ANALYSIS OF SPATIO-TEMPORAL VARIABILITY OF SOIL ERODIBILITY VALUES BY WATER EROSION

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Abstract

In current dynamic development of GIS and remote sensing methods, especially the use of accurate LiDAR data, there is a significant disproportion in the accuracy of morphological and soil data in the assessment of erosion. In current practice, the map of main soil units (MSU) is used to determine soil erodibility (expressed by K factor), which in many cases lead to a step change in values within one field or erosion closed unit (ECU). However, the soil properties included in the calculation of the K factor usually change smoothly in the direction of the slope, but also due to other morphometric characteristics. Terrain morphology should therefore be taken into account when determining the K factor values. The K factor values change dynamically both according to the terrain morphology within ECU and depending on climatic conditions that change during the year and within the geographical location in the Czech Republic (CR) and given physio-geographical conditions. In assessing the seasonal dynamics of K factor values, they appear to be key erosion rainfalls. By including this spatio-temporal variability of K factor values, it will be possible to significantly refine soil loss calculations and proposals for erosion control measures and retention elements and their intangible services for environment and increasing the landscape character and recreational potential of the site.

Key words: soil erodibility, K factor, erosion, USLE, cultural intangible services

Introduction

The Universal soil loss equation (USLE) (Wischmeier & Smith, 1978) is one of the most widely used methods for assessing soil loss by water erosion over the world. Analysis of soil loss and erosion risk is often the first step in the design and deployment of erosion control measures and retention elements in a monocultural agricultural landscape as part of land consolidation process. The essence of this equation is the relationship between rainfall erosivity, the ability of rain to cause soil loss, and soil erodibility, the ability of soil to withstand the effects of erosion factors - erosion rainfall. Refining the individual factors of this equation will also leads to achievement of a more effective proposal for the deployment of erosion control and retention elements in the landscape, as well as achieve more effective intangible benefits of these measures. The essence of this research is the correction of soil erodibility factor (K) values according to the characteristics of variables in space and time. These characteristics include, in particular, terrain morphology and geographical location within the CR and related changes in climatic and soil conditions during the year.

In today's dynamic development of GIS and remote sensing methods, especially the use of accurate LiDAR data, there is a significant disproportion in the accuracy of morphological and soil data in the assessment of erosion. Individual countries use national soil geodatabases to determine K-factor values based on correlation and regression analysis. For the conditions of the CR, this dependence with the main soil units (MSU) was determined by Vopravil et al. (2007), similar to Germany Schwertmann et al. (1989), in Hungary Pasztor et al. (2016), using the European LUCAS database (Toth et al. 2013) Panagos et al. (2014) etc. These methods in many cases leads to a step change in values within one field or ECU. However, the soil properties included in the calculation of the K factor usually change smoothly in the direction of the slope, but also due to other morphometric characteristics. Terrain morphology should therefore be taken into account when determining the K factor values. The use of interpolation methods made it possible to determine the K values in a fully distributed form on the basis of sampling and analysis of a network of soil samples (marked by GPS coordinates) within the land block or river basin. The application of these geostatistical interpolation methods Kriging or Cokriging (Goovaerts 2005, Bskan et al. 2010, etc.) enabled the inclusion of the influence of terrain morphology in the calculation as the so-called covariates.

In addition to the spatial variability of K factor values according to the morphology of the terrain within ECU, there is also variability according to geographical location, not only due to different soil properties, but also climatic conditions. Of these conditions, precipitation is key, especially the so-called erosion rainfall and the frequency of their occurrence in a given geographical location. Because these characteristics are consistent over time and months for long-term averages, can be used to correct K values for months or parts of the year and reduce errors in soil loss calculations.
From the above, it is important to emphasize that the aim of the research in this phase was to demonstrate the importance of spatiotemporal variability of K values depending on the terrain morphology and changes in climatic conditions during the year and depending on the geographical location in the CR. And subsequently the need to revise and update the methods for determining the erosion risk and proposals for designing of erosion control measures and retention elements in the landscape.

Materials and methods
For the needs of this research, 43 sampling sites were selected (Fig. 1). Soil sampling is performed from the surface layer up to 10 cm and each sampling point is marked with GPS coordinates. Soil samples are taken in the form of a point network of soil samples (type A main), focused on testing the influence of terrain morphology (spatial characteristics), and repeated sampling of mixed soil samples from the middle part of the slope at intervals of 1.5 month (sample type B), focused on time analysis characteristics - resp. changes in the K factor values during the year. In the laboratory, the samples are first air-dried, sieved to skeleton and fine earth and then subjected to grain size analysis using the densitometer method and humus content determination based on oxidometric determination of oxidizable carbon (Cox) content. Subsequently, using these soil properties data, the values of the K factor were calculated according to the equation by Wischmeier and Smith (1978), which was applied to the CR in the form according to Janeček et al. (2012) and is used in the CR in land use planning. The resulting K values were assigned GPS coordinates and were further processed as spatial data in the GIS environment. The K values were then interpolated using the geostatistical interpolation method Kriging and Cokriging (with covariates of relevant morphometric characteristics, which exhibited statistically significant correlations with given soil properties) into fully distributive rasters with a resolution of 5 m. The interpolation procedure setting were optimized - especially empirical semivariogram (ES) model.

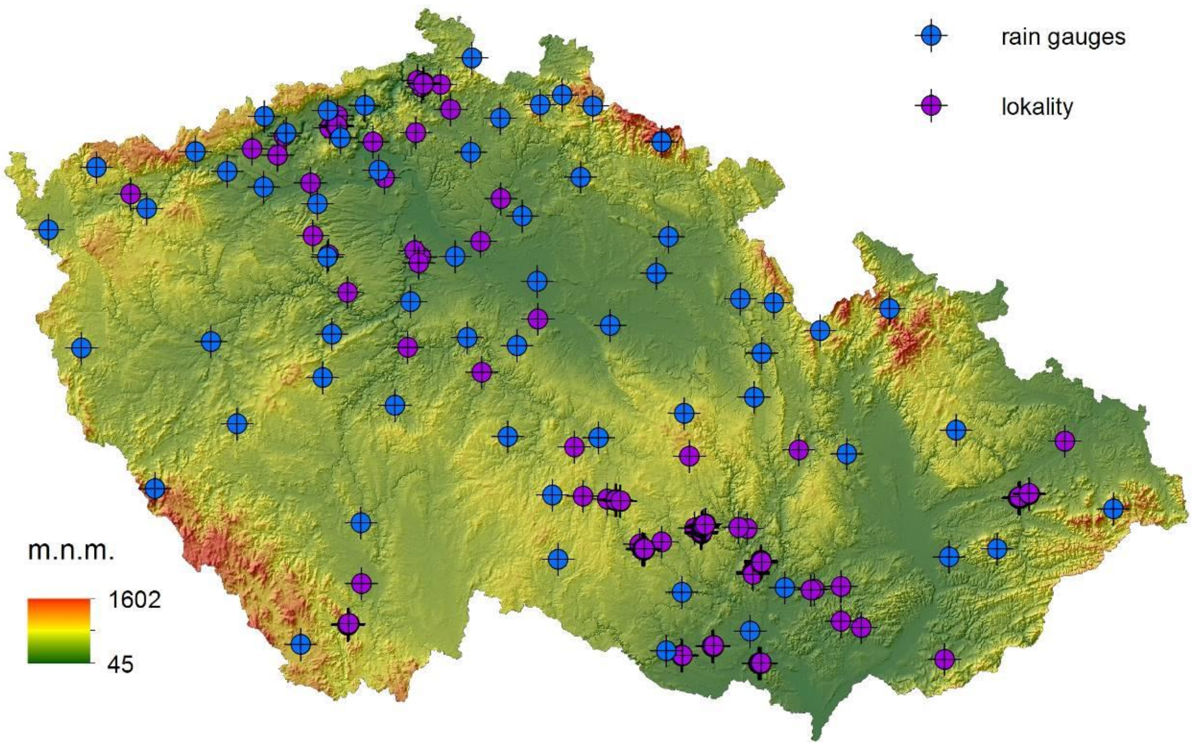

Fig. 1: Geographical location of sites of soil samples and rain gauges.

The RUSLE methodology (Renard et al. 1997) was used for evaluation of type B soil samples for the analysis of changes in the K values during the year depending in the CR conditions. For these purposes, it was necessary to process 10-min precipitation totals for 60 available weighted rain gauges stations for the period 2010 to 2020 and to determine the values of rainfall erosivity factor R (annual and monthly). The geographical location of the weather stations is shown in Fig.1. The calculation of the R factor values was performed with the kinetic energy equation according to Brown and Foster (1987) and the criterion for determining the precipitation intensity of 8.47 mm / 20 min and simultaneously minimum total of 12.5 mm. Furthermore, it was necessary to determine the values and periods of occurrence of the highest and lowest values of the K factor in various locations in the CR based on the analysis of soil samples of type B.

Results and discussion

Already in the original methodology, Wischmeier and Smith (1978) tried to express changes in the K factor values according to the distance from the beginning of the slope. However, current modern technical means and GIS tools in conjunction with highly accurate LiDAR data allow significantly more accurate differentiation of K factor values according to morphometric characteristics.

Soil samples were taken from soil blocks with an average size of 29.98 ha. The calculated K factor values based on the evaluated soil samples were subsequently interpolated using the geostatistical interpolation methods Kriging or Cokriging (Fig. 2), which were set and optimized according to the results of the cross-validation process. (Fig. 3). For these purposes, a geodatabase of 537 soil samples from 43 localities (Fig. 1) in various geographical locations of the CR was created. Using this geodatabase, the spatial variability within individual ECU of localities was verified (Fig. 2).

As mentioned above, K values change dynamically both according to the morphology of the terrain within ECU and depending on climatic conditions changing during the year and within the geographical location in the CR and given physical and geographical conditions. In assessing the seasonal dynamics of K values, they appear to be key erosion precipitation. This was proved by a number of authors who evaluated seasonal changes in the values of K factors depending on the course of values of rain erosivity during the year (Renard et al. 1997, Zanchi 1983). For these purposes, a geodatabase of meteodata was created, which includes 60 stations of weight rain gauges with a measured period of 2010 to 2020 and a geodatabase of soil samples of type B taken from 10 localities 6 times a year at intervals of 1.5 months.

The calculation of the R factor values was performed with the kinetic energy equation according to Brown and Foster (1987) and the criterion for determining the precipitation intensity of 8.47 mm / 20 min. Similar conditions were also used by Meusburger et al. (2012) or Schmidt et al. (2016).

The average K values from 10 localities from samples taken during the year are shown in Figure 4. The resulting values are average values within 30 daily intervals. The highest value K_{max} = 0.73 occurred in the term t_{max} = 23rd April and the lowest value of K_{min} = 0.1 occurred in the term t_{min} = 10th September.

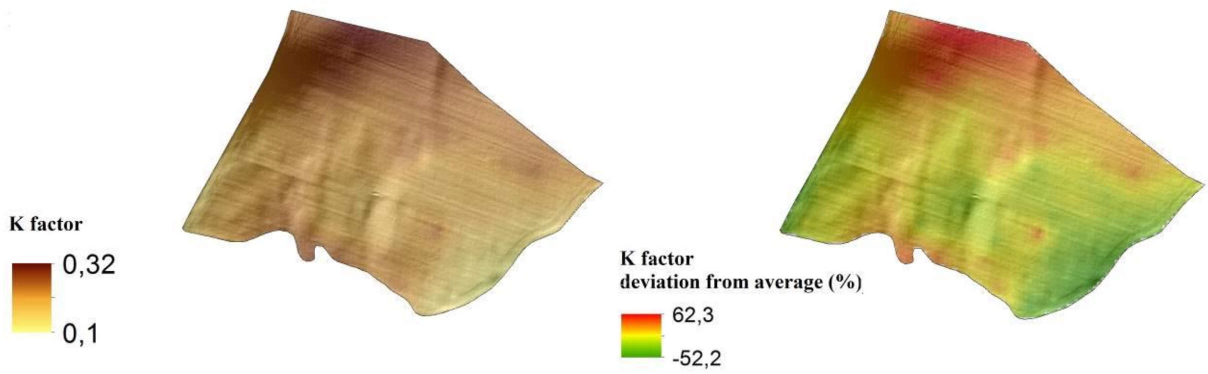

Fig. 2: Variability of soil erodibility.

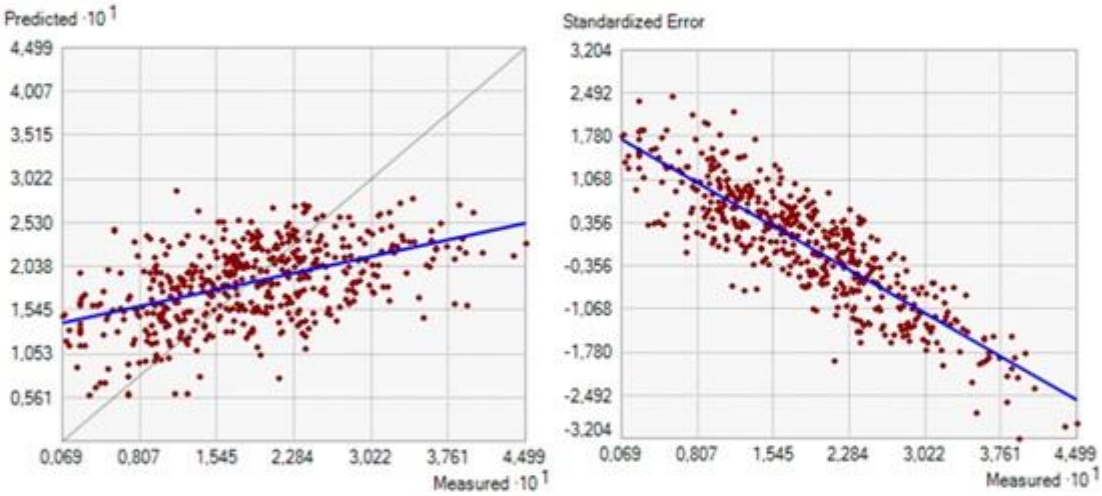

Fig. 3: Results of cross validation process.

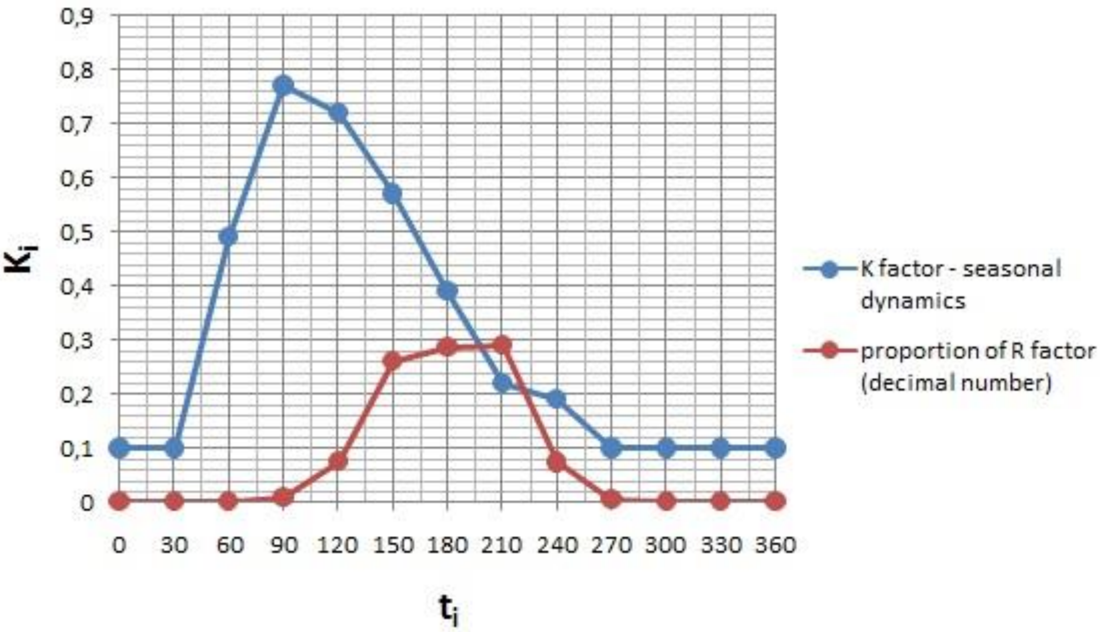

Fig. 4: The average K values and proportion of R values during the year.

Conclusion

The results of this research confirmed the significant spatiotemporal variability of soil erodibility depending on the terrain morphology and changes in climatic conditions during the year. The critical period occurs mainly in the period of combination of the occurrence of higher frequency of erosion rainfall (expressed by the R factor) and high values of soil erodibility (expressed by the K factor) as shown on Fig. 4. This variability must be implemented in current methodologies for determining the risk of water erosion using USLE. With the revised methodology will be achieved also more effective proposal for the deployment of erosion control and retention elements in the landscape, as well as more effective intangible benefits of these measures including improvement of the landscape character and recreational potential of the site with designed protection, retention and adaptation landscape elements.

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Souhrn
Výzkum byl zaměřen na prokázání významné časo-prostorové variability hodnot K faktoru v závislosti na morfologii terénu a změnách klimatických podmínek v průběhu roku v podmínkách ČR. Výsledky tuto variabilitu potvrzují a doporučujeme revize a aktualizace metod pro stanovení rizika eroze a návrhy dimenzování a umístění protierozních opatření a retenčních prvků v krajině.
Za kritické období lze označit zejména období kombinace výskytu vyšší četnosti erozních srážek (vyjádřeno faktorem R) a vysokými hodnotami erodovatelnosti půdy (vyjádřené faktorem K). Tato variabilita by měla být implementována v současných metodikách pro stanovení rizika eroze vody pomocí USLE. S revidovanou metodikou lze dosáhnout také efektivnějšího rozdělení finančních prostředků pro návrhy erozních opatření a retenčních prvků v krajině, i nehmotných užitků těchto opatření, včetně zlepšení krajinného rázu a rekreačního potenciálu místa s navrženými ochrannými, retenčními a adaptačními krajinnými prvky.

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