DE GRUYTER
OPEN

DOI: 10.1515/ssa-2015-0021

SOIL SCIENCE ANNUAL
Vol. 66 No. 2/2015: 67–74

PIOTR HULISZ[1]*, ADAM MICHALSKI[1], MICHAŁ DĄBROWSKI[1], GRZEGORZ KUSZA[2], LESZEK ŁĘCZYŃSKI[3]

[1] Nicolaus Copernicus University in Toruń, Faculty of Earth Sciences, Department of Soil Science and Landscape Management, Lwowska St. 1, 87-100 Toruń
[2] University of Opole, Department of Land Protection, Oleska St. 22, 45-052 Opole
[3] University of Gdańsk, Institute of Oceanography, Laboratory of Applied Geology, Piłsudskiego St. 46, 81-378 Gdynia

Human-induced changes in the soil cover at the mouth of the Vistula River Cross-Cut (northern Poland)

Abstract: The aim of this paper is to determine the impact of human activity on the soil formation at the mouth of the Vistula Cross-Cut (northern Poland). The detailed research was conducted in the test area (about 500 ha) for which the soil map was created. The three major soil belts were distinguished, grouping the soils formed on marine, aeolian and technogenic sediments, deposited both naturally and anthropogenically as a result of the hydrotechnical works. Initial soils, arenosols, gleysols, brackish marsh soils and industrial soils predominate across the study area. Most of them were characterized by high spatial diversity and multi-layering. Their properties reflected varied dynamics of the local environment on both sides of the river channel, greatly enhanced by the human activity. Based of the obtained results, some proposals concerning arenosols, marsh soils and industrial soils for the Polish Soil Classification (2011) were presented.

Keywords: anthropogenic transformation, hydrotechnical works, river mouth, soil classification, soil mapping, Vistula River

INTRODUCTION

The river mouth areas are specific zones of intense interaction between river and sea waters. Several hydrological, geomorphological, sedimentological, and pedological processes are overlapping in these conditions (Wright 1985, Hulisz 2013, Wang et al. 2015). Very dynamic processes of deposition and redeposition of alluvial and marine sediments makes the environment very unstable. In such conditions pedogenesis is interrupted by geogenetic processes, which led to destruction or overbuilding of soil profiles. The soil formation in the coastal zones with combination of geogenetic processes is known as geo-pedogenesis (Schroeder and Brümmer 1969, Giani 1992, Giani et al. 2003). Human activity aiming to harness the nature forces can manage all those processes to some extend. This can lead to both changes in soil morphology and properties, and the creation of human-transformed soil cover patterns.

The Vistula River Cross-Cut (in Polish: Przekop Wisły) is an artificial channel between Przegalina and Świbno villages. The excavation of this new riverbed, finished in the 1895, is undoubtedly the biggest investment for the permanent flood protection in the Vistula River Delta. This is also considered to be one of the most radical and the most important hydrographical changes in the modern history of the Vistula River (Makowski 1995, Kowalik 2008). The channel is about 3000 m long, 400 m wide and its depth is up to 10 m. The good indicator of the scale of these hydrotechnical works is the high cubature of the aeolian, marine and alluvial sediments removed from the area of the constructed river outlet reaching about $7.2 \cdot 10^{-6}$ m^3 (Makowski 1995, Robakiewicz 2010). The last stage of the investment was the digging of the small trench of 50 m width (in German: Künette) to connect the Baltic Sea and the Vistula River waters. The material was deposited on both sides within the Vistula Spit (two embankments with elevation about 8 m a.s.l.) – Makowski (1995). The trench has widened very quickly as a result of natural processes reaching a width up to 300 m. After completion of the channel the formation of the river mouth fan has been started (Koszka-Maroń and Jegliński 2009). As a result, the risk of ice-jams increased, as well as some problems with navigation have appeared. That is why the further regulation works by the construction of breakwaters were done. Both eastern and western jetties are still being modernized and elongated (Kowalik 2008, Robakiewicz 2010).

* dr hab. P. Hulisz, hulisz@umk.pl

The aim of this paper is to determine the impact of human activity on the soil formation at the mouth of the Vistula Cross-Cut. Although there are relatively many comprehensive studies on soils of the Żuławy region (e.g. Witek 1965, Piaścik et al. 2000, Chojnicki 2002, Orzechowski et al. 2005), the soils in the area of the Vistula River outlet have not been described yet. The general approach to the soil characterization in both horizontal and vertical gradients was presented. The detailed research is still in progress and will be reported in other articles. Having regard to the complex and long-term transformations of the environment due to the construction and functioning of the Vistula River Cross-Cut, we can expect a large diversity of soil cover in the study area.

MATERIALS AND METHODS

The research was carried out between 2013 and 2015. The test plot (about 500 ha) located at the mouth of the Vistula River Cross-Cut was selected (Fig. 1), where 50 soil pits were dug. Their location corresponded to local environmental conditions, such as relief, hydrological and geological conditions, and vegetation cover. The soil materials taken from genetic horizons were submitted for the following analyses: (i) particle size distribution by the hydrometer Bouyoucos method modified by Casagrande and Prószyński, combined with the sieve method, (ii) actual soil moisture (M) by time domain reflectometry (TDR), (iii) pH potentiometrically in H_2O and 1M KCl, (iv) organic carbon (OC) by sample oxidation in the mixture of $K_2Cr_2O_7$ and H_2SO_4 (Tiurin and Alten methods), (v) electrical conductivity in 1:5 soil-water extract ($EC_{1:5}$) and (vi) magnetic susceptibility (κ) using an MS2 meter with MS2B sensor by Bartington Instruments Ltd. Additionally, the pH peroxide test (pH–H_2O_2) was performed to indicate the presence of iron sulphides in selected soil samples (IUSS Working Group WRB 2015). Three representative soil profiles were selected for detailed study as most suitable to typify the human impact on transformation of the soil cover.

FIGURE 1. Location of the study area

The maps were done in ArcGIS 9.3 programme based on field research and analysis of cartographic sources: i.a. orthophotomaps, historic topographic maps 1:25 000, digital terrain model (DTM), maps of forest site types and hydrological maps 1:50 000. In the description of soil map units the terminology in accordance with the Polish Soil Classification (2011) was adopted. The other figures were prepared with the use of MS Excel 2003, CorelDraw X3, and Statistica 9.0 packages.

RESULTS AND DISCUSSION

Changes in the land area in the period 1903–2014

The construction of the Vistula River Cross-Cut triggered the accelerated deposition of large amount of sediments. The river delta front and the prodelta were formed in the last 100 years being active today. The material coming mainly from erosion of sandy spit, backward erosion of the riverbed, transportation of sediments by the river and sea currents has been accumulated (Koszka-Maroń and Jegliński 2009, Wróblewski et al. 2015). The rate of the sedimentation is very high. As given by Łomniewski (1960), between 1895 and 1929 the volume of the accumulated mass in the fan reached 56.6 millions m^3. However, Kowalski (1976) estimated the mouth fan's increase at 0.45 million m^3 per year for the period from 1960 to 1995.

This very dynamic process contributed to the development of the new land area. For the purpose of this work the calculations were made based on the comparison of the shoreline in 1903, 1936 and 2014 years (Nickelswalde 1903, Nickelswalde 1936, Google Earth 2014) The state of the year 1903 (the oldest available topographic map) was taken as reference (Fig. 2). The obtained results demonstrate that in 1936 the newly formed land area was about 80 ha, which gives an increase of 615% comparing to 1903. Nowadays (state of the year 2014) the land area occupies about 315 ha (an increase of 2305% comparing to 1903, 2.84 ha per year on average).

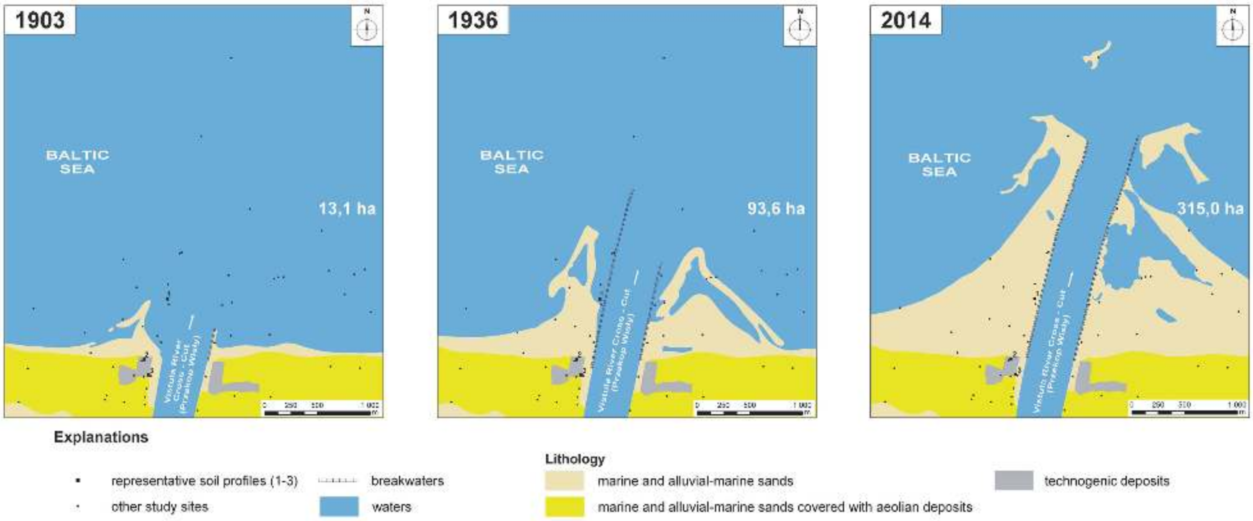

FIGURE 2. Changes in the shoreline at the mouth of the Vistula River in the period 1903–2014 (Source: Nickelswalde 1903, 1936; Google Earth 2014). Increase of the land area since 1903 is expressed in hectares

Human impact on morphology, properties and spatial variability of soils

The knowledge about the differentiation of soil cover at the mouth of the Vistula Cross-Cut is significantly reduced. Witek (1965) distinguished in this area only aeolian sands in various stages of podzolization, but the results of his investigations indicated that spatial pattern of soils is more complicated. The hydrotechnical works conducted in the area of the Vistula Cross-Cut highly altered the processes of soil formation. There are both naturally deposited and technogenic sediments covered by aeolian and alluvial sediments. The multi-stratified soils, mainly initial soils, arenosols, gleysols, marsh, and industrial soils were developed from these sediments. The figure 3 shows the representative profiles of soils formed on marine, aeolian and technogenic parent materials. Some of them (e.g. profiles 2 and 3) may be characterized by vertical diversification in texture (from sand to silt loam), organic carbon content (OC), as well as the presence of buried horizons (profile 3). Undoubtedly, it could suggest the development of those soils in highly dynamic local environment.

In the studied area, three soil belts can be distinguished according to horizontal differentiation of sediments (Fig. 4). The first one is represented by beach sands and initial soils, which are in various stages of alteration due to preliminary stages of weathering and soil formation. These sediments cover 47.1 ha, which gives more than 9% of the total study area (Table).

The second soil belt lies southward and is dominated by soils developed from marine sands, in some places covered with thin layers of the aeolian deposits (Fig. 4). According to the Polish Soil Classification (2011) they can be labelled as arenosols (in Polish: arenosole). Some of them show initial phases of podzolization (Fig. 3,

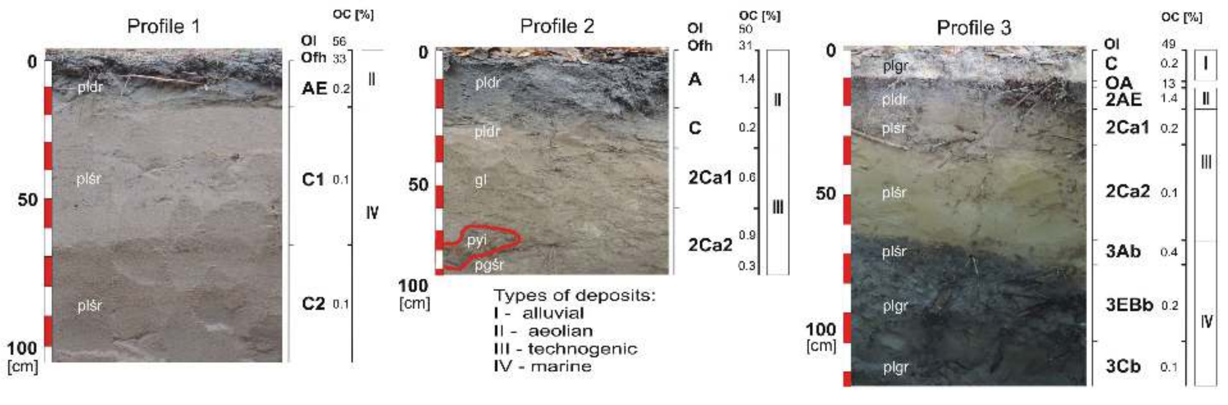

FIGURE 3. Examples of soil profiles located on the left bank of the Vistula River Cross-Cut (profile 1 – podzolized arenosol developed from marine sands, profile 2 – arenosol developed from aeolian sands over technogenic deposits, profile 3 – industrial soil over podzolic soil). Symbols of soil horizons according to the Polish Soil Classification (2011). Soil texture classes according to PTG – 2008 (2009): pldr – fine sand, plśr – medium sand, plgr – coarse sand, pgśr – loamy sand, pyi – silt loam, gl – sandy loam

profile 1), which was included in the names of soil map units. As shown in the figure 5, these soils are acid (pH–H_2O 4.4–6.0; pH–KCl 3.8–5.9), poor in organic carbon (OC <0.4%), and are also characterized by the presence of morphologically visible features of podzolization (initial character of E and B horizons) in the uppermost 5–10 centimetres. The soil unit cover area of about 240.7 ha, which gives 48% of total study area (Table). The podzolized arenosols that are common also in the third ("aeolian") soil belt (Fig. 4) with northern boundary along the former shoreline (i.e. before 1895) show the similar properties. These soils are developed from aeolian sands of the Vistula Spit and cover more than 1/3 part of the total study area (Table).

This simplified spatial pattern is interrupted by semihydrogenic, marsh and anthropogenic soils (Fig. 4). First two units can be found within second soil belt, the last one in "aeolian" belt. Semihydrogenic soils are represented mainly by gley soils (in Polish: gleby glejowe) or gley-podzol soils (in Polish: glejobielice). For the purpose of this work the soils mentioned were grouped into two soil cartographic units (Fig. 4). The first one are represented by gley soils with gley-podzols (6.3 ha, 1.3% of the total area, Table) and the second one by gley soils with marsh soils. Gley soils with gley-podzol soils were identified only in the western part of the study area. These soils are common in the inter-dune depressions. In contrast, gley soils with marsh soils (in Polish: marsze) are common east of the Vistula Cross-Cut and occupy area of about 24.2 ha (4.8% of the total area, Table). It can be explained by different conditions of sedimentation on the both sides of the channel mainly induced by the construction of breakwaters. As a result, the changes in the river current and the formation of the new mouth cone have been observed since 1897 (Makowski 1995, Koszka-Maroń and Jegliński 2009). This also affected the differentiation of the western and eastern parts of the study area both in altitude (higher elevation of eastern part) and relief (the occurrence of small depressions and lagoons) (Fig. 2). That is why the lowest land areas in the eastern part of the river mouth are more susceptible to Baltic Sea waters inundation. As stated by Hulisz (2013), under these conditions

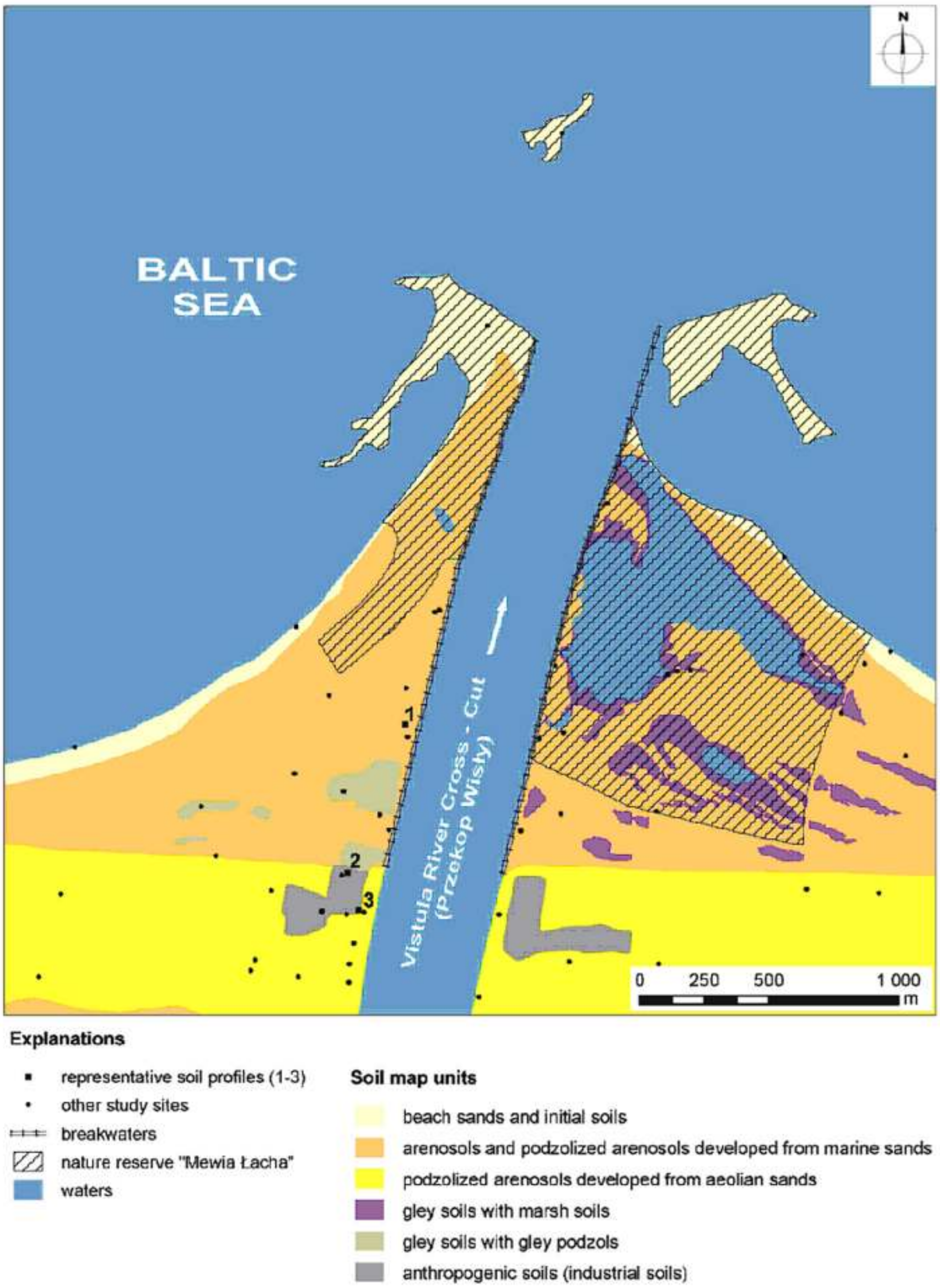

FIGURE 4. Soil map of the study area

TABLE. The area and occupation (in %) of each soil map unit on the both banks of the Vistula Cross-Cut

Soil map units	Left bank		Right bank		Total	
	[ha]	[% of land area]	[ha]	[% of land area]	[ha]	[% of land area]
Marine sands (beach sands) and initial soils	28.5	11.8	18.6	7.2	47.1	9.4
Arenosols and podzolized arenosols developed from marine sands	121.9	50.4	118.8	45.9	240.7	48.1
Podzolized arenosols developed from aeolian sands	79.9	33.1	90.3	34.9	170.2	34.0
Gley soils with marsh soils	0.0	0.0	24.2	9.3	24.2	4.8
Gley soils with gley podzols	6.3	2.6	0.0	0.0	6.3	1.3
Anthropogenic soils (industrial soils)	5.1	2.1	7.1	2.7	12.2	2.4
Total area	241.7	100.0	259.0	100.0	500.7	100.0

brackish marsh soils can develop. The marsh soils were distinguished also in western part of the Sobieszewska Island (vicinity of Ptasi Raj Lake and Górki Wschodnie, district of Gdańsk) occupying area of about 150 ha (Witek 1965). Despite the formation of those soils in the terrestrial-marine environment, they are characterized by low salinity level. This is probably caused by a salt leaching and very limited supply of saline waters due to hydrotechnical works.

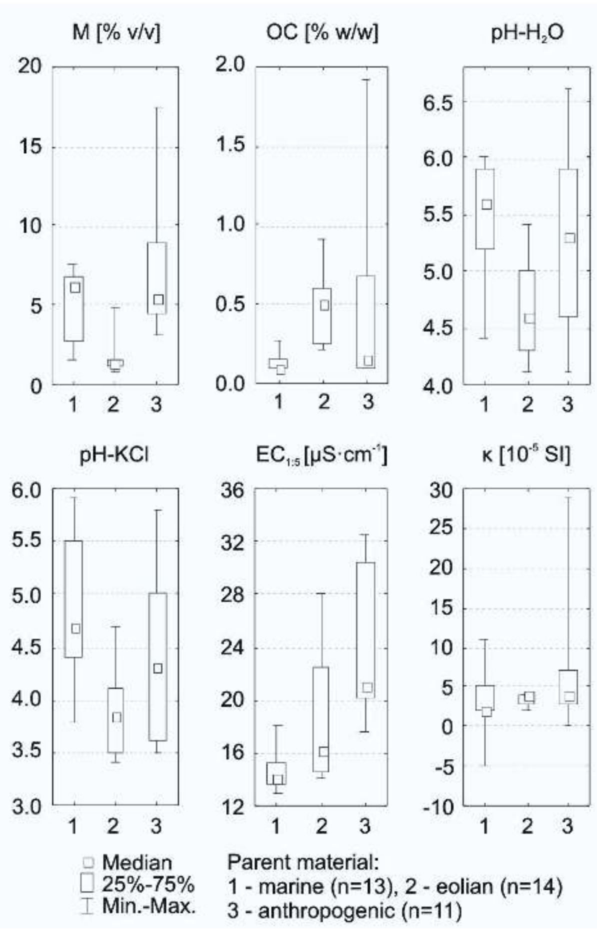

FIGURE 5. Selected properties of soils developed from different parent materials (left bank of the Vistula River Cross-Cut)

There are no river alluvial soils (floodplain soils, in Polish: mady) in the study area, because there are no conditions for formation of floodplain (high slopes of former dunes, strengthening of river banks with stones). However, in some soils the initial stage of the alluvial process is observed (Fig. 3, profile 3).

In the third belt, anthropogenic soils can be found (Fig. 3 and 4). They are developed from sediments (of technogenic origin) of the Vistula Cross-Cut. According to the Polish Soil Classification (2011) these soils can be classified as industrial soils (in Polish: gleby industrioziemne), and more precisely as industrial humus soils (in Polish: gleby industrioziemne próchniczne). They occupy small areas (5.1 ha on the west bank and 7.1 ha on the east bank, Table) on the artificial embankments on both sides of the Vistula River channel being evidence of intentional human activity during hydrotechnical works. In some places the technogenic deposits can be covered with a thin layer (up to 40 cm) of aeolian deposits (Fig 3, profile 2). Analysis of topographic map (from 1903) indicate intentional usage of fresh sediments (probably of deltaic and marine origin mainly) taken from the Vistula Cross-Cut. High natural fertility of sediments were surely taken into account during construction of mentioned, artificial embankments. That is why newly formed soils (nowadays classified as industrial soils) were covered with mixed forests. Such habitats represent “enclaves” of fertile soils and mixed forests in the environment dominated by sandy and weakly developed soils covered with coniferous (pine) forests. The industrial soils have the widest ranges of actual moisture (M 3.2–17.5%), organic carbon (OC 0.1–1.93%), pH–H_2O (4.1–6.6), pH–KCl (3.5–5.8), electrical conductivity ($EC_{1:5}$ 17.6–32.5 $\mu S \cdot cm^{-1}$) and magnetic susceptibility (κ 0–29·10^{-5} SI), and the highest values of analysed parameters (except for pH–KCl) among all studied soils (Fig. 5). Strong acidification of some industrial soils probably results from the leaching of carbonates and the presence of iron sulphides (primarily accumulated in the marine sediments). These soils show some properties similar to potential acid sulphate soils occurring along the Polish coast (Pracz 1989, Hulisz 2013). It can be explained well by the results of the accelerated oxidation test using 30% H_2O_2 solution performed in 10 selected soil samples (Fig. 6). Due to poor soil buffering (lack of $CaCO_3$) the highest differences between the pH–H_2O and pH–H_2O_2 values exceed even three pH units. In some cases the pH values dropped below 2.5 what can suggest the presence of the *hypersulfidic* material (IUSS Working Group WRB 2015) (Fig. 6). Industrial soils do not show contamination by heavy metals (not shown) despite the technogenic origin, which is indicated by their low magnetic susceptibility.

Problems related to the classification of the studied soils

The latest version of the Polish Soil Classification (2011) was used for mapping of the study soils. Unfortunately, a satisfactory description of their taxonomic position was not possible due to lack of adequate criteria and thus units. Based on the obtained results some improvements are proposed to increase the usefulness of a soil classification system in Poland. They concern four major aspects, which are discussed below.

Presently, there are no subtypes in the type of arenosols. However, some authors pay attention to the properties related to podzolization of these soils, which may then evolve into podzols (e.g. Kawałko and Kaszubkiewicz 2008, Jankowski 2010). Therefore, it should be consider adding the subtype of podzolized arenosols to the type of arenosols, especially that such subunit has been distinguished in the Classification of Polish Forest Soils (2000). Observed morphological characteristics clearly suggest an initial stage of podzolization process in case of the investigated soils, as emphasized in their description. However, further detailed research focusing on soil micromorphology and chemistry is necessary.

In the Polish Soil Classification (2011), similarly to the WRB system, *fluvic* material also refers to marine sediments. On the other hand, the soils developed from the marine and marine-alluvial sediments (marsh soils) have not been distinguished yet. The comprehensive proposal of classification of marsh soils, compatible with the Polish Soil Classification (2011), was given by Hulisz (2013). Some of the investigated soils developed from marine sands do not meet the criteria for *fluvic* horizon and consequently they should be classified as arenosols (Fig. 3, profile 1).

In recent years, the knowledge on technogenic soils occurred in urban, industrial, traffic, mining and military areas (SUITMAs) has been extensively developed (e.g. Charzyński et al. 2013a, Burghardt et al. 2015). As a result, the Technosols were introduced to the international soil classification system WRB in 2006 (IUSS Working Group WRB 2006). This unit groups soils affected by other types of human activity than agricultural or horticultural use, and consequently Technosols were excluded from Anthrosols. The studied

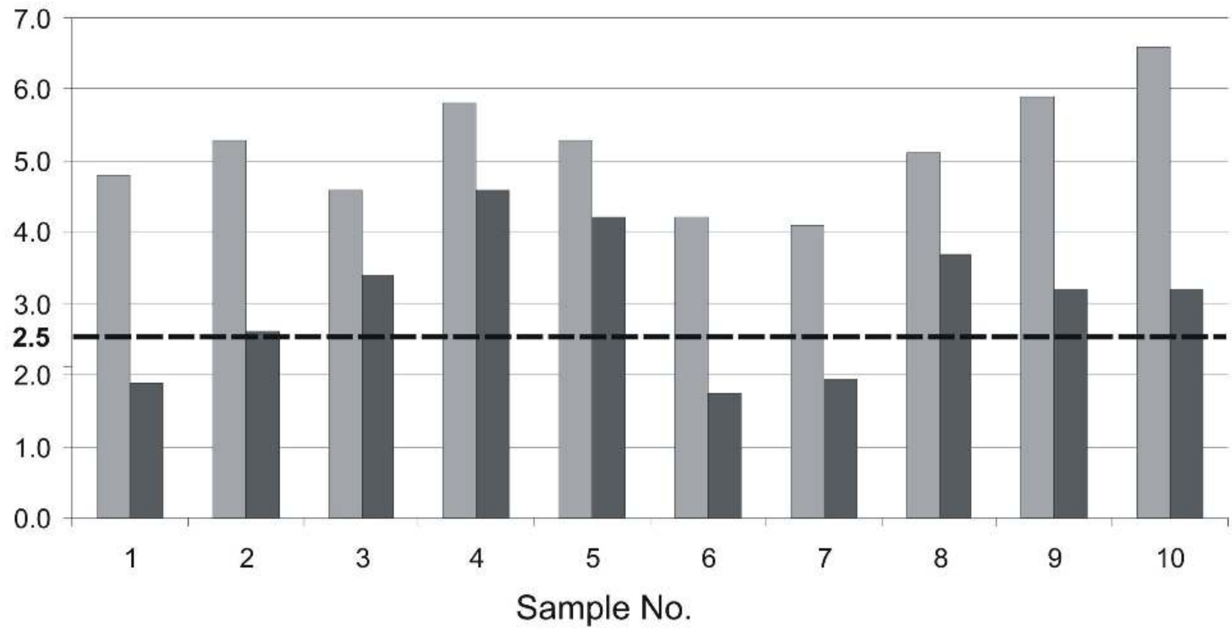

FIGURE 6. The susceptibility to acidification of the studied industrial soils determined on the basis of the pH measurements (pH–H_2O, pH–H_2O_2)

industrial soils are developed from intentionally deposited technogenic material (Spolic Technosols), which fulfils the WRB diagnostic criteria of artefacts (IUSS Working Group WRB 2015). Therefore, referring to the latest trends and discussions (e.g. Charzyński et al. 2013b), the addition of new order „technogenic soils" (including both urban and industrial soils types) to the Polish classification system should be considered. Undoubtedly, this would enable more precise description of such soils.

The accumulation of mineral forms of sulphur (mainly sulphides), stated in the studied industrial soils (Fig. 6), is typical of Polish coastal soils (Pracz 1989, Hulisz 2013). The sulphurization is a secondary process in relation to other soil-forming processes occurring previously or simultaneously. As already suggested by Pracz (1989) and Hulisz (2013), such feature could be considered on the subtypes level of the Polish Soil Classification. Similar rules are used in the WRB classification (qualifiers).

CONCLUSIONS

1. The construction of the Vistula River Cross-Cut and the regulation works at the river mouth significantly contributed to the enlargement of the land area and transformation of the soil cover.
2. High dynamics of the local environment on both banks of the Vistula River Cross-Cut, mainly directed by hydrotechnical works and forest management (podzolization), is reflected in the great spatial diversity of soil cover and development of the multi-layered soils.
3. According to horizontal differentiation of sediments, three soil belts were distinguished in the study area. The spatial pattern of soils in the western part of the study area is clearly different from the eastern one, what can be explained by the impact of a specific set of local environmental factors (both natural and anthropogenic). Due to the human influence the formation of typical alluvial soils is nowadays very limited.
4. The appropriate classification of the studied soils according to the Polish Soil Classification (2011) is generally not possible. In Author's opinion, there is a need to introduce a new soil units (type 'marsh soils' in the order of weakly developed soils and subtype "podzolized arenosols" in the type of arenosols, order "technogenic soils") and to define the soil materials related to sulphurization process.

ACKNOWLEDGMENTS

This study was financed by the Polish National Science Centre (grant DEC 2012/07/B/ST10/04080, 2013–2016).

REFERENCES

Burghardt W., Morel J.L., Zhang G-L., 2015. Development of the soil research about urban, industrial, traffic, mining and military areas (SUITMA). Soil Science and Plant Nutrition, 61 (Suppl.1): 3–21.

Charzyński P., Hulisz P., Bednarek R. (eds.), 2013a. Technogenic soils of Poland. Polish Society of Soil Science, Toruń: 357 pp.

Charzyński P., Bednarek R., Greinert A., Hulisz P., Uzarowicz Ł., 2013b. Classification of technogenic soils according to WRB system in the light of Polish experiences. Roczniki Gleboznawcze – Soil Science Annual 64 (4): 145–150.

Chojnicki J., 2002. Soil-forming processes in alluvial soils of the Middle Vistula River Valley and Żuławy. Fundacja Rozwój SGGW, Warszawa: 5–83 (in Polish).

Classification of Polish Forest Soils (Klasyfikacja gleb leśnych Polski), 2000. Centrum Informacyjne Lasów Państwowych, Warszawa: 123 pp. (in Polish).

Giani L., 1992. Entwicklung und Eigenschaften von Marschböden im Deichvorland der südlichen Nordseeküste. Habilitationsschrift. Oldenburg (in German).

Giani L., Ahrens V., Duntze O., Irmer S.K., 2003. Geo-Pedogenese mariner Rohmarschen Spiekeroogs. Journal of Plant Nutrition and Soil Science, 166: 370–378 (in German).

Google Earth, 2014. Orthophotomaps available on the Google website (19.07.2014).

Hulisz P., 2013. Genesis, properties and systematics position of the brackish marsh soils in the Baltic coastal zone (Geneza, właściwości i pozycja systematyczna marszy brakicznych w strefie oddziaływania wód Bałtyku). Rozprawy habilitacyjne. Wyd. UMK: 137 pp. (in Polish).

IUSS Working Group WRB, 2006. World Reference Base for Soil Resources 2006. World Soil Resources Reports No. 103. FAO, Rome.

IUSS Working Group WRB, 2015. World Reference Base for Soil Resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.

Jankowski M., 2010. Some aspects of site conditions of heathlands in the Toruń Basin. Ecological Questions 12: 145–151.

Kawałko D., Kaszubkiewicz J., 2008. Properties of soils in selected forest habitats of Landscape Park „Jezierzyca River Valley" (Właściwości gleb wybranych siedlisk leśnych na terenie Parku Krajobrazowego Dolina Jezierzycy). Roczniki Gleboznawcze – Soil Science Annual, 59(3/4): 115–121 (in Polish).

Koszka-Maroń D., Jegliński W., 2009. Development of the Vistula River mouth fan. Zeitschrift der Deutschen Gesellschaft für Geowissenschaften, 160: 137–141.

Kowalik P., 2008. Flood control in the Vistula River delta (Poland). Environmental Biotechnology, 4(1): 1–6.

Kowalski T., 1976. State and dynamics of the Vistula River cone and the balance of its deposits since 1953 (Stan i dynamika stożka ujściowego Wisły oraz bilans jego osadów od roku 1953). Instytut Morski, Gdańsk: 76 pp. (in Polish).

Łomniewski K., 1960. The Vistula River mouth (Ujście Wisły). Roczniki Polskiego Towarzystwa Geologicznego, 29(4): 391–417 (in Polish).

Makowski J., 1995. The hundredth anniversary of the creating the Vistula Cross-Cut 1895-1995 (Setna rocznica wykonania Przekopu Wisły 1895 –1995). IBW PAN, Gdańsk (in Polish).

Nickelswalde, 1903. Topographische Karte 1:25 000. Geognostisch-Agronomische Ausgabe, Königlich Preussischen Geologischen Landesanstalt und Bergakademie, Berlin (in German).

Nickelswalde, 1936. Topographic map 1:25 000. Wojskowy Instytut Geograficzny, Warszawa (in Polish).

Orzechowski M., Smólczyński S., Sowiński P., 2005. Sorption properties of alluvial soils in the Żuławy Wiślane (Właściwości sorpcyjne gleb aluwialnych Żuław Wiślanych). Roczniki Gleboznawcze – Soil Science Annual, 56 (1/2): 119–127 (in Polish).

Particle size distribution and textural classes of soils and mineral materials – classification of Polish Society of Soil Science 2008 (Klasyfikacja uziarnienia gleb i utworów mineralnych – PTG 2008), 2009. Roczniki Gleboznawcze – Soil Science Annual, 60(2): 7–16 (in Polish).

Piaścik H., Orzechowski M., Smólczyński S., 2000. Soil habitats of the Vistula River delta (Siedliska glebowe delty Wisły). Roczniki Akademii Rolniczej w Poznaniu 317, Rolnictwo 56: 115–124 (in Polish).

Polish Soil Classification (Systematyka gleb Polski), 2011. Roczniki Gleboznawcze – Soil Science Annual, 62(3): 1–193 (in Polish).

Pracz J., 1989. Properties of soils formed under the influence of saline ground water in the region of the Polish Baltic coast (Właściwości gleb tworzących się przy udziale słonej wody gruntowej w polskiej strefie przybałtyckiej). Rozprawy naukowe i monografie. Wyd. SGGW-AR, Warszawa (in Polish): 91 pp.

Robakiewicz M., 2010. Vistula River mouth – History and recent problems. Archives of Hydro-Engineering and Environmental Mechanics, 57(2): 155–166.

Schroeder D., Brümmer G., 1969. Beitrage zur Genese und Klassifizierung der Marschen. Zeitschrift für Pflanzenernährung und Bodenkunde 122 (3): 228–249 (in German).

Wang N., Li G., Xu J., Qiao L., Dada O.A., Zhou C., 2015. The marine dynamics and changing trend of the modern Yellow River mouth. Journal of Ocean University of China (Oceanic and Coastal Sea Research), 14 (3): 433–445.

Witek J., 1965. Soils of the Żuławy Wiślane (Gleby Żuław Wiślanych). Pamiętnik Puławski, Prace IUNG, 18: 157–266 (in Polish).

Wright L.D., 1985. River deltas. [In:] Coastal sedimentary environments (Davis Jr. R.A., ed.). Springer New York: 1–76.

Wróblewski R., Rudowski S., Gajewski Ł., Sitkiewicz P., Szefler K., Kałas M., Koszałka J., 2015. Changes of the Vistula River external delta in the period of 2009–2014. The Bulletin of Maritime Institute in Gdańsk, 2(1):16–22.

Received: October 27, 2015
Accepted: December 18, 2015

Zmiany pokrywy glebowej spowodowane działalnością człowieka w rejonie ujścia Przekopu Wisły

Streszczenie: Celem badań było określenie wpływu działalności człowieka na powstawanie gleb w rejonie ujścia Przekopu Wisły. Szczegółowe badania przeprowadzono na obszarze testowym (około 500 ha), dla którego została wykonana mapa gleb. Wydzielono trzy główne pasy grupujące gleby wytworzone z osadów morskich, eolicznych i technogenicznych, naturalnie i antropogenicznie zdeponowanych w wyniku regulacji hydrotechnicznych. Do dominujących gleb należą: gleby inicjalne, arenosole, glejowe, marsze i gleby industrialne, które charakteryzują się dużą zmiennością przestrzenną oraz występowaniem profili wieloczłonowych. Ich właściwości odzwierciedlają zróżnicowaną dynamikę środowiska w skali lokalnej po obu stronach kanału, znacznie spotęgowaną przez działalność człowieka. Na podstawie uzyskanych wyników przedstawiono propozycje modyfikacji Systematyki gleb Polski (2011). Dotyczą one arenosoli, marszy oraz gleb industroziemnych (wytworzonych z osadów technogenicznych).

Słowa kluczowe: przekształcenia antropogeniczne, regulacje hydrotechniczne, ujście rzeki, klasyfikacja gleb, mapy gleb, Wisła