https://doi.org/10.17221/231/2018-SWR

An approach to identifying and evaluating the potential formation of ephemeral gullies in the conditions of the Czech Republic

Miroslav Dumbrovský[1], Karel Drbal[2], Veronika Sobotková[1], Jana Uhrová[2]*

[1]*Institute of Water Landscape Management, Faculty of Civil Engineering, Brno University of Technology, Brno, Czech Republic*
[2]*T.G. Masaryk Water Research Institute, Brno Branch, Brno, Czech Republic*
**Corresponding author: sobotkova.v@fce.vutbr.cz*

Citation: Dumbrovský M., Drbal K., Sobotková V., Uhrová J. (2020): An approach to identifying and evaluating the potential formation of ephemeral gullies in the conditions of the Czech Republic. Soil & Water Res., 15: 38–46.

Abstract: Soil erosion, including ephemeral gully erosion, is a serious degradation process in the Czech Republic. It currently threatens more than half of the agricultural acreage through negative changes in the whole complex of soil properties. The unfavourable consequences of surface runoff are seen in the erosion processes degrading agricultural soils. The South Moravia Region was selected as the case study area – mainly for its natural conditions and high soil degradation risk . A set of data, collected from 2012 to 2017 in a maize-growing area, especially on deep loess soils in the South Moravia Region, was used to analyse the morphological characteristics of the ephemeral gullies (EGs). The relationship was confirmed between the ephemeral gully (EG) length and the size of its contributing drainage area in accordance with studies conducted in other countries. It is also important that the closest relationship was confirmed between the length of the gully and its calculated volume. Dependence was sought on the data of 51 cases of the detailed, measured and evaluated EGs. These results will become the basis for finding a predictive relationship and the quantification of EG erosion. Locating EGs and predicting their length is crucial for estimating the sediment load and planning conservation strategies. The aim of this paper is to contribute to the understanding of this issue, i.e., define and verify the basic crucial causal factors and propose guidelines for locating the potential EG occurrence and predicting the sediment load. A research effort to better understand the EG mechanism and causal factors over a wide range of watershed conditions is fundamental to the establishment of basic rules for the adoption of optimal conservation strategies.

Keywords: concentrated surface runoff; field measurements; gulliometer; gully volume; soil erosion

Water erosion is a serious degradation process in the Czech Republic (CZ), currently threatening more than half of the agricultural acreage. Surface runoff resulting in the formation of ephemeral gullies (EGs) can significantly contribute to the total soil loss in agricultural areas. EGs can occur in natural swales – so-called paths of concentrated surface runoff (PCR), or along other linear landscape features such as plot boundaries, furrows due to farming activity or tracks in field. They occur on convex-concave agricultural slopes where, first, sheet flow covers a larger area, but gradually turns into a stream of concentrated runoff (Holý 1994). The term "ephemeral", i.e., transient, volatile is used as these phenomena are temporary,

Supported by the Ministry of Agriculture of the Czech Republic, Project No. QJ1520268 – New approaches to optimization of systems of integrated area protection in the context of their economic sustainability and Project No. QK1720303 – Retention capacity of the soil and landscape and possibilities of increasing in terms of climate change.

https://doi.org/10.17221/231/2018-SWR

eliminated at the end of a vegetation period by farming activity and re-appearing on the same sites again during the next vegetation period (Laflen *et al.* 1986). Erosion from EGs shows both on-site and off-site impacts including the loss of crop productivity, the loss of arable topsoil, eutrophication and siltation of reservoirs, dams, water courses and negative impacts on wildlife habitat. The transported sediments get into water courses and settle in water reservoirs. As another off-site effect, the sediment-transporting concentrated flow causes damage to built-up areas with property damage during torrential rain. Ephemeral gully erosion in the South Moravia Region is most obvious in the spring, when erosive rainfall occurs on freshly prepared seedbeds. The freshly tilled soil surface has a low critical shear stress and is highly erodible. All the EGs were finally measured before harvesting, as the gullies are destroyed by the farm machinery during the harvesting operation.

EGs also occur in winter cereal crops where they appear longer after sowing. Although the soil is already consolidated and more resistant to erosion, the subsoil strength is very low, making it quite susceptible to erosion by runoff, as snow melting and thawing in early spring apparently reduces the critical shear stress (Øygarden 2003).

Ephemeral gully erosion is a serious problem in many cultivated fields in the Czech Republic. The Universal Soil Loss Equation often underestimates erosion on agricultural land because it does not account for the loss of soil from ephemeral gullies. In the measured erosion gullies, the erosion runoff of EGs was compared with the level of erosion runoff within the EG contributing area. The quantified proportion of EGs in the total volume of the erosion product – sediment load can be up to 40%, as was found in the conditions of loess layers in the South Moravia Region. The authors wish to emphasise the seriousness of the problem, which is underestimated in the Czech Republic. This is in accordance with the results in published studies by other authors. Poesen *et al.* (2003) noted that EG erosion is an important soil degradation process affecting many soils, especially in loess areas. Studies by Foster (1986, 2005), Vandaele *et al.* (1996), Casalí *et al.* (1999), Poesen *et al.* (1999) report that soil loss due to EG erosion can account for between 30% and 63% of the total worldwide erosion.

Therefore, the authors of this paper have aimed at contributing to the understanding of this issue, i.e., define and verify the basic crucial causal factors, and propose guidelines for locating the potential EG occurrence and predicting the sediment load.

A review of the existing studies about ephemeral gullies in the Czech Republic. The chapter deals with the existing studies in the Czech Republic, reference to studies conducted abroad are referred to in other chapters. The identification and mapping of the potential PCR from blocks of arable land throughout the Czech Republic was carried out for the Ministry of Agriculture (MoA) in 2010 and 2011. The project was based on modelling the accumulation of the flow from drainage areas contributing to the potential PCR, interpretation of terrain's character, and visual interpretation of an orthophoto map, on the relevant physical blocks of the Land Parcel Identification System (LPIS). The output includes a database of structured items describing the location and character of the individual identified and mapped PCR. More than 33 000 PCR were identified, with a total length of nearly 12 000 km. In the course of the project, the contributing drainage areas and their acreage were defined for the individual PCR on the basis of the flow direction and an accumulation analysis over a Digital Elevation Model (DEM). This was performed in an automated process, and, subsequently, manually corrected using raster topography maps, and aerial orthophoto maps (EKOTOXA 2011).

The studied indicators also included the character of the PCR outlet to different places. This is an important factor in terms of the potential property damage coming from the arable land with identified PCR. Most PCR outlets end in water courses, reservoirs and ponds (37%), 14% in forests, and 19% of the PCR water goes into channels and ditches. Nearly 6% of the PCR end in built-up areas. Approximately 4% of all PCR pose a potential threat to the quality of the drinking water in reservoirs. The remaining approximate 20% of PCR end in grassland and other areas (EKOTOXA 2011).

The main aim of the study was to identify the erosion-threatening PCR and their contributing drainage areas.

MATERIAL AND METHODS

The South Moravia Region was selected as the case study area mainly for its natural conditions and high soil degradation risk (Figure 1). Climatically, South Moravia is within a warm region, a warm and dry district, with mild winters and a moderate duration of sunshine and with a short duration of snow cover.

https://doi.org/10.17221/231/2018-SWR

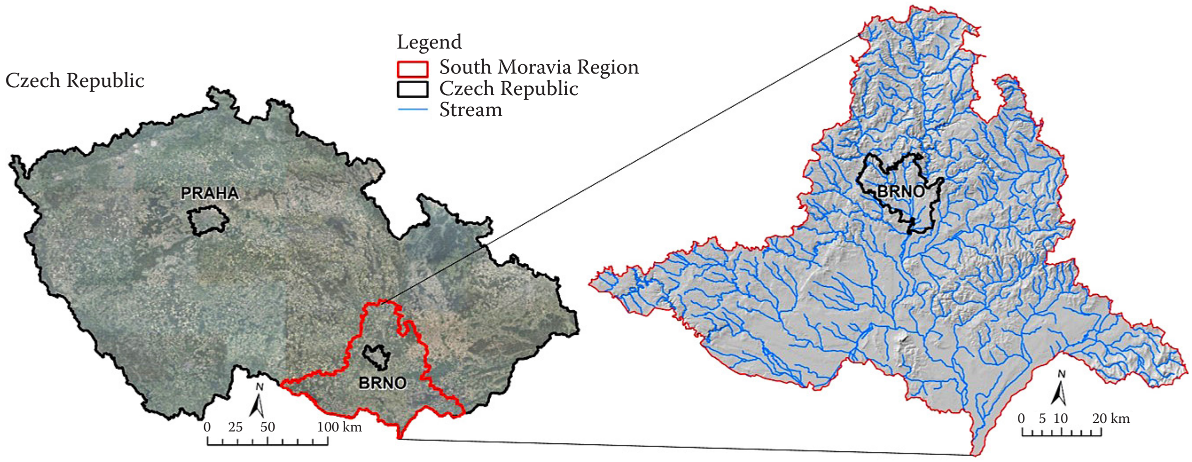

Figure 1. Situation map of the location of the case study area
The source of the orthophoto is ČÚZK (2018)

The average precipitation is 400 to 425 mm for the vegetation period of IV–IX. With 60–80 mm, July has the highest precipitation.

According to geomorphologic division, this area is part of the Carpathian System. Geologically, the area is made up of early and late Tertiary sediments.

Another reason for the choice of the case study area is the good access to the available numerical and graphical data for this area, mostly GIS-obtained in several previous projects.

Deep loess chernozem soils prevail on the agricultural land which makes up 60% of the South Moravia Region. Farmland is characterised in more detail by Evaluated Soil-Ecological Units (ESEU), which are the basic mapping and evaluation units in the Czech Republic.

Between 2012 and 2017, field surveys were conducted on arable land across the study areas especially after periods of rain. During this period, a search of the land was carried out to identify the developing EGs on the basis of information on the occurrence of torrential rain in the given region. Information was also provided by the State Land Office within the monitoring of the erosion processes, the potential PCR were localised by means of GIS, in accordance with the stated study (Figure 2). All the measured ephemeral gullies (length and volume) occurred on arable land sown with wide row crops (maize) using conventional technologies. Field measurements of the EG length and erosion volume were carried out by measuring several cross sections in the selected profiles of 51 EGs. The first step was to explore the entire length of an EG, divide it into morphologically homogeneous segments and determine several representative profiles. The EGs measured in the study area mostly had irregular trapezoidal and rectangular cross-sections. The contributing drainage area of each gully was determined on the basis of the DEM (Figure 2).

During the field survey, the actual EG length was measured and cross sections of the eroded terrain were produced by a gulliometer (Figure 3). The beginning of an EG is the point where sheet flow changes into concentrated flow (both sheet and rill erosion

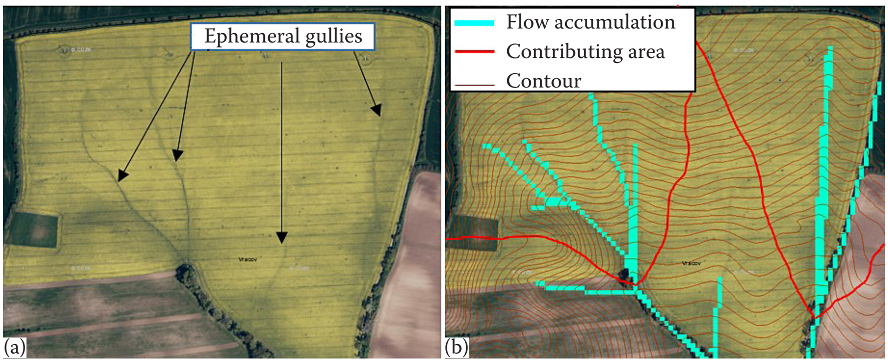

Figure 2. Ephemeral gullies in the terrain of an ortophoto map (a) and in the digital elevation model using the flow accumulation analysis (b)

https://doi.org/10.17221/231/2018-SWR

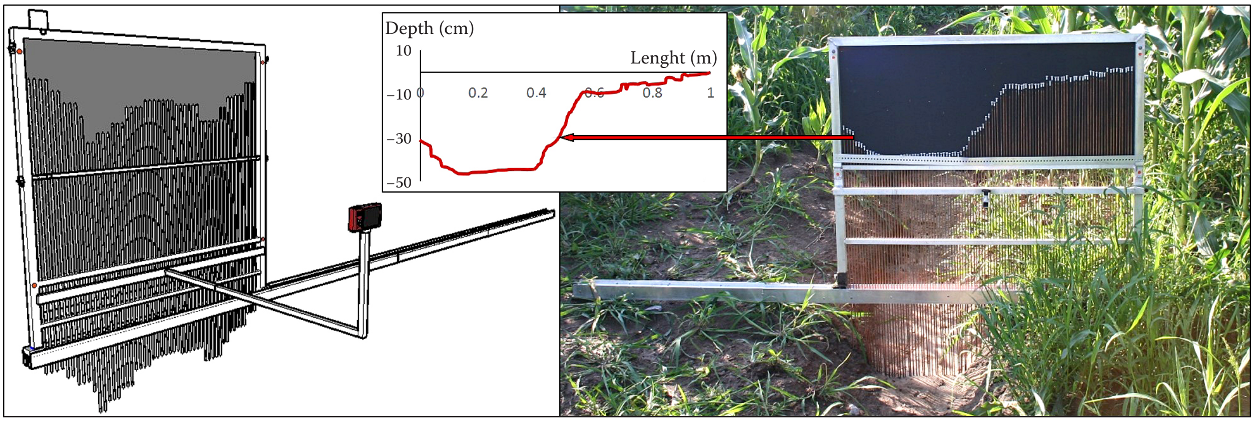

Figure 3. Actual image of the gulliometer for quantifying the ephemeral gully (EG) erosion (the red curve is the level of the terrain)

are often clearly visible). The end of an EG is the point where the gully profile disappears due to a significant amount of sediment.

Based on these measurements, performed during the vegetation period, the volume of erosion ephemeral gullies was obtained. EG erosion only occurred with wide row crops (e.g., maize) growing during the measurement period. The EG cross sections in maize fields were measured with a gully erosion bridge – gulliometer. The gulliometer was developed at the Brno University of Technology in the Institute of Landscape Water Management (Sobotková & Dumbrovský 2014; Sobotková *et al.* 2015). The first idea leading to measuring the soil surface change using a soil erosion bridge originated from the authors Ranger and Frank (1978) and Smith (1993).

In order to monitor the erosion dynamics of the EGs, the EGs were measured three times to record and quantify the EG erosion: after the first heavy rains, during the growing season after the second heavy rains, and at the end of the vegetation period before harvesting. The EGs are measured before harvesting, as the gullies are destroyed by the farm machinery during harvesting. All the measurements were processed according to the previously defined methodology.

The volumetric quantification of the ephemeral gullies was carried out using a specially developed gulliometer = mechanical erodometer measuring the area of the individual EG cross sections and calculating the total volume of each gully. The results were used to create a model for predicting the EG volume. A mechanical erodometer uses metal pins set in a frame to measure the cross sections of the soil surface. The actual measuring device is an aluminium frame with one hundred pins set at constant distances. After lowering the upper bar, the pins copy the ground surface and this is documented photographically for any subsequent evaluation. A specially adapted camera mount, set at a fixed distance, is attached to the lower part of the frame. The camera on this mount produces images from a distance and position which are consistent in relation to the gulliometer (Figure 3). The photographs of the individual positions of the bridge are then processed through software, which evaluates the position of all pin ends and determines the shape and area of the cross sections.

As the manual evaluation was very time-consuming, a software was developed within the research, which can identify the individual pins on each photo and calculate the area of a given cross section. The software is based on image resolution – the white pin ends are in contrast to a dark plastic board behind them. The resolution process and subsequent operations (formatting coordinates, area calculation, etc.) can be put in the category of processing the image. After a photograph is taken, the programme executes a set of operations under precisely defined conditions. The conversion results in a set of points represents the measured curvature.

Photographs of all the measurements were taken and then curves were obtained in vector form showing the soil surface cross section (Figure 3). The gully volume is calculated by multiplying the length of the gully segment (between two photographed cross sections) by the average area of the two cross sections. The total gully volume for each gully is the sum of the volumes for all the gully segments. The

https://doi.org/10.17221/231/2018-SWR

measured volume in cubic metres shall be converted into tonnes through bulk density.

Gully volume calculation. The following equation was used to calculate the volume of a gully:

$$V = \sum_{i=1}^{n} \frac{A_{i-1} + A_i}{2} \times Lc \quad (1)$$

where:

V – the total volume of the erosion gully (m^3)

A_i – the area of the gully cross section (m^2)

A_{i-1} – the area of the previous cross section of the gully (m^2)

Lc – the distance between the individual cross sections of the gully (m)

Other EG measuring methods which would allow the continuous measurement of the entire gully, thus, removing the factor of uncertainty caused by the point-measurement of the individual cross sections, were considered before the actual measuring process began. One of the possibilities was to use Photogrammetry or Lidar for ground or aerial laser scanning (Sobotka 2017), respectively. However, these technologies did not prove suitable due to the present vegetation cover significantly distorting the resulting image. Therefore, the gulliometer option was chosen.

Prediction of the EG spatial localisation was made possible by means of GIS tools. Based on this finding, an estimate of the accumulated runoff in the individual PCR was generated using ArcGIS software (Ver. 8.3, 2003) hydrological extensions. The DEM enabled the identification of the factors for calculating the runoff characteristics – e.g., the flow direction, the flow accumulation, the size of the contributing area, the slope of the valley lines and the slope of the contributing area. A hydrologically correct DEM (resolution of 10 m) was used as the initial layer for the hydrological analysis.

Two methods were used to assess the length of the PCR and their contributing drainage areas.

The first method was identifying the visible erosion symptoms, i.e., the EGs in the PCR, on orthophoto maps (resolution of 10 m). 35 EGs in the PCR were identified and their length and slope gradient and altitude of their outlet profile were measured. Special attention was given to identifying the starting and ending points of each EG and digitising the trajectory of each EG located on the aerial orthophoto image. The contributing drainage areas were determined for the end profiles of these EGs, with an average curve number (CN) specified besides its size. The CN was determined in accordance with the Czech methodology for Soil Conservation (Janeček *et al.* 2012). The landscape cover was determined on the basis of orthophotos and LPIS. The hydrologic soil group was determined from the estimated pedologic soil-ecological unit from the soil database of the State Land Office.

The minimum possible size of the contributing drainage area necessary to form an EG was determined as 0.03 km^2, in accordance with the evaluation of the flooding in the catchment basin of the Luha and the Jičínka rivers in 2009 (Dumbrovský *et al.* 2009), and the subsequent measurements of the manifestations of erosion in the PCR in the following years. Within the study for the Ministry of the Environment (Dumbrovský *et al.* 2009) over one hundred sites were identified and confirmed in a detailed field survey as entry points for sheet flow into the built-up areas of towns and villages. The end profiles of the contributing drainage areas of 0.03 km^2 and more were defined as problematic, especially with the on-site damage to the soil, and the transported wash load caused partial damage to property.

The results were the basis for the analysis comparing the length of the selected PCR set (generated from the DEM and ArcGIS software hydrological extensions – generated flow accumulation classified as the value) with the PCR length measured on the orthophoto maps. The size of the contributing drainage areas was also specified for the evaluated PCR.

The second method was the generation of the PCR using ArcGIS software hydrological extensions (the flow accumulation over DEM, which is documented in Figure 2). This analysis was the basis for both the location of the potential EG occurrence and for the creation of the models allowing the length of the EG in the PCR to be predicted due to the dependence of the EG length on its contributing drainage area. The minimum possible size of the contributing drainage area necessary to form an EG was determined as 0.03 km^2 as in the first method.

RESULTS AND DISCUSSION

Using methods of mathematical probability and statistics, a simple and multiple regression analysis was carried out, studying the relationship between the calculated or measured characteristics of the ephemeral gullies and the factors affecting the development of the gullies. Statistical analyses were

https://doi.org/10.17221/231/2018-SWR

performed using the S-PLUS® (Ver. 6.1, 2002) software for Windows Professional Edition. The results of the analyses were used as the basis for the creation of regression models representing the dependence of the main EG characteristics (length, volume) on other selected characteristics (the contributing drainage area, the average curve number of the contributing drainage area, the altitude of the outlet profile). This improved the models significantly (Eqs. (2), (3), (4)).

An interesting result is the relationship between the measured EG length L_{ortho} obtained from the orthophoto map and the length generated (predicted – L_p) by the flow accumulation on the DEM. We could identify an EG on orthophoto two years old, where the visual evidence of an EG has been identified. The value of the multiple correlation coefficient (R) indicates that the correlation is proven ($0.4 < |R| < 0.817$), as documented in Figure 4.

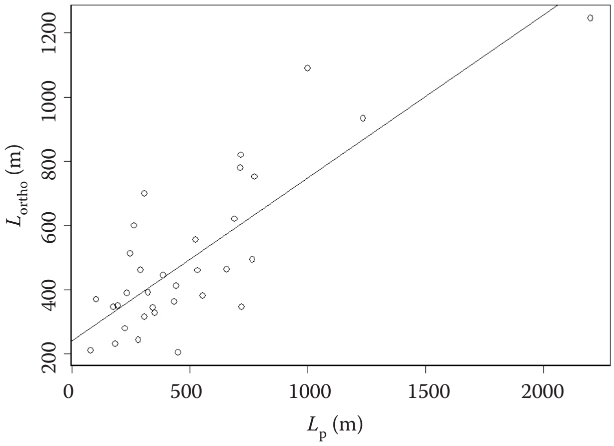

Figure 4. The relationship between the measured L_{ortho} and predicted L_p ephemeral gully (EG) length (multiple correlation coefficient $R = 0.817$)

On the basis of 35 EGs, we have statistically derived the significant relationships between the EG length measured L_{ortho} and the contributing drainage area A. The input EG file contained the characteristics listed in Table 1. Standard deviations apply to the individual parameters of the selection group (Table 1). The variation coefficient for the size of a contributing area, which significantly exceeds 50%, indicates the disparity of the statistical group. However, according to evaluation via the EG altitude Al_{min} and Al_{max}, the group is homogenous (by virtue of the evident fact that the research was carrried out especially within the territory of South Moravia Region). The stated figures show the results of an occurrence of an accidental phenomenon, i.e., the development of the EGs on the farmed land.

In addition to classical linear regression (Least Squares – LS method), models of robust parameter estimation (Least Trimmed Squares Robust Regression – LTS method) have been used to estimate the regression parameters for the ephemeral erosion lengths in general on the size of the contributing surface. The same approach was used to find the dependence of the ephemeral gully volume on the ephemeral gully length (Figures 5–8).

The methods used for the identification and localisation of the EGs are also based on topographic attributes such as upstream drainage area, the plan of the curvature and slope area (SA) as key topographic controls in the EG formation process (Knapen & Poesen 2010; Daggupati *et al.* 2013). Zevenbergen and Thorne (1987) used the compound topographic index (CTI) model to predict the EG volume and formation.

Parametres a_1, b_1, b_2, b_3 and c_1 (Eqs. (2), (3), (4)) were determined by means of the robust regression analysis method, on the basis of the stated regression relationship.

Table 1. Summary statistics for the input data

	L_{ortho}	Al_{min} (m)	Al_{max}	S (%)	A (ha)	S_{ca} (%)	CN (–)
Minimum	205.11	183.01	224.36	2.29	3.63	3.99	64.26
1st quartile	335.84	212.74	235.00	4.65	11.71	7.38	80.03
Mean	484.28	245.82	274.59	6.64	24.45	9.06	80.38
Median	390.70	240.88	278.80	6.17	20.97	8.90	80.86
3rd quartile	577.38	271.57	291.09	8.74	27.85	10.87	81.00
Maximum	1246.39	334.55	373.25	11.43	135.60	17.18	90.89
SD	249.71	40.11	41.56	2.58	23.38	2.86	4.09

L_{ortho} – ephemeral gully (EG) length measured; Al – EG altitude; S – average slope EG; A – contributing drainage area; S_{ca} – average slope of the contributing drainage area; CN – curve number; SD – standard deviation

https://doi.org/10.17221/231/2018-SWR

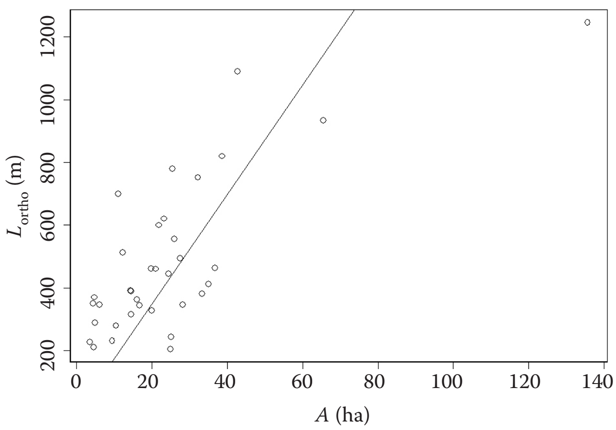

Figure 5. Dependence of the ephemeral gully (EG) length L_{ortho} – Model (Eq. (2)) – on the size of the contributing drainage area A (multiple correlation of determination R^2 = 0.850)

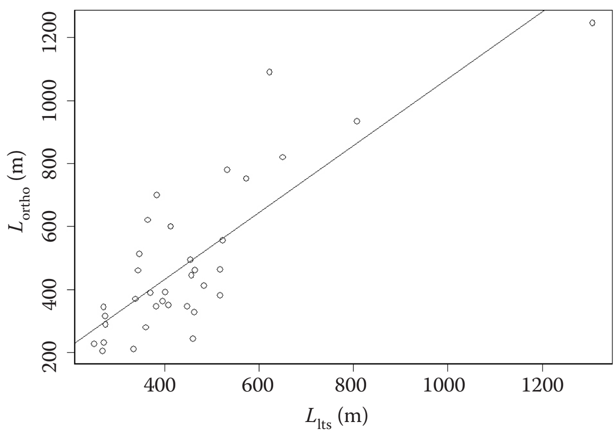

Figure 6. The relationship between the digitised ephemeral gully (EG) length L_{ortho} and fitted length L_{lts} – Model (Eq. (3)) – (multiple correlation of determination R^2 = 0.950)

From the data models tested (Table 2), the following proved to be the most appropriate:

$$L = a_1 \times A \quad (2)$$

where:
L – the EG length (m)
A – the contributing drainage area (ha)
a_1 – the model parameter

It is also presented by Steegen *et al.* (2000) who reported that there is a positive relationship between the EG development and the given watershed.

The other model, in addition to the effect of the size of the contributing drainage area A, includes two other variables which, on the basis of input tests, proved to be important for increasing the quality of the model (t-test).

$$L = b_1 \times Al_{min} + b_2 \times A + b_3 \times CN \quad (3)$$

Table 2. Summary statistics for the valid data

	$L_{ortho\text{-}Etx}$ (m)	Al_{min} (m)	S (%)	A (ha)
Minimum	86.00	183.50	0.65	6.37
1st quartile	321.00	222.15	3.25	13.92
Mean	547.42	258.97	5.58	32.27
Median	499.00	264.10	5.59	23.88
3rd quartile	670.00	288.30	7.40	45.11
Maximum	1486.00	334.30	12.07	128.26
SD	291.17	43.86	2.66	26.36

$L_{ortho\text{-}Etx}$ – ephemeral gully (EG) length digitised by Ekotoxa (Etx); Al_{min} – minimum altitude EG; S – average slope EG; A – contributing drainage area; SD – standard deviation

where:
Al_{min} – the minimum EG altitude (outlet profile)
CN – the average curve number of the contributing drainage area (–)
b_i – the model parameters for i = 1, .., 3

The created models were compared with, and verified by the valid data (71 EG lengths digitised from the aerial orthophoto image) obtained within the study by EKOTOXA (2011). For the valid data set, the variance ranges for the variables: the size of the contributing drainage area A and the minimum altitude EG Al_{min}, as documented in the summary of the basic characteristics (Table 2), have been observed. Valid for CN – row crops and hydrological group B.

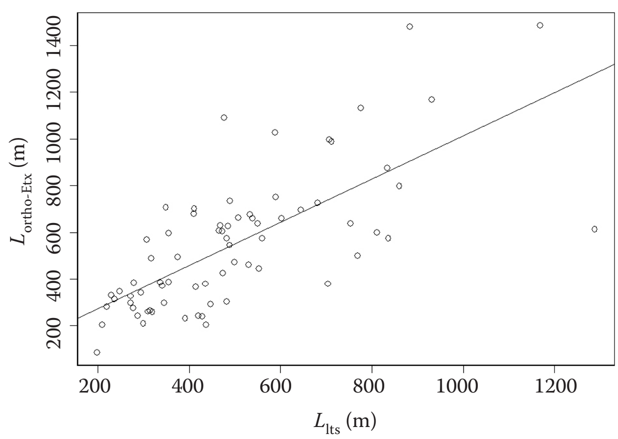

Figure 7. The relationship between the measured ephemeral gully (EG) length (orthophoto) $L_{ortho\text{-}Etx}$ and the predicted EG length, model L_{lts} – Model (Eq. (3)) – (multiple correlation coefficient R = 0.710)

https://doi.org/10.17221/231/2018-SWR

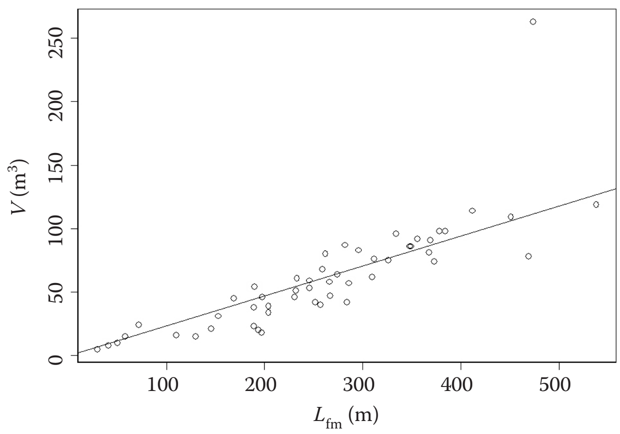

Figure 8. Dependence of the ephemeral gully (EG) volume V, measured using the gulliometer, on the field-measured EG length L_{fm} (multiple correlation of determination $R^2 = 0.970$)

The strength of the model values, i.e., the predicted EG length – model (Eq. (3)) and the digitised EG length – orthophoto Etx (Ekotoxa) for 71 cases of the EGs is documented in Figure 7.

The relationship was confirmed between the EG length and the size of its contributing drainage area A (Figure 5). It is also important that the closest relationship was confirmed between the length of the EG (L_{fm}) and its calculated EG volume V. Dependence was sought on the data of 51 cases of the detailed, measured and evaluated EGs (Figure 8). These results will become the basis for finding the predictive relationship and quantification of the EG erosion.

$$V = c_1 \times L \quad (4)$$

where:
V – the EG volume (m^3)
c_1 – the model parameter

It is in accordance with the analysis (Bruno *et al.* 2008; Capra *et al.* 2009) which presents a relationship between the eroded volume of an EG channel segment and its length. Also, Zhang *et al.* (2007) performed stepwise multiple regressions between the EG length and the EG catchment area parameters (the catchment area and slope) for gullies mainly formed in natural drainage lines.

CONCLUSION

Ephemeral gully erosion is an important cause of soil loss and soil degradation on arable land. EGs have both negative on-site and off-site impacts including loss of natural crop productivity, reduced quality of water resources (rivers, lakes), as well as being a flood threat in terms of transporting sediment to built up areas, with a negative impact on the infrastructure and property damage. In spite of this, surface runoff and soil loss prediction technology is not yet used in the Czech Republic. Locating EGs and predicting their length is crucial in estimating the sediment load and planning conservation strategies (Daggupati *et al.* 2013). This situation needs to be addressed by a proposal for the relevant bodies to implement adequate soil erosion control measures to stabilise the threatened PCR. It was confirmed that the vegetation cover, management practices, the type of crops (especially wide row crops under conventional farming management) and the size of the catchment area have the greatest influence on the EG length. The land cover and management practices greatly influence the vegetation cover and the ability of the land to reduce the overland flow. This complies with the results reported by other authors Poesen *et al.* (2011), Vandekerckhove *et al.* (2000). Land users should be motivated to reduce the size of the individual fields and apply conservation technologies to avoid any EG formation.

In the Czech Republic, attention has not yet been paid to the problem of ephemeral gullies. The relevant control measures have not yet been designed or implemented, despite the proven fact that concentrated flow paths and ephemeral gullies, occupying less than 1% of the total arable acreage in CZ can be effectively prevented, and erosion problems, both on- and off-site, can be reduced by almost 50% (Nachtergaele & Poesen 2002). Therefore, this study endeavours to contribute to the knowledge of this issue, to define and verify the basic causal factors, and provide a methodical procedure for the identification, prediction and proposal of the PCR stabilisation, especially in the process of land-use planning. The developed approach addresses the basic identification and spatial prediction of ephemeral gullies according to their contribution area characteristics. An effort to better understand the EG mechanism and the causal factors over a wide range of watershed conditions is fundamental to the establishment of basic rules for the adoption of optimal conservation strategies.

References

Bruno C., Di Stefano C., Ferro V. (2008): Field investigation on rilling in the experimental Sparacia area, South Italy. Earth Surface Processes and Landforms, 33: 263–279.

https://doi.org/10.17221/231/2018-SWR

Capra A., Di Stefano C., Ferro V., Scicolone B. (2009): Similarity between morphological characteristics of rills and ephemeral gullies in Sicily, Italy. Hydrological Processes, 23: 3334–3341.

Casalí J., Lopez J.J., Giraldez J.V. (1999): Ephemeral gully erosion in southern Navarre (Spain). Catena, 36: 65–84.

ČÚZK (2018): WMS View Service – Orthophoto. Geoportal ČÚZK. Available at https://geoportal.cuzk.cz (accessed January 2019). (in Czech)

Daggupati P., Douglas-Mankin K.R., Sheshukov A.Y. (2013): Predicting ephemeral gully location and length using topographic index models. Transactions of the ASABE, 56: 1427–1440.

Dumbrovský M., Sobotková V., Pavlík F., Uhrová J. (2009): Evaluation of the impacts of floods on the landscape and the environment. In: Evaluation of Floods in June and July 2009 in the Czech Republic. Prague, Ministry of the Environment of the Czech Republic: 117–125. Available at http://voda.chmi.cz/pov09/doc/01.pdf (accessed August 2018). (in Czech)

EKOTOXA (2011): Determination of Contributing Areas Over the Sealing Profiles of Erosively Threatened Arable Drainage Pathways for Needs of the Water Framework Directive 2000/60/EC. Opava, EKOTOXA s.r.o. (in Czech)

Foster G.R. (1986): Understanding ephemeral gully erosion. Chapter 4. In: Soil Conservation: Assessing the National Resource Inventory. Washington, D.C., National academies Press: 90–125.

Foster G.R. (2005): Modeling ephemeral gully erosion for conservation planning. International Journal of Sediment Research, 20: 157–175.

Holý M. (1994): Erosion and the Environment. Prague, ČVUT. (in Czech)

Janeček M. *et al.* (2012): Protecting Agricultural Land from Erosion: Methodology. Prague, CULS. (in Czech)

Knapen A., Poesen J.W.A. (2010): Soil erosion resistance effects on rill and gully initiation points and dimensions. Earth Surface Processes and Landforms, 35: 217–228.

Laflen J.M., Watson D.A., Franti T.G. (1986): Ephemeral gully erosion. In: Proc. 4th Federal Interagency Sedimentation Conf. Interagency Advisory Committee on Water Data, Subcommittee on Sedimentation, Las Vegas, March 24–27, 1986: 3-29–3-37.

Nachtergaele J., Poesen J. (2002): Spatial and temporal variations in resistance of loess-derived soils to ephemeral gully erosion. European Journal of Soil Science, 53: 449–463.

Øygarden L. (2003): Rill and gully development during an extreme winter runoff event in Norway. Catena, 50: 217–242.

Poesen J.W.A., De Luna E., Franca A., Nachtergaele J., Govers G. (1999): Concentrated flow erosion rates as affected by rock fragment cover and initial soil moisture content. Catena, 36: 315–329.

Poesen J.W.A., Nachtergaele J., Verstraeten G., Valentin C. (2003): Gully erosion and environmental change: Importance and research needs. Catena, 50: 91–133.

Poesen J.W.A., Torri D.B., Vanwalleghem T. (2011): Gully erosion: procedures to adopt when modelling soil erosion in landscapes affected by gullying. In: Morgan R.P.C., Nearing M.A. (eds.): Handbook of Erosion Modelling. Chichester, Blackwell Publishing, Ltd.: 360–386.

Ranger G.E., Frank F.F. (1978): The 3-F Erosion Bridge – A New Tool for Measuring Soil Erosion. Publication No. 23. Sacramento, Department of Forestry.

Smith L.M. (1993): Investigation of Ephemeral Gullies in Loessial Soils in Mississippi. Vicksburg, Soil Conservation Service, U.S. Army Engineer Waterways Experiment Station.

Sobotka J. (2017): Designing on the new elevation database of the Czech Republic. Key Engineering Materials, 755: 333–339.

Sobotková V., Dumbrovský M. (2014): The new volumetric approach for field measurements of rill erosion. Eurasian Journal of Soil Science, 4: 94–99.

Sobotková V., Dumbrovský M., Sobotka J. (2015): The methods for field assessment of rill erosion in the Czech Republic. In: Proc. 15th Int. Multidisciplinary Scientific GeoConference: SGEM. Albena, June 18–24, 2015: 371–378.

Steegen A., Govers G., Nachtergaele J., Takken I., Beuselinck L., Poesen J. (2000): Sediment export by water from an agricultural catchment in the Loam Belt of central Belgium. Geomorphology, 33: 25–36.

Vandaele K., Poesen J.W.A., Govers G., Wesemael B. (1996): Geomorphic threshold conditions for ephemeral gully incision. Geomorphology, 16: 161–173.

Vandekerckhove L., Poesen J.W.A., Wijdenes D.O. (2000): Thresholds for gully initiation and sedimentation in Mediterranean Europe. Earth Surface Processes and Landforms, 25: 1201–1220.

Zevenbergen L.W., Thorne C.R. (1987): Quantitative analysis of land surface topography. Earth Surface Processes and Landforms, 12: 47–56.

Zhang Y., Wu Y., Liu B., Zheng Q., Yin J. (2007): Characteristics and factors controlling the development of ephemeral gullies in cultivated catchments of black soil region, Northeast China. Soil and Tillage Research, 96: 28–41.

Received for publication December 20, 2018
Accepted after corrections May 13, 2019
Published online June 17, 2019