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DISTRIBUTION OF ELEMENTS IN SOIL CATENAS DEVELOPED IN ICE-DAMMED LAKE AND IN MORAINIC LANDSCAPES IN NE POLAND*

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Abstract

The research was carried out on a soil catena sequence, in three sections of river valleys: the Liwna and Guber rivers flowing through landscapes shaped by ice-dammed lakes on Sępopol Lowland, and the Łyna river in the morainic landscape of Olsztyn Lakeland. Along transects, from the upland edge towards the river bed, soil exposures were made, soil samples were collected, and the soil reaction, cation exchange capacity, content of organic carbon and total content of Ca, Fe, Mg, K, P, Na, Mn, Zn and Cu were analyzed.

The soils of the landscape of ice-dammed lake origin contained more elements than the ones in the morainic landscape. In the catena, the highest cation exchange capacity and the highest content of macro- and microelements were determined in Histosols and Fluvisols. Among the studied Fluvisols, the highest content of Ca (19.5 g kg^{-1}), Mg (12.60 g kg^{-1}), Fe (41.92 g kg^{-1}), Mn (691.38 mg kg^{-1}) was found in the soils of the Guber catena, and the highest content of K (13.00 g kg^{-1}), Na (0.60 g kg^{-1}), P (3.20 g kg^{-1}), Cu (55.90 mg kg^{-1}), Zn (271.46 mg kg^{-1}) was in the soils of the Liwna catena. The amounts of the elements (except Fe and Mn) were statistically positively significantly correlated with the amount of organic carbon as well as the silt fraction 0.05-0.002 mm (all elements) and clay fraction <0.002 mm (Ca, K, Na, Fe, Mn).

Fluvisols and Histosols in river valleys, owing to their high accumulation capacity, play a very important role in the circulation of elements and strengthen the resistance of landscapes of ice-dammed lake origin and morainic hills to human activity.

Key words: young glacial landscape, alluvial soils, deluvial soils, macro-and microelements.

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INTRODUCTION

The content of elements in soils depends on lithological (type of parent material and soil texture), pedological (soil-forming processes) and anthropogenic factors. In the diversified relief of north-eastern Poland, processes of soil material translocation down the slope and accumulation at the bottom are common (processes of anthropogenic denudation). These processes lead to the formation of specific toposequences and affect the circulation and distribution of soil macro- and microelements in pedons (Kruk 2000, Sowiński et al. 2004*b*, Smólczyński, Orzechowski 2010*a*,*b*).

The research carried out in young glacial landscapes, both morainic and of ice-dammed lake origin, proved that mid-moraine soils accumulate elements above natural levels (Smólczyński et al. 2004, Sowiński et al. 2004*a*). Soils in land depressions and river valleys were formed from the youngest, Holocene deluvial and alluvial deposits. Among the examined Holocene sediments, alluvial deposits in riverine and delta landscapes (having the lowest location in the catena) contained more macro- and microelemenrs than deluvial deposits in morainic landscape (Orzechowski, Smólczyński 2010).

Studies of alluvial and deluvial soils in young landscapes should be focused on many issues, including their chemical characteristics, as there are still insufficient data concerning these soils (Kalisz, Lachacz 2009, Kobierski Dąbkowska-Naskręt 2012, Świtoniak 2014).

The aim of this study has been to determine the total content of elements in soils and their distribution in the soil profiles and soil catenas based on three cross-sections of river valleys and surrounding uplands, in a young glacial landscape of ice-dammed lake origin and in a morainic landscape.

MATERIAL AND METHODS

The research was carried out in the Łyna river valley (54°01′14.9″ N, 20°24′14.3″ E), in a section which represents the basin of materials of ice dammed lake origin, in the morainic landscape of Olsztyn Lakeland as well as in the valleys of the Guber (54°10′36.0″ N, 21°14′43.3″ E) and Liwna (54°15′06.0″ N, 21°14′03.7″ E) rivers, in the landscape shaped by of ice-dammed lakes situated on Sępopol Lowland. Transects were made from the top of the upland towards the river bed. The description of the sites was presented previosuly (Orzechowski 2009, Smólczyński 2009).

Along the transects, the drillings and soil exposures were made and soil samples were collected. The following parameters were analyzed: soil texture, loss-on-ignition (LOI) after dry ashing of soil samples during 6 hours at the temperature of 550°C (for organic horizons), total organic carbon (OC) after oxidation with potassium dichromate (for other horizons than organic

Table 1

Physical and chemical properties of soils in the Guber catena

Location	Horizon	Depth (cm)	% of fraction of diameter (mm)				Texture class	CEC	BS (%)	pH	
			> 2,0	2.0-0.05	0.05-0.002	<0.002		(mmol(+) kg^{-1})		H_2O	KCl
1, Gleyic Phaeozem*											
Top of the slope	Ap*	0-28	1	47	39	14	L	278.6	91.7	6.1	5.4
	A2	28-38	1	46	40	14	L	260.3	92.7	6.1	5.5
	Ckg	38-103	0	30	32	38	CL	258.9	95.0	7.4	6.4
	Ckg	< 103	0	17	47	36	CL	307.4	98.5	7.8	6.7
2. Mollic Gleysol (Colluvic)											
Lower part of the slope	Ap	0-30	1	45	36	19	L	270.7	94.4	6.8	6.0
	A2	30-55	1	44	34	22	L	240.2	95.0	6.6	5.9
	A2	55-83	0	37	35	28	CL	372.6	97.3	7.0	6.1
	Cg	< 83	0	13	22	65	HC	411.5	99.0	7.9	6.8
3. Mollic Gleysol (Colluvic)											
Bottom of the slope	Ap	0-27	1	50	36	14	L	325.2	97.3	7.1	6.5
	A2	27-55	1	51	29	20	L	207.0	97.3	7.5	6.5
	A3	55-99	1	39	40	21	L	296.1	97.3	7.6	6.4
	Cg	< 99	0	18	51	31	CL	486.7	96.2	7.3	6.3
4. Mollic FluvisolEutric											
River valley	A	0-22	0	24	55	21	SiL	390.3	97.8	7.5	6.7
	A2	22-43	0	11	43	46	SiC	459.8	98.7	7.6	6.8
	Ag3	43-80	0	9	39	52	C	502.5	98.8	7.7	6.7
	Ag4	< 80	0	11	39	50	C	480.5	98.9	7.9	6.9
5. Mollic Fluvisol Eutric											
River valley	A	0-26	0	19	51	30	SiCL	687.6	99.0	7.7	6.8
	A2	26-48	0	16	47	37	SiCL	580.6	99.1	7.8	6.6
	Ag3	48-88	0	11	41	48	SiC	680.2	98.5	7.5	6.5
	Ag4	< 88	0	10	47	43	SiC	685.0	98.7	7.6	6.3

* according to WRB (IUSS WORKING GROUP WRB 2006), L – loam, CL – clay loam, HC – heavy clay, SiL – silt loam, SiC – silty loam, SiCL – silty clay loam

Table 2

Physical and chemical properties of soils in the Liwna catena

Location	Horizon	Depth (cm)	% of fraction of diameter (mm)				Texture class	CEC	BS (%)	pH	
			>2.0	2.0-0.05	0.05-0.002	<0.002		(mmol(+) kg^{-1})		H_2O	KCl
1. Vertic Luvisol											
Top of the slope	Ap	0-28	2	65	19	16	SL	129.0	77.7	5.8	5.3
	Bti	28-60	0	7	29	64	HC	274.2	92.6	6.6	5.9
	Ci	< 60	0	12	27	61	HC	326.3	96.0	6.8	6.1
2. Vertic Luvisol											
Top of the slope	Ap	0-24	0	64	26	10	SL	137.71	99.6	6.2	5.6
	Bti	24-70	0	12	20	68	HC	268.82	94.05	6.8	5.7
	Ci	70-150	0	5	24	71	HC	303.55	95.45	6.9	6.0
3. Mollic Gleysol (Colluvic)											
Bottom of the slope	Ap	0-26	1	78	20	2	LS	181.1	80.8	5.7	5.1
	A2	26-45	1	80	15	5	LS	127.2	82.3	6.4	5.9
	A3	45-65	1	84	8	8	LS	87.2	85.2	6.5	5.9
	Cg	< 65	0	29	50	21	L	155.9	91.9	6.5	6.0
4. Mollic Fluvisol											
River valley	A	0-25	0	43	48	9	L	495.4	91.4	5.3	4.9
	A2	25-78	0	23	47	30	CL	211.7	92.1	6.9	6.1
	Lc	78-105	-	-	-	-	gyttja	812.0	94.1	6.5	5.9
	Oa	< 105	-	-	-	-	fen peat	996.0	86.8	6.1	5.8
5. Mollic Fluvisol											
River valley	A	0-25	0	47	44	9	L	738.7	92.1	6.3	5.8
	A2	25-60	0	36	40	24	L	727.9	92.6	6.5	5.9
	A3	60-110	0	10	49	41	SiC	611.7	93.7	6.3	5.6
	Oa	< 110	-	-	-	-	fen peat	975.0	84.4	6.0	5.5

Table 3

Physical and chemical properties of soils in Łyna catena

Location	Horizon	Depth (cm)	% of fraction of diameter (mm)				Texture class	CEC (mmol(+) kg^{-1})	BS (%)	pH	
			> 2,0	2.0-0.05	0.05-.002	<0.002				H_2O	KCl
1. Haplic Arenosol											
Top of the slope	Ap	0-30	1	84	14	2	LS	55.3	62.6	5.9	5.0
	C	30-150	8	96	2	2	S	13.6	45.6	5.8	5.0
2. Mollic Gleysol (Colluvic)											
Bottom of the slope	Ap	0-28	6	82	16	2	LS	94.5	86.5	6.1	5.4
	A2	28-46	9	81	16	3	LS	108.3	79.1	6.2	5.4
	A3	46-102	2	90	9	1	S	426.7	90.9	6.5	5.6
	C	102-150	14	91	5	4	S	47.6	90.5	6.8	6.1
3. Sapric Histosol (Drainic)											
River valley	M	0-15	-	-	-	-	morsh	969.2	70.1	6.6	6.0
	M	15-33	-	-	-	-	morsh	1081.0	77.5	6.4	5.9
	Oa	33-65	-	-	-	-	fen peat	1504.5	80.9	6.3	5.8
	Oe	< 65	-	-	-	-	fen peat	1468.5	80.8	6.2	5.6
4. Sapric Histosol (Novic)											
River valley	AO	0-15	-	-	-	-	alluvium	552.7	69.9	6.5	5.7
	AO	15-30	-	-	-	-	alluvium	686.6	75.6	6.7	5.8
	Oa	30-60	-	-	-	-	fen peat	1420.0	81.1	6.6	5.9
	Oe	< 60	-	-	-	-	fen peat	1394.0	82.0	6.4	5.6
5. Mollic Fluvisol Eutric											
River valley	A	0-23	0	20	71	9	SiL	442.7	94.9	6.6	5.5
	A2	23-40	0	21	68	11	SiL	419.3	95.3	6.8	5.6
	A3	40-58	0	11	64	25	SiL	503.2	96.5	7.0	6.3
	Ag4	58-72	0	6	74	20	SiL	330.5	96.1	6.7	6.0
6. Mollic Fluvisol Eutric											
River valley	A	0-18	0	24	68	8	SiL	408.6	94.9	6.7	5.7
	A2	18-43	0	22	67	11	SiL	398.2	97.6	7.1	6.1
	A3	43-70	0	24	62	14	SiL	321.5	96.4	7.1	6.2
	Ag4	70-112	0	13	61	26	SiL	427.8	97.2	7.3	6.3
	Ag5	< 112	0	10	60	30	SiCL	315.0	95.7	7.2	6.3

Table 4

Mean content of mineral fractions as well as macro- and microelements in soil humus horizons in the Guber catena

Genetic horizon	Feature	2.0-0.05	0.05-.002	<0.002	C	N	Ca	Mg	K	Na	P	Fe	Cu	Zn	Mn
		(%)			(g kg^{-1})								(mg kg^{-1})		
A	X	46.5	39.5	14.0	18.30	0.24	6.40	4.80	5.60	0.30	1.10	19.00	12.95	48.65	446.0
	SD	0.71	0.71	0,001	1.27	0.03	0.50	0.01	0.001	0.01	0.42	0.25	0.49	0.49	38.00
	CV	1.53	1.90	0.001	6.94	12.50	7.81	0.21	0.001	3.33	38.19	1.34	3.78	1.01	8.52
B	X	44.1	36.3	19.6	14.60	1.90	7.20	5.20	5.80	0.20	0.80	18.32	12.68	45.20	431.70
	SD	5.72	3.68	4.19	7.05	0.82	1.84	0.61	0.88	0.05	0.25	2.21	1.63	9.29	44.56
	CV	12.97	10.14	21.38	48.29	43.16	25.56	11.73	15.17	25.00	31.25	12.06	12.85	20.55	10.32
C	X	13.9	45.3	40.9	25.61	3.30	19.50	12.60	9.80	0.40	1.12	41.92	24.91	114.31	691.38
	SD	5.30	5.80	10.80	18.16	2.19	2.88	1.23	1.30	0.06	0.20	6.51	3.18	12.02	267.19
	CV	38.13	12.80	26.41	70.91	66.36	14.77	9.76	13.27	15.00	17,86	15.53	12.77	10.52	38.65
Statistically significant differences $\alpha = 0.05$		A>C B>C	B<C	A<C B<C			A<C B<C	A<C B<C	A<C B<C	A<C B<C	B<C	A<C B<C	A<C B<C	A<C B<C	B<C

A – humus horizon of Phaeozems, B – humus horizon of Gleysols, C – humus horizon of Fluvisols, X – mean, SD – standard deviation, CV – coefficient of variation ones), total nitrogen (TN) by the Kjeldahl method, soil reaction – potentiometrically in H_2O and 1 M KCl dm^{-3}, exchangeable base cations (Ca^{+2}, Mg^{+2}, K^+, Na^+) and exchangeable hydrogen in an extract of 1M ammonium acetate. Ca and Mg were analyzed with the AAS method on a SOLAAR 969 Pye Unicam; K and Na were analysed using the AES method on a FLAPHO 4. The cation exchange capacity (CEC) and base saturation (BS) were calculated.

The total content of Ca, Mg, K, P, Na, Fe, Mn, Zn and Cu was measured after digestion in a mixture of $HClO_4$ and HNO_3 (van Reeuwijk 2002). Ca, K and Na were determined using a Jenway flame photometer; P was assessed with the vanadium-molybdenum method (Pansu, Gautheyrou 2006) on a Specol EK 1 spectrocolorimeter and Mg was determined with an AAS 1 Zeiss Jena analyzer. The total content of Fe, Mn, Zn and Cu was measured applying AAS techniques on a 30 Zeiss Jena analyser.

In order to show the distribution of elements in a soil profile, the ratio of the content of these elements in the surface layer to the content in the underlying layer as well as the ratio of the content of these elements in the surface layer to the content in the soil parent material at the top of the valley were calculated.

Statistical calculations (mean, correlation coefficients, standard deviation (SD), coefficient of variation (CV) were conducted using Statistica 8.0.

In tables, the symbols of soil horizons were given according to the Polish Soil Classification system (2011) and the types of soils were given according to the *World Reference Base for Soil Resources* (2006).

RESULTS AND DISCUSSION

The soil reaction ranged from slightly acid to neutral. The highest values of pH (in H_2O and KCl) among the studied catenas were noted in the soils of the Guber catena (Table 1). However, in the toposequences of the analyzed valleys, the highest pH was found in Fluvisols located closest to the river bed (Tables 1, 2, 3).

The highest CEC was found in Histosols in the Łyna river valley (Table 3). The CEC of Fluvisols was 2- to 3-fold higher than Gleysols (Tables 1, 2, 3). The soils in the Guber river valley had the highest BS (Table 1). The lowest base saturation occurred in soils at the top of the slopes, and the highest one was in Fluvisols (Tables 1, 2, 3). With respect to the BS, Fluvisols had the highest degree (10) of resistance to degradation.

In the analyzed catenas, Fluvisols contained more clay fraction (< 0.002 mm) than Gleysols and the soils in the uplands. The highest amounts of clay fraction were in Fluvisols in the Guber catena (mean 40.9%) and these amounts were statistically significantly different than in Gleysols (mean 19.6%) or Phaeozems (mean 14.0) – Table 4.

Table 5

Mean content of mineral fractions as well as macro- and microelements in soil humus horizons in the Łyna catena

Soil	Feature	2.0-0.05	0.05-0.002	<0.002	C	N	Ca	Mg	K	Na	P	Fe	Cu	Zn	Mn
		(%)			(g kg^{-1})								(mg kg^{-1})		
Ap		84	14	2	9.20	1.05	0.78	0.70	1.00	0.16	0.52	5.72	3.80	20,80	22.50
A	X	84.3	13.7	2.0	34.73	4.45	5.87	0.77	1.43	0.14	0.57	5.78	13.37	21.50	111.00
	SD	4.93	4.04	1.00	18,67	2.62	5.14	0.06	0.23	0.02	0.29	1.54	8.27	11.62	11.62
	CV	5.65	29.45	50.00	53.76	57.78	87.56	7.79	16.08	14.29	50.88	26.64	61.85	54.05	10.47
B	X				28.01*	11.10	25.40	3.40	3.80	0.40	1.70	17.16	15.40	43.90	263.10
	SD				14.42	0.51	10.59	1.37	1.16	0.09	0.71	4.83	3.79	24.24	105.76
	CV				51.48	4.59	41.69	40.29	30.53	22.50	41.76	28.15	24.61	55.22	40.20
C	X	16.8	66.1	17.1	20.88	2.30	15.00	4.90	6.20	0.40	1.10	30.13	12.18	61.18	683.89
	SD	6.80	4.73	8.28	8.37	1.15	3.81	1.15	2.04	0.07	0.36	7.30	1.11	14.60	321.56
	CV	40.48	7.16	48.42	40.09	50.00	25.40	23.47	32.90	17.50	32.73	24.23	9.11	23.86	47.02
Statistically significant differences $a = 0.05$		A>C	A<C	A<C			A<B A<C B>C	A<B A<C B<C	A<B A<C B<C	A<B A<C	A<B A<C B>C	A<B A<C B<C	B>C	A<C	A<C B<C

Ap – humus horizon of Arenosols, A – humus horizon of Gleysols, B – organic horizon , C – humus horizon of Fluvisols, * loss-on-ignition (LOI)

Table 6

Mean content of mineral fractions as well as macro- and microelements in soil humus horizons in the Liwna catena

Genetic horizon	Feature	2.0-0.05	0.05-.002	<0.002	C	N	Ca	Mg	K	Na	P	Fe	Cu	Zn	Mn
		(%)			(g kg^{-1})								(mg kg^{-1})		
A	X SD CV	61.5 4.95 8.05	21.5 3.54 16.47	13.0 4.24 32.62	5.86 0.93 15.87	0.09 0.02 22.22	3.10 0.42 13.55	3.60 0.35 9.72	1.15 0.07 0.64	0.20 0.001 0,05	1.50 0.21 14.00	13.20 0.64 4.85	26.00 0.85 3.27	121.10 9.90 8.18	417.60 46.17 11.06
B	X SD CV	80.6 3.06 3.80	14.3 6.03 42.17	5.0 3.00 60.00	13.73 9.53 69.41	1.33 1.26 94.74	3.57 1.15 32.21	1.67 0.42 25.15	4.17 1.80 43.17	0.17 0.06 35.29	0.97 0.45 46.39	8.93 1.79 20.04	25.57 3.01 11.77	75.77 27.82 36.72	200.50 95.93 47.85
C	X SD CV	31.8 15.22 47.86	45.6 3.65 8.00	22.6 13.83 61.19	44.70 20.56 45.99	4.90 3.04 62.04	17.00 5.09 29.94	11.50 2.07 18.00	13.00 4.36 33.54	0.60 0.18 30.00	3.20 0.66 20.63	34.86 5.32 15.26	55.90 14.49 25.92	271.46 27.93 10.29	427.46 163.29 38.20
Statistically significant differences $a = 0.05$		A>C A<B B>C	A<C B<C				A<C B<C	A<C A>B B<C	A<C B<C	A<C B<C	A<C B<C	B<C	A<C B<C	A<C B<C	

A – humus horizon of Luvisols, B – humus horizon of Gleysols, C – humus horizon of Fluvisols

Table 7

Significance of differences of mean properties of Fluvisols and Gleysols between the catenas

Soil	Feature	2.0-0.05	0.05-0.002	<0.002	C	N	Ca	Mg	K	Na	P	Fe	Cu	Zn	Mn
					(g kg-1)								(mg kg-1)		
Gleysols	A B C	A<B A<C	A>B A>C	A>B A>C	A<C	A<C	A>B	A>B A>C	A>B A>C			A>B A>C	A<B	A<B B>C A>C	A>B A>C
Fluvisols	A B C	B>C	A<C B<C	A>C	B>C	B>C	A>C	A>C B>C	A>C B>C	A<B B>C	A<B B>C	A>C	A<B A>C B>C	A>C B>C	

A – Guber catena, B – Liwna catena, C – Łyna catena

Table 8

Correlation coefficients between the content of organic matter, mineral particles and total amounts of elements in the soils

Properties	Ca	Mg	K	Na	P	Fe	Mn	Zn	Cu
	($g\ kg^{-1}$)						($mg\ kg^{-1}$)		
< 0.002 mm	0.624*	0.234	0.438*	0.535*	0.072	0.491*	0.556*	0.077	-0.034
0.05-0.002 mm	0.373*	0.833*	0.440*	0.405*	0.346*	0.734*	0.336*	0.484*	0.443*
Corg	0.963*	0.488*	0.417*	0.532*	0.550*	0.282	-0.019	0.522*	0.629*

* significance level at $\alpha = 0.05$

The highest mean amounts of OC and TN, excluding Histosols, were determined in humus horizons of Fluvisols in the Liwna catena (44.7 $g\ kg^{-1}$ and 4.9 $g\ kg^{-1}$). The amounts of OC and TN in Fluvisols in the Guber catena were higher than in Gleysols. In the Łyna catena, these amounts were lower in alluvial soils than in deluvial soils (Table 5).

In the pedons of the three catenas, Fe and Ca predominated. The mean amounts of the other analyzed elements in Phaeozems, Histosols, Gleysols and Fluvisols can be ordered as follows: K>Mg>P>Na>Mn>Zn>Cu. An exception was found in the Guber river valley, where Fluvisols contained more Mg than K (Table 4).

In the catena sequence, the highest mean amount of the analyzed elements was detected in Fluvisols. Only Histosols in the Łyna river valley contained more Ca, P and Cu than Fluvisols (Tables 4, 5, 6). Among the Fluvisols, the highest amounts of Ca, Mg, Fe and Mn were in the soils of the Guber catena, the highest amounts of K, Na, P, Cu and Zn were in the soils of the Liwna catena (Table 4, 6). In Gleysols of the Guber and Liwna catenas, the content of the elements was statistically significantly lower than in Fluvisols. Gleysols in these catenas contained less Fe, P, Na, Mn, Zn and Cu than the soils located higher in the valley (Phaeozems and Luvisols).

Arenosols contained the smallest amounts of the elements. Among Fluvisols and Gleysols, the lowest amounts of elements (except Na and Mn in Fluvisols and Ca, Na , Mn in Gleysols) were determined in the Łyna river valley. The differences between the amounts of Mg, K, Fe, Zn and Mn in Gleysols of the Łyna and Guber catenas were statistically significant. In Fluvisols of these catenas, the differences between the amounts of Ca, Mg, K, Fe, Cu and Zn were also statistically significant (Table 7).

The content of all the elements, except Fe and Mn, was statistically positively significantly correlated with the amount of OC. All the elements were positively correlated with the amount of the 0.5-0.002 mm fraction, and the amounts of Ca, K, Na, Fe and Mn were positively correlated with the amount of the <0.002 mm fraction (Table 8).

The content of macro-and microelements in Gleysols (the Guber and Liwna catenas) in the young glacial landscape of ice-dammed lake origin was similar to their content in analogous soils of glaciolimnic plains in NE

Table 9

Enrichment or impoverishment coefficients of total amounts of elements in surface horizons in relation to underlying horizon* and to the parent material**of Luvisols in the Liwna catena

Profile No and location	Ca	Mg	K	Na	P	Fe	Cu	Mn	Zn
	Vertic Luvisol								
1. Top of the slope	*0.42^{---} **0.30^{---}	0.27^{---} 0.23^{---}	0.27^{---} 0.20^{---}	0.67^{--} 0.40^{---}	0.38^{---} 0.35^{---}	0.34^{---} 0.29^{---}	0.48^{---} 0.42^{---}	0.75^{-} 0.92	0.45^{---} 0.41^{---}
	Vertic Luvisol								
2 Top of the slope	*0.51^{--} **0.36^{---}	0.21^{---} 0.20^{---}	0.19^{---} 0.19^{---}	0.67^{--} 0.40^{---}	0.48^{---} 0.43^{---}	0.28^{---} 0.27^{---}	0.54^{--} 0.44^{---}	1.32^{+} 0.79^{-}	0.53^{--} 0.46^{---}
	Mollic Gleysol (Colluvic)								
3. Lower part of the slope	*1.31^{+} **0.50^{--}	1.66^{+} 0.12^{---}	1.87^{+} 0.80	2.00^{+} 0.40^{---}	1.40^{+} 0.38^{---}	1.41^{+} 0.23^{---}	1.24^{+} 0.48^{---}	2.38^{++} 0.63^{--}	1.86^{+} 0.29^{---}
	Mollic Gleysol (Colluvic)								
4. Bottom of the slope	*1.83^{+} **1.69^{+}	1.21^{+} 0.64^{--}	1.41^{+} 2.06^{++}	1.25^{+} 1.00	1.68^{+} 1.14	1.53^{+} 0.85^{-}	1.65^{+} 0.95	1.68^{+} 1.12	1.19 0.99
	Mollic Fluvisol								
5. River valley	*1.83^{+} **1.69^{+}	1.21^{+} 0.64^{--}	1.41^{+} 2.06^{++}	1.25^{+} 1.00	1.68^{+} 1.14	1.53^{+} 0.85	1.65^{+} 0.95	1.68^{+} 1.12	1.19 0.99
	Mollic Fluvisol								
6. River valley	*0.95 **2.16^{++}	0.83^{-} 0.67^{--}	0.70^{--} 2.06^{++}	0.88 1.4^{+}	1.03 0.89	1.06 0.81	1.07 1.19	1.99^{+} 1.33^{+}	1.05 1.07

Key:1.20-2.00 – evident enrichment (+); 2.01-5.00 – strong enrichment (++); > 5.00 very strong enrichment (+++); 0.85-0.71 – evident impoverishment (-); 0.70-0.51 – strong impoverishment (--); <0.50 very strong impoverishment (---).

Table 10

Enrichment or impoverishment coefficients of total amounts of elements in surface horizons in relation to underlying horizon* and to the parent material** of Phaeozems in the Guber catena

Profile No and location	Ca	Mg	K	Na	P	Fe	Cu	Mn	Zn
	Gleyic Phaeozem								
1. Top of the slope	*1.11 **0.63^{--}	0,98 0.37^{---}	1.00 0.60^{--}	1.50^{+} 0.60^{--}	1.75^{+} 2.33	1.00 0.58^{--}	0.94 0.62^{--}	1.12 0.90	0.97 0.67^{--}
	Mollic Gleysol (Colluvic)								
2. Lower part of the slope	*0.97 **0.54^{--}	1.11 0.44^{---}	1.06 0.75^{-}	1.00 0.40^{---}	1.00 1.33^{+}	1.08 0.61^{--}	0.62^{--} 1.09	0.91 0.76^{-}	1.38^{+} 0.75^{-}
	Mollic Gleysol (Colluvic)								
3. Lower part of the slope	*0.94 **0.48^{---}	1.00 0.38^{---}	1.09 0.53^{--}	1.00 0.40^{---}	2.33^{++} 2.33^{++}	0.98 0.50^{--}	0.98 0.56^{--}	0.91 0.79^{-}	1.12 0.66^{--}
	Mollic Gleysol (Colluvic)								
4. Bottom of the slope	*1.36^{+} **0.92	1.38^{+} 0.46^{---}	1.13 0.65^{--}	2.00^{+} 0.40^{---}	1.33^{+} $1,33^{+}$	1.34^{+} 0.60^{--}	1.52^{+} 0.76^{-}	1.05 0.76^{-}	1.98^{+} 0.87
	Mollic Fluvisol								
5. River valley	*0.91 **1.42^{+}	1.01 1.09	1.12 1.18	0.60^{--} 0.60^{--}	1.40^{+} 2.33^{++}	0.96 1.06	1.04 1.42^{+}	1.17 1.35^{+}	1.06 1.90^{+}
	Mollic Fluvisol								
6. River valley	*1.18 **2.19^{++}	1.19 1.05	1.33^{+} 1.00	1.00 0.88	1.20^{+} 2.00^{+}	0.68^{--} 1.01	1.36^{+} 1.37^{+}	0.71^{-} 0.98	1.15 1.67^{+}

Key under Table 9

Table 11

Enrichment or impoverishment coefficients of total amounts of elements in surface horizons in relation to underlying horizon* and to the parent material** of Arenosols in the Łyna catena

Profile No and location	Ca	Mg	K	Na	P	Fe	Cu	Mn	Zn
1. Top of the slope	Haplic Arenosol								
	*2.33^{++}	1.14	1.15	2.28^{++}	1.67^{+}	1.12	2.53^{++}	4.43^{++}	3.13^{++}
2. Bottom of the slope	Mollic Gleysol (Colluvic)								
	*0.93 **9.33^{+++}	1.00 1.14	1.31^{+} 1.31^{+}	1.00 1.86^{+}	0.17^{---} 0.17^{---}	1.08 1.36^{+}	0.48^{---} 3.87^{++}	1.47^{+} 3.66^{++}	1.31^{+} 4.39^{++}
3. River valley	Sapric Histosol (Drainic)								
	*0.76 **86.67^{+++}	0.94 4.57^{++}	1.06 2.92^{++}	1.02 6.85^{+++}	1.64^{+} 3.00^{++}	1.06 3.87^{++}	0.95 11.00^{+++}	1.11 7.57^{+++}	1.15 8.18^{+++}
4. River valley	Sapric Histosol (Novic)								
	*0.67^{--} **53.33^{+++}	0.72^{-} 5.86^{+++}	0.71^{--} 2.77^{++}	0.93 5.57^{+++}	1.36^{+} 3.17^{++}	0.60^{--} 3.10^{++}	0.96 11.00^{+++}	0.97 5.02^{+++}	1.10 10.17^{+++}
5. River valley	Mollic Fluvisol								
	*0.96 **55.00^{+++}	1.00 8.86^{+++}	0.94 3.69^{++}	1.00 6.00^{+++}	0.53^{--} 1.33^{+}	0.75^{-} 6.47^{+++}	1.01 8.93^{+++}	0.89 13.62^{+++}	1.09 10.78^{+++}
6. River valley	Mollic Fluvisol								
	*0.86 **3.90^{++}	1.07 5.75^{+++}	0.89 3.08^{++}	1.00 2.77^{++}	1.00 1.67^{+}	0.92 4.06^{++}	1.16 1.12	0.84^{-} 7.10^{+++}	0.45^{---} 1.16

Key under Table 9

Poland (Orzechowski, Smólczyński 2010, Smólczyński, Orzechowski 2010*a*). Fluvisols in these catenas, as compared to young glacial Fluvisols in river valleys and in the Vistula Delta, had a higher content of Mg and Zn, while the content of other elements remained on similar levels (Orzechowski, Smólczyński 2010).

Gleysols in the Łyna catena contained less Mg, K, Fe and Mn than similar soils in mid-moraine depressions of young glacial landscape (Sowiński et al. 2004*b*, Smólczyński, Orzechowski 2010*b*).

According to soil quality standards (*Regulation*... 2002), the amounts of zinc and copper did not exceed the threshold limit values (Cu 150 mg kg^{-1} and Zn mg kg^{-1}) and the analyzed soils are not contaminated with the above elements. However, according to the threshold limit values which include soil texture and soil reaction (Kabata-Pendias et al. 1993), the amount of copper and zinc in Luvisols (26.00 mg kg^{-1}, 121.1 mg kg^{-1}, respectively), deluvial soil (25.57 mg kg^{-1}, 75.77 mg kg^{-1}, respectively) and alluvial soils (55.90 mg kg^{-1}, 271.46 mg kg^{-1}, respectively) of the Liwna catena suggested an elevated content. According to Terelak et al. (2001), the mean content of zinc and copper in the soils of Warmia and Mazury was 6.1 mg kg^{-1} and 29.4 mg kg^{-1}, respectively, and elevated concentrations of copper were found in 0.63% of the region's total area, while for zinc that percentage was 4.24%.

The ratio of the content of elements in surface layers to underlying layers informs us about the vertical distribution of elements. During transport and accumulation of deluvial deposits, sediments are sorted and their texture is a derivative of the texture of eroded soils. Humus horizons of Luvisols located at the top of the valley of the Liwna catena were poorer in the analyzed elements than the underlying horizons and to soil parent material. In the surface horizons of Gleysols and adjacent Fluvisols, the accumulation of these elements was evident (Table 9).

In the Guber catena, the surface horizons were not poorer in the analyzed elements than the underlying horizons. The enrichment factors for these soils were close to 1, being considerably higher in the case of sodium and phosphorus (Table 10). However, in comparison to the parent material (except P and Mn) the impoverishment was strong or very strong. Distinct accumulation of elements (except K and Mn) was revealed in Gleysols located at the bottom of the slope. In Fluvisols, K, P and Cu were accumulated. The calculated factors suggest that the surface horizons of Phaeozems and Gleysols contain less elements (except P) than the parent material. In Fluvisols, these concentrations were similar or higher in the surface horizons.

Soils in the *Łyna* catena had the highest values of enrichment factors for the analyzed elements as compared to the parent material of Arenosols, which is a result of the low content of these elements in the parent material (fluvioglacial sand) – Table 11. The surface horizons of Gleysols contained more K, Mn and Zn in relation to the depth of 35-40 cm. Humus horizons of Fluvisols were impoverished in P, Fe, Mn, and Zn, and the enrichment factors for the other elements oscillated around one.

The study showed differences between the content of elements in the soils of the landscape of ice-dammed lake origin (the Guber and Liwna catenas), and their content in analogous soils in the morainic landscape (the *Łyna* catena), arising from the morphogenesis and lithology of young glacial landscape. The distribution and mobility of elements in the landscape are associated with geomorphological conditions and the geochemical background level (CZARNOWSKA1996, BIENIEK PIAŚCIK 2005, DU LAING et al. 2009, DIATTA 2013).

The study revealed that the location of soils in the relief is an important factor differentiating the content of macro-and microelements. It was also confirmed by the previous studies on the soil cover of young glacial areas (SMÓLCZYŃSKI et al 2004, SOWIŃSKI 2004 *a*,*b* SMÓLCZYŃSKI, ORZECHOWSKI 2010*a*). Erosional processes, which are common in a diversified relief, are the cause of variability of the chemical composition and properties of soils along slopes. During erosion, Ca, Mg, K and P are easily translocated in the form of solution or with soil particles (CHODAK et al. 2005). Accumulation of elements takes place in deluvial deposits at the bottom of slopes, in depressions or at the edge of river valleys, where deluvial and alluvial processes overlap (the Liwna and Guber catenas).

The considerable impoverishment of the humus horizons of Luvisols in Liwna catena in the analyzed elements is related to erosional processes and to the eluviation of clay fraction (clay migration process, "lessive" process).

Spatial variability and the content of elements in soils of river valleys are mainly associated with the fluvial sedimentation of alluvial deposits and with hydrological conditions, which favour sedentation of organic formations with high accumulation capacity (MIDDELKOOP 2000, WALLING et al. 2003, CISZEWSKI et al. 2004, KALISZ ŁACHACZ 2009, GLIŃSKA-LEWCZUK et al. 2014).

CONCLUSIONS

1. In the soils examined, differences were confirmed in sorption properties and amounts of elements in the catena sequences, in soil profiles and between the landscapes.

2. The soils of the landscape shaped by ice-dammed lakes contained more elements than soils in the morainic landscape. In a catena sequence, the highest cation exchange capacity and the highest content of elements were observed in Fluvisols. The content of elements in these soils can be ordered as follows: Ca and Mg>K and Mg>P>Na>Mn>Zn>Cu.

3. The macro- and microelements were significantly positively correlated with the content of the 0.05-0.002 mm fraction and 0.002 mm fraction (Ca, K, Na, Fe, Mn) as well as with the amount of organic carbon (except for Fe

and Mn).

4. According to the quality standards, the content of the analyzed heavy metals did not exceed the threshold limits, indicating that the above soils are not contaminated with heavy metals.

5. Fluvisols and Histosols in the river valleys, owing to their high cation exchange capacity and high accumulation capacity, play a very important role in the circulation of elements and in the resistance of landscapes shaped by ice-dammed lakes or morainic landscape to human activity. They may act as natural biogeochemical barriers. These soils serve to maintain the equilibrium between the environment and human activity.

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