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Microscale spatial variation of soil erodibility factor (K) in a young hummocky moraine landscape in Northern Poland

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Abstract. Soil erodibility is one of the crucial parameters for modelling soil erosion, expressed as the K-factor. The presented study tries to illustrate the spatial variance of K-factor on a local scale through the investigation of soil properties and descriptive spatial analysis utilising GIS tools at microscale in a young hummocky moraine landscape in Northern Poland. The results of the interpolation of K-factor values illustrate their changing from high values in eroded pedons on the tops of hummocks to low values in kettle holes. The middle position is occupied by slightly and non-eroded pedons. The mean weight results were very similar to data that were found on the scale of Europe and Poland.
In landscapes with heterogeneous soil cover, there are significant differences in maps based on different approaches to data visualisation. There are advantages and disadvantages to both (1) referring to mean values of the K index for soil contours representing different soil types and (2) interpolating the values obtained from individual points (GIS tool). Interpolation can be used for a thoroughly examined area with a high number of input points, while a map based on mean K index values for soil contours would be more effective in homogeneous areas.

Key words:
young hummocky moraine landscape,
soil erodibility,
erosion truncation,
spatial variation

Introduction

Soil erosion control is one of the key issues in current land management. The estimation of soil erosion rates based on calculated approaches has many followers internationally. Hummocky landscape in Poland is associated with highly heterogeneous soil cover, moraine parent materials, and high intensity of anthropogenic impact. Thereby, anthropogenic denudation is the most common problem not only in Poland (Sinkiewicz 1991, 1998) but everywhere in young hummocky moraine landscapes in the Northern Hemisphere (Sommer et al. 2008).

One of the parameters for modelling soil erosion is soil erodibility, expressed as the K-factor. Being most widely used in soil erosion models, such as the Universal Soil Loss Equation (USLE) and its revised version (RUSLE), the K-factor expresses the susceptibility of a soil to erosional degradation. According to numerous studies, the K-factor is related to soil properties such as organic matter content and soil texture (Święchowicz 2016; Vaezi et al. 2008; Villa et al. 2012; Wang, Zheng and Guan 2016). In its first definition, K-factor was estimated based on field experiments. However, as direct measurements of K-factor on field plots are not financially sustainable at the regional or national levels, different calculation approaches based on the nomogram of Wischmeier and Smith were developed (Wischmeier and Smith 1978). One is the EPIC model proposed by Williams (Williams 1984) and next improved by Arnold with co-authors (Arnold et al. 2012). Previous studies (Panagos et al. 2015; Wang et al. 2016; Zhang et al. 2019) have well-developed approaches to large-scale K-factor estimation. However, data about K-factor variability in specific local soil conditions are limited. Despite criticism of the K-factor as an insufficient parameter by some authors (Panagos et al. 2016; Fiener and Auerswald 2015), it is widely accepted and used (Wang et al. 2016; Zhang et al. 2019). Moreover, it seems to be very important that after decades of large-scale erosion modelling for countries and continents, the understanding is coming that effective soil erosion control can be managed only at the small scale of separate fields and landscapes. The review of the literature on the calculated K-factor for the specific soils in a hummocky landscape in Poland discovered the knowledge gap in this type of landscape. Wawer et al. (2005) made an estimation of K-factor for Polish soils in different texture groups without association with landscapes. In our study, we will try to give important additional information on the spatial distribution of soil erodibility in a young hummocky landscape influenced by anthropogenic denudation. Understanding of spatial distribution is important for precision agriculture and the use of smart technologies in heterogeneous landscapes.

This article is a continuation of a previous study (Radziuk and Świtoniak 2021) that described the main regularity of erodibility K-factor for a young hummocky moraine landscape, and the results are partly included in the presented work. The mentioned study indicated evident changes in soil erodibility K-factor calculated with Williams' equation (1984) depending on the degree of soil truncation. According to the obtained results, subsequent stages of soil transformation – from fully developed to completely eroded – are increasingly susceptible to erosion. The main factor affecting this rapid erodibility growth was revealed in a decrease of both carbon content and sand fraction in humus horizons. In the studied agricultural areas, the slope processes were stimulated not only by exposing the soil to external erosive factors (precipitations) but also by changing the properties of the soil material itself. Subsequent stages of soil truncation were marked by gradual but much slower growth of soil erodibility. The exposure of the Bt or C(k) horizons of richer clay fraction would possibly reduce erosion risk. Nevertheless, the clay content in these soils is too small to create wash-resistant aggregates but high enough to reduce soil permeability in favour of increased potential surface runoff. At the same time, these soils were characterised by a further decrease in soil organic carbon content, which can also reduce their resistance to water erosion. A comparison of the erodibility of strongly and completely eroded soils revealed that the small differences in mean K values are not statistically significant.

The presented study tries to designate the spatial variance of K-factor on a local scale based on an investigation of soil properties and descriptive spatial analysis (GIS tools). The main aim of the study was to create maps of K-factor spatial variation and compare two approaches in K-factor visualisation. The first approach examined the spatial distribution of K-factor values based on a soil map and mean K-factor values calculated and attributed for each soil type. The other approach used GIS tools for automatic interpolation of K-factor values relying on a network of input points. Each approach has advantages and disadvantages: in areas with complicated soil cover, it could be difficult to create a precise soil map without using expensive additional equipment and getting aerial or UAV images; moreover, specific soil contours can have high heterogeneity of K-factor values at their borders. On the other hand, automatic interpolation does not need soil maps, which are not always available at satisfactory quality, but it utilises soil data from expensive and time-consuming field and laboratory works. Moreover, this approach should have many input points to obtain satisfactory results.

Study objects

Geographically, the study area is situated in the Chełmińsko-Dobrzyński Lake District (Solon et al. 2018). Administratively, the research plot is in the north of the Kuyavian-Pomeranian Voivodeship, Ryńsk Commune, Northern Poland (53°12′50.53″ N and 18°48′05.08″E). The experimental plot in

Orzechowo was selected primarily based on satellite observation data. It represents a typical hummocky and undulating moraine plateau of the Chełmno Lake District meso-region, with a high rate of anthropogenically denudated soils (truncated and accumulated by slope processes) and high heterogeneity of soil cover (Świtoniak 2014; Świtoniak et al. 2018). The satellite data allow a soil map of the experimental plot to be created (Fig. 1) based on a photo-interpretation key for aerial and satellite images (Świtoniak et al. 2013).

The area of the experimental plot is 39.4 hectares. The main landform of the research area is a plateau. The altitudes change from 87.5 m a.s.l. to 103.3 m a.s.l. and the territory generally has an inclination from north-east to south-west. The relief range is 15.8 m. Several hummocks rising about 4–5 m above the surrounding area are visible in the central and north-eastern part of the experimental plot (Fig. 1). Nearly half of the area (53.1%) lies in the 90–95 m altitudes, and an additional 36.9% are 95–100 m a.s.l. The area below 90 m a.s.l. occupies 7.8%, and above 100 m occupies 2.2%. Additionally, the relief of the experimental plot is characterised by several kettle holes located in the south and north-west parts that accumulate water and sediments from surrounding hummocks and form a specific feature of the landscape. Despite a seemingly insignificant decrease in altitude in the kettle holes – less than 5 m – these values influence soil processes and change the soil cover from Luvisol to Mollic Gleysol and Phaeozems. The largest kettle hole is in the northern part of the experimental field and has an area of 2.3 hectares.

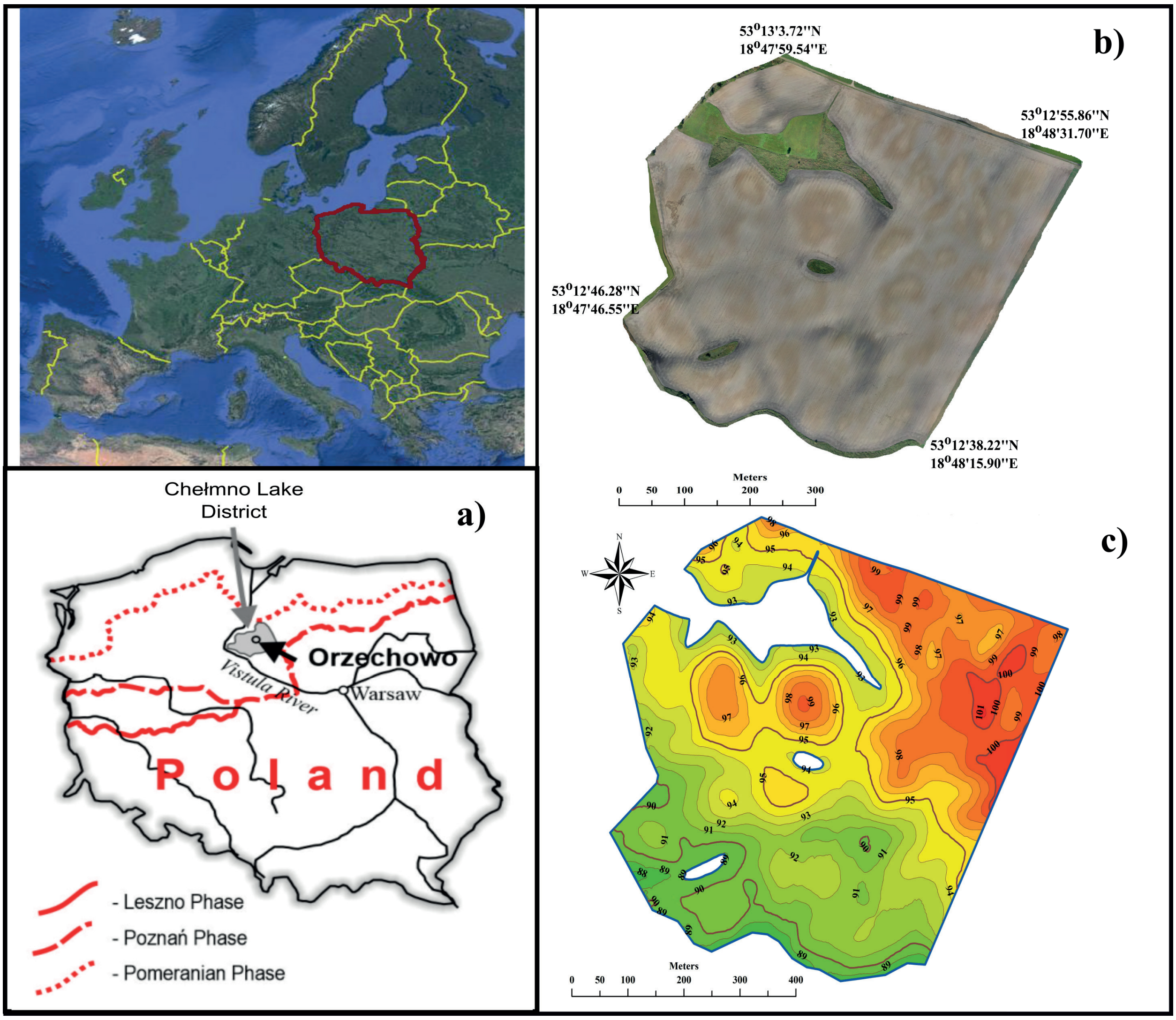

Fig. 1. Location of the experimental plot in Orzechowo (Northern Poland). a) region of location; b) satellite imaginary; c) relief of the territory

Soil cover is represented by soils in different stages of soil truncation. According to the WRB classification (IUSS Working Group WRB 2015) these soils can be classified as Eutric Regosol (Protocalcaric), Haplic Luvisol (Protocalcaric), Albic Luvisol, Endogleyic Phaeozem and Mollic Gleysol.. The detailed soil description is given below in the article as a part of the study results.

Study methods

The first step of research was to create a soil map with the help of a photo-interpreting key developed at the Department of Soil Science and Landscape Management NCU in Toruń (Świtoniak et al. 2013). The approach relies on expert delineation of soil contours based on the comparison of variability of specific colour hues of surface soil horizons in aerial or satellite photographs. The change in texture and other properties of soils transformed by human-induced erosion leads to a change in their spectral properties, and thus to change their image (colour) on the aerial photo. The most eroded pedons – weakly developed calcareous soils – have a light-brown colour of surface horizons, sometimes almost white, which is related to drying of these soils and presence of carbonates that lighten the brown colour of moraine tills. The contours of these soils are oval and coincide with the summit zone of vast plateau hills. In the case of clay-illuvial eroded soils, surface horizons are brown due to the major pigments accumulated in illuvial argic horizons' oxidised iron compounds and clay fraction. In general, the contours of these soils have the shape of oval rings surrounding weakly developed calcareous soils, and they cover the upper and middle sides of the slopes. The light grey colour of the arable horizons corresponds to the association of clay-illuvial soils and colluvial soils covering gley and clay-illuvial soils. This association creates a specific "soil background" and it occupies by far the largest areas. The determination of the range of shallow colluvial soils (30–50 cm of colluvium) covering black earths and peat soils was relatively simple due to the dark grey colour of surface horizons.

Field sampling was conducted in October of 2019. The choice of places for soil sampling obeyed the need to have four catenae with full soil sequences from completely eroded soils through slightly eroded and non-eroded soils to colluvial soils. Every point has precise GPS coordinates to further include into GIS analyses. An additional 50 input points were sampled in different places of the experimental plot to create the input data network. The points were chosen based on satellite imagery and should be placed in main polygons with visible colour differences ensuring a regularly spaced distribution. The choice of points for soil sampling was made randomly inside separate soil contours.

The basic soil properties were analysed for both soils from catenae and additional input points. The analyses were performed according to the methods as follows: soil organic carbon (SOC) content by Tiurin method (PN-ISO 14235:2003); texture by sieves and sedimentary aerometric method of Casagrande as modified by Prószyński (PN-ISO 11277:2005) (*Systematyka gleb Polski* 2019). Determining characteristics were required for a general description of soils and calculation of soil erodibility factor (K).

In the study, we used the method of K-factor calculation proposed by Williams in the EPIC model (Williams 1984; Williams et al. 1983; Arnold et al. 2012). In contrast to the first USLE approach by Wischmeier and Smith (1978) that used soil texture, soil organic carbon content and four soil structure classes, the EPIC model used even fewer soil characteristics, based on soil textural classes and content of soil organic carbon. The availability of data in a wide range of research makes Williams' equation very useful for soil erodibility assessment in different landscapes. In the study, K-factor is expressed in the International System of units as $t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1}\ mm^{-1}$. The equation of Williams (1–5) (Arnold et al. 2012) calculates the K-factor ($t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$) as:

$$K = f_{sand} \times f_{sl\text{-}cl} \times f_{hisand} \times f_{orgc} \times 0.1317 \quad (1)$$

$$f_{sand} = (0.2 + 0.3 \times \exp[-0.256 \times m_s \times (1 - m_{silt}/100)] \quad (2)$$

$$f_{sl\text{-}cl} = (m_{silt}/(m_c + m_{silt}))^{0.3} \quad (3)$$

$$f_{hisand} = 1 - (0.7 \times (1 - m_s/100)/((1 - m_s/100) + \exp[-5.51 + 22.9 \times (1 - m_s/100)]) \quad (4)$$

$$f_{orgc} = 1 - (0.25 \times orgC/(orgC + \exp[3.72 - 2.95 \times orgC]) \quad (5)$$

where m_s is the percentage of sand content (0.05–2.00 mm diameter particles), m_{silt} is the percentage of silt content (0.002–0.05 mm diameter particles), m_c is the percentage of clay content (<0.002 mm diameter particles), and *orgC* is the percentage of organic carbon content of the layer.

Mapping of soil erodibility (K-factor) was made by two methods. The first approach to soil mapping included attributing each soil contour a mean K-factor value. The mean value was calculated from all available points, both from catenae and input points. The other one is to use the Spline tool in ArcGIS software. Spline is a deterministic method of data interpolation. Surface interpolation tools create a continuous (or prediction) surface from sampled point values. The main idea of interpolation is to eliminate the need to visit every location in a study area to measure the basic soil properties (which is difficult and expensive). Instead, a network of input points is used to create the prediction surface. In our study, we used the regularised option of Spline to create a smooth, gradually changing surface with values that may lie outside the sample data range (Franke 1982; Urbański 2011). For visualisation of results of K-factor interpolation, the classification was made dividing into ten classes with a step of 0.0010 $t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$. Comparison of surfaces with different values of K-factor, created using the GIS interpolation tool and mean values attributed to soil contours, was made by the imposition of two maps in ArcMap.

Results

Description of the soil cover of the experimental plot

The primary soil map, created based on satellite imagery of 10-m resolution, was clarified with the data of UAV images and verified by the detailed description of 16 soil profiles and the addition of 50 augering points. All points were divided into four groups (designated A through D), representing different stages of soil truncation (groups *A, B, C*) and colluvial soils (D) (Table 1, Fig. 2):

- *Soils A* – completely eroded soils on the tops of hummocks – Eutric Regosol (Protocalcic) (IUSS Working Group WRB 2015). *Soils A* have a weakly developed soil profile with a characteristic minimal development of soil horizon sequence: ACkp-Ck. Clods of parent materials (from Ck) occur widely in the arable layer. The textural class according to USDA is sandy loams with a clay content of about 15 to 18%. The common feature of these soils is the low content of soil organic carbon (SOC) in the plough horizon: approximately 0.62%. At the same time, the plough layers are rich in calcium carbonates (with C-$CaCO_3$ content reaching 0.79) derived from parent materials (Ck). The principal singularity is the highest C-$CaCO_3$ content of all studied soil varieties in the entire soil profile. These soils occur in 13 soil contours with a mean area of 0.05 hectares. The total area of *Soils A* within the experimental plot is 0.48 hectares or 1% of the total area of the field.
- *Soils B* – strongly eroded Luvisols with an argic horizon in the surface horizons (ABtp) in the shoulder slope position. The group comprises mostly Haplic Luvisol (Protocalcic) with a typical horizon sequence of ABtp-Bt-Ck. On the study plot, this group generally has the highest clay content of all the arable layers investigated, with a mean value of 18% and minimal inclusion of sand particles. The SOC content is similar to that of *Soils A* in the entire profile. These soils occupy 9.6 hectares and lie in 41 soil patterns. The mean area of the soil contour is about 0.26 hectares, which is five times more than in *Soils A*. However, all these soil spots have an area of less than 1 hectare, which in combination with *Soils A* provides high heterogeneity of soil cover.
- *Soils C* – slightly eroded or non-eroded pedons in the bottom part of the slope. Some pedons have an admixture of colluvial material in the arable horizon. This group is the most diverse, including Albic Luvisols with a horizon sequence of Ap-E-Bt-Ckg and Mollic Gleysol (Luvic) (Ap-A-Eg-2Btg-2Ckl). Additionally, the group has the largest number of representative points – 24 – which could be explained by maximum spread within the experimental plot and 58% occupation of the total area (22.9 hectares). These soils surround hills in a middle-slope position, closing into one soil contour. We observed the greatest content of sand particles

Table 1. Summary statistics of basic soi properties for experimental plot in Orzechowo

	Soils A	Soils B	Soils C	Soils D	Soils A	Soils B	Soils C	Soils D
	Sand, [%]				Silt, [%]			
Number	14	14	24	14	14	14	24	14
Mean	58	58	66	59	26	24	25	32
Median	58	58	66	60	27	24	25	32
Min	55	51	55	49	21	20	16	24
Max	62	62	76	68	29	30	33	40
Stand. error	0.53	0.88	1.02	1.38	0.56	0.72	0.80	1.17
Stand. deriv.	1.99	3.28	5.00	5.18	2.10	2.71	3.93	4.38
K variance	3.43	5.65	7.61	8.73	7.95	11.11	15.74	13.79
	Clay, [%]				SOC, [%]			
Number	14	14	24	14	14	14	24	14
Mean	16	18	9	9	0.62	0.82	0.96	2.46
Median	15	18	9	9	0.64	0.83	0.93	2.07
Min	14	15	4	5	0.33	0.60	0.69	1.0
Max	19	21	20	16	0.76	1.03	1.39	6.45
Stand. error	0.37	0.53	0.67	0.79	0.03	0.04	0.04	0.38
Stand. deriv.	1.38	1.98	3.27	2.95	0.13	0.13	0.22	1.40
K variance	8.79	11.03	34.85	31.53	20.7	16.11	22.38	57.06

Source: authors' own work

of all examined profiles, comprising virtually 66.0% in the soil texture. *Soils C* are depleted of clay particles (which is a specific feature of this group). The soil organic carbon content increases in comparison with soils in the top and shoulder positions and exhibits a significant spread in values.

- *Soils D* – soils with thick colluvium (in the plough and under-plough horizons) in the depressions (kettle holes) in the landscape. This group represents Endogleyic Phaeozem and Mollic Gleysol according to the WRB classification (IUSS Working Group 2015). The main difference from the previous groups is the high soil organic carbon content with significant fluctuation between the soils. Also, it was revealed that these soils have comparatively low clay content. *Soils D* constitute a single category with increasing C-SOC content from the plough horizon to the subsoil. The deeper horizons contain organic matter from the original humus (or even organic) horizons developed in the past under the strong influence of groundwater and now covered with slope materials. These soils are included in 11 contours and their total area is 6.41 hectares. The minimal contour has the same area as *Soils A* and *B*, but the mean area of soil contour is 0.8 hectares.

K-factor estimation

As previously stated, an estimation of K-factor value was made according to the equation of Williams (1984). The most congenerous group of soils by K-factor values is Soils A. K-factor fluctuates from 0.0298 to 0.0345 $t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$ with a mean value of 0.0330 $t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$ (Table 2). This group of soils has a minimal coefficient of variation that indicated more homogeneous results, comparing with other groups. The values of K-factor

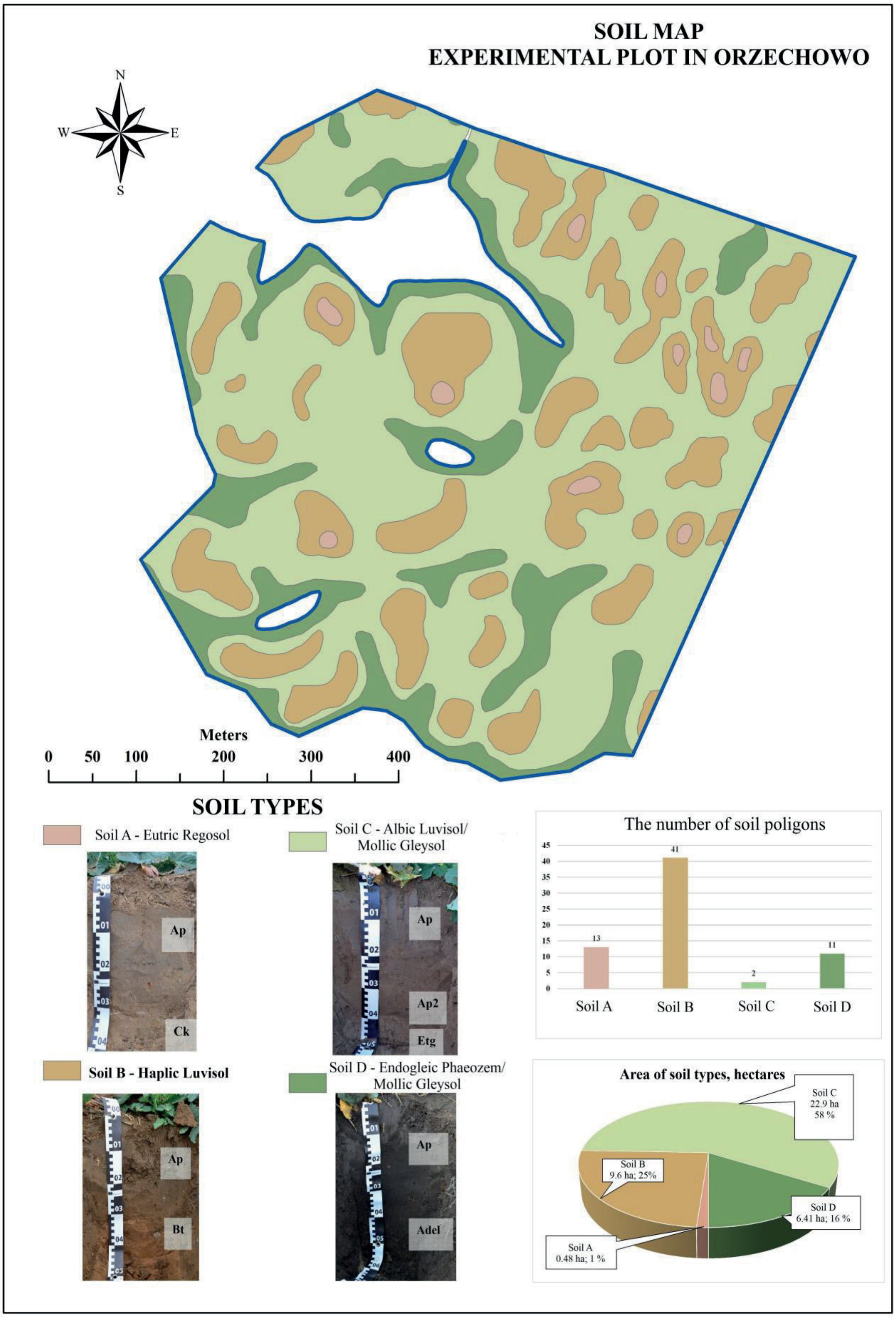

Fig. 2. Soil map of experimental plot in Orzechowo (Northern Poland)

Table 2. Summary statistics of K-factor values for Orzechowo experimental plot

K (t·ha·h·ha^{-1}·MJ^{-1}·mm^{-1})	**Soils A**	**Soils B**	**Soils C**	**Soils D**
Number	14	14	24	14
Mean	0.0330	0.0310	0.0301	0.0285
Median	0.0334	0.0309	0.0299	0.0289
Min	0.0298	0.0290	0.0248	0.0250
Max	0.0345	0.0340	0.0349	0.0320
Stand. error	0.0003	0.0004	0.0005	0.0005
Stand. deriv.	0.0013	0.0015	0.0022	0.0020
K variance	3.84	5.06	7.42	6.68

Source: authors' own work

for *Soils A* are the largest both in absolute numbers and mean values.

Soils B have very similar K-factor values comparing with *Soils A*, varying from 0.0290 to 0.0340t·ha·h·ha^{-1}·MJ^{-1}·mm^{-1}. The previous study (Radziuk and Świtoniak 2021) used ANOVA statistical analyses to find differences between different soil groups. In the present study, we cannot utilise this analysis because of the different numbers of samples in different soil groups. Based on the previous study, it can be assumed that *Soils A* and *B* have the same predisposition to soil erosion. The K-factor values for group *B* are not so homogeneous as in *Soils A*, having a higher coefficient of variance, but the data distribution is more concentrated, comparing to *Soils C* and *D*.

Soils C as the most widespread group has the highest coefficient of variance, at 7.42, which indicates the most heterogeneous data of K-factor. The K-factor values vary from 0.0248 to 0.0349 t·ha·h·ha^{-1}·MJ^{-1}·mm^{-1}, presented the minimal and maximum values for the whole dataset. Such significant data fluctuation confirms the conclusion that *Soils C*, by reason of an intermediate position between eroded soil varieties and colluvial soils, would have variable susceptibility to soil erosion depending on their slope location and intensity of other factors.

The lowest values of K-factor were recorded in *Soils D*. The data varied from 0.0250 to 0.0320 with a mean of 0.0285 t·ha·h·ha^{-1}·MJ^{-1}·mm^{-1}. As was mentioned before, *Soils D* were characterised with the minimal clay content and high SOC content. Therefore, this group has the lowest susceptibility to soil erosion.

Spatial distribution of K-factor

Digital soil mapping is a rapidly emerging research front for predicting soil properties, including K-factor. Creation of digital maps with the help of GIS tools gives good results, especially at local scale with a good sampling base (Tian et al. 2021). In the present study, Spline interpolation was used to illustrate the most common spatial variation of K-factor. Figure 3 illustrates a comparison between two approaches: colours illustrate Spline interpolation; hatching shows K-factor distribution according to mean value of K referring to each soil type (presented by soil contours).

Mean value of K-factor, referring to soil types. By utilising a soil map and mean values of K as an attribute of each soil type for visualisation of spatial variation, it was shown that K-factor varies in the same way as soil cover (Fig. 3, hatching). *Soils C* (*Albic Luvisols*) occupy the most significant area (58.0% of total experimental plot). All soil types are included into four categories by the K-factor values. The highest values of K-factor (0.033-0.034 t·ha·h·ha^{-1}·MJ^{-1}·mm^{-1}) indicate strongly eroded *Soils A* that occupy 1% of area. *Soils D* with minimal K-factor values (0.028–0.029 t·ha·h·ha^{-1}·MJ^{-1}·mm^{-1}) cover 16% of area (Table 3). The mean weight value of K-factor for the whole experimental field, calculated for this approach, was 0.0305 t·ha·h·ha^{-1}·MJ^{-1}·mm^{-1}.

Table 3. Areas with different values of K-factor ($t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$) depending on approach to visualization of spatial distribution

Approach to visualization	Areas with different values of K-factor ($t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$), % from total area										
	0.026 and less	0.026-0.027	0.027-0.028	0.028-0.029	0.029-0.030	0.030-0.031	0.031-0.032	0.032-0.033	0.033-0.034	0.034 and more	Mean weight K
Spline interpolation.	4.8	1.4	2.8	10.8	14.0	10.9	15.0	16.2	11.5	12.7	0.0312
Mean value of K-factor referring to soil types.	n.d.	n.d.	n.d.	16.0	n.d.	58.0	25.0	n.d.	1.0	n.d.	0.0305

Source: authors' own work

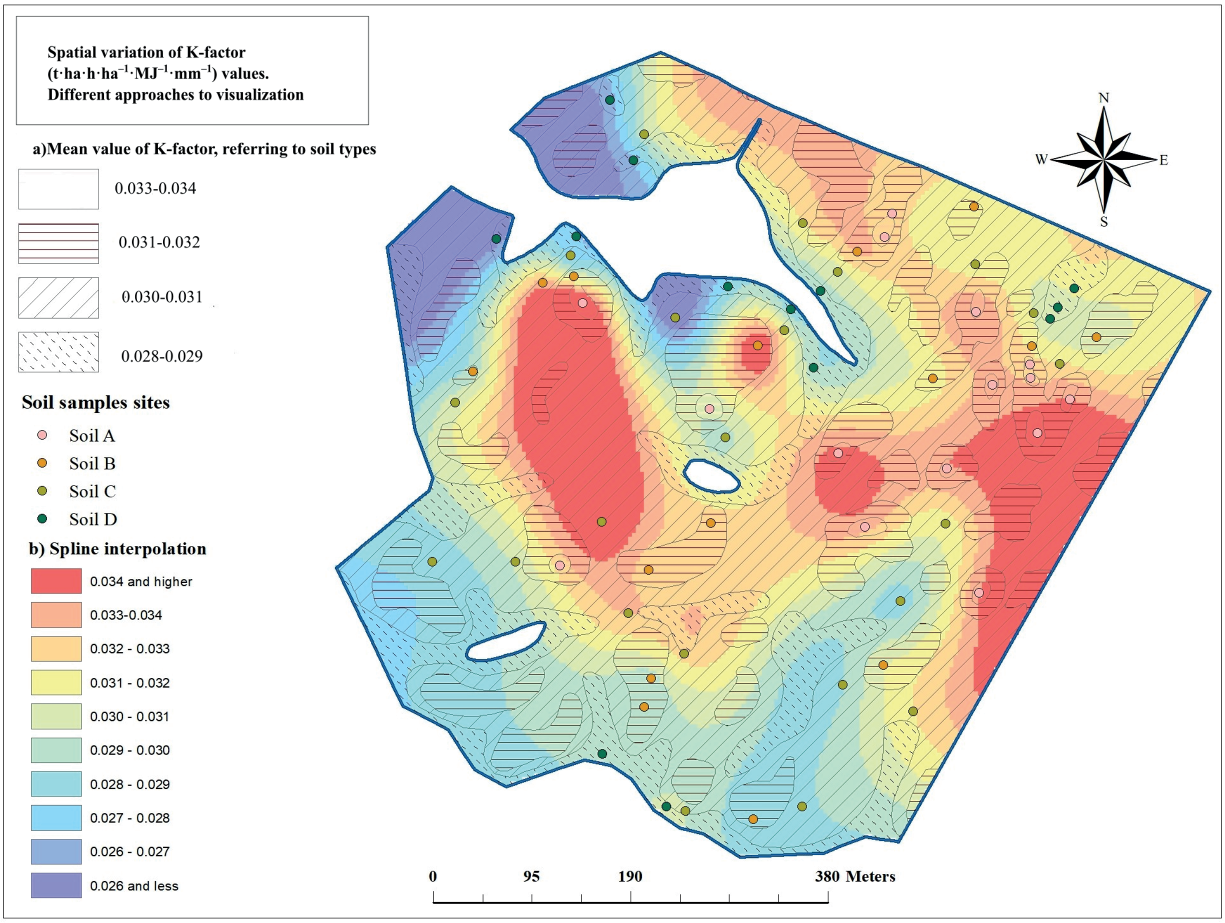

Fig. 3. Spatial variation of soil erodibility (K-factor) based on different approaches

Spline interpolation. As could be seen from Figure 3, higher K-factor values correspond to high altitudes in central and north-eastern parts. As was mentioned, this position was the main locations of Eutric Regosols (*Soils A*) and Haplic Luvisols (*Soils B*), which characterised different stages of soil truncation. A common decrease in K-factor values corresponds with kettle holes. The maximum K-factor values are consistent with hills and their shoulders. The areas of K-factor values distribution of the experimental plot in Orzechowo illustrates some specific features (Table 3). Interpolation shows that areas with different levels of K-factor values have very similar spreading and contain from 10 to 16% for all categories of K above 0.028 $t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$. Low values of K-factor (less than 0.028 $t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$) occupy areas from 1.4 to 4.8% in categories 0.026–0.027 and less than 0.026 t·ha·h·ha^{-1}·MJ^{-1}·mm^{-1}, respectively. The mean weight value of K-factor for the whole experimental field was 0.0312 t·ha·h·ha^{-1}·MJ^{-1}·mm^{-1}.

Spline interpolation shows satisfactory results in the north-eastern part of the experimental plot, where there was an evident increase in K-factor values, connected with eroded soils. Moreover, spline interpolation illustrates a small depression as an area with lower K-factor values. The south-western part of the experimental plot with lower altitudes and mainly non-eroded soils was shown as unsatisfactory by spline interpolation. Despite smooth transition of K-factor values from high to relatively low levels, the large number of eroded contours was included into areas with low values as soils with slight erodibility. This was not confirmed by our study, so to exclude this error more input point should be used. On the other hand, the traditional approach of referring mean values of K-factor value to soil types does not offer smooth transferring of data and demonstrates an abrupt transition of data among neighbouring soil contours that is not possible in natural systems.

According to Panagos et al. (2014), the mean K-factor for Europe was estimated at 0.032 t·ha·h·ha^{-1}·MJ^{-1}·mm^{-1}. This study also gives the mean values of K-factor for Poland as 0.0299 t·ha·h·ha^{-1}·MJ^{-1}·mm^{-1}. Our results have very similar values. However, it should be noted that the study of soil erodibility at microscale gives the possibility to determine the areas of potential erosion more precisely. Moreover, we could divide the potential transit and accumulation zones with lower values of K-factor, which was not possible at macroscale.

Conclusions

This paper includes the results of interpolation K-factor values at microscale in a young hummocky moraine landscape in Northern Poland. Interpolation was based on analysis of basic soil properties and calculation of K-factor with the EPIC equation. The values of K-factor varied from 0.0250 t·ha·h·ha^{-1}·MJ^{-1}·mm^{-1} for slightly eroded or non-eroded pedons in the bottom part of the slope and soils with colluvial horizons in kettle holes to 0.0345 t·ha·h·ha^{-1}·MJ^{-1}·mm^{-1} for eroded pedons in the top and shoulder position of a slope. The spatial distribution showed that the diversity of the K-factor is mainly connected with relief and stage of soil truncation – the upper parts of slopes and hummocks are occupied by with soils characterised by the highest soil erodibility, and soils in kettle holes have the lowest values of K-factor.

In the landscapes with heterogeneous soil cover, there are significant differences in maps based on different approaches to data visualisation. There are advantages and disadvantages to both (1) referring the mean values of the K index for soil contours representing different soil types and (2) interpolating the values obtained from individual points (GIS tool). Interpolation can be used for a thoroughly examined area with a high number of input points, while referring the mean values of the K index for soil contours representing different soil types would be more effective in homogeneous areas with less differentiation of soil cover. Maps, created based on both approaches, show some overlapping areas, mostly associated with high K-factor values. However, the differences between them are too large to speak of interchangeability of methods. Despite similar mean weight values for the entire area being obtained using both approaches, they are not fully satisfactory. The maps created with both approaches have significant disadvantages from the point of view of their practical use, e.g. in precision farming in young hummocky moraine landscape.

The results are planned to be compared with soil erodibility estimated based on structure stability to water impact. This research will be the next step for a comprehensive assessment of spatial diversity of soil erodibility characteristics in a young hummocky moraine landscape.

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Disclosure statement

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Author contributions

Study design: MŚ; data collection HR, MŚ, MN; statistical analysis: MN; result interpretation: HR, MŚ; manuscript preparation MŚ, MN; literature review: HR.

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