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Differentiation of soils and land use changes in the vicinity of the disappeared Gardeja lake (Northern Poland)

Abstract: The aims of the study were to characterize shoreline soil development and evolution and to determine land use changes (19th to 20th centuries) in the direct catchment of the completely vanished Gardeja lake. The study was based on pedological research and analysis of cartographic materials. The main factor determining the current development of shoreline zone soil cover at the former Gardeja lake was human activity (lake dewatering, further drainage and human-induced erosion). Studied soil profiles were developed from mineral, non-lacustrine materials (upper parts of the slopes) and lacustrine sediments covered with colluvium. The analyzed soil catenas are representative for the undulated young glacial landscape of Northern Poland. The biggest changes of the land use were observed for the class of grasslands that is combined with shrubs (increase of cover area).

Keywords: Limnic soils, colluvial soils, land use changes, lake dewatering, post-lacustrine deposits

INTRODUCTION

Post-glacial lakes have been subject to a processes leading to their disappearance since the very beginning of their existence (e.g. Kalinowska 1961). These could be both natural processes (e.g. climatic, hydrological, geological and biological factors) as well as anthropogenic factors (Galon 1954, Kalinowska 1961, Smith et al. 2005, Liu et al. 2006, Radatz et al. 2010, Ptak 2013, Skowron and Jaworski 2017). The main anthropogenic factors causing the lakes disappearance include drainage work, industrial and agricultural water consumption, channel constructing or river engineering (Niewiarowski and Kot 2011). However, natural mechanisms can be initiated and/or accelerated by human activity. The pace of lake disappearance has increased distinctly in the 19th and 20th centuries (Churski 1988, Marszelewski et al. 2011). The lake area has been decreasing mainly as a result of escalating anthropic pressure. In extreme cases, especially in Northern Poland, some lakes have totally disappeared (Srokowski 1930, Kalinowska 1961, Marszelewski 2005).

Lake water-level decrease often leads to major changes in the environment of the vanishing lake's direct catchment. The change of the water relation influences plant cover transformations and land-use alterations. Furthermore, it also causes changes in the direction of pedogenetic processes (Łachacz et al. 2009, Gonet et al. 2010, Mendyk and Markiewicz 2013, Markiewicz et al. 2015, Mendyk et al. 2016). Completely new soils are being developed from the dehydrated limnic sediments as gyttja and/or peat often surrounds the former reservoirs (Uggla 1968, Olkowski 1971, Łachacz et al. 2009). In the case of agricultural use, these soils are mainly covered with pastures and meadows (Kalisz et al. 2015, Glina et al. 2016). Areas of arable lands are also increasing (Gonet et al. 2010, Markiewicz et al. 2015). Erosion processes were triggered by tillage in the areas characterized by strongly undulated relief. This situation causes the development of colluvial soils, mainly in the aggradation zone at the foot of slopes (Sowiński et al. 2004, Smólczyński and Orzechowski 2010, Smólczyński et al. 2011, Wysocka-Czubaszek 2012, Świtoniak 2014, 2015, Markiewicz et al. 2015, Mendyk et al. 2016).

The aims of this paper were to characterize soil development and evolution in the shoreline and determine land use changes (19th to 20th centuries) in the direct catchment of the now completely vanished Gardeja lake. The study was based on pedological field and laboratory research as well as analysis of the available cartographic materials.

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STUDY AREA

The study area included the direct catchment of the now vanished Gardeja lake, located in the Iława Lake District (Kondracki 2001) in northern Poland (Figure 1, part I). The total lake catchment area determined for research purposes was about 4.9 km^2 and was situated on an undulating morainic plateau consisting of glacial tills. There were several closed depressions within the ground moraine, including post-lacustrine depressions filled with peat and gyttja or lacustrine and fluvioglacial sands (Detailed Geological Map of Poland, sheet No. 207, Gardeja, 1: 50 000). Catchment soil cover was strictly connected with relief and lithology (Detailed Geological Map of Poland, 1:50 000, sheet No. 207, Soil-agricultural map of Poland, 1:25 000, Gardeja sheet). Clay-illuvial soils (in Polish: gleby płowe; also eroded soils) and black earths (in Polish: czarne ziemie) developed from ground moraine tills dominated. Depressions were covered with organic soils (in Polish: gleby organiczne), gleysols (in Polish: gleby glejowe) and colluvial soils (in Polish: gleby deluwialne).

MATERIALS AND METHODS

Six soil profiles were selected in two transects (Profiles 1–3 at the western and Profiles 4–6 at the eastern parts) located at the former Lake Gardeja shoreline (Figure 1, parts II-A and II-B respectively). Both transects was delineated from a lower slope position up to the former lake shoreline (estimated from 13^{th} century documents, Figure 1, parts III-A and III-B, respectively).

The studied soils were described according to Guidelines for Soil Description (Jahn et al. 2006) and mean samples were collected by genetic soil horizons. The following soil properties were determined in collected samples: loss of ignition (LOI) after placing dried samples for 3 h in 550°C, bulk density by the oven-dry method, particle size distribution by the sieve method and the hydrometer (the Bouyoucos aerometric, modified by Cassagrande and Prószyński) method, texture class names were provided in line with the Polish Soil Science Society classification (Polskie Towarzystwo Gleboznawcze 2009), soil-to-solution pH ratio of 1:2.5 using 1M KCl and H_2O as the suspension medium, total organic carbon (TOC) content by sample oxidation in the $K_2Cr_2O_7$ and H_2SO_4 mixture and total nitrogen content (Nt) by the Kjeldahl method. Content of carbonates in soil was determined in the field after 10% HCl treatment. The soils were classified according to the Polish Soil Classification (PSC 2011) and WRB classification system (IUSS Working Group WRB 2015). The English equivalents for the soil taxa names in the Polish Soils Classification were provided after Świtoniak et al. (2016). Soil horizons were designated in respect to PSC 2011.

Polish and German topographic maps from different periods were used in order to define land use changes. Cartographic materials were scanned and georectified into a PUWG 1965 coordinate system using ESRI ArcGIS 9.3 software.

The following materials were used:

German topographic maps on a 1:25 000 scale:
- Garnsee sheet, Agronomische Bohrungen, mapped 1872, printed 1900;
- Garnsee sheet, Meβtischblatt 987, mapped 1906, printed 1936.

Polish topographic maps on a 1:25 000 scale:
- Gardeja sheet 335.43, mapped 1973, printed 1982.

The direct catchment of Lake Gardeja was determined using a Polish topographic map. Within this limited area, each map was digitized afterwards to 7 classes: water bodies, arable lands, grasslands and shrub, forests, orchards, residential areas, graveyards. Lake Gardeja water level in the 13^{th} century was based on historical records (Reymann's Topographic Special-Map of Central Europe ca. 1850 A.D., No. 32, Marienwerder sheet, 1:200 000 scale, Powierski 1979) and field mapping of limnic deposits.

RESULTS AND DISCUSSION

Changes in lake surface area

Changes in the Gardeja lake surface area were closely related to the history of local human activity. The first mention of the lake's existence dates back to 1334 A.D in a prerogative from the Pomezanian Bishop Bertold to the town of Gardeja, in which it was stated that the residents were allowed to use the lake (the one and only lake; Figure 2) surrounding the settlement (Powierski 1979). After that there were two documents dated from 1338 and 1361 A.D. talking about two lakes consisting of twenty-one "fishing deep sites" (lake parts). The hypothetical area covered by the lake at that time was about 143.9 ha. There was no mention about the water level decrease and reasons of the lake's division into two parts in the historical documents. These changes were most probably connected with natural climate fluctuations and drainage works intensively conducted in this area since the beginning of the 17^{th} century (Churski 1988, Marszelewski 2005). Analysis of the oldest map researched in this study has confirmed that in the

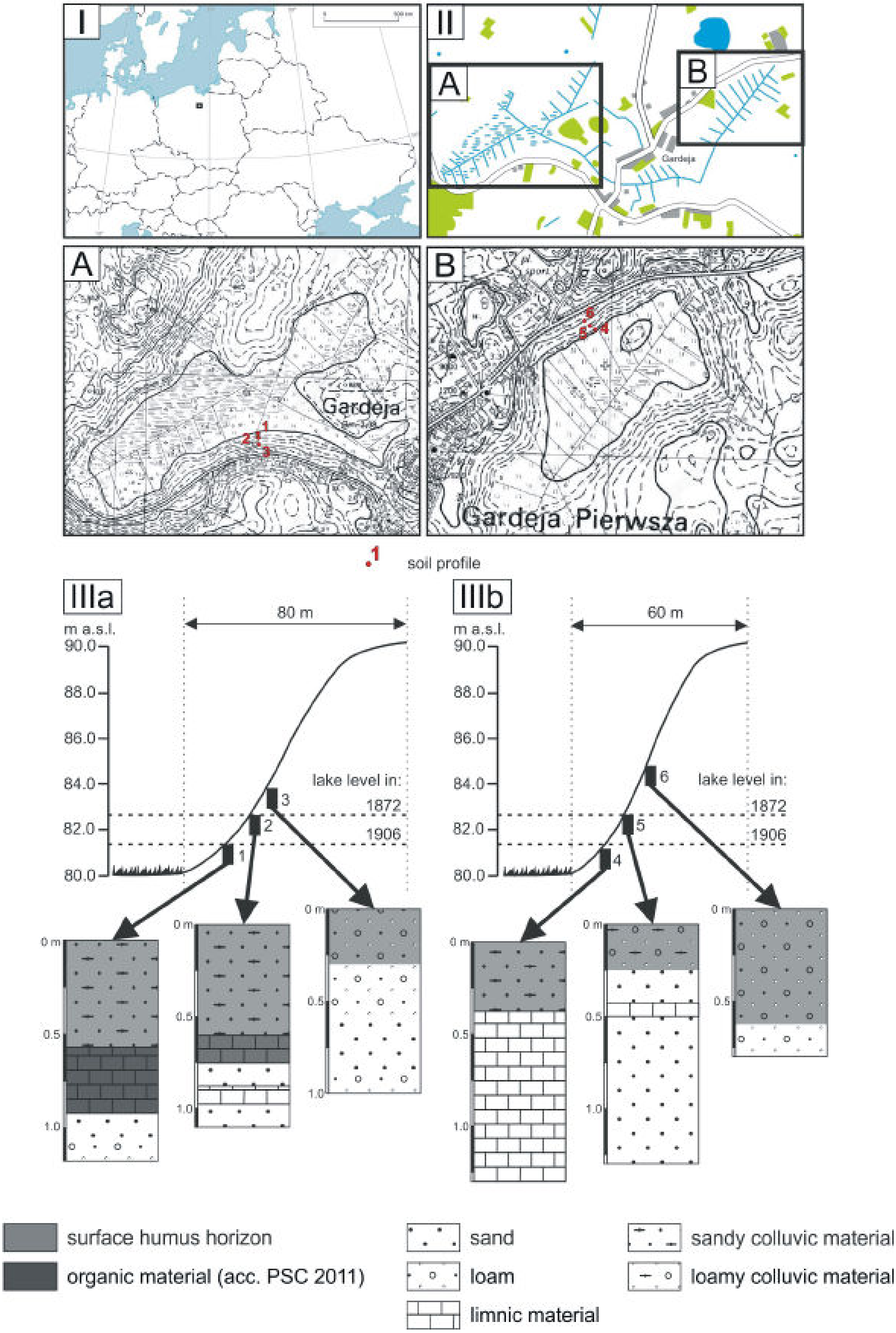
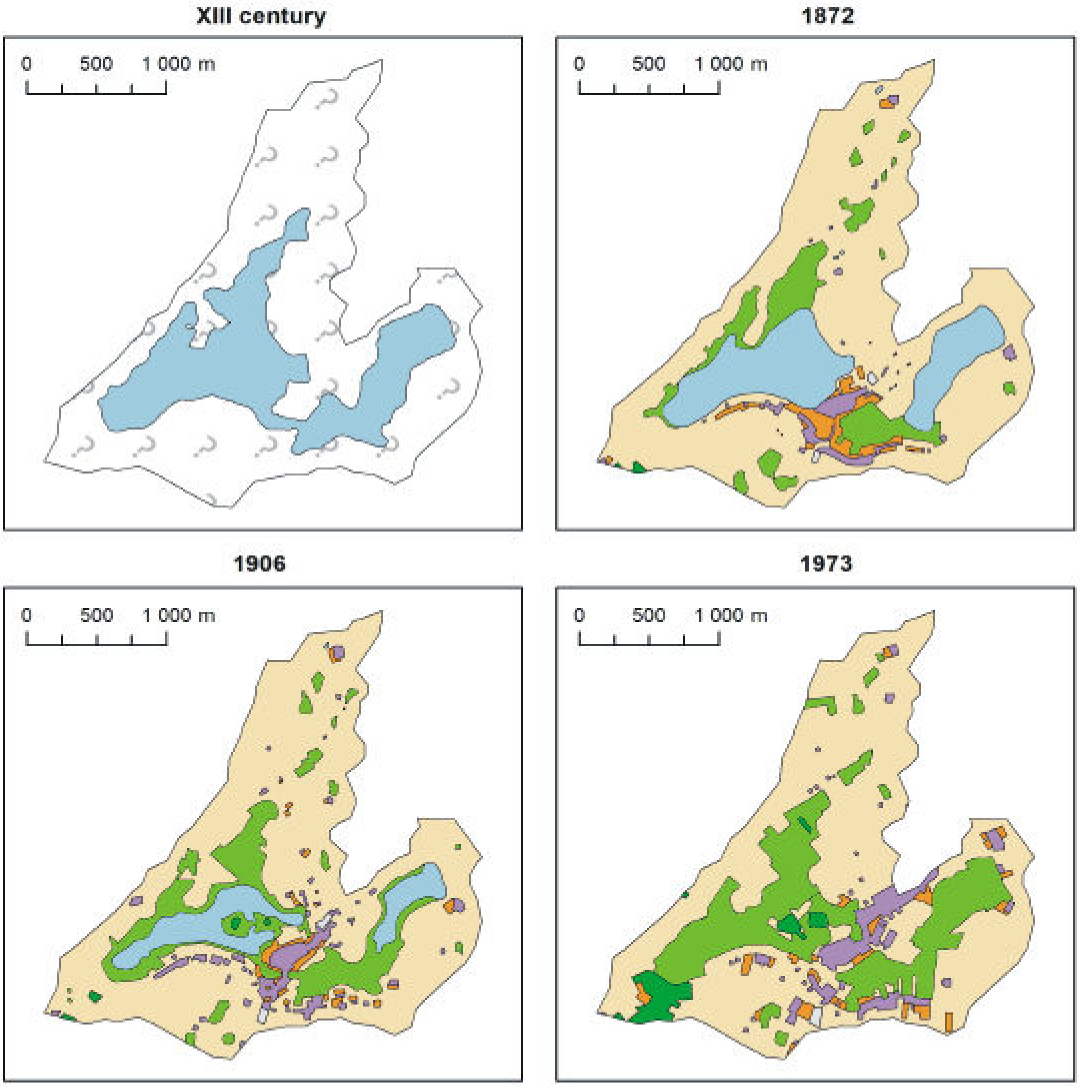


FIGURE 1. Location of the study area (part I), transects (part II) and studied soil profiles (part III)



symbol	XIII century [ha]	1872 [ha]	1872 %	1906 [ha]	1906 %	1973 [ha]	1973 %
water bodies	143.9 (estimated)	84.8	17.1	42.4	8.6	0.0	0.0
arable lands	UNKNOWN	335.8	67.7	351.1	70.8	322.9	65.1
grasslands and shrub		47.8	9.6	73.7	14.9	117.7	23.7
forests		0.7	0.1	1.3	0.3	14.1	2.8
orchards		13.6	2.7	7.7	1.6	12.5	2.5
residential areas		12.3	2.5	18.3	3.7	27.5	5.5
graveyards		0.8	0.2	1.3	0.3	1.1	0.2
	Σ	495.8	100.0	495.8	100.0	495.8	100.0

FIGURE 2. Land use changes in direct catchment of Lake Gardeja

second half of the 19th century there was no single, but two "twin" Gardeja lakes covering about 84.8 ha, which comprises about 17.1% of the total catchment area (later in this paper – TCA; Agronomische Bohrungen 1900). It was clearly visible on the German maps from the beginning of the 20th century (Meβtischblatt 1936) that Lakes Gardeja was in the advanced overgrowth stage. By 1906, the lake decreased by half to about 8.6% (42.4 ha) of TCA.

After the plebiscite of 1920, Gardeja lost part of the fertile soils to the west of its territory due to the subsequent changes in the Polish-German border. Later on, the town received a subsidy for lake draining and to enlarge the agricultural useable areas in the close vicinity of the water body (Figure 2). The main reason for the draining works was the large amount of wasted grain cultivation, especially wheat, caused by high ground water level during spring (Schachschneider 1970). The surface area of Gardeja lakes was consistently decreasing and there is no evidence of water bodies on the map as of 1973 (Figure 2).

Land-use changes in direct catchment

The direct catchment of Gardeja lake is 495.8 ha in size. The draining of the lake significantly influenced land use changes. The area of the pastures and meadows (together with the shrubs) extended from 9.6% (47.8 ha) of TCA in 1872 to 14.9% (73.7 ha) in 1906. The surface area of the grasslands and shrubs increased after the lake was ultimately drained. This was 23.7% (117.7 ha) in 1973 (Figure 2). Other changes in the land use were not caused directly by the lake's drainage. Among the analyzed land-use types, arable land has the largest share and was much more stable during the analysed period. This shifted from 67.7% of TCA (335.8 ha) in 1872, through 70.8% in 1906 to 65.1% in 1973 (Figure 2). The slight decrease was a result of the afforestation of the sandy, less fertile part of the catchment. This was a widely observed tendency (Sewerniak et al. 2014, Mendyk et al. 2016). Another explanation could be the economic transition from mainly agriculture to industry and services. Progressive urbanization has forced the acquisition of arable land and orchards for building development (an increase in the share of residential areas from 2.5% of TCA in 1872 to 5.5% in 1973; Figure 2).

Morphology, properties and genesis of studied soils

The uppermost parts of all the described soil profiles consist of mineral sediments transported from a higher slope position. While aggradation was the main process in the case of profiles 1, 2, 4 and 5, the redeposition of colluvium transported along the slope from higher positions took place as shown in profiles 3 and 6 (Figure 1 – IIIa and IIIb). A situation of this kind is common in strongly undulated areas and could lead to preservation of soils in the middle part of the slopes against erosion (Świtoniak 2014). These materials were characterized with subangular or single grain structures and texture of sands, loamy sands and sandy loams (Table 1). The contents of total organic carbon (TOC) in these colluvial materials varied from 1.21 $g \cdot kg^{-1}$ (A2-profile 2, Table 2) to 32.1 $g \cdot kg^{-1}$ (A2 – profile 1, Table 2) while the C:N ratio had a span from 9.2 (A1 – profile 4, A – profile 6, Table 2) to 15.5 (A(p) – profile 5, Table 2). The higher content of TOC was observed in profiles located at the lower slope positions. This was probably connected with the high level of groundwater affecting the decrease in the rate of organic matter decomposition (PSC 1989, 2011, Jonczak and Kuczyńska 2008, Świtoniak 2015). There was probably no ploughing process on the former surface horizons into the colluvium cover observed e.g. in the area of Brodnica Lake District (Markiewicz et. al. 2015). In horizons developed from colluvium materials, no reaction with 10% HCl were observed, nevertheless the pH in H_2O were relatively high 6.2–7.5 (Table 2). The thickness of the colluvium cover in profiles 1, 2 and 4 was the reason to classify these soils with the preference (PSC 2011, IUSS Working Group WRB 2015). Surface horizons did not meet the criteria for the mollic epipedon in both of the used classification systems. Thus they have been classified as the arenosols (in Polish: arenosole, PSC 2011) because of their sandy texture. It should be stated that there is no information about the specific colluvial origin in the name of these soils according to PSC (2011). This was already noticed by Świtoniak et al. (2016) for the soils derived from the sandy colluvium in the area of the Brodnica Lake District. In the case of the IUSS WRB classification (2015), these soils are too shallow to be classified as arenosols. For this reason, its systematic position was Colluvic Regosol (Arenic).

Despite the fact that erosion processes are the last processes modifying all of the studied profiles, these could simply be divided into two subgroups. Profile 1, 2, 4 and 5 were located within the former Lakes Gardeja bottom while profiles 3 and 6 represent the dry parts of the depression slopes (about 1.5 m over the water level in 1873; Figure 1, parts IIIa and IIIb, respectively). Soil materials lying under the colluvium in profiles located in the former lake bottom had a lacustrine (gyttjas and lacustrine sands) or glaciofluvic genesis (Detailed Geological Map of Poland, sheet No. 207, Gardeja, 1: 50 000). These materials were characterized by their large variety of chemical properties, especially in terms of the TOC content. Organic materials (according to PSC 2011) were observed in profiles 1 (2Lcb – 159 $g \cdot kg^{-1}$ TOC, Table 2) and 2 (2Lcb – 136 $g \cdot kg^{-1}$ TOC, Table 2). Other limnic horizons developed from limnic materials different than lacustrine sands (in profile 2 – 2GLb, in profile 4 – 2GLb1

TABLE 1. Physical properties of the studied soils

Soil horizon	Depth (cm)	Color (moist)	Structure	Soil moisture	Percent of fraction with diameter in mm			Texture class	Horizon boundary
					2.0–0.05	0.05–0.002	<0.002		
Profile 1, h=81.25 m a.s.l. Arenosol over buried limnic gleysol* (arenosol na kopalnej glebie limnowo-glejowej*) WRB – Eutric Colluvic Regosol (Arenic, Humic) over Eutric Gleysol (Drainic, Limnic)									
A1	0–45	2.5Y 4/1	SA	Slightly moist	82	13	5	pg – LS	G
A2	45–58	2.5Y 5.5/1	SG	Slightly moist	85	13	2	pg – LS	C
2Lcb	58–94	7.5Y 3.5/1	PL	Slightly moist	n.d.	n.d.	n.d.	n.d.	C
2Gb1	94–110	7.5Y 4/1	SG	Moist	92	6	2	pl – S	C
2Gb2	110–120	7.5Y4.5/1	MA	Moist	60	20	20	gl – SL	–
Profile 2, h=82.50 m a.s.l. Arenosol over buried limnic gleysol* (arenosol na kopalnej glebie limnowo-glejowej*) WRB – Colluvic Regosol (Arenic) over Eutric Gleysol (Drainic, Limnic)									
A1	0–12	2.5Y 4/1	SA	Slightly moist	87	6	7	pg – LS	A
A2	12–37	2.5 Y 6.5/1	SG	Slightly moist	98	2	0	pl – S	C
A3	37–60	2.5Y 5/1	SG	Slightly moist	97	2	1	pl – S	C
2Lcb	60–76	7.5Y 3.5/1	PL	Slightly moist	n.d.	n.d.	n.d.	n.d	A
2Gb1	76–80	2.5Y 5/1	SG	Slightly moist	n.d.	n.d.	n.d.	pl – S***	A
2GLb	80–90	7.5Y 3.5/1	PL	Slightly moist	n.d.	n.d.	n.d.	n.d.	A
2Gb2	90–97	2.5Y 6.5/1	SG	Moist	98	1	1	pl – S	C
2Gb3	97–110	2.5Y 5/1	SG	Moist	94	4	2	pl – S	–
Profile 3, h=83.75 m a.s.l. Typical gleysol (gleba glejowa typowa) WRB – Eutric Relictigleyic Regosol (Aric)									
Ap	0–29	2.5Y 4/1	SA	Slightly moist	77	14	9	gp – SL	C
2Cg1	29–43	2.5Y 6/2	MA	Slightly moist	73	6	21	gpi – SCL	G,W
2Cg2	43–60	2.5Y 6.5/1	SG	Slightly moist	83	12	5	pg – LS	C, W
2Cg3	60–65	2.5Y 6/1	SG	Slightly moist	n.d.	n.d.	n.d.	pg – LS***	C
2Cg4	65–80	2.5Y 5.5/1	MA	Slightly moist	n.d.	n.d.	n.d.	pg – LS***	C
2Cg5	80–100	2.5Y 5/1	MA	Moist	62	22	16	gl – SL	–
Profile 4, h= 81.0 m a.s.l. Arenosol over buried limnic gleysol* (arenosol na kopalnej glebie limnowo-glejowej*) WRB – Colluvic Regosol (Arenic) over Eutric Gleysol (Drainic, Limnic)									
A1	0–51	2.5Y 6/2	SA	Slightly moist	84	10	6	pg – LS	C
A2	51–56	2.5Y 6.5/2	MA	Slightly moist	76	18	6	pg – LS	C
2GLb1	56–82	7.5Y 3.5/1	PL	Moist	n.d.	n.d.	n.d.	n.d.	C
2GLb2	82–130	7.5Y 3/1	PL	Wet	n.d.	n.d.	n.d.	n.d.	–
Profile 5, h-82.5 m a.s.l Typical gleysol (gleba glejowa typowa) WRB – Eutric Relictigleyic Fluvisol (Aric)									
Ap	0–20(30)	2.5Y 4/1	SA	Slightly moist	77	14	9	gp – SL	C, W
2Cg1	20(30)–42	2.5Y 6.5/1	SG	Slightly moist	96	1	3	pl – S	C
2GL	42–50	7.5Y 3.5/1	PL	Moist	n.d.	n.d.	n.d.	n.d.	C
2Cg2	50–80	2.5Y 6.5/1	SG	Slightly moist	n.d.	n.d.	n.d.	n.d.	C
2Cg3	80–88	2.5Y 4.5/2	SG	Moist	99	1	0	pl – S	C
2Cg4	88–130	2.5Y 6/2	SG	Moist	89	7	4	pl – S	–
Profile 6, h=85 m a.s.l. Proper colluvial soil** over buried typical gleysol (Gleba deluwialna właściwa** na kopalnej glebie glejowej typowej) WRB – Colluvic Regosol (Aric, Loamic)									
Ap	0–34	2.5Y 4.5/2	SA	Slightly moist	76	17	7	gp – SL	D
A	34–62	2.5Y 5/2	SA	Slightly moist	77	14	9	gp – SL	C
2Cgb	62–81	2.5Y 6/1.5	MA	Slightly moist	68	15	17	gp – SL	–

* new proposal, not included in PSC 2011, **according to suggestions by Świtoniak (2015), ***determined in the field.

Explanations, Structures: SG – single grain, MA – masive, SA – subangular, PL – platy; Horizon boundaries: C – clear, G – gradual, D – diffuse, A – abrupt, W – wavy; Texture class: pl – S – sand (piasek luźny), ps – S – sand (piasek słabogliniasty), pg – LS – loamy sand (piasek gliniasty), gp – SL – sandy loam (glina piaszczysta), gl – SL – sandy loam (glina piaszczysta), gpi – SCL – sandy clay loam (glina piaszczysto-ilasta).

TABLE 2. Chemical and physico-chemical properties of the studied soils

Horizon	Depth (cm)	LOI	TOC	Nt	C:N	pH		$CaCO_3$	Bulk density ($g \cdot cm^{-3}$)
		($g \cdot kg^{-1}$)				in H_2O	in KCl		
Profile 1, h=81.25 m a.s.l. Arenosol over buried limnic gleysol* (arenosol na kopalnej glebie limnowo-glejowej)* WRB – Eutric Colluvic Regosol (Arenic, Humic) over Eutric Gleysol (Drainic, Limnic)									
A1	0–45	43.7	21.4	2.05	10.4	6.7	5.9	N	1.43
A2	45–58	62.8	32.1	2.66	12.1	6.7	5.9	N	n.d.
2Lcb	58–94	305	159	13.5	11.8	6.9	6.4	N	0.41
2Gb1	94–110	71.3	40.0	2.97	13.5	6.7	6.1	N	n.d.
2Gb2	110–120	16.3	3.50	0.34	10.3	8.1	6.8	SL	1.62
Profile 2, h=82.50 m a.s.l. Arenosol over buried limnic gleysol (arenosol na kopalnej glebie limnowo-glejowej)* WRB – Colluvic Regosol (Arenic) over Eutric Gleysol (Drainic, Limnic)									
A1	0–12	21.8	9.00	0.84	10.7	6.2	5.1	N	1.51
A2	12–37	2.94	1.21	0.10	12.1	6.5	5.4	N	1.54
A3	37–60	10.5	5.12	0.42	12.2	6.1	5.4	N	1.39
2Lcb	60–76	275	136	10.5	13.0	7.0	6.4	N	0.48
2Gb1	76–80	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	N	n.d.
2GLb	80–90	59.2	37.2	3.50	10.6	6.5	6.0	N	n.d.
2Gb2	90–97	9.71	5.93	0.47	12.6	7.0	6.4	N	1.61
2Gb3	97–110	15.9	7.63	0.57	13.4	7.5	6.4	N	1.68
Profile 3, h=83.75 m a.s.l. Typical gleysol (gleba glejowa typowa) WRB – Eutric Relictigleyic Regosol (Aric)									
Ap	0–29	34.1	13.8	1.33	10.4	7.1	6.2	N	1.52
2Cg1	29–43	10.6	3.72	0.37	10.1	7.6	7.0	SL	1.63
2Cg2	43–60	9.63	3.51	0.30	11.7	7.8	7.2	SL	1.57
2Cg3	60–65	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	SL	n.d.
2Cg4	65–80	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	SL	n.d.
2Cg5	80–100	13.3	1.42	0.15	9.5	8.3	7.3	SL	1.76
Profile 4, h= 81.0 m a.s.l. Arenosol over buried limnic gleysol* (arenosol na kopalnej glebie limnowo-glejowej)* WRB – Colluvic Regosol (Arenic) over Eutric Gleysol (Drainic, Limnic)									
A1	0–51	18.5	7.12	0.77	9.2	6.5	5.5	N	1.51
A2	51–56	54.3	28.5	2.56	11.1	5.8	4.9	N	n.d.
2GLb1	56–82	90.6	48.8	3.86	12.6	5.5	4.6	N	0.88
2GLb2	82–130	36.8	22.0	1.68	13.1	7.7	7.1	SL	0.77
Profile 5, h-82.5 m a.s.l Typical gleysol (gleba glejowa typowa) WRB – Eutric Relictigleyic Fluvisol (Aric)									
A(p)	0–20(30)	24.4	9.62	0.92	15.5	7.5	6.7	N	1.42
2Cg1	20(30)–42	6.23	3.51	0.29	12.1	7.3	6.7	N	1.45
2GL	42–50	198	93.0	6.60	14.1	7.2	6.4	N	0.91
2Cg2	50–80	13.1	6.92	0.50	13.8	7.4	6.7	N	1.35
2Cg3	80–88	51.6	23.2	1.47	15.8	7.3	6.6	N	1.29
2Cg4	88–130	10.2	3.93	0.21	18.7	7.4	6.3	N	1.43
Profile 6, h=85 m a.s.l. Proper colluvial soil** over buried typical gleysol (Gleba deluwialna właściwa** na kopalnej glebie glejowej typowej) WRB – Colluvic Regosol (Aric, Loamic)									
A(p)	0–34	22.5	8.93	0.87	10.3	7.0	6.2	N	1.52
A	34–62	16.2	5.51	0.60	9.2	7.6	6.9	N	1.38
2Cg	62–81	10.6	1.43	0.17	8.4	7.8	6.3	SL	1.81

*new proposal, not included in PSC 2011, ** according to suggestions by Świtoniak (2015); LOI – loss of ignition; Carbonates: N – non-calcareous, SL – slightly calcareous.

and 2GLb2, in profile 5-2GL) contained from 22 to 93 $g \cdot kg^{-1}$ TOC. In lacustrine and fluvioglacial sands (profiles 1-2 and 4-5), this parameter ranged from 3.5 to 40 $g \cdot kg^{-1}$. On the other hand, all of the above mentioned sediments did not contain carbonates and a pH determined in H_2O from 5.5 to 8.1. Higher pH values were observed in bottom horizons, which is most probably connected with the influence of ground water rich in base cations. There were no symptoms of the murshing process taking place in the organic horizons. This could be the influence of the colluvium cover preserving the limnic horizons that has already been reported (e.g. Smólczyński 2006, Łachacz et al. 2009, Mendyk et al. 2016). There was an inconvenience with the classification of the buried soils in profiles 1, 2 and 4 according to PSC (2011). They were finally classified as limnic gleysols (in Polish: gleby limnowo-glejowe). This is a new proposal for gleysols with organic horizons of limnic genesis, as similar soils developed from an alluvial environment are present in PSC (2011; muddy gleysols, in Polish: gleby mułowo-glejowe). According to the IUSS WRB (2015) these soils were classified as Eutric Gleysols (Drainic, Limnic). No buried soils were described in profile 5 due to the small thickness of the colluvium (30 cm). Thus the soil was classified as it is in the entire analysed profile. There was a clearly visible TOC content and morphology features alternation indicating fluvic properties and the gleyic properties (in the bottom part). After all, this is best suited for the typical gleysol (in Polish: gleba glejowa typowa) according to PSC (2011) and Eutric Relictigleyic Fluvisol (Aric) in IUSS WRB (2015).

Profiles 3 and 6 located above the former water lake's level (Figure 1, parts IIIa and IIIb) represent soils fully developed from mineral, non-lacustrine materials. Colluvium covering the bottom soil horizons was described before. The lower parts of both soils are of loamy sand, sandy loam and sandy clay loam texture. The TOC content in these horizons amounted from 1.42 to 3.72 $g \cdot kg^{-1}$, pH values were between 7.6 and 8.3, and there was small amount of carbonates. The soil profile 3 was classified as typical gleysol (in Polish: gleba glejowa typowa; PSC 2011) and Eutric Relictigleyic Regosol (Aric) in IUSS WRB (2015). On the other hand, there was a difficulty in determining soil taxonomy position in profile 6. As it was classified as the Colluvic Regosol (Loamic) according to IUSS WRB (2015), there was no unit to fit the criteria in PSC (2011). If the surface horizon meets the criteria for mollic epipedon, the soil could be classified as humic colluvial, otherwise the best name seemed to be the proposal given by Świtoniak (2015), which is proper colluvial soil.

CONCLUSIONS

1. Human activity (drainage works and human-induced erosion) was the main factor determining the current development of the soil cover in the shoreline zone of the former Lake Gardeja.
2. Together with evolution of the soils there were significant changes of the land use in the direct catchment of the lakes. The biggest shift was observed for the class of grassland that is combined with shrubs, the area of which increased, along with the disappearance of Lake Gardeja.
3. The introduction of the limnic gleysols soils subtype (in Polish: gleby limnowo-glejowe) within the type of gleysols could be considered during the development of the next Polish Soil Classification update. It should comprise soils that include both soils derived from mineral-organic limnic materials and soils with organic limnic material not thick enough to be classified as limnic organic soil.
4. As was suggested before, restoration of the proper colluvial soil type (in Polish: gleby deluwialne właściwe) within the order of weakly developed soils (in Polish: gleby słabo ukształtowane) should be considered (Świtoniak 2015).

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Zróżnicowanie i zmiany użytkowania gleb w otoczeniu zanikłego jeziora Gardeja (Polska północna)

Streszczenie: Celem badań była charakterystyka rozwoju pokrywy glebowej linii brzegowej oraz zmian użytkowania terenu (XIX i XX wiek) jako czynników wpływających na użytkowanie terenu na obszarze zlewni bezpośredniej zanikłego Jeziora Gardeja. Wykorzystano badania gleb oraz analizę dostępnych materiałów kartograficznych. Stwierdzono, że głównym czynnikiem determinującym współczesny rozwój gleb strefy brzegowej dawnego Jeziora Gardeja była działalność człowieka (odwodnienie jeziora, melioracje i denudacja antropogeniczna). Badane gleby powstały zarówno z utworów mineralnych nie posiadających jeziornej genezy (górne części stoków), jak i osadów jeziornych przykrytych deluwiami. Analizowane kateny glebowe są typowe dla młodoglacjalnych krajobrazów północno-wschodniej Polski. Największe zmiany użytkowania terenu zaobserwowano w odniesieniu do obszarów trawiastych i zakrzewień (wzrost powierzchni).

Słowa kluczowe: Gleby limnowe, gleby deluwialne, zmiany użytkowania gleb, odwodnienie gleb, osady pojeziorne