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QUANTIFICATION OF WATER EROSION RATES ON THE NAREW RIVER VALLEY-SIDES USING UNIVERSAL SOIL LOSS EQUATION**

Abstract: This paper presents the results of the quantification of water erosion rate in the rolling old-glacial area of the Narew River valley-sides using the Universal Soil Loss Equation (USLE). The soil loss estimated using USLE for 7 study sites ranged from about 1 to 5 Mg ha^{-1} yr^{-1}. These differences are the result of varied slope steepness ranging from 1.8% to 7.5% and the average slope length ranging from 172 m to 480, as well as varied soil texture. The impact of various crop rotations on the erosion rate was also studied. The results revealed that crop rotations with corn and potatoes caused higher rates of erosion. On the most gentle slope, the annual soil erosion increased by 0.5 Mg ha^{-1} yr^{-1}, while on the steepest slope the soil erosion rate increased by 2 Mg ha^{-1} yr^{-1}.

Water-induced erosion is one of the main factors degrading arable land all over the world [9]. In Poland, 16.5% of soils are threatened with actual water erosion and most severe erosion occurs on 7% of the country area [53]. The highest rates of water erosion are reported on loess soils, but significant soil losses are also observed in mountains [20] and lake districts [45]. Experimental measurements based on the amount of soil collected on study plots under natural or simulated rainfall are the most common method of obtaining water erosion rates in Poland. Other methods are based on qualitative and quantitative measurements of soil relocated from the watershed or based on qualitative and quantitative inventories of rills and deposits after every rainfall [21]. The ^{137}Cs measurement to document total water and tillage erosion was also used [57].

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However, this method has to be used in combination with other methods, such as the physical tracer method, to obtain the exact proportion of water and tillage erosion [37]. These methods are useful for calculating the erosion rates for single slopes or single fields. They are, however, not so useful for larger areas due to technical reasons. Plot data cannot be extrapolated to microwatersheds or larger areas [15]. The mathematical models describing the processes of water erosion are becoming more popular. The Universal Soil Loss Equation (USLE), developed by Wischmeier and Smith [54], is the simplest model which allows to assess the amount of soil loss related to rainfall, soil erodibility, topography, tillage practices, land cover and management. The model is designed to predict average soil losses for given natural and anthropogenic conditions. The USLE only estimates the amount of soil loss that results from sheet and rill erosion and does not account for additional soil losses from gully or tillage erosion. It was created to support the soil conservation planning at the field scale [54]. The equation was developed for United States, but its simplicity encouraged researchers from other countries to use it [1, 2, 27, 28, 40, 51]. In Poland, the USLE was used for calculation not only the water erosion rates [27, 28, 39, 47] but also for quantitative assessment of sediments transported from small watershed [4].

The aim of the study was the quantification of the erosion rate in the rolling old-glacial area of the Narew River valley-sides, using the universal soil loss equation (USLE). The old-glacial areas are considered not highly sensitive to erosion due to the gentle slopes and the soils rather resistant to runoff. However, observations of soil relocation after rainfall or spring thawing and the colluvial soils found on the toeslopes [55] and on the bottom of dry valleys [7] are the evidence of erosional processes occurring in the rolling old-glacial areas.

MATERIAL AND METHODS

The study area is located south-west of Białystok (NE Poland) on the valley-sides of the Narew River within the borders of the Narew National Park (NNP) protection area. The NNP stretches between Suraż and Rzędziany and protects the fluviogenous wetlands in the Narew River valley and its unique anastomosing river system preserved in its almost pristine form [13]. This is one of the largest and best preserved areas of wetlands in Poland, rich in flora and fauna. The topography of the uplands surrounding the valley is rather moderate and the surface slope ranges from leveled plains to gentle slopes. The soils located on the valley-sides are built of glacial deposits, mainly sands and loamy sands, and rarely loams [6]. The soils are mainly Luvisols and Arenosols. The land use on the valley-sides is dominated by agriculture. The arable fields on the valley-sides are narrow and their longer borders are parallel with the major slope, so it is common practice to conduct tillage along the slope. Major crops are rye, potato, oat and maize.

Mean daily temperature ranges between – 4.3°C in January and 17.3°C in July. Mean annual rainfall is 593 mm with peaks in June, July and August. Thunderstorms occur approx. 25 days per year, mostly during summer. Maximum monthly snowfall varies between 8 and 80 cm and occurs 82–85 days per year, with midwinter thawing [12].

Seven study sites located on the valley-sides with mean slopes range between 1.8% and 7.5% were chosen (Table 1) to be representative of the landscape type and field geometry and crop production, as well as tillage methods used in the region. The tillage operations on all study sites were conducted along the slope gradient. The study sites consist of several arable fields extending from upland to the valley boarder.

TABLE 1. SHORT DESCRIPTION OF THE STUDY SITES

Study site	Mean slope	Mean length	Area of arable land
	%	m	ha
A	1.8	270	31.4
B	2.4	360	22.0
C	3.0	330	46.6
D	3.6	172	37.1
E	4.2	480	151.9
F	6.0	310	28.8
G	7.5	200	11.4

The USLE was used to calculate the annual soil erosion rate. It computes the soil loss for a given site as the product of six major factors:

$$A = R\,K\,L\,S\,C\,P \tag{1}$$

where:

A – computed soil loss per unit area in a given time, usually expressed in Mg ha^{-1} yr^{-1}

R – rainfall and runoff factor [MJ ha^{-1} cm^{-1} h^{-1} yr^{-1}]

K – soil erodibility factor [Mg ha^{-1} (MJ ha^{-1} cm^{-1} $h^{-1})^{-1}$]

L – slope-length factor (dimensionless)

S – slope-steepness factor (dimensionless)

C – cover and management factor (dimensionless).

P – support practice factor (dimensionless).

The *R* factor is computed for a specified region from data obtained using a rain-recording gauge continuously over at least 22 years. The R factor consists of the rainfall index *Rr* and snow melt runoff subfactor *Rs*:

$$R = Rr + Rs \tag{2}$$

When factors other than rainfall are held constant, storm soil losses from cultivated fields are directly proportional to the product value of two rainstorm characteristics: total kinetic energy of storm multiplied by its maximum 30-minute intensity (*EI*). This product reflects the combined potential of the raindrop impact and turbulence of runoff to transport dislodged soil particles from the field. The sum of computed storm *EI* values for a given period of time is a measure of the erosion propensity of all rainfalls within that period. The rainfall erosion index *Rr* is the longtime-average yearly total of the storm *EI* values. Calculation of *Rr* index for particular location requires very detailed continuous recording of data for at least 22-year period [54], which is difficult to obtain. Therefore, in Poland the Rr index was calculated only for few weather stations [3, 5, 30]. The *Rr* index (50,6 MJ ha^{-1} cm^{-1} h^{-1} yr^{-1}) was obtained from Banasik and Górski [5] for the weather station in Ostrołęka, which was the closest to the study area. The comparison of mean monthly rainfall values and annual precipitation values for study area and Ostrołęka (Table 2) revealed that the rainfall rate and distribution were statistically similar (Mann-Whitney U test, $p<0.05$). The precipitation data for the study area was obtained from Górniak [12] and for Ostrołęka from the Central Statistical Office of Poland.

TABLE 2. THE MEAN MONTHLY AND ANNUAL SUM OF PRECIPITATION IN PERIOD OF 1951–2000 FOR STUDY AREA AND OSTROŁĘKA WEATHER STATION

Month	Precipitation in mm	
	Study area	Ostrołęka weather station
I	30	30
II	25	28
III	29	29
IV	36	43
V	58	52
VI	69	70
VII	74	70
VIII	73	69
IX	56	51
X	44	43
XI	43	43
XII	38	41
I-XII	574	569

Source: Górniak [12], Central Statistical Office of Poland.

The *Rs* subfactor estimates early spring erosion by snowmelt runoff, thaw or light rain falling on frozen soil. The estimate of the *Rs* may be obtained by taking 1.5 times the local December-through-March precipitation, measured in cm of water [54]. However, Schwertmann [40] proposes *Rs* as 0.1 times mean monthly precipitation in mm in the period from 1.XII to 31.III. In Poland, the early spring erosion caused by snowmelt runoff is significant [35] and therefore the *Rs* subfactor should be added to the *Rr* value to obtain *R* factor. The higher similarity of Polish climatic conditions to the Bavarian region than to north-western part of United States leads to the conclusion that *Rs* calculation proposed by Schwertmann [40] should be used in Polish conditions [4, 28]. Therefore, it is the method used in this paper. The *Rs* value was calculated by the authors for the Ostrołęka weather station on the basis of the precipitation data from the 49-year period obtained from the Central Statistical Office of Poland.

The soil erodibility factor *K* is the rate of soil loss per erosion index unit, as measured on a unit plot defined as follows: unit plot is 22.1 m long, 1.87 m wide, with a uniform slope of 9%, in continuous fallow, tilled up and down slope and kept without vegetation for more than 2 years. The *L*, *S*, *C* and *P* factors are considered as equal to 1. The *K* factor can be read from the nomograph published by Wischmeier and Smith [54]. For soils containing less than 70% of silt, which prevail in the studied region, the soil erodibility *K* can be calculated from following equation:

$$K=2.77\ 10^{-6}\ M^{1,14}\ (12\text{-}OS)+0.043\ (A\text{-}2)+0.033\ (D\text{-}3) \qquad (3)$$

where:

M – product of percent of particles of size 0.002–0.1 mm and particles of size 0.002–2.0 mm

OS – percentage of organic matter

A – soil structure class (very fine granular = 1, fine granular = 2, medium or coarse granular = 3, blocky, platy or massive = 4),

D – permeability class (rapid = 1, moderate to rapid = 2, moderate = 3, slow to moderate = 4, slow = 5, very slow = 6).

The *K* factor has been calculated using formula (3) for most common soil textures in the region. The soil samples from 0–5 cm layer were taken for texture determination from soils representative of the region. The representative samples were taken from 27 rectangles of dimensions 20 m x 14 m. Every rectangle was designed on an area with a uniform soil texture. From every rectangle, 12 individual samples were taken in regular intervals. Then, the samples were mixed to obtain a representative sample. In total, 7 representative soil samples were taken from weakly loamy sand, 9 representative soil samples from light loamy sand, 9 representative soil samples from heavy loamy sand and 2 from light loam. The texture was analyzed using the Bouyoucos method in modification by Casagrande and Prószyński. This method allows for estimating the content of the sand fraction with a 1.0–0.1 mm size range, instead of the 2.0–0.1 mm size range according to Wschmeier and Smith [54]. Similar method was used by other Polish authors [39]. The organic matter was estimated in the 27 soil samples as loss on ignition (550°C). The class of soil structure was determined in the field. The weakly loamy sand was classified as soil structure class 1 (very fine granular), the light loamy sand and heavy loamy sand were classified as soil structure class 2 (fine granular) and light loam was classified as soil structure class 3 (medium or coarse granular). The permeability class was based on the infiltration coefficient for the given texture taken from previous publications [46, 56], which were compared with the coefficient range taken from Koreleski [27] and the permeability class numbers with names were adopted from Wischmeier and Smith [54]. The light loam, light loamy sand and heavy loamy sand were classified as permeability class 4 (slow to moderate; 40–100 cm d^{-1}) and weakly loamy sand was classified to permeability class 3 (moderate; 10–40 cm d^{-1}). The *K* factor was calculated as a weight average from areas of varying texture (Table 3) and their *K* factors. The texture of soils in the study area was obtained from soil maps and therefore the nomenclature for texture used in this paper is according to the Systematics of Polish Soils 1989 [36].

TABLE 3. DEPOSITS OF SURFACE SOIL LAYER IN HA AND PERCENTAGES

Study site	Texture of surface deposits									
	Loose sand		Weakly loamy sand		Light loamy sand		Heavy loamy sand		Light loam	
	ha	%	ha	%	ha	%	ha	%	ha	%
A	0.0	0.0	16.4	52.2	10.1	32.2	4.9	15.6	0.0	0.0
B	0.0	0.0	8.2	36.8	3.6	16.6	10.2	46.6	0.0	0.0
C	0.0	0.0	0.0	0.0	20.3	43.5	12.4	26.7	13.9	29.8
D	0.0	0.0	7.8	20.8	25.4	68.6	3.9	10.6	0.0	0.0
E	0.0	0.0	6.8	4.5	20.5	13.5	75.8	50.0	48.8	32.0
F	2.5	8.7	16.0	55.7	9.7	33.9	0.6	1.7	0.0	0.0
G	1.2	10.6	1.3	11.8	5.2	45.2	3.7	32.4	0.0	0.0

The *LS* factor represents the slope length (*L*) and the slope steepness (*S*). This factor is dimensionless. These two factors are combined using the following formula:

$$LS = [\lambda/22{,}1]^{m}\,(0{,}065+0{,}0454\,s+0{,}0065\,s^{2}) \tag{4}$$

where:

λ – slope length in m;
s – angle of slope (%);
m = 0.2 for gradients less than 1%, 0.3 for 1 to 3% slopes, 0.4 for 3.5 to 4.5% slopes, and 0.5 for slopes of 5% and greater.

In this study the slope gradient and the slope length were estimated on the basis of a topographical map with the scale 1:10 000.

Factor *C* in the soil loss equation is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from a clean-tilled area along the slope gradient with continuous fallow [54]. Factor *C* was calculated using the following formula taken from Banasik and Górski [4]:

$$C = \frac{\sum_{i,j} \Delta p_j \cdot C_j}{\sum_j \Delta p_j} \tag{5}$$

C – average factor of the rotation system
C_{ij} – factor *C* for plant *i* and growth stage *j*
p_j – rainfall erosivity in growth stage *j*

The information about the rotations used in the study area was gathered during the interviews with farmers. The *C* values were calculated for four most popular rotations:

- rye, oat, potatoes;
- oat, beets, oat;
- maize, oat, potatoes;
- maize, triticale, potatoes.

The *C* values for particular crops and management were taken from Schwertmann [40] and Banasik and Górski [4], dates of sowing and harvest were taken from Koźmiński and Michalska [29], dates of 10%, 50% and 75% canopy cover – from Klima *et al*. [22, 23], Gabriels *et al*. [11] and Rejman and Brodowski [38].

Factor *P* is the ratio of soil loss with a support practice, such as contouring, strip-cropping or terracing to that with straight-row farming up and down the slope. On the valley-sides, it is common practice to conduct tillage up and down the slope; therefore, the *P* factor was 1.

RESULTS AND DISSCUSSION

The exact calculation of all six factors is difficult. In Poland, the *Rr* indicator has been calculated only for few weather stations [3,5]. In this paper, the *Rr* factor calculated according to Wischmeier and Smith [54] by Banasik and

Górski [5] for the closest town Ostrołęka, was used. The *Rs* factor, calculated according to Schwertmann [40], was equal to 12.85.

Soils with texture of loamy sands prevail in the studied area. In soils with texture of weakly loamy sands, the sand fraction ranges from 71% to 79%, the silt fraction ranges between 11% to 19% and the clay fraction is almost the same in all samples. Light loamy sands consist of sand in the range of 66–76%, small percentage of silt in a range of 11–20% and a rather small percentage of clay (12–15%). In heavy loamy sands, the percentage of sand is smaller than in previously described soils and is equal to 60–63%. This texture is characterized by higher percentage of silt and clay, 17–22% and 16–20%, respectively. In light loams, the percentage of silt and clay is even higher. The organic matter (*OM*) in weakly loamy sands ranges from 1.61 to 2.18%; in light loamy sands the amount of *OM* increases to 1.95–3.17%. In heavy loamy sands, it ranges from 2.90% to 4.25% and in light loams the average *OM* is 2.85% (Table 4). The erodibility factors *K* for textures found on the Narew River valley-sides were calculated according to equation (3) and are as follows:

– weakly loamy sand – 0.106 Mg ha^{-1} (MJ ha^{-1} cm $h^{-1})^{-1}$,
– light loamy sand – 0.200 Mg ha^{-1} (MJ ha^{-1} cm $h^{-1})^{-1}$,
– heavy loamy sand – 0.244 Mg ha^{-1} (MJ ha^{-1} cm $h^{-1})^{-1}$,
– light loam – 0.301 Mg ha^{-1} (MJ ha^{-1} cm $h^{-1})^{-1}$.

In this paper, the same erodibility factor for loose sand and weakly loamy sand was adopted. The *K* factor calculated according to Wischmeier and Smith [54] rises with the increasing clay fraction in texture. Similarly, the studies of Jadczyszyn [18] and Nowocień *et al*. [33, 34] revealed that loose sand and weakly loamy sands are less prone to water erosion than loamy sands or light loams. This is contrary to the data from the instruction for the survey of water erosion [17].

The soil loss estimated using USLE for 7 study sites ranges from about 1 to 5 Mg ha^{-1} yr^{-1} (Table 5). These differences are a result of the varying slope steepness ranging from 1.8% to 7.5% and the average slope length ranging from 172 m to 480 (Table 1). The average annual soil loss is the lowest, compared with the other study sites, on the A study site, located on the gentle slope (1.8%). Gentle slopes and soil resistant to erosion, which prevail in this area, cause such a small soil loss of 1.070 Mg ha^{-1} yr^{-1}. Next to the gentle slopes are the B-E study sites located on the moderate slopes (2.4–4.2%). The average annual soi l loss estimated for these four study sites ranges from 1.433 Mg ha^{-1} yr^{-1} to 3.718 Mg ha^{-1} yr^{-1}. However, the average soil loss rate is higher from the study site C located on the slope of 3.0% compared with study site D located on the steeper slope of 3.6%. In this case, the lower *K* values and the shorter slope cause mainly the lower soil loss from study site D, which is 1.919 Mg ha^{-1} yr^{-1} comparing to 2.336 Mg ha^{-1} yr^{-1} from study site C. According to Wischmeier and Smith [54] equation for the *K* factor, more prone to erosion are light loams, which prevail on study site C. The annual soil loss from study site F is similar to that from site D,

TABLE 4. THE GRAIN-SIZE DISTRIBUTION AND ORGANIC MATTER IN STUDIED SOILS

Texture classes	Soil sample	Percentage of fraction with particle diameter [mm]						In total [mm]				Organic matter
		1–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	>1	1–0.1	0.1–0.02	<0.02	%
Weakly loamy sands	5.ś	74	11	5	4	2	4	8	74	16	10	1.61
	6.ś	75	11	4	3	1	6	9	75	15	10	1.65
	9.g	75	11	4	4	1	5	13	75	15	10	1.90
	9.d	71	14	5	4	1	5	5	71	19	10	1.91
	10.g	76	11	4	3	1	5	5	76	15	9	2.03
	7.d	79	9	2	5	0	5	3	79	11	10	1.83
	12.g	79	10	2	3	1	5	16	79	12	9	2.18
Light loamy sand	5.g	68	11	6	6	3	6	8	68	17	15	2.43
	6.g	74	9	4	5	2	6	10	74	13	13	1.95
	7.g	76	9	2	6	1	6	3	76	11	13	2.00
	1.g	72	10	5	3	3	7	5	72	15	13	2.36
	1.d	73	11	4	3	3	6	3	73	15	12	2.27
	10.d	67	12	6	6	3	6	2	67	18	15	3.17
	10.ś	69	14	4	6	1	6	3	69	18	13	2.19
	11.d	75	7	6	5	1	6	30	75	13	12	2.62
	12.d	66	14	6	6	3	5	8	66	20	14	2.80

TABLE 4. CONTINUATION

Heavy loamy sand	11.g	63	9	8	7	2	11	32	63	17	20	4.25
	1.g	62	12	6	6	4	10	2	62	18	20	2.49
	1.d	62	15	6	6	3	8	2	62	21	17	2.50
	2.g	61	13	7	6	4	9	3	61	20	19	2.44
	2.d	62	17	5	6	3	7	1	62	22	16	2.42
	3.g	60	12	8	6	6	8	5	60	20	20	3.28
	3.d	62	15	6	7	4	6	3	62	21	17	2.79
	4.g	61	13	7	5	4	10	3	61	20	19	3.10
	4.d	60	15	7	7	3	8	3	60	22	18	2.79
Light loam	5.d	58	12	8	8	4	10	4	58	20	22	2.77
	6.d	56	14	7	7	5	11	4	56	21	23	2.93

TABLE 5. THE WATER EROSION RATES ON THE STUDY SITES CALCULATED USING USLE

Study site	Factor LS	Factor K Mg ha^{-1} (MJ ha^{-1} cm h^{-1})$^{-1}$	Factor C		Soil loss A Mg ha^{-1} yr^{-1}
A	0.510	0.159	C1*	0.156	0.804
			C2	0.158	0.814
			C3	0.254	1.310
			C4	0.262	1.351
			C av	0.207	1.070
B	0.587	0.186	C1	0.156	1.077
			C2	0.158	1.091
			C3	0.254	1.754
			C4	0.262	1.810
			C av	0.207	1.433
C	0.738	0.241	C1	0.156	1.756
			C2	0.158	1.779
			C3	0.254	2.859
			C4	0.262	2.949
			C av	0.207	2.336
D	0.785	0.186	C1	0.156	1.443
			C2	0.158	1.461
			C3	0.254	2.349
			C4	0.262	2.423
			C av	0.207	1.919
E	1.139	0.248	C1	0.156	2.795
			C2	0.158	2.831
			C3	0.254	4.552
			C4	0.262	4.695
			C av	0.207	3.718
F	1.289	0.143	C1	0.156	1.821
			C2	0.158	1.844
			C3	0.254	2.965
			C4	0.262	3.059
			C av	0.207	2.422
G	2.058	0.193	C1	0.156	3.928
			C2	0.158	3.978
			C3	0.254	6.396
			C4	0.262	6.597
			C av	0.207	5.224

*C1 – rye, oat, potatoes; C2 – oat, beets, oat; C3 – maize, oat, potatoes; C4 – maize, triticale, potatoes. Factor R is equal to 63.45 MJ ha^{-1} cm h^{-1} yr^{-1}, factor P is equal 1 for every study area.

even though site F is located on a steeper slope of 6%. The short slope length and soils resistant to the erosion prevailing on this slope cause an average annual soil loss of 2.422 Mg ha^{-1} yr^{-1}.

The topographic factor *LS* depends on the length, shape and gradient of the slope, which results in the higher soil loss prediction on the longer slopes. Wischmeier and Smith [54] recognized the toeslope and depressions as a depositional area on the rectilinear slope and the local deposition was not taken into account. The complex slopes are divided into parts with a similar angle and the topographic factor *LS* is calculated for the whole slope as a weight average of *LS* factors for these parts of a slope. In Poland, the local deposition within the slope is observed. Szpikowski [48] observed the soil losses on the upper convex slope position and the soil accumulation occurring on the lower part of the slope. The studies of Rejman and Usowicz [39] revealed higher erosion rates from slopes of the length of 5 m than from longer slopes, what means that the soil material was transported with the runoff only on a short distance. In the case of rectilinear and long valley-sides of the Narew River valley, the methodology proposed by Wischmeier and Smith [54] was used.

Although farmers use rather fixed crop rotations, the weather and especially economic conditions can change the cropping system. Thus, for every study site the annual soil loss was calculated for four different, but most popular, crop rotations. The results revealed that crop rotations with corn and potatoes caused higher rates of erosion. On the most gentle slope, the annual soil erosion increases by 0.5 Mg ha^{-1} yr^{-1}, but on the steepest slope soil erosion rate increases by 2 Mg ha^{-1} yr^{-1}. The *C* factors calculated according to formula (5) are as follows:

– rye, oat, potatoes – 0.156;
– oat, beets, oat – 0.158;
– maize, oat, potatoes – 0.254;
– maize, triticale, potatoes – 0.262.

The *C* factors for the first two rotations are similar, because in both cases they consider cereals with rather small C_i factors. Higher *C* factors for the other two crop rotations are the result of introducing maize with much higher C_i factors (Table 6). It is also important to note that maize needs a long time period to develop sufficient cover (Table 7).

The soil losses from the study sites are rather small. As a threshold value, Wischmeier and Smith [54] proposed 12.5 Mg ha^{-1} yr^{-1}. Koreleski [27] suggests that measures against water erosion should be taken when erosion rate is larger than 5 Mg ha^{-1} yr^{-1}. Soil loss calculated with USLE model for watershed in the Gniezno Lake District was estimated as 0.7 Mg ha^{-1} yr^{-1} [43, 44] and it was two times higher than the results obtained during experimental studies. Consequently, the authors suggest that the USLE model can be used only for very rough estimations of soil losses and the study on model's parameters is needed. However, an earlier study conducted also in the Gniezno Lake District on the slope built up of light loam with bare soil tilled along the slope angle, estimated an erosion rate from 0.1 to 7.1 Mg ha^{-1} yr^{-1}, depending on the precipitation [47]. The soil losses calculated for the watershed of the Płonia River ranged from 0.081 to 0.125 Mg ha^{-1} yr^{-1} [25] and for the Trzebnickie Hills the erosion rate equal to 3–4 Mg ha^{-1} yr^{-1} was estimated [31]. It should be noted that the USLE model is primarily used for estimates of the average soil loss calculated for the individual slopes [14], and its use for the calculation of the catchment does not always produce good results [16].

TABLE 6. C_i FACTORS FOR CROP-GROWTH STAGES OF CROPS OCCURING IN THE STUDIED AREA

Crop-growth stages	Crop			
	cereals	potatoes	beets	maize
From inversion ploughing to seedbed	0.32	0.32	0.32	0.32
From seedbed to 10% crop cover	0.46	0.80	0.85	0.94
From 10% to 50% crop cover	0.38	0.40	0.45	0.45
From 50% to 75% crop cover	0.03	0.05	0.05	0.12
From 75% crop cover to harvest	0.01	0.08	0.03	0.09
From harvest to ploughing or other tillage preparing for sowing	0.02	0.44	0.44	0.44

Source: Banasik and Górski [4], Schwertmann [44].

TABLE 7. TIME OF SOWING OR PLANTING AND HARVESTING OF CROPS AND NUMBERS OF DAYS FOLLOWING SOWING OR PLANTING NEEDED TO DEVELOP THE CANOPY COVER

Crop	Time of		Numbers of days from sowing or planting needed to develop		
	sowing or planting	harvesting	10% canopy cover	50% canopy cover	75% canopy cover
rye	20.IX	10.VIII	34	180	191
oat	15.IV	15.VIII	27	36	43
triticale	27.IX	10.VIII	34	180	191
potatoes	5.V	10.X	42	55	62
beets	25.IV	20.X	50	60	75
maize	15.V	25.IX	39	59	73

Source: dates of sowing or planting and harvest from Koźmiński and Michalska [31], dates of 10%, 50% and 75% canopy cover from Klima et al. [23, 24], Gabriels et al. [11], Rejman and Brodowski [41].

The accelerated water erosion occurs not only on strongly susceptible soils [20, 32, 52] or on the steep slopes [24, 25, 26] but is also recorded in the areas where the slope gradient is relatively small [10, 15]. In the rolling landscapes, the change of land usage is the main factor causing water erosion. Clear-cutting of forests and the introduction of ploughing as one of the tillage operations in crop production initiated the denudation processes, which were the largest in the first years of tillage [50]. The relationship between the denudation rates and development of settlement was indicated, among others, by Starkel [41, 42] and Twardy [49]. In the Narew River valley, the oldest evidence of human activity was that left by nomadic hunter-gatherers on the dunes in the valley. Since Neolith (4500 BC), the crop cultivation and cattle breeding have been the main human activities with addition of gathering and hunting. In younger pre-Roman times (II century BC), the role of slash-and-burn agriculture decreased and set-aside cultivation was introduced along with the use of new tools, such as a lister. The settlement was located on the terraces located in the upper parts of the valley. In early Middle Ages, the settlement developed [8] and in III and IV century AC the Narew valley was an area of people relocation, next to the Vistula River valley and the Bug River valley [19]. The first tillage near the Tykocin located in the Narew River valley was introduced in III century AC. This assumption was based on the ^{14}C inventory of peat found under the colluvial deposits in the dry valley [7].

CONCLUSIONS

1. The soil loss from the arable land located on the Narew River valley-sides estimated using USLE in this study ranges from about 1 to 5 Mg ha^{-1} yr^{-1}.

2. The introduction of maize and potatoes to the crop rotation results in increasing of the erosion rates. On the most gentle slope, the annual soil erosion increases by 0.5 Mg ha^{-1} yr^{-1}, but on the steepest slope soil erosion rate increases by 2 Mg ha^{-1} yr^{-1}.

3. The exact soil loss quantification with USLE model needs a better estimation of rainfall and runoff factors, as well as the slope length and steepness factor.

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OCENA EROZJI WODNEJ NA ZBOCZACH DOLINY NARWI PRZY POMOCY UNIWERSALNEGO RÓWNANIA STRAT GLEBY[2]

W pracy przedstawiono wyniki oszacowania ilości gleby przemieszczonej na skutek erozji wodnej powierzchniowej w krajobrazie staroglacjalnym, na łagodnych zboczach doliny Narwi. Ilość przemieszczanych w wyniku tego procesu mas ziemnych obliczono wykorzystując uniwersalne równanie strat gleby (Universal Soil Loss Equation Ratio – USLE). Roczna ilość przemieszczanego materiału glebowego na każdej z 7 powierzchni badawczych waha się od ok. 1 do ponad 5 Mg z hektara w ciągu roku. Przyczynia się do tego zróżnicowanie średniego nachylenia zboczy sięgające od 1,8% do 7,5% i średniej długości zboczy wynoszącej od 172 m do 480 m, a także zróżnicowane uziarnienie gleb. Określono również wpływ zastosowania różnych płodozmianów na nasilenie natężenia procesów erozyjnych. Wprowadzenie do uprawy roślin okopowych i kukurydzy powoduje znaczne zwiększenie ilości wyerodowanej gleby, w przypadku zbocza o najmniejszym nachyleniu o ok. 0,5 Mg, przy największym – o ponad 2 Mg.