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Hydraulic efficiency of the discontinuous gullies

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Abstract

Most discontinuous gullies overlying the almost tabular sedimentary strata of the Moldavian Plateau, Eastern Romania exhibit gullying by gully head advance and aggradation of the gully basin floor. According to Heede [Z. Geomorphol. N. F. 18 (1974) 260] the shape factor of the gullies, relating maximum to minimum depth, expresses both channel shape and hydraulic efficiency of channels.

Based on a geomorphic approach, this paper shows that a better understanding of gully hydraulic efficiency may be assessed by another shape factor obtained by relating present to filled gully cross-section. A value of 1.0 for this shape factor, S_p/S_f, represents the threshold of hydraulic efficiency. Strong relationships were established between the shape factor and gully length. In addition, an appropriate substitute expressed as the ratio of gully bottom width (W_b) to gully top width (W_t) was found, which is easy to apply and very fast to determine in the field.
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Keywords: Discontinuous gullies; Gullying; Aggradation; Shape factor; Hydraulic efficiency

1. Introduction

During a study of channel characteristics of streams in the Western United States, Schumm (1960) discovered that the shape of the channel of a stable river expressed as a width–depth ratio (F) is related to the percentage of sediment finer than 0.074 mm in the perimeter of the channel (M) as follows:

$$F = 255M^{-1.08}$$

This shape factor (F), which is defined as the bankfull top width divided by the bankfull maximum depth, was often used in the quantitative study of gullies.

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The Soil Conservation Service of the US Department of Agriculture in the "Technical Release No. 32 (Geology)" of 1966 (USDA-SCS, 1966), recommended comparison of the top widths (TW) and depth (D) as one method of determining the gully channel widening that will occur. The following relationships were established:

$$D = 0.34\text{TW for cohesive materials and}$$

$$D = 0.57\text{TW for noncohesive soils.}$$

Therefore, the gully width is about three times the depth for cohesive materials and about 1.75 times the depth for noncohesive materials.

To establish gully morphology and possible stages of gully development, Heede (1974, 1976) analyzed the hydraulic geometry of 17 gullies located on Alkali Creek watershed, on the western flank of the Colorado Rocky Mountains. Three hydraulic parameters were considered:

- stream order analysis;
- longitudinal gully profile; and
- the shape factor, relating maximum to mean depth; mean depth is the cross-sectional area divided by the bankfull channel width.

The new shape factor is more elaborate than the width–depth ratio (F) established by Schumm. However, Heede suggests that this parameter must be interpreted cautiously because it can relate to a variety of unusual gully cross-sections. According to Heede (1974) the value 2.0 of the shape factor represents the threshold of hydraulic efficiency. The relatively high values of the shape factor of Alkali Creek gullies indicate hydraulic inefficiency of the channels. Rivers in dynamic equilibrium have an average shape factor smaller than 2.0 and thus a greater hydraulic efficiency.

Based on this concept Radoane et al. (1990) investigated eight discontinuous gullies located on the northern part of the Moldavian Plateau from Eastern Romania. The Heede's shape factor was determined in 133 gully cross-sections for gullies of 173–428 m length. By comparing the shape factor (F) values versus gully length (L) they derived the following relationship:

$$F = 1.287 + 0.00199L$$

The correlation coefficient for this relationship is 0.39. The intersection point between the regression line and the threshold line of hydraulic efficiency is located at an average distance of 350 m downstream of the gully head. This would indicate the reach where the gullies express mature stage of development and have even begun to stabilize.

Long-term investigations undertaken by Ionita (1997) in the southern part of the Moldavian Plateau, near Barlad City, have permitted the establishment of a tentative classification of discontinuous gullies that may be a useful guide to further research. The purpose of this study is to report the development of a new shape factor based on these studies.

2. Methods

An Eijkelkamp auger kit was used to drill and sample the recent alluvia deposited along the gully floor to identify the initial gully floor in different cross-sections as well as the thickness of sediment progressively deposited within the gullies. Such detail makes the examination of the total gully cross-section possible as follows.

– The present section or the available section at one time in a specific place that is visible to the naked eye.
– The filled or siltated section, which is revealed by drilling into the recent alluvia or which outcrops in some active gully heads.

These studies made it possible to make classical measurements (width, depth, length) as well as to determine the aggradation in the gully.

3. Results and discussion

Three groups of discontinuous gullies have been distinguished on the basis of data limited to gully morphology and the rate of aggradation.

(1) Single (isolated, classical) gullies where aggradation begins immediately below the headcut area and moves downstream as the gully floor gets progressively wider. The average proportion of the aggraded area is around 59% of the total gully area. It has the shape of a converse, prolonged funnel named divergent system or long diffusor (Fig. 1).
(2) Successive (chain, cascade) gullies divided by the rate of aggradation into:
  (2.1) Alluvial gullies, where the depositional gully floor averages 17–45% of the total gully area. By their configuration two types were identified. Convergent gullies, which through their lobate shape (confusor) look like normal funnel, and divergent gullies where the flaring and short gully floor resembles a converse funnel or short diffusor (Fig. 2). These are the most common gullies in the study area.
  (2.2) Erosional gullies, where erosion processes are prevailing and aggradation is subsequent.
(3) Batteries of discontinuous gullies, which combine features from the previous two main groups, single and successive gullies.

Analysis of the total section of discontinuous gullies near Barlad City enabled a new indicator of hydraulic efficiency to be established by relating the present section (S_p) to the filled section (S_f). A value of 1.0 of this shape factor (S_p/S_f) represents the threshold of hydraulic efficiency within discontinuous gullies. Higher values than this threshold are characterizing the efficient gully reach with little aggradation. Values below the threshold define inefficient gully reach that in the long-term becomes clogged with alluvia. The significance of these values differs from Heede's.

Plotting of shape factor values (S_p/S_f) from 11 total cross-sections versus gully length is illustrated in Fig. 3. Measurements were made on three isolated gullies of 112–120 m

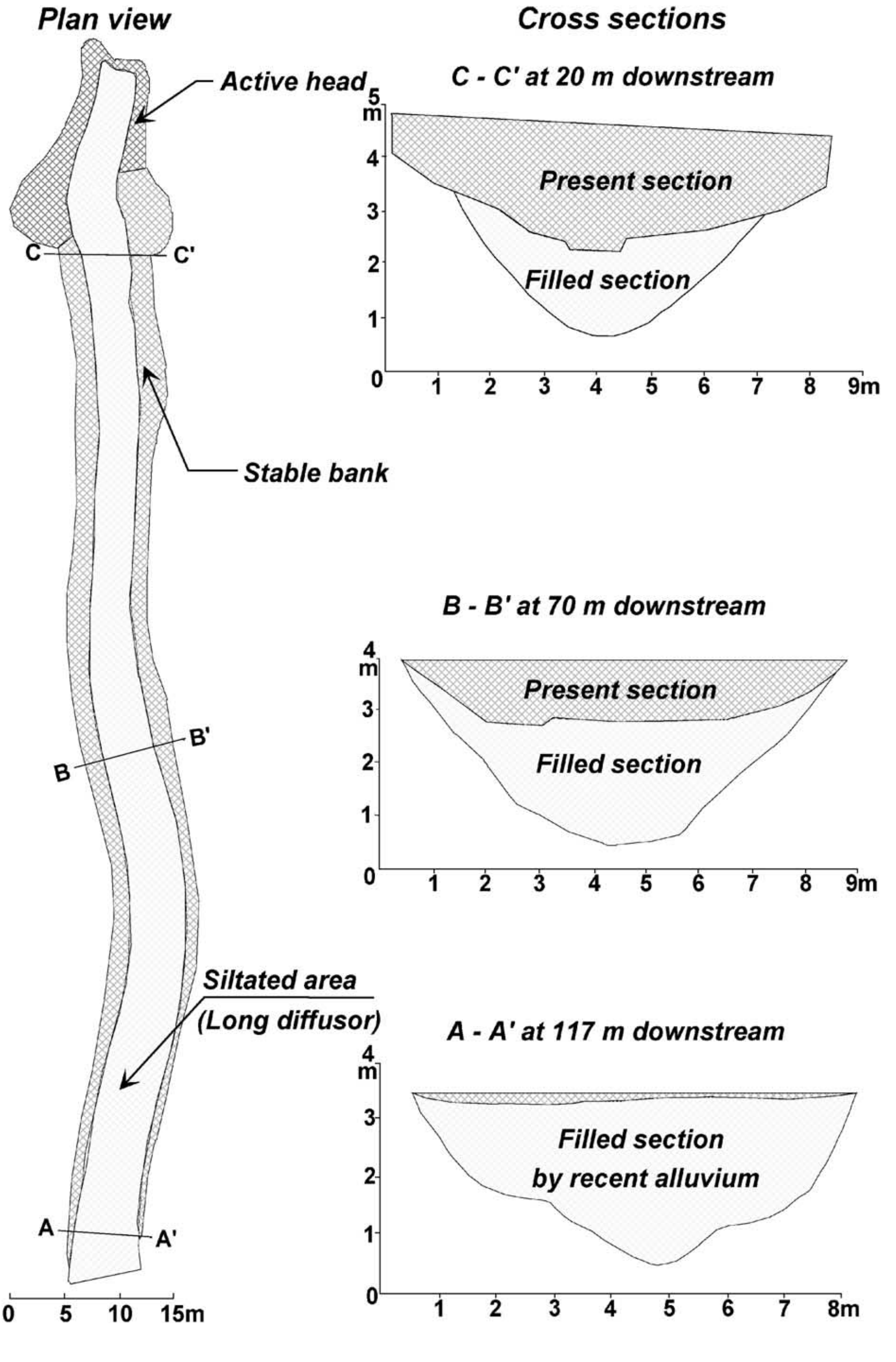

Fig. 1. Single discontinuous gully no. 1 Caldarea Valley.

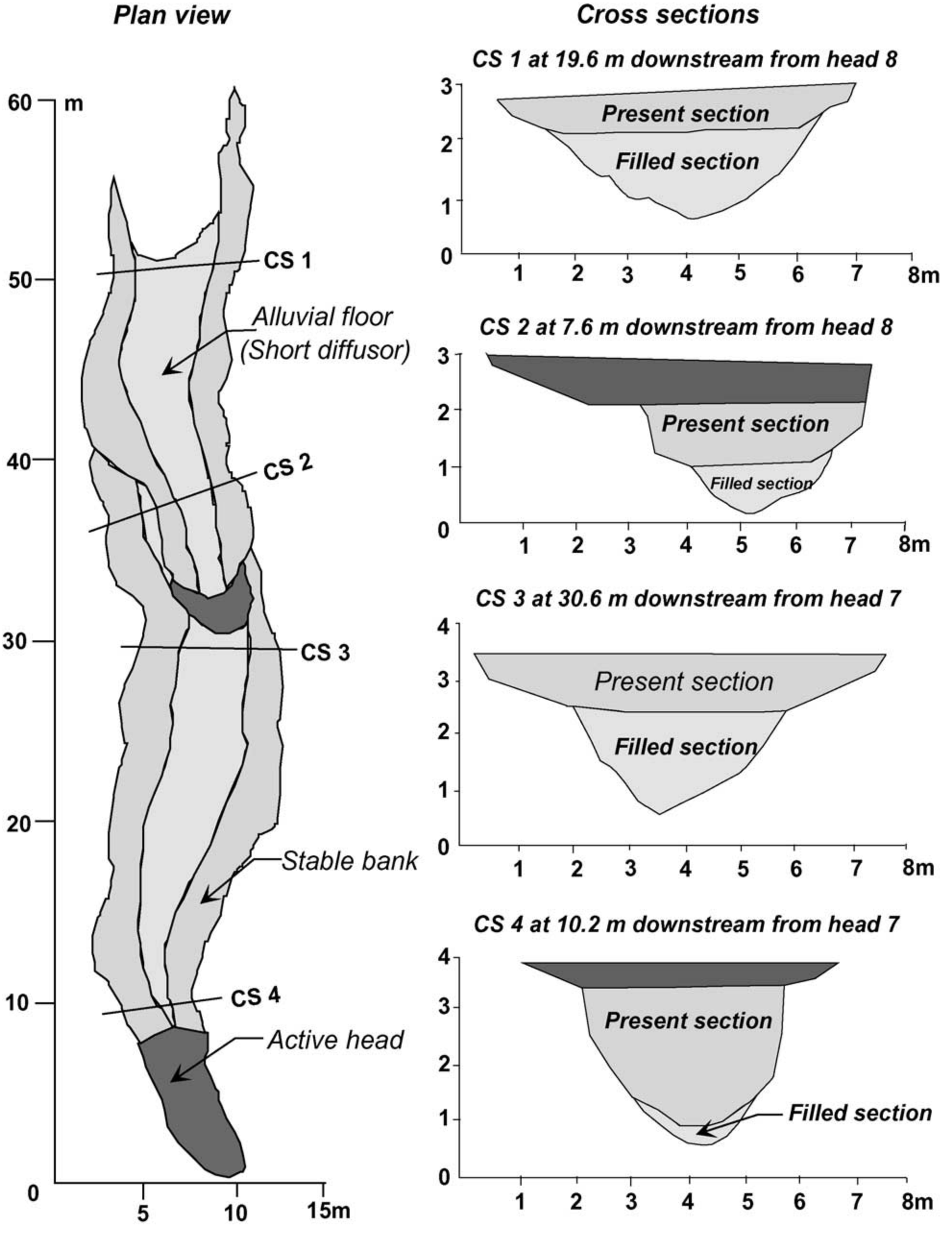

Fig. 2. Successive discontinuous gullies with alluvial, divergent floor ("short diffusors") on Timbru Valley, Falciu Hills, Romania, May 1995.

length, from Caldarea and Harcioaia Valleys in the Moldavian Plateau of Eastern Romania. The regression equation suggests an inverse but strong relationship ($R^2 = 0.93$) between the variables. Single discontinuous gullies are exceeding the critical threshold 1.0 along 43% of

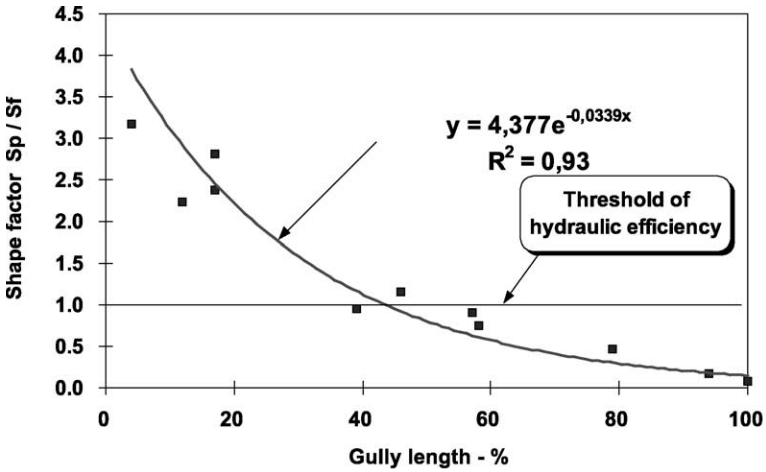

Fig. 3. Relation between shape factor S_p/S_f and length of the single discontinuous gullies (“long diffusors”).

their length. Thus they are associated with low hydraulic efficiency. Conversely, successive flaring gullies (short diffusors) are efficient for twice the length of the previous type because only a limited reach, averaging 15% of the gully length, has an S_p/S_f ratio below 1.0. This conclusion is graphically drawn in Fig. 4 that defines the same inverse but strong relationship between variables.

These two relationships ($y = 4.377 \cdot e^{-0.0339x}$ for single gullies and $y = 767.67 \cdot x^{-1.491}$ for successive, flaring gullies) can be used to distinguish predominantly aggrading from

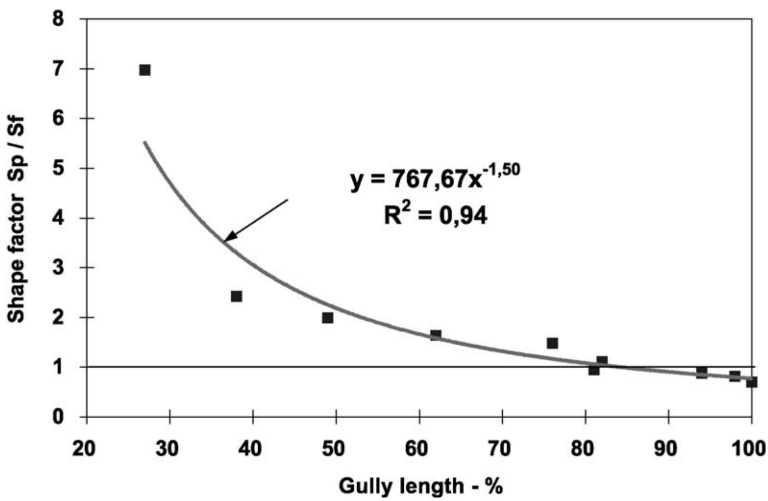

Fig. 4. Relation between shape factor S_p/S_f and length of the successive discontinuous gullies (“short diffusors”) in Timbru Valley, Moldavian Plateau, Romania.

predominantly eroding gullies in terms of the position of the total cross-sections versus the critical threshold of hydraulic efficiency.

Comparative analysis of data obtained through both indicators (Heede's D_{max}/D_{mean} and Ionita's S_p/S_f) is of interest in the case for successive discontinuous gullies. Figs. 5 and 6 present plots the values of these indicators derived from 25 cross-sections along two gullies. The first gully, in the upper Jeravat basin, is 542 m in length and has a drainage area of 139.8 ha. The second is in Ibana-Simila basin and is 212 m in length and 216.5 ha in size.

According to Ionita's indicator (S_p/S_f) these gullies are hydrologic efficient for about 79% of their length and only a short reach at the gully outlet is below the threshold efficiency limit. For Heede's indicator (D_{max}/D_{mean}) these gullies are hydraulic efficient only on 24% of their total length, the first quarter downstream the gully head, respectively.

Surprisingly, the Heede's indicator presents fluctuating values around the threshold of 2.0 even at the gully inlet, where the gully floor has no aggradation. Under these circumstances the ratio S_p/S_f cannot be estimated. In addition, Heede's indicator suggests that the middle reach of gullies is inefficient. However, the present gully cross-section is very well defined and during heavy rainfalls the peak stream never flows out of the bank. Therefore, the use of Heede's indicator in analyzing most discontinuous gullies, that are associated with aggradation, is not applicable. Heede's approach appears to be particularly valuable when investigating continuous gullies.

To determine siltated or filled cross-sectional area is difficult and time consuming. Consequently, it is useful to determine another indicator that would allow an easier way to assess hydraulic efficiency. Since the present cross-section of discontinuous gullies associated with sedimentation along the gully floor is trapezoidal, it was concluded that the ratio of bottom width (W_b) to top width (W_t) is an appropriate indicator. The relationship between this new morphometric indicator (W_b/W_t), that is very easy to be

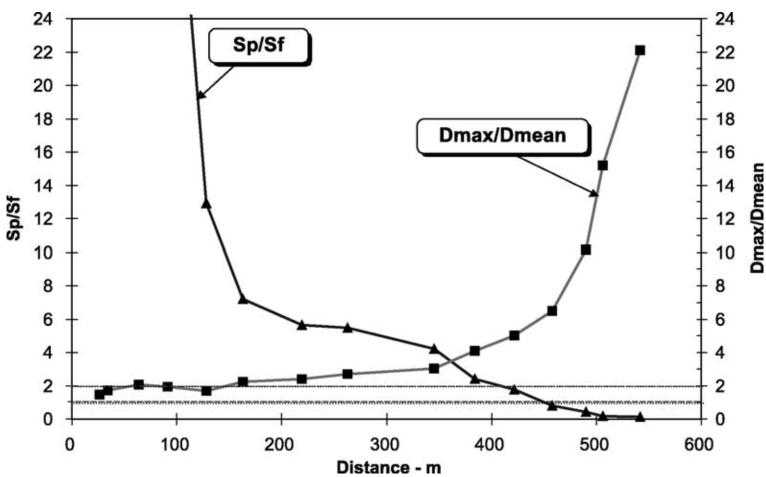

Fig. 5. Comparative distribution of the indicators S_p/S_f and D_{max}/D_{mean} in Pustii Valley, upper Jeravat basin.

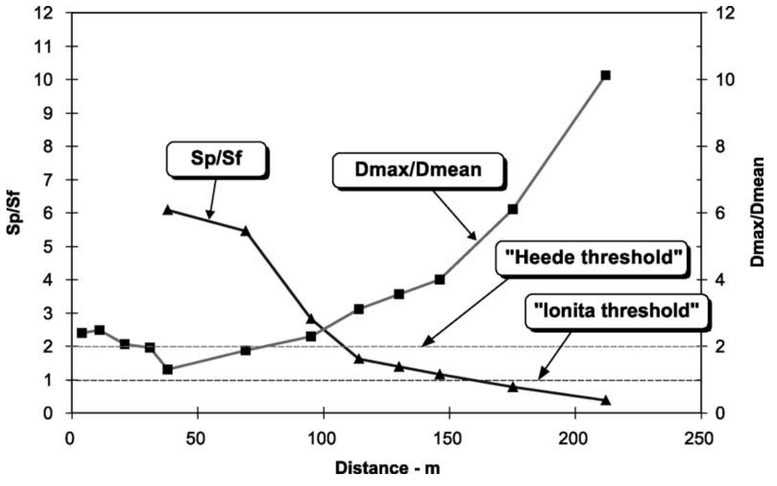

Fig. 6. Comparative distribution of the indicators S_p/S_f and D_{max}/D_{mean} in Gornei-Ibana Valley, Romania.

determined in the field, and the indicator of hydraulic efficiency, S_p/S_f, was derived by means of regression. A strong but inverse relation ($R^2 = 0.95$ or 0.97) between these indicators (W_b/W_t and S_p/S_f) has been found. For single discontinuous gullies the crossing point of the regression line with the threshold line of hydraulic efficiency is around a value of 0.47–0.48 of the ratio W_b/W_t (Fig. 7). The higher values actually reflect the hydraulic inefficiency of the gully and account for the majority of the data points.

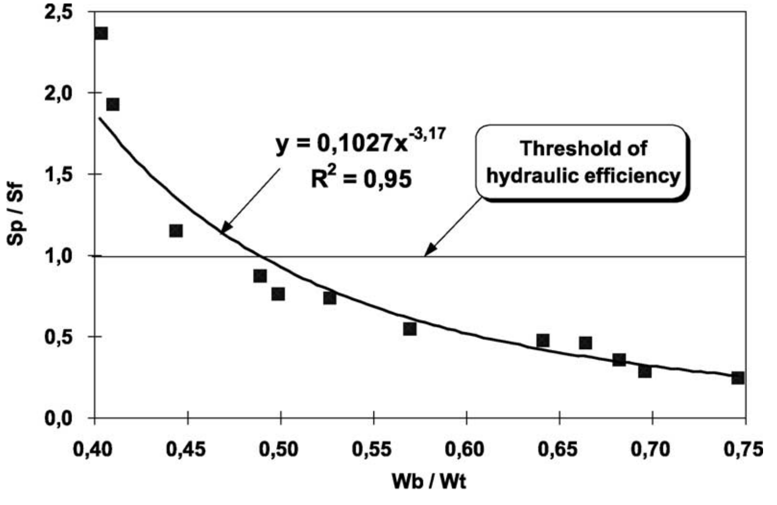

Fig. 7. Relation between the morphometric indicators S_p/S_f and W_b/W_t within single, discontinuous gullies ("long diffusors") in Caldarea Valley, Romania.

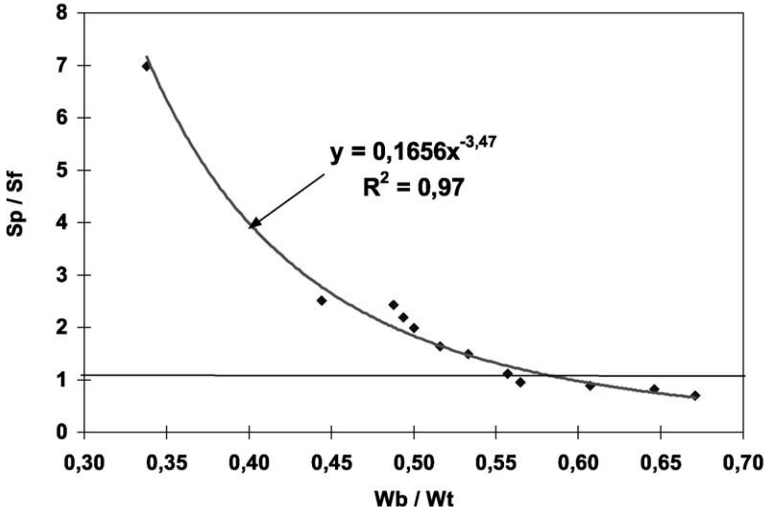

Fig. 8. Relation between the morphometric indicators S_p/S_f and W_b/W_t within successive gullies ("short diffusors") in Timbru Valley.

In the case for successive, flaring discontinuous gullies (short diffusor) the crossing point rises to 0.59–0.60 value of the ratio W_b/W_t. This finding is illustrated in Fig. 8 by plotting of the values from 12 cross-sections in Timbru Valley. A strong relationship ($R^2=0.97$) between those indicators was derived on successive, convergent (confusor) gullies from Vasilache and Timbru Valleys. The critical value of the ratio W_b/W_t is 0.48 but on this type of discontinuous gully the inefficient reach is almost nonexistent. Most of the gully is characterized by over unit values of ratio S_p/S_f (Fig. 9). The influence of soil

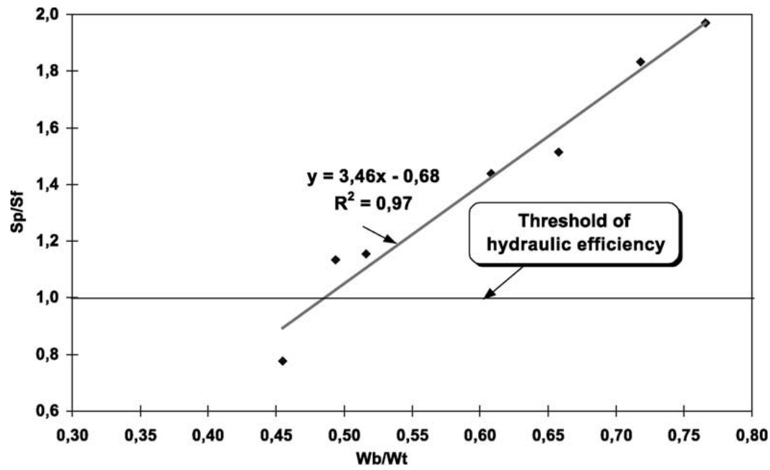

Fig. 9. Relationship between S_p/S_f and W_b/W_t indicators on successive, convergent ("confusor") gullies.

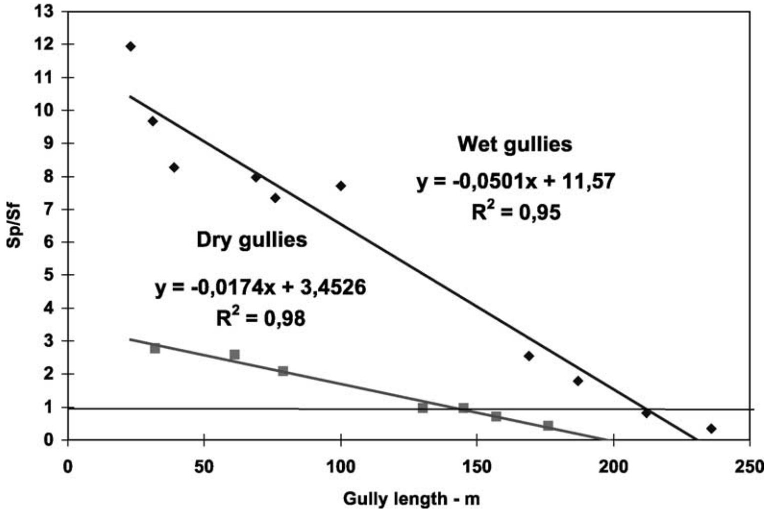

Fig. 10. The influence of soil moisture on hydraulic efficiency of the discontinuous gullies.

moisture on hydraulic efficiency of gullies should be emphasized. Fig. 10 clearly suggests the doubling or even tripling of the hydraulic efficiency under wet gullies as compared with dry gullies in the Upper Harcioaia basin.

4. Conclusions

- Gully morphology and the rate of aggradation were used to distinguish three groups of discontinuous gullies. The proportion of the depositional gully floor decreases from 59% under single isolated gullies to 17–45% of the total gully area within the alluvial family of successive gullies.
- The hydraulic efficiency of discontinuous gullies is assessed by a new shape factor, obtained by relating present (S_p) to a filled (S_f) gully cross-section. Value of 1.0 of this shape factor, S_p/S_f, represents the threshold of hydraulic efficiency.
- Isolated discontinuous gullies are exceeding this threshold along 43% of their length, while divergent successive gullies (short diffusors) have a doubled hydraulic efficiency.
- Based on a geomorphic approach, a new indicator expressed as the ratio of gully bottom to gully top width (W_b/W_t) was found.

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