

## Surface and Subsurface Water Runoff and Selected Matter Components From the Forested Loess Slope

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### ABSTRACT

In the years 2008–2011, the study on the surface and subsurface water runoff from the forested loess slope was carried out to determine the concentrations of selected chemical indicators of water quality, soil suspension and loss of the pure matter component. The maximum tested concentrations of water quality indicators were low and amounted to: 1.841 mg·dm<sup>-3</sup> N-Nog, 0.943 mg·dm<sup>-3</sup> N-NH<sub>4</sub>, 0.478 mg·dm<sup>-3</sup> N-NO<sub>3</sub>, 0.213 mg·dm<sup>-3</sup> N-NO<sub>2</sub>, 0.423 mg·dm<sup>-3</sup> P, 1.621 mg·dm<sup>-3</sup> K. The masses of the eroded matter constituents were low and amounted to: 0.808 kg·ha<sup>-1</sup> N, 0.157 kg·ha<sup>-1</sup> P, 0.142 kg·ha<sup>-1</sup> K and 2.989 kg·ha<sup>-1</sup> soil. The parameters of erosive precipitation and water outflow were statistically significantly correlated with the concentration of soil suspended matter and losses of the analyzed components of matter, as well as negligible concentration of chemical indicators of water quality. Afforestation of the loess slopes threatened by erosion is a treatment that effectively protects the soil against water erosion.

**Keywords:** soil erosion, forest, surface and subsurface outflow, water quality, loess soil

### INTRODUCTION

The soils developed from loess belong to the most fertile soils in the world [Catt 2001], but they are highly susceptible to soil erosion [Józefaciuk, Józefaciuk 1999]. Water erosion is a destructive process. Currently, it is considered one of the major soil degradation factors in the world. As a result of its operation, nutrients for plants and humus are leached from the soil [Lal 2005, Mazur 2018, Olson 2007], the physicochemical properties of soils deteriorate [Hladký et al. 2016, Ijaz et al. 2006], which leads to a decrease in their fertility [Duan et al. 2011, Lobo et al. 2005] and in the obtained crop yields [Arriaga, Lowery 2003, Papiernik et al. 2005]. The plant nutrients and soil material eroded from the fields [Mazur 2018], contribute to water eutrophication [Dupas et al. 2015, Gabryszewska et al. 2016, Grzywna et al. 2015] and silting of technical infrastructure devices [Asiedu 2018].

For many years, interdisciplinary research on soil erosion has been carried out. However, the studies covering the quantitative and qualitative surface and subsurface water runoff in the zone of eroded slopes, especially on forested slopes, are still poorly recognized and significantly less ac-

centuated in the scientific literature [Mazur 2018, Świąchowicz 2012, Żmuda 2006]. It has long been believed that the forest provides best protection for the soil against water erosion [Tyszka 2008], which does not mean that there is no soil erosion at all [Robichaud et al. 2010]. Therefore, it is necessary to strive for a better identification of the functioning of fluvial transport on the erosion-threatened forested areas, in order to rationally manage soil resources, in accordance with the principle of sustainable development.

The paper presents the results of research from 2008–2011, carried out under the conditions of a forested loess slope in the Lublin Upland, regarding the quantity and quality of surface and subsurface water runoff as well as selected components of matter.

### MATERIAL AND METHODS

The research was carried out in the area of loess catchment with a periodic outflow of water in Wielkopole village, located in the eastern part of the Wyniosłość Giełczewska mesoregion (Lublin Upland) [Kondracki 2000]. The measure-

ments of surface and subsurface outflows were carried out on a forested slope of 0.5 ha, with an average slope of about 11% and an NE exhibition. The slope was overgrown by a 13-year-old young tress pine (*Pinus sylvestris* L.) planted in a 1.5 x 1.0 m rectangular spacing. The surface coverage was 100%. The brushwood was not found, but few herbaceous plants grew in the undergrowth.

At the beginning of April 2008, a catcher of the surface runoff and subsurface outflows was installed in the lower part of the slope. The volume of outflowing water was measured and samples were taken for a laboratory analysis to determine: suspension, total nitrogen, ammonium nitrogen, nitrate nitrogen and nitrite nitrogen as well as phosphorus and potassium.

In April 2008, a soil research was carried out. A description of the soil profile was made, the soil samples were taken from the distinguished diagnostic horizon and the following parameters were determined: granulometric composition, density of the solid phase of the soil and soil bulk density, total porosity and water permeability coefficient.

The atmospheric precipitation in the basin was measured using a daily recording pluviograph and the Hellmann rain gauge. The meteorological station was established within the catchment area, about 400 m from the site of research. On the basis of pluviographs, the unit kinetic energy of rainfall and the erosive indicator of rain and surface runoff were calculated –  $EI_{30}$  index.

On the basis of the obtained research results, the dependences pertaining to the quality indicators of outflowing waters and losses of matter

components on the parameters of precipitation and outflows were determined, based on the Pearson's linear  $r_{x,y}$  correlation index, at a significance level of  $\alpha = 0.05$ . A detailed description of the research methodology was given in the work of Mazur [2018].

## RESULTS AND DISCUSSION

On the basis of the stratification of the distinguished diagnostic horizons made in the soil outcrop, in this study area the soils developed from loess and are of the lessive type (Haplic Luvisols). These are medium-eroded soils with an O-A-B2t-BC-Cca. The dominant fraction in the granulometric composition was dust, constituting about 62% (Table 1). The alluvial parts (<0.02 mm) also constituted a high percentage (about 34%), and a thick dusty loam constituted the largest share of these.

The average specific soil density was  $2.6 \text{ Mg m}^{-3}$  and increased with depth (Table 2), as well as the bulk density, which ranged from 1.34 to  $1.48 \text{ Mg}\cdot\text{m}^{-3}$ . In contrast, the total porosity decreased with depth and fluctuated between 44.2 and 47.5%. The water permeability coefficient also decreased with depth. Its highest value ( $26.245\cdot 10^{-6} \text{ m}\cdot\text{s}^{-1}$ ) was recorded in the humus horizon.

The meteorological conditions have a very significant impact on the intensity of soil erosion [Żmuda 2006, Świąchowicz 2012]. Their characteristics during the research period are presented in the publication of Mazur [2018]. The study

**Table 1.** Soil granulometric composition

Horizon	Depth [cm]	Percent of fraction of diameter [mm]						Sum of floatable parts <0.02
		1 – 0.1	0.1 – 0.05	0.05 – 0.02	0.02 – 0.006	0.006 – 0.002	<0.002	
O	0-4	-	-	-	-	-	-	-
A	4-17	4.0	15.5	46.2	16.9	11.1	6.3	34.3
Bt2	17-48	3.7	15.7	46.8	16.2	10.2	7.4	33.8
BC	48-65	2.9	16.5	45.9	16.5	9.8	8.4	34.7
Cca	>65	3.3	15.5	47.6	17.6	8.8	7.2	33.6

**Table 2.** Selected physical properties of the studied soils

Horizon	Depth [cm]	Specific density [ $\text{Mg}\cdot\text{m}^{-3}$ ]	Bulk density [ $\text{Mg}\cdot\text{m}^{-3}$ ]	Total porosity [%]	Water permeability [ $\times 10^{-6} \text{ m}\cdot\text{s}^{-1}$ ]
A	4-17	2.55	1.34	47.5	26.245
Bt2	17-48	2.61	1.39	46.7	17.326
BC	48-65	2.62	1.42	45.8	14.547
Cca	>65	2.65	1.48	44.2	12.258

of surface runoff on a forested slope was carried out in 9 periods, while the subsurface outflow in 7 measurement periods. Rainfall heights then varied from 31.5 to 63.6 mm (Table 3). The calculated coefficient of variation was 24.21% (Table 4) – an average variation [Mucha 1994]. Out of all the recorded instances of erosive precipitation, they occurred most frequently in July (55.6%). In August, their incidence was 33.3%, and in June 11.1%.

The  $EI_{30}$  precipitation and surface runoff intensity index values ranged from 145.3 to 450.2  $MJ \cdot mm \cdot ha^{-1} \cdot h^{-1}$  (Table 4). The variation of the  $EI_{30}$  index amounted to 41.77% – high variation [Mucha 1994]. Dependence between the  $EI_{30}$  index and the total rainfall is shown in Figure 1. High precipitation erosion potential, expressed by the  $EI_{30}$  index, does not necessarily depend on the sum of the rainfall. The calculated value of the

correlation coefficient between the  $EI_{30}$  index and the sum of rainfall  $r = 80$ , indicates a very high correlation [Stanisz 1998]. The  $R^2$  determination index was 0.64. The high dependence ( $R^2 = 0.54$ ) between the  $EI_{30}$  index and the amount of precipitation was also confirmed by the results obtained by Rejman [2006]. The correlation coefficient between  $EI_{30}$  and the precipitation height calculated by Świąchowicz [2012] amounted to 0.51.

The variation of surface water runoff from the slope was 79.75%, indicating high variability [Mucha 1994]. The surface water runoff level on the slope was from 0.11 to 2.84 mm (Table 4), which constituted from 0.3 to 4.5% of the precipitation causing the erosive event. These are low rates in relation to the maximum surface outflows on arable lands, which can account for even more than 40% of precipitation causing the ero-

**Table 3.** Date of occurrence and amount of erosive precipitation: a – surface runoff, b – subsurface runoff

Month	2008		2009		2010		2011	
	Date	Rainfall [mm]	Date	Rainfall [mm]	Date	Rainfall [mm]	Date	Rainfall [mm]
Jun	-	-	25 (a, b)	50.8	-	-	-	-
Jul	7 (a)	31.5	-	-	24 (a, b)	59.8	3-4 (a, b) 5 (a, b) 20 (a)	63.5 57.2 32.1
Aug	-	-	-	-	6-7 (a) 9 (a, b) 30 (a, b)	44.2 63.6 41.5	-	-

**Table 4.** Indicators characterizing rainfall, surface and subsurface runoff: a – surface runoff, b – subsurface runoff

Indicator		Medium	Standard Deviation	Variation	Minimum	Maximum
Rainfall [mm]		49.4	11.9	24.21	31.5	63.6
Kinetic energy [ $J \cdot h^{-1}$ ]		491.7	153.4	31.19	245.3	699.3
Index $EI_{30}$ [ $MJ \cdot mm \cdot ha^{-1} \cdot h^{-1}$ ]		277.7	115.9	41.77	145.3	450.2
Outflow [mm]	a	1.27	1.01	79.75	0.11	2.84
	b	0.05	0.02	30.38	0.03	0.08
Soil suspension [ $g \cdot dm^{-3}$ ]	a	0.033	0.02	53.77	0.012	0.059
	b	0.018	0.01	30.39	0.011	0.025
N-Nog [ $mg \cdot dm^{-3}$ ]	a	1.139	0.22	19.15	0.895	1.464
	b	1.485	0.30	20.31	1.025	1.841
N-NH <sub>4</sub> [ $mg \cdot dm^{-3}$ ]	a	0.591	0.12	20.66	0.442	0.819
	b	0.795	0.15	20.35	0.548	0.943
N-NO <sub>3</sub> [ $mg \cdot dm^{-3}$ ]	a	0.301	0.07	22.53	0.218	0.386
	b	0.382	0.09	23.62	0.254	0.478
N-NO <sub>2</sub> [ $mg \cdot dm^{-3}$ ]	a	0.146	0.03	18.96	0.104	0.185
	b	0.178	0.03	18.92	0.162	0.213
P [ $mg \cdot dm^{-3}$ ]	a	0.257	0.05	19.72	0.194	0.379
	b	0.331	0.07	22.25	0.212	0.423
K [ $mg \cdot dm^{-3}$ ]	a	1.123	0.16	14.36	0.946	1.421
	b	1.335	0.18	13.12	1.311	1.621

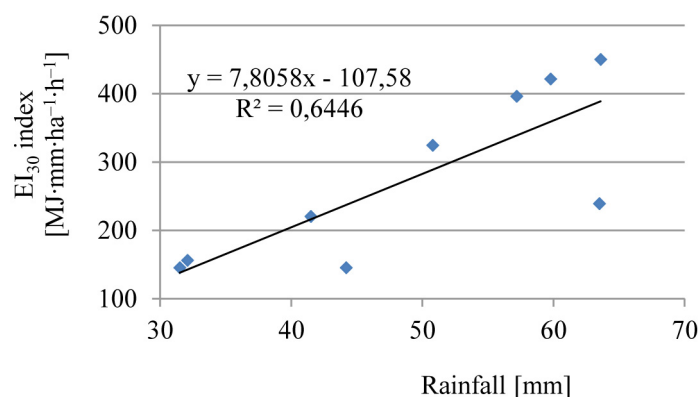


Fig. 1. Rainfall erosivity index  $EI_{30}$  in dependence on rainfall amount

sive event [Rejman 2006]. The subsurface runoff during the research period occurred only from the confined layer up to 0.25 m. Their variation amounted to 30.38% – average variability [Mucha 1994].

The subsurface water outflows ranged from 0.03 to 0.08 mm (Table 4), which accounted for 0.07 and 0.13%, respectively, of the precipitation causing the erosive event. In total, the largest outflows were recorded in 2010 (a wet year with precipitation of 867.7 mm). The surface runoff was then 5.74 mm, and the subsurface outflow was 0.17 mm, which accounted for 0.66% and 0.02%, of annual precipitation, respectively. Very low runoff rates are the result of the high retention capacity of forest ecosystems. According to a study conducted by Tyszka [2008], interception, retention of forest litter and a relatively high permeability of forest soils enable the retention of a large part of the precipitation and conversion of surface runoff into a vertical ground drain. Thus, the forest increases the resources of groundwater.

The concentration of the soil suspension contained in the surface runoff waters was characterized by high variability (53.77%) and ranged from 0.012 to 0.059 g·dm<sup>-3</sup>, and in the subsurface runoff waters 0.011-0.025 g·dm<sup>-3</sup> (Table 4). With respect to the concentrations of soil suspended in waters flowing from arable land reaching the maximum values of 170-240 g·dm<sup>-3</sup> [Mazur 2018, Źmuda 2006], they should be recognized as very low. The mass of the eroded soil on the slope during individual events was also very low, from 0.01 to 1.67 kg·ha<sup>-1</sup> during the surface runoff and 0.003 to 0.020 kg·ha<sup>-1</sup> during the subsurface outflow. In the field of sugar beet cultivation, the maximum surface soil wash during a single event was estimated by Źmuda [2006] at 60.132 Mg·ha<sup>-1</sup> and

Rejman [2006] at 20.640 Mg·ha<sup>-1</sup> (cultivation of root crops). The surface wash of the soil from the forested slope during the four years of research was 5.390 kg·ha<sup>-1</sup>. The largest amount of the eroded soil (54.8%) flowed in 2010 (2.953 kg·ha<sup>-1</sup>), and the lowest in 2008 (0.013 kg·ha<sup>-1</sup>) (Figure 2a). During the subsurface outflow, the mass of the eroded soil during the four-year study period was 0.066 kg·ha<sup>-1</sup>. The highest soil losses (0.036 kg·ha<sup>-1</sup>, which is 54.52% of the total eroded soil mass) were recorded in 2010, while the lowest (0.008 kg·ha<sup>-1</sup>) in 2009 (Figure 2b). In comparison with arable land, soil loss from the forested slope, should be considered as very low. According to the studies by Mazur [2018] and Rejman [2006], the annual soil losses on arable lands can even exceed 160 Mg·ha<sup>-1</sup>.

The chemistry of waters flowing from the slope was characterized by low diversity. This is evidenced by the calculated values of variation coefficients ranging from 19.15 to 23.62% (Table 4) – small variability [Mucha 1994]. The concentration of total nitrogen in the surface flowing waters ranged from 0.895 to 1.464 mg·dm<sup>-3</sup> N-Nog. On the other hand, the concentrations of other forms of nitrogen were at the level of: ammonium 0.442-0.819 mg·dm<sup>-3</sup> N-NH<sub>4</sub>, nitrate 0.28-0.386 mg·dm<sup>-3</sup> N-NO<sub>3</sub>, nitrite 0.104-0.185 mg·dm<sup>-3</sup> N-NO<sub>2</sub>. The concentration of phosphorus flowing away in the dissolved form was in the range of 0.194-0.379 mg·dm<sup>-3</sup> P, and potassium 0.946-1.421 mg·dm<sup>-3</sup> K. In the subsurface flowing waters, total nitrogen concentrations ranged from 1.025 to 1.841 mg·dm<sup>-3</sup> N-Nog. The concentrations of other forms of nitrogen were at the level of: ammonium 0.548-0.943 mg·dm<sup>-3</sup> N-NH<sub>4</sub>, nitrate 0.254-0.478 mg·dm<sup>-3</sup> N-NO<sub>3</sub>, nitrite 0.162-0.213 mg·dm<sup>-3</sup> N-NO<sub>2</sub>. The concentration of phosphorus was on the level of 0.212-0.423 mg·dm<sup>-3</sup> P, and potas-

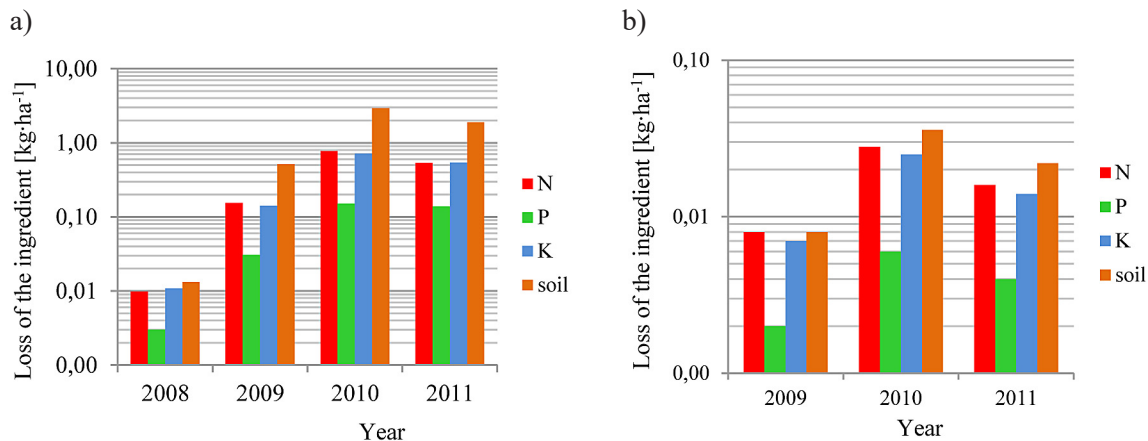


Fig. 2. Losses of N, P, K and soil as a result of surface (a) and subsurface (b) runoff from the slope

sium 1.311-1.621 mg·dm<sup>-3</sup> K. It is worth noting that only in the case of ammonium nitrogen and phosphorus, the maximum concentration exceeded the limit values for the I class of water purity established in the Regulation of the Minister of Environment of November 9, 2011 [Reg... 2011]. The maximum concentrations of the remaining water quality indicators tested were at a low level and did not exceed the limit values of indicators for the first class of water purity.

The average annual concentration of the tested water quality index was varied in individual years of research, both in the surface (Figure 3a) and in subsurface water runoff (Figure 3b). In the surface outflow, the difference between the minimum, maximum and average annual concentrations of the tested indicator was at the level of 14 to 308%. The least diverse (14-22%) was the average annual concentration of N-NO<sub>2</sub>, P and K. For N-Nog and N-NH<sub>4</sub>, the difference was 40 and 41%, respectively. However, for N-NO<sub>3</sub> it was 77%, and for soil suspension as much as 308%. A smaller variation in average annual concentrations occurred in the subsurface outflow waters (12-40%). For N-Nog, K and N-NO<sub>3</sub> the difference was from 12 to 14%. For the soil suspension, N-NH<sub>4</sub> and N-NO<sub>2</sub> it amounted to 19, 23, 25%, respectively. However, for P it was 40%.

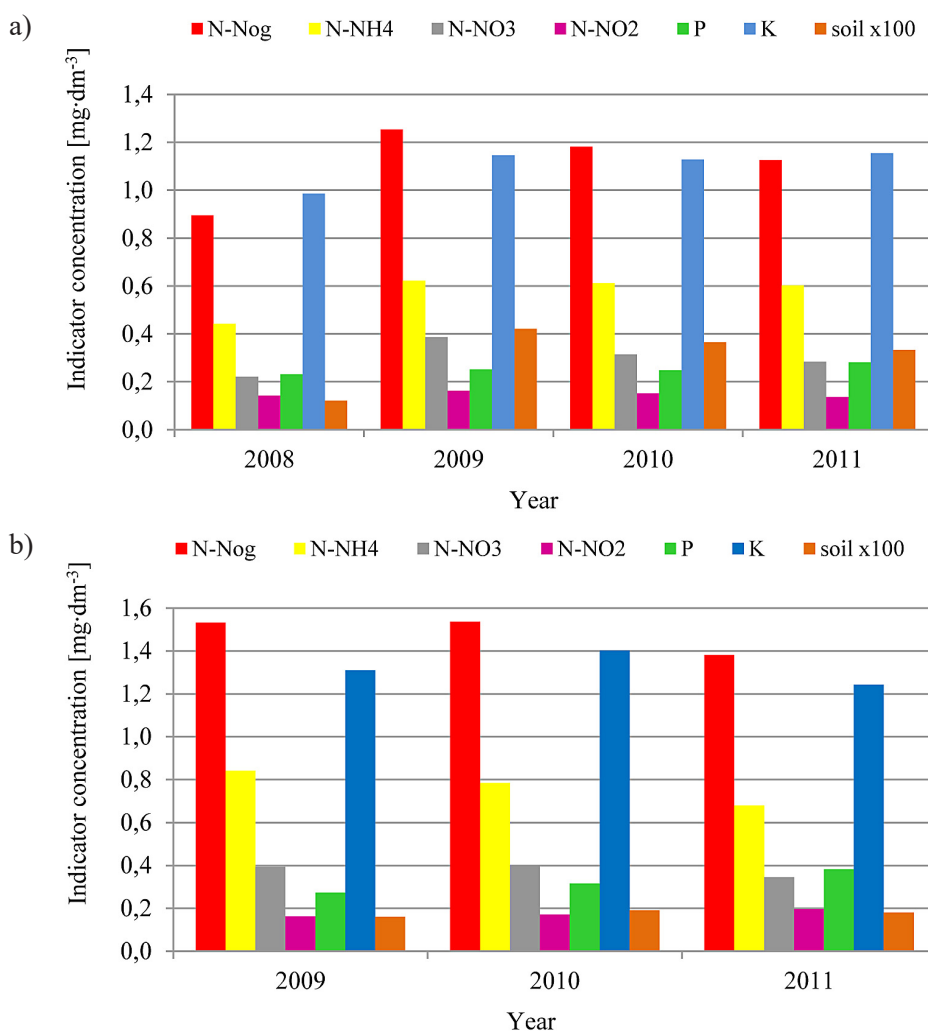
Together with water during surface runoff of waters, in a form dissolved from the forested slope, in the following year flowed: from 0.010 to 0.780 kg·ha<sup>-1</sup> N-Nog, 0.003-0.151 kg·ha<sup>-1</sup> P, 0.011-0.117 kg·ha<sup>-1</sup> K (Figure 2a). During the subsurface outflow of water, in the dissolved form, it flowed annually: from 0.008 to 0.028 kg·ha<sup>-1</sup> N-Nog, 0.002-0.006 kg·ha<sup>-1</sup> P, 0.007-0.025 kg·ha<sup>-1</sup> K (Figure 2b). These are low losses in relation to N, P, K losses occurring on agriculturally used

lands. Kim et al. [2018] determined that the nitrogen losses range from 5.63-13.97 kg·ha<sup>-1</sup>, and the phosphorus losses from 0.96-11.00 kg·ha<sup>-1</sup>. However, according to Mazur's research [2018], the annual nitrogen losses range from 5.762 to 23.448 kg·ha<sup>-1</sup>, phosphorus from 0.696 to 4.644 kg·ha<sup>-1</sup>, and potassium from 5.937 to 19.216 kg·ha<sup>-1</sup>.

The calculated low values of Pearson's correlation coefficients enable to conclude that the concentration of the tested chemical indicator of water quality cannot be inferred from the parameters of erosive rainfall (its height, kinetic energy and EI<sub>30</sub> index) or the size of water outflow. The analysis of the dependence, at the significance level of  $\alpha = 0.05$ , did not show any statistically significant correlations between the analyzed factors (Table 5), both for surface and subsurface flowing waters – correlations from faint to weak [Stanisz 1998]. The statistically significant dependencies were obtained between the precipitation parameters as well as the surface and subsurface outflows (correlations from high to almost certain [Stanisz 1998]). Additionally, the soil suspension concentrations, as well as soil losses, N, P and K were in most cases significantly statistically correlated with precipitation erosive rainfall and the size of the water outflow (correlations from high to almost certain [Stanisz 1998]).

## CONCLUSIONS

The research carried out on the forested loess slope, on the outflow of surface and subsurface water and selected components of matter, prove that this is an area threatened by erosion, and the flowing waters are laden with chemical and me-



**Fig. 3.** Average annual concentration of tested indicators of water quality in surface (a) and subsurface (b) runoff from forested slope

chanical pollution. This is the result of the denuding processes. However, the losses of N, P, K and soil are low in relation to the losses recorded on arable lands. The following conclusions can be drawn on the basis of the research:

The surface runoffs from the slopes were at a low level of 0.11 to 2.84 mm, representing 0.3 to 4.5% of the precipitation causing the erosive event. The subsurface outflows occurred only from the layer up to 0.25 m and ranged from 0.03 to 0.08 mm, which accounted for 0.07 and 0.13%, of erosive precipitation, respectively.

The maximum concentrations of ammonium nitrogen and phosphorus in the waters flowing from the slope exceeded the limit values for the class I water purity and were: 0.943 mg·dm<sup>-3</sup> N-NH<sub>4</sub>, 0.423 mg·dm<sup>-3</sup> P, respectively. In contrast, the maximum concentrations of the other quality indicators tested water (total nitrogen, ammonium and nitrite, potassium and slurry) were at a

low level and did not exceed the limit values for class I water purity.

The maximum annual losses of plant nutrients and soil were: 0.808 kg·ha<sup>-1</sup> N, 0.157 kg·ha<sup>-1</sup> P, 0.142 kg·ha<sup>-1</sup> K and 2.989 kg·ha<sup>-1</sup> soil.

There were no statistically significant relationships between the concentration of the tested chemical indicator of water quality and erosive precipitation and its parameters. water outflow, a concentration of soil suspension, soil losses and N, P, K were significantly correlated with erosive precipitation and its parameters. High correlation was also obtained between water outflow and soil suspension concentration as well as soil losses, N, P and K.

Afforestation of the loess slopes threatened by erosion is a treatment that effectively protects the soil against water erosion, as well as surface waters against eutrophication, due to the low level of leaching of biogenic elements.

**Table 5.** Correlation between the quality indicators of outflowing waters and losses of constituents of matter, precipitation parameters and outflow

Indicator		Rainfall [mm]	Kinetic energy [J·h <sup>-1</sup> ]	Index EI <sub>30</sub> [MJ·mm·ha <sup>-1</sup> ·h <sup>-1</sup> ]	Outflow [mm]
Outflow [mm]	a	0.898*	0.875*	0.948*	1
	b	0.678*	0.812*	0.951*	1
Soil suspension [g·dm <sup>-3</sup> ]	a	0.878*	0.913*	0.983*	0.972*
	b	0.535	0.739*	0.967*	0.981*
N-Nog [mg·dm <sup>-3</sup> ]	a	-0.148	-0.195	-0.254	-0.142
	b	-0.194	-0.243	-0.301	-0.199
N-NH <sub>4</sub> [mg·dm <sup>-3</sup> ]	a	-0.189	-0.252	-0.235	0.195
	b	-0.275	-0.297	-0.352	-0.295
N-NO <sub>3</sub> [mg·dm <sup>-3</sup> ]	a	-0.254	-0.289	-0.292	-0.164
	b	-0.312	-0.398	-0.324	-0.253
N-NO <sub>2</sub> [mg·dm <sup>-3</sup> ]	a	-0.325	-0.381	-0.415	-0.299
	b	-0.392	-0.465	-0.451	-0.354
P [mg·dm <sup>-3</sup> ]	a	-0.256	-0.251	-0.245	-0.189
	b	-0.323	-0.359	-0.321	-0.256
K [mg·dm <sup>-3</sup> ]	a	-0.199	-0.342	-0.235	-0.195
	b	-0.232	-0.389	-0.298	-0.248
Soil [kg·ha <sup>-1</sup> ]	a	0.835*	0.861*	0.955*	0.983*
	b	0.566	0.731*	0.942*	0.991*
N-Nog [kg·ha <sup>-1</sup> ]	a	0.864*	0.875*	0.964*	0.993*
	b	0.594	0.813*	0.974*	0.992*
P [kg·ha <sup>-1</sup> ]	a	0.803*	0.788*	0.907*	0.956*
	b	0.665	0.743*	0.790*	0.927*
K [kg·ha <sup>-1</sup> ]	a	0.841*	0.845*	0.945*	0.990*
	b	0.599	0.790*	0.954*	0.987*

Comments:

\* statistically significant.

a – surface runoff, b – subsurface runoff.

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## REFERENCES

- Arriaga F.J., Lowery B. 2003. Corn production on an eroded soil: effects of total rainfall and soil water storage. *Soil and Till. Res.*, 71, 87–93.
- Asiedu J.K. 2018. Assessing the Threat of Erosion to Nature-Based Interventions for Stormwater Management and Flood Control in the Greater Accra Metropolitan Area, Ghana. *Journal of Ecological Engineering*, 19(1), 1–13.
- Catt J.A. 2001. The agricultural importance of loess. *Earth-Sci. Reviews*, 54, 213–229.
- Duan X., Xie Y., Ou T., Lu H. 2011. Effects of soil erosion on long-term soil productivity in the black soil region of northeastern China. *Catena*, 87, 268–275.
- Dupas R., Delmas M., Dorioz J.M., Garnier J., Moatar F., Gascuel-Oudou C. 2015. Assessing the impact of agricultural pressures on N and P loads and eutrophication risk. *Ecol. Indic.*, 48, 396–407.
- Gabryszewska M., Kucharczak K., Maciaszek D., Gworek B., Kijewska M., Tokarz L. 2016. The computational models for determining predicted substance concentrations in surface waters. *Przem. Chem.*, 95/3, 609–612 (in Polish).
- Grzywna A., Tarkowska-Kukuryk M., Bochniak A., Marczuk A., Józwiakowski K., Marzec M., Mazur A., Obroślak R., Nieścioruk K., Zarajczyk J. 2015. Application of chemical and biological indicators for assessment of an ecological potential

- of artificial watercourses. *Przem. Chem.*, 94/11, 1954–1957 (in Polish).
8. Hladký J., Novotná J., Elbl J., Kynický J., Juříčka D., Novotná J., Brtnický M., 2016. Impacts of Water Erosion on Soil Physical Properties *Acta Univ. Agric. Silvic. Mendelianae Brun.*, 64, 1523–1527.
  9. Ijaz A., Khan F., Bhatti A.U. 2006. Some physico-chemical properties of soil as influenced by surface erosion under different cropping systems on upland-sloping soil. *Soil and Environ.*, 25(1), 28–34.
  10. Józefaciuk A., Józefaciuk Cz. 1999. Mechanism and methodical guidelines for the study of erosion processes. *PIOŚ, Bibl. Monit. Środ.* (in Polish).
  11. Kondracki J. 2000. Regional geography of Poland. *Wyd. Nauk. PWN* (in Polish).
  12. Kim K., Kim B., Eum J., Seo B., Christopher L., Shope C.L., Peiffer S. 2018. Impacts of land use change and summer monsoon on nutrients and sediment exports from an agricultural catchment. *Water*, 10, 544, doi:10.3390/w10050544.
  13. Lal R. 2005. Soil erosion and carbon dynamics. *Soil Till. Res.*, 81, 137–142.
  14. Lobo D., Lozano Z., Delgado F. 2005. Water erosion risk assessment and impact on productivity of a Venezuelan soil. *Catena*, 64, 297–306.
  15. Mazur A. 2018. Quantity and Quality of Surface and Subsurface Runoff from an Eroded Loess Slope Used for Agricultural Purposes. *Water*, 10, 1132, doi:10.3390/w10091132.
  16. Mucha J. 1994. Geostatistical methods in documenting deposits. *Skrypt Katedry Geologii Kopalnianej AGH* (in Polish).
  17. Olson K.R. 2007. Soil organic carbon storage in southern Illinois woodland and cropland. *Soil Sci.*, 172, 623–630.
  18. Papiernik S.K., Lindstrom M.J., Schumacher J.A., Farenhorst A., Stephens K.D., Schumacher T.E., Lobb D.A. 2005. Variation in soil properties and crop yield across an eroded prairie landscape. *J. Soil Water Conserv.*, 60, 388–395.
  19. Regulation of the Minister of Environment of November 9, 2011 on the method of classification of uniform state surface water bodies and environmental quality standards for priority substances. *Dz. U.* 2011. nr 257 poz. 1545 (in Polish).
  20. Rejman J. 2006. Effect of water and tillage erosion on transformation of soils and loess slopes. *Acta Agroph.*, 136 (in Polish).
  21. Robichaud P. R., Wagenbrenner J. W., Brown R. E. 2010. Rill erosion in natural and disturbed forests: 1. Measurements. *Water Resources Research*, 46, W10506.
  22. Stanisław A. 1998. An affordable statistics course. Vol. 1. *StatSoft Polska Sp. z o.o. Kraków* (in Polish).
  23. Święchowicz J. 2012. Rainfall thresholds for erosion processes in agricultural catchments. *Wyd. IGiP UJ, Kraków* (in Polish).
  24. Tyszka J. 2008. Hydrological functions of forests in small lowland catchments. *Prace IBL Rozprawy i Monografie*, 10 (in Polish).
  25. Żmuda R. 2006. Fluvial transport system functioning in small catchment threatened by soil water erosion. *Zesz. Nauk. AR we Wrocławiu*, 544 (in Polish).