control measures. In: J. Boardman, I. D. L. Foster and J. A. Dearing, Eds. *Soil Erosion*
18 *on Agricultural Land*. John Wiley & Sons, London: 513-530.
19

20 Poesen, J., Nachtergaele, J., Verstraeten, G., Valentin, C., 2003. Gully erosion and
21 environmental change: importance and research needs. *Catena* 50, 91-133.
22

23 Sancho, C., Benito, G., Gutiérrez, M., 1991. Agujas de erosión y perfiladores
24 microtopográficos. Cuadernos Técnicos de la Sociedad Española de Geomorfología 2.
25 Geofoma Ediciones, Logroño.

1
2 Smith, L.M., 1993. Investigation of Ephemeral Gullies in Loessial Soils in Mississippi.
3 U. S. Army Corps of Engineers. Technical Report GL-93-11. Vicksburg.
4
5 Spomer, R.G., Hjelmfelt, A.T., 1986. Concentrated flow erosion on conventional and
6 conservation tilled watersheds. *Trans. ASAE* 29, 129-147.
7
8 Thorne, C.R., Zevenbergen, L.W., Grissinger, E.H., Murphey, JB., 1986. Ephemeral
9 gullies as sources of sediment. *Proceedings of the Fourth Federal Interagency*
10 *Sedimentation Conference* 1, 3-152, 3-161.
11
12 Vandaele, K., Poesen, J., 1995. Spatial and temporal patterns of soil erosion rates in an
13 agricultural catchment, central Belgium. *Catena* 25, 213-226.
14
15 Zheng, F., Huang, C., 2002. Gully erosion. In: Lal, R. (Ed.), *Encyclopedia of Soil*
16 *Science*. Marcel Dekker, New York, pp. 630-634.
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7 **Accuracy of methods for field assessment of rill and ephemeral gully**

8 **erosion**

9

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1 **Abstract**

2

3 To properly assess soil erosion in agricultural areas, it is necessary to determine
4 precisely the volume of ephemeral gullies and rills in the field by using direct
5 measurement procedures. However, little information is available on the accuracy of the
6 different methods used. The main purpose of this paper is to provide information for a
7 suitable assessment of rill and ephemeral gully erosion with such direct measurement
8 methods. To achieve this objective: a) the measurement errors associated to three
9 methods used for field assessment of channel cross sectional areas are explored; b) the
10 influence of the number of cross sections used per unit channel length on the assessment
11 accuracy, is analysed and; c) the effect of the channel size and shape on measurement
12 errors is examined. The three methods considered to determine the cross sectional areas
13 were: micro-topographic profile meter (1); detailed measurement of section
14 characteristic lengths with a tape (2); measurement of cross section width and depth
15 with a tape (3). Five reaches of different ephemeral gully types 14.0 or 30.0 m long and
16 a set of six 20.4 to 29.4 m long rill reaches were selected. On each gully reach, the cross
17 sectional areas were measured using the three above mentioned methods, with a
18 separation (s) between cross sections of 1 m. For rills, the cross sectional areas were
19 measured with methods 1 and 3, with $s= 2$ m. Then, the corresponding total erosion
20 volumes were computed. The volume calculated with method 1 with $s= 1$ m for gullies
21 and $s= 2$ m for rills was taken as the reference method. For each channel, and for each
22 one of the possible combinations of s and measurement method (m), the relative
23 measurement error and the absolute value of the relative measurement error (E_{sm}^r and
24 $|E_{sm}^r|$), defined with respect to the reference one, was calculated. $|E_{sm}^r|$ much higher
25 than 10% were obtained very easily, even for small s values and for apparently *quasi*

1 prismatic channels. Channel size and shape had a great influence on measurement
2 errors. In fact, the selection of the more suitable method for a certain gully shape and
3 size seemed to be much more important than s , at least when $s < 10$ m. Method 1 always
4 provided the most precise measurements, and its results were the less dependent on s .
5 However, s must be < 5 m to guarantee an error smaller than 10%. Method 2 is not
6 recommended, because it is difficult, time consuming and can lead to large errors.
7 Method 3 seems to be enough for small, wide and shallow gullies, and for small rills,
8 but only if s is shorter than 5 m. Results obtained after the analysis of rill measurement
9 errors were similar to those of gullies. The analysis of E'_{sm} and $|E'_{sm}|$ when calculating
10 channel volumes using a unique representative cross section highlighted the importance
11 of correctly selecting the adequate cross section. Due to the high error values that this
12 method can entail, it is not considered as advisable whenever accurate erosion
13 measurements are pursued.

14

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

17

18

19 **1. Introduction**

20

21 Ephemeral gullies are channels of various sizes, formed by the scouring of concentrated
22 surface runoff flowing on agricultural soils during rain events, refilled by the farmers
23 usually shortly after the rains, but often reappearing in the next rainy season (Foster,
24 1986; Thorne *et al.*, 1986; Zheng and Huang, 2002). Rill erosion (Foster, 1986; Bryan,
25 1987; Flanagan, 2002) consists on the development of numerous minute closely spaced

1 channels resulting from the uneven removal of surface soil by running water that is
2 concentrated in streamlets of sufficient discharge and velocity to generate cutting
3 power. It is an intermediate process between sheet erosion and gully erosion (Jackson,
4 1997). While the presence of rills is restricted to planar elements of watersheds,
5 ephemeral gullies occur on valley bottoms, within swales. Ephemeral gullies and rills
6 are common in cultivated soils in many areas around the world, and can cause large soil
7 losses (Bryan, 1987; Govers and Poesen, 1988; Benito *et al.*, 1992; Auzet *et al.*, 1993;
8 Bennett *et al.*, 2000; De Alba and Benito, 2001; Zheng and Huang, 2002; Poesen *et al.*,
9 2003; De Santisteban *et al.*, 2004).

10

11 Considering the importance of this erosion types, measurement methods to precisely
12 determine the volume of rills and ephemeral gullies are required. Methods based on the
13 assessment of a number of cross sectional areas with microtopographic profilers, or with
14 a tape or ruler along the channels, have been, and still are, widely used (Spomer and
15 Hjelmfelt, 1986; Govers, 1987; Govers and Poesen, 1988; Govers, 1991; Auzet *et al.*,
16 1993; Smith, 1993; Ludwig *et al.*, 1995; Vandaele and Poesen, 1995; Casali *et al.*,
17 1999; Bennett *et al.*, 2000; Nachtergaele *et al.*, 2001 a,b; De Santisteban *et al.*, 2004). In
18 fact, direct assessment is often essential, because it can be very precise, simple and low-
19 cost compared with other methods, which in turn require direct assessments for
20 validation purposes. Accurate ground measurements are difficult, costly and time
21 consuming. Therefore, authors have been forced to use approximated cross section
22 and/or volume measurement methods. Authors very rarely provide information on
23 probable errors that can be associated to each method.

24

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

16

17

18 **2. Area descriptions, methods and materials**

19

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

1 corresponded to a steep slope of approximately 2,000 m². The main characteristics of
2 the selected rills are summarised in table 2.

3

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

7

8 Micro-topographic profiler (1) (Sancho *et al.*, 1991; Casali *et al.*, 1999; De Santisteban,
9 2003). Cross-section morphologies were characterized using a pin profiler that consisted
10 of 50 stainless steel pins spaced 20 mm apart (figure 1), placed perpendicularly to the
11 channel axis. The pin configuration and hence channel geometry was photographed, and
12 pin heights were digitized directly from these pictures, finally obtaining the cross
13 sectional area.

14

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

21

22 Approximated characterization of cross sections with a tape (3). This method consists in
23 assuming that a rectangle is a good representation of all cross sections. One of its
24 advantages is that a high number of cross sections can be measured very quickly. For
25 characterizing the cross section representative depth, an average value was considered

1 when required. It was also the case when the cross sections were complex and more
2 than one gully bed could be identified.

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

13

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

17

$$18 \quad V = \sum_{i=1}^n V_i = \sum_{i=1}^n \frac{A_{i-1} + A_i}{2} \cdot s \quad (1)$$

19

20 where:

21

22 V : Volume of eroded soil in the reach

23 n : Number of sub-reaches considered

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

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

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

2 s : Distance between adjacent cross sections

3

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

12

$$13 \quad E_{sm}^r = \frac{V_{sm} - V_{11}}{V_{11}} \cdot 100 \quad (2)$$

14

15 where:

16

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

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

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

23

$$24 \quad |E_{sm}^r| = \left| \frac{V_{sm} - V_{11}}{V_{11}} \right| \cdot 100 \quad (3)$$

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where:

$|E'_{sm}|$ (%): 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).

$|E'_{sm}|$ and E'_{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.

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

13

14 Let us start the discussion with the average absolute value of the relative measurement
15 error ($|E_{sm}^r|$) for all gullies (figure 4h). The smallest errors, on average, clearly occurred
16 with method 1, with errors ranging from 4.0% ($s=2 \text{ m}$) to 8.5% ($s=4 \text{ m}$). For method 2,
17 average errors ranged between 9.0% ($s=3 \text{ m}$) and 15.0% ($s=5 \text{ m}$). As expected, method
18 3 was on average the less precise, with errors ranging from 8.0 to 17.0% ($s=3 \text{ m}$ and $s=$
19 5 m , respectively). Results from the linear regression between $|E_{sm}^r|$ and s (figure 4h)
20 indicated that, when method 1 was used, the dependence of $|E_{sm}^r|$ on s was the smallest,
21 and that when method 3 was used, such dependence was the largest.

22

23 For group I gullies (figure 4f), method 2 was leading the largest errors on both average
24 and maximum errors. Curiously, methods 1 and 3 yielded almost the same results. On
25 the other hand, any trend was found between $|E_{sm}^r|$ and s . Method 1 was the most

1 precise and its errors were on average 10.1%. Average errors for methods 2 and 3 were
2 10.3 and 18.8% respectively. Maximum errors ranged between 22.0% for method 1 and
3 30.0% for method 2, meaning that, for that kind of gullies, large errors can occur with
4 any measurement method. Besides, a great variability and dispersion of $|E'_{sm}|$ was
5 observed, mainly in Navafría 2 gully (figure 4b), with sudden and often alternating
6 changes on its values. This variability may be bound to the high value of the cross
7 section area variation coefficient A_{cv} (table 1) of that gully, meaning that, for irregular
8 gullies (i. e., those with high A_c values) a small value of s is necessary to ensure small
9 measurement errors. The dispersion of $|E'_{sm}|$, tended to increase with s for the group I
10 gullies: when s increases, the probability that the surface area of few representative
11 cross sections plays an important role in the final value of the computed volume, and
12 thus in the error. Explanations for some of these results can come from the analysis of
13 the characteristics of the gullies, mainly Navafría 2 (figure 4b), the smallest and the one
14 with the largest WDR . In small, shallow and relatively wide gullies like these, the
15 assessment of the characteristic lengths required for method 2 can be especially
16 difficult. Even the uncomfortable posture of who is measuring can have an influence on
17 the results, because small lengths have to be accurately assessed with a tape and a ruler
18 for quite a long time, also assimilating an often unclear gully form. It seems that a
19 simpler assessment of gully width and depth can result in higher accuracy than a more
20 complex, uncomfortable and time-consuming assessment of characteristic lengths. This
21 can explain the better results obtained with method 3 compared with those with method
22 2 for Navafría 1 gully. On the other hand, is in Navafría 1 gully where the highest errors
23 were found, reaching up to 50% with method 2 ($s= 6$ m), and 30% with method 3 ($s= 6$
24 m).
25

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

4

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

14

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

18

19 The errors associated to gully volumes calculated from one unique representative cross
20 section were calculated (figure 6a). In this case, results show a wide range of error
21 values. Using the selected as most representative cross section (triangles in figure 6a),
22 error values were quite low (below 20%) in all gullies. However, if the representative
23 cross section was selected randomly (box plots on figure 6a) error values could be much
24 higher. This fact is remarkable, considering that the studied gully reaches are quite
25 uniform (figure 2, table 1). Logically, the error ranges on figure 6a are in complete

1 agreement with A_{cv} values on table 1. So, the widest error range occurs in Navafria 2
2 gully (around 100%), which in turn shows the highest A_{cv} value (0.43). On the other
3 hand, the narrowest range occurs in Lakar 2 gully (around 40%), with the lowest A_{cv}
4 value (0.23). On average (white dashed lines on figure 6a), error values ranged from 20
5 to 40%. Thus, the selection of the adequate representative cross section, even in short
6 reaches and in very uniform channels, seems to be very important. An inadequate cross
7 section selection can entail high error values and, being a completely subjective
8 selection, the experience of the observer seems to be a big issue.

9

10 From this study, we have found that, even for small s values, probably much smaller
11 than the ones used in the majority of field surveys, large measurement errors occurred.
12 In many cases, errors to be expected showed a high level of randomness and dispersion.
13 The selection of the more suitable method for a certain gully shape and size, defined by
14 A , WDR and A_{cv} , seemed to be much more important than the distance between cross
15 sections s , at least when $s < 10$ m. For the same gully, errors when applying one method
16 or another could differ in up to 6 times (figure 4e). The highest difficulties seemed to
17 arise for small but wide gullies (group I) because large errors were obtained, even using
18 method 1. On the contrary, with group II gullies (large but narrow) quite accurate
19 assessments could be made with methods 1 and 2. The smallest probability of large
20 errors always occurred with method 1. For this method, s did not influence the error
21 values so, s could be as high as 5 m without errors greater than 10%. When the gullies
22 were homogeneous (i. e., for example, for $A_{cv} < 40\%$), s could be even greater. Results
23 with method 2 were similar to the ones from method 1, except for small and wide cross
24 sections, where errors were not acceptable. For big gullies where method 1 cannot be
25 used, method 2 must be always selected instead of 3. The use of profiler (method 1) is

1 also recommended compared to method 2: the main possible supposed advantage was
2 rapidity but, in fact, a lot of time was required for a suitable assessment of characteristic
3 lengths in many cross sections. For group I gullies, method 3 should be used when a
4 profiler was not available, since it was giving similar measurements for this gully type,
5 but it was not valid for group II gullies.

6

7

8 3.2. Rills

9

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

18

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

23

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

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

3
4 The smallest $|E_{sm}^r|$ values (figure 8g) occurred on average again with method 1, despite
5 in some particular rills, like rill 2 and rill 4, the error values for both methods were
6 similar. r^2 values for the regression lines are 0.24 for method 1 and 0.37 for method 3.

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7 Los valores de r^2 para las correspondientes líneas de regresión son de 0.24 para el
8 método 1 y de 0.37 para el método 3. Average errors with method 1 ranged from 5% ($s=$
9 4 m) to 21% ($s=$ 8 m). For method 3, average errors ranged between 9% ($s=$ 2 m) to
10 19% ($s=$ 6 m). For this set of rills, the dependence of $|E_{sm}^r|$ on s for method 1 was
11 slightly largest than for method 3. For $s=$ 5 m, average $|E_{sm}^r|$ for gullies and rills could
12 be compared (figures 4h and 8g). After this analysis, very similar errors values were
13 observed for both channel classes.

14
15 Thus, for assessing volumes of this rill class, it seems to be necessary to use s values
16 less than 4 m with methods 1 and 3 to guarantee that errors remain below 10%.

17
18 Results on figure 9 show that the assessment errors can be a consequence of either
19 overestimating or underestimating the eroded volumes. A clear tendency in this
20 response is not observed.

21
22 Considering a unique representative cross section for each rill reach, obtained results are
23 very similar to the case of gullies (figure 6b). When the selected representative sections
24 were used, error values were quite low (below 20%). But, if the representative cross
25 sections were randomly defined, the range of errors obtained were quite high, ranging

1 on average between 20 and 40%, and with very high peak values. Thus, the selection of
2 the adequate representative cross section, even in short reaches and in very uniform
3 channels, seems very important.

4

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

9

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

16

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

19

20

21 **4. Conclusions**

22

23 This paper intended to offer some first guidance for selecting the most suitable
24 procedure when assessing rill and ephemeral gully erosion in the field by direct
25 measurement methods. Error values much higher than 10% can be obtained very easily,

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

23

24

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2

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13

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15 **REFERENCES**

16

17 Auzet, A.V., Boiffin, J., Papy, F., Ludwig, B., Maucorps, J., 1993. Rill erosion as a
18 function of the characteristics of cultivated catchments in the North of France. *Catena*
19 20,41-62.

20

21 Benito, G., Gutiérrez, M., Sancho, C., 1992. Erosion Rates in Badland Areas of the
22 Central Ebro Basin (NE-Spain). *Catena* 19, 269-286.

23

1 Bennett, S.J., Casalí, J., Robinson, K.M., Kadavy, K.C., 2000. Characteristics of
2 actively eroding ephemeral gullies in an experimental channel. *Trans. ASAE* 43(3),
3 641-649.
4
5 Bryan RB (Ed.), 1987. Rill erosion. Processes and Significance. *Catena Supplement 8*.
6 Catena Verlag, Cremlingen.
7
8 Casalí, J., López, J., Giráldez, J.V., 1999. Ephemeral gully erosion in Southern Navarra
9 (Spain). *Catena* 36, 65-84.
10
11 De Alba, S., Benito, G., 2001. Effects of soil surface management on erosion during
12 extreme rainfall events in semiarid agricultural lands (Central Spain). Final Proceedings
13 Int. Symposium: The significance of soil surface characteristics in soil erosion,
14 Strasburg, France.
15
16 De Santisteban, L.M., 2003. Análisis de factores topográficos para predecir la erosión
17 por cárcavas efímeras. PhD diss. Department of Projects and Rural Engineering, Public
18 University of Navarre, Pamplona, Spain.
19
20 De Santisteban, L.M., Casalí, J, López, J.J., 2004. Evaluation of rill and ephemeral
21 gully erosion in cultivated areas of Navarre (Spain). Final Proceedings 3rd Int.
22 Symposium on Gully Erosion, Oxford (Mississippi), USA.
23

1 Elliot, W.J., Laflen, J.M., Thomas, A.W., Kohl, K.D., 1997. Photogrammetric and
2 rillmeter techniques for hydraulic measurement in soil erosion studies. *Trans. ASAE*
3 40(1), 157-165.
4
5 Flanagan, D., 2002. Erosion. In: Lal, R. (Ed.), *Encyclopedia of Soil Science*. Marcel
6 Dekker, New York, pp. 395-398.
7
8 Foster, G. R., 1986. Understanding ephemeral gully erosion. In: *Committee on*
9 *Conservation Needs and Opportunities, Board on Agriculture, National Research*
10 *Council Soil Conservation. (Eds.), Assessing the National Resources Inventory, 2.*
11 *National Academy Press, Washington, pp. 90-125.*
12
13 Govers, G., 1987. Spatial and temporal variability in rill development processes at the
14 Huldenberg experimental site. In: Bryan, R. B. (Ed.), *Rill erosion, processes and*
15 *significance. Catena Supplement 8, Cremlingen, pp. 17-34*
16
17 Govers, G., 1991. Rill erosion on arable land in Central Belgium: rates, controls and
18 predictability. *Catena* 18, 133-155.
19
20 Govers, G., Poesen, J., 1988. Assessment of the interrill and rill contributions to total
21 soil loss from an upland field plot. *Geomorphology* 1, 343-354.
22
23 Imeson, A.C., Kwaad, F.J.P.M., 1980. Gully types and gully prediction. *K.N.A.G.*
24 *Geografisch Tijdschrift XIV* 5, 430-441.
25

1 Jackson, J.A., 1997. Glossary of Geology. American Geological Institute, Alexandria.
2

3 Ludwig, B., Boiffin, J., Chadoeuf, J., Auzet, A. V., 1995. Hydrological structure and
4 erosion damage caused by concentrated flow in cultivated catchments. *Catena* 25, 227-
5 252.
6

7 Nachtergaele, J., Poesen, J., Steegen, A., Takken, I., Beuselinck, L., Vandekerckove, L.,
8 Govers, G., 2001a. The value of a physically based model versus an empirical approach
9 in the prediction of ephemeral gully erosion for loess-derived soils. *Geomorphology*
10 1007, 1-16.
11

12 Nachtergaele, J., Poesen, J., Vandekerckove, L., Oostwoud, D., Roxo, M., 2001b.
13 Testing the ephemeral gully erosion model (EGEM) for two Mediterranean
14 environments. *Earth Surf. Proc. Landforms* 26, 17-30.
15

16 Poesen, J., Govers G., 1990. Gully erosion in the Loam Belt of Belgium: Typology and
17 control measures. In: J. Boardman, I. D. L. Foster and J. A. Dearing, Eds. *Soil Erosion*
18 *on Agricultural Land*. John Wiley & Sons, London: 513-530.
19

20 Poesen, J., Nachtergaele, J., Verstraeten, G., Valentin, C., 2003. Gully erosion and
21 environmental change: importance and research needs. *Catena* 50, 91-133.
22

23 Sancho, C., Benito, G., Gutiérrez, M., 1991. Agujas de erosión y perfiladores
24 microtopográficos. *Cuadernos Técnicos de la Sociedad Española de Geomorfología* 2.
25 *Geoforma Ediciones, Logroño.*

1

2 Smith, L.M., 1993. Investigation of Ephemeral Gullies in Loessial Soils in Mississippi.

3 U. S. Army Corps of Engineers. Technical Report GL-93-11. Vicksburg.

4

5 Spomer, R.G., Hjelmfelt, A.T., 1986. Concentrated flow erosion on conventional and
6 conservation tilled watersheds. Trans. ASAE 29, 129-147.

7

8 Thorne, C.R., Zevenbergen, L.W., Grissinger, E.H., Murphey, JB., 1986. Ephemeral
9 gullies as sources of sediment. Proceedings of the Fourth Federal Interagency
10 Sedimentation Conference 1, 3-152, 3-161.

11

12 Vandaele, K., Poesen, J., 1995. Spatial and temporal patterns of soil erosion rates in an
13 agricultural catchment, central Belgium. Catena 25, 213-226.

14

15 Zheng, F., Huang, C., 2002. Gully erosion. In: Lal, R. (Ed.), Encyclopedia of Soil
16 Science. Marcel Dekker, New York, pp. 630-634.

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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.