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Origin, transformation and classification of alluvial soils (mady) in Poland – soils of the year 2022

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Abstract

The Soil Science Society of Poland has elected alluvial soils (Polish: mady) to be the Soils of the Year 2022. Although alluvial soils cover less than 5% of Poland, they have high importance for agriculture and forestry due to their specific location in river valleys, moisture status and high potential productivity. Moreover, alluvial soils play crucial role for functioning of many protected natural and semi-natural ecosystems in river valleys. Stratified alluvial soils, commonly involving buried topsoil horizons, are also important for the reconstruction of natural environmental changes (in particular climatic and hydrological ones) and human impact on the landscape. This paper presents: (a) a concept of alluvial soils in Poland; (b) a review of the development and transformation of alluvial soils in relation to river valley dynamics and human influences, (c) historical and present classification schemes for alluvial soils in Poland and their correlation with international classification systems (WRB and Soil Taxonomy); and (d) utility of alluvial soils for agriculture and forestry based on their physicochemical properties and water regime.

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1. Introduction

The soils of river valleys have always been considered moist and fertile, thus preferentially suitable for agricultural production (Borkowski and Mikołajczak, 1993; Dąbkowska-Naskręt, 1990; Flis-Bujak and Darwish, 1995; Marcinek, 1988). Many famous ancient cultures in the Near East, China and Americas started their development in the river valleys, exploring the resources of alluvial soils (Bunbury, 2019; Kidder and Liu, 2017; Lima et al., 2022; Sherratt, 1980). The high productivity of alluvial soils results from seasonal flooding and accumulation of the fine mineral and organic particles, as well as from chemical precipitation of substances dissolved in the river water (Tomaszewski, 1959). Moreover, the regular flooding or at least seasonally high ground water level maintain the high moisture content in the alluvial soils (Bednarek and Sowiński, 2000; Kercheva et al., 2017; Łabaz and Kabała, 2016; Niedźwiedzki et al., 2010b; Olszewska and Pływaczyk, 2013). However, spatially diversified morphology of the river valleys, related to instable long-term behaviour of the rivers, leads to large differentiation of environmental conditions and soils in the river valleys (Dyderski and Wrońska-Pilarek, 2015; Roj-Rojewski and Banaszuk, 2004). The groundwater level in some sections of the valley may be very high during the majority of the year, thus reducing conditions may occur permanently, leading to the development of gleyic properties throughout the soil profiles or even to an accumulation of organic matter (Banaszuk, 1996, 2000; Kalisz and Łachacz, 2008; Malinowski, 2007; Marcinek and Komisarek, 2004; Okruszko, 1969; Roj-Rojewski and Walasek, 2013; Zawadzki, 1980). These specific properties result in soil classification as Gleysols or Histosols, which are not involved in the definition of alluvial soils. In Poland, the term 'mady' (singular: 'mada'), used here as a synonym of alluvial soils, includes mineral soils developed from fluvial sediments and occurring on Holocene terraces (thus excluding soils developed from older, e.g. Pleistocene river sediments), which still preserve alluvial stratification in their profiles and are not gleyed near the soil surface (Kabała et al., 2019).

Large agricultural potential of alluvial soils as well as attractiveness of the valley landscapes for human settlement have resulted in a large-scale transformation of the river valleys, commonly involving the river canalization and soil drainage (Jarosińska, 2016). The regulation projects have resulted in an elimination of flooding and in a decrease and stabilisation of the ground water level in the valley, which led to significant environmental changes (Brandyk and Skąpski, 1993; Chojnicki, 2002; Cieśla, 2009; Kabała et al., 2011). Therefore, the knowledge about the transformation of alluvial soils has large importance for agriculture, forestry, spatial management, water and waste-water management, as well as for climate regulation and nature conservation. Soil Science Society of Poland has elected the alluvial soils ('mady') the Soils of the Year 2022 to focus the society interest on these soils, by gathering the existing knowledge and highlighting the gaps and further research needs, as well as to increase the national awareness of the alluvial soils' roles and services.

2. Alluvial soil formation and pedogenic transformation

Although the concept of 'mady' comprises presently the soils developed from the material accumulated in river, lacustrine, and marine environments, in Poland it has been studied mainly in the river valleys. The lacustrine sediments commonly consist of highly organic or calcareous deposits, which transform into organic soils or specific lacustrine rendzinas after lake drainage (Jonczak and Florek, 2013; Lemkowska, 2013; Łachacz and Nitkiewicz, 2021; Mendyk et al., 2015). Moreover, soils developed from lacustrine sediments, even after drainage, commonly maintain high ground-water level and meet the criteria for gleyed soils (Markiewicz et al., 2017; Mendyk et al., 2016). The soils developed from the marine sediments on the coast of Baltic Sea typically are featured by extremely sandy texture and high ground-water level; whereas the older/drained marine sands suffer from eolian remodelling and lose their original (water-originated) stratification. Therefore, soils considered marine fluvial soils ('mady morskie', 'marsze') have been identified in isolated and small patches only (Hulisz, 2016).

The formation of 'mady' has been identified as a specific process of an interweaving sedimentation of parent material and development of pedogenic features (Tomaszewski, 1959). The first remark of pedogenic transformation of alluvial soil is a development of a thin humus-enriched topsoil horizon, supported by sedimented allochthonous organic matter and abrupt colonization of alluvial sediments by living organism (Dyderski and Wrońska-Pilarek, 2015; Furtak et al., 2019, 2021). The rapid formation of the humus-rich topsoil horizon may be hampered in some cases. Coarse textured sediments, consisting mainly of gravel or stones, occuring in the valleys (or valley sections) of high-energy mountain and sub-mountain rivers, do not contain fine mineral and organic particles, have little water retention and fertility, and thus do not support succession of living organisms (Kabała et al., 2013; Kasprzak, 1979; Skiba and Drewnik, 2001). Furthermore, large activity of the downward and lateral river erosion may lead to destruction and relocation of recent alluvial sediments, together with developing humus horizons (Plesiński, 2018).

The aforementioned phenomena may have a specific evidence in the non-ploughed bottoms of the non-regulated river valleys with large seasonal or annual regularity of flooding. In such case, the humus-enriched horizons have a little thickness (commonly 1–3 cm) and their further thickening is hampered by coverage with new humus-poor mineral materials deposited during the next flooding season (Teisseyre, 1988). The latter case is considered to occur rarely in contemporary Poland. First of all, the river valleys and water flow are commonly regulated, which results in a hampering of flooding at all, or at least their rare and irregular occurrences, with flooding limited to the narrow inter-dike zone, as well as to significant decrease in the volume of deposited sediments (Chodak et al., 1999; Kusza and Ciesielczuk, 2008; Piaścik et al., 1998; Szerszeń et al., 2000). All these reasons reduce or eliminate the first component of alluvial process, i.e., the continuous upbuilding of parent material, lead to stabilization of soil surface and allow rapid pedogenic transformation, in particular if connected with arable land use (Kawałko, 2021; Ligęza, 2016). Even excluding ploughing, many flooding terraces are presently covered with a dense meadow of pasture vegetation, supporting an effective involvement of the sediments into organic-mineral complexes, forming the dark-coloured granular structure and supporting the 'grow-up' of the humus-rich topsoil horizon (Tomaszewski, 1959; Zawadzki, 1980).

In the non-managed soils, the topsoil humus horizon thickness typically does not exceed 20 cm, but it is rich in organic matter (often >5% of soil organic carbon, SOC), has a stable fine granular structure and high biological activity (Banaszuk, 2000; Niemyska-Łukaszuk et al., 2004; Skiba et al., 2006). In managed soils, the thickness of topsoil A horizon reflects the depth of ploughing and may reach 40 cm and more (Chojnicki 2002; Dąbkowska-Naskręt, 1990). Thicker A horizons typically are bi- or tripartial due to their multistep or polygenetic origin, i.e., older soil burial with younger sediments, episodes of ponding, mechanical disturbances connected with bog iron mining, deforestation and deep 'ameliorative' ploughing, etc. (Kabała et al., 2011a; Łabaz an Kabała, 2012; Żyromski et al., 2016). Excluding extremely sandy dry soils, these A horizons typically contain 2–5% of SOC, have very dark grey colours (Munsell value and chroma ≤3) and strong granular structure (Bieganowski et al., 2013; Łabaz an Kabała, 2016). The lower boundary of A horizons typically is abrupt or clear (Fig. 1), confirming the human contribution to their formation (Głąb and Gondek, 2013). Nevertheless, it is clear that the high humus content and stable aggregate structure have developed in natural way under higher moisture, typical for alluvial soils (Malinowski, 2007; Pranagal and Ligęza, 2011). Particularly high content of SOC was reported from soils initially having thin organic topsoil layer (peat, gyttja or mursh), mixed with mineral subsoil after soil was drained (Łabaz an Kabała, 2016; Łachacz and Nitkiewicz, 2021; Roj-Rojewski and Walasek, 2013; Rytelewski, 1965).

In the non-drained and imperfectly drained sites, the A horizon is typically directly underlain with gleyed subsoil horizons (Hulisz et al., 2015; Kacprzak et al., 2012; Laskowski and Szozda, 1985). In the lowland river valleys featured by seasonally alternating ground-water level and redox conditions, an accumulation of iron (and manganese) may intensely occur in subsurface layer, leading to the formation of hard nodules/concretions or layers called "bog iron" (PL: żelaziak, ruda darniowa; Fig. 1c). In case of long-term accumulation, the nearly continuous cementation with iron may develop in the layer, those thickness could reach 100 cm (Czerwiński and Kaczorek, 1996). Due to intense exploitation of the 'bog iron' since the early medieval period, the

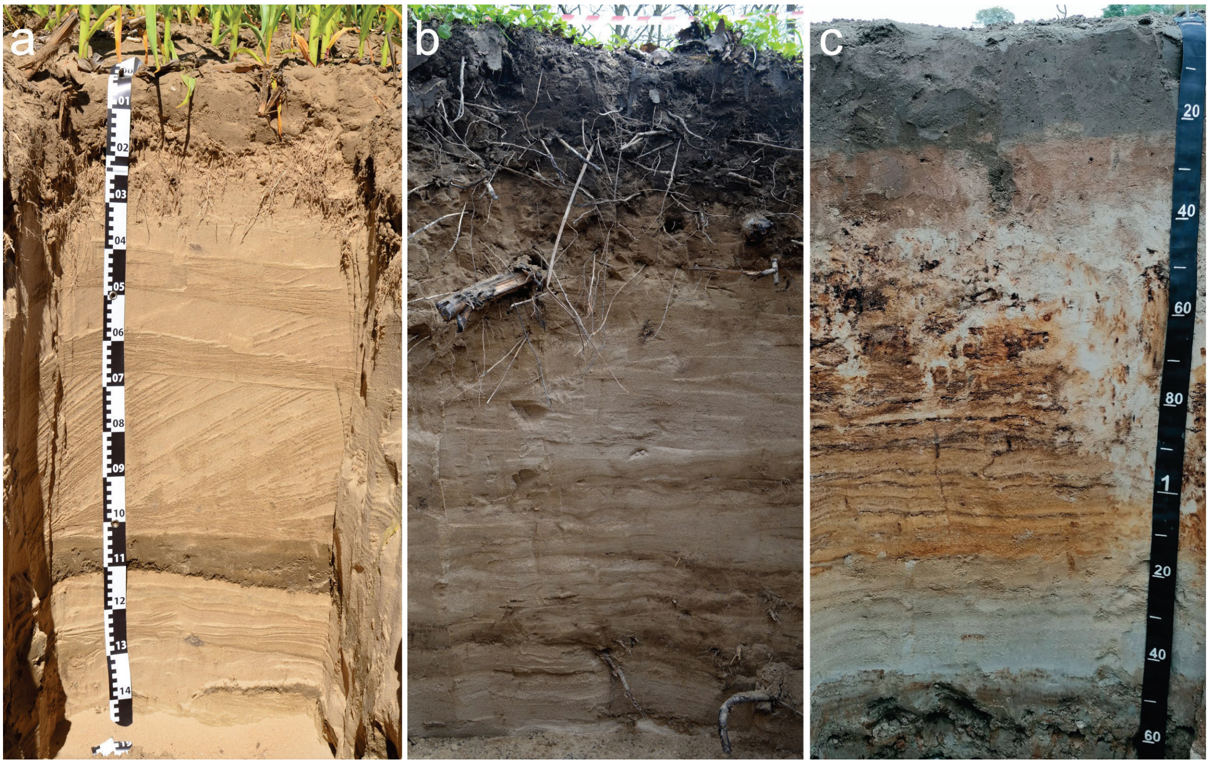

Fig. 1. Alluvial soils of Poland: (a) typical ordinary alluvial soil (SGP: 'mada właściwa typowa') with buried A horizon – WRB: Eutric Fluvisol (Pantoarenic, Ochric, Panpaic); (b) humic rusty alluvial soil (SGP: 'mada rdzawa próchniczna') – WRB: Brunic Fluvic Phaeozem (Katoarenic, Aric); (c) humic rusty alluvial soil with bog iron (SGP: 'mada rdzawa próchniczna (rudawcowa, głęboko gruntowo-glejowa)') – WRB: Brunic Fluvic Phaeozem (Arenic, Limonic, Endogleyic). Abbreviations: SGP – Polish Soil Classification (Systematyka gleb Polski, 2019), WRB – World Reference Base for Soil Resources (IUSS Working Group WRB, 2022)

horizons enriched with Fe/Mn-enriched rarely at present have a thickness larger than 30 cm and typically are not cemented continuously, but contain crushed Fe/Mn-nodules of various size giving the total Fe content up to 30% (Czerwiński and Kwasowski, 2001; Kaczorek and Sommer, 2003; Kalembasa et al., 2001; Wicik, 2001). Such features have been recently defined in WRB classification as limonic diagnostic horizon (IUSS Working Group WRB, 2022).

After river regulation and soil drainage, the mean groundwater level decreases that permanently changes the redox conditions at least in the upper part of the alluvial soil profiles. The change of moisture regime is well visible in both coarse-textured (sandy) and fine-textured (loamy) soils. The oxidation of dispersed Fe/Mn compounds may be particularly rapid in sandy layers and produce the homogeneously rusty-coloured horizon (Dąbkowska-Naskręt, 2000). Whereas in drained loamy horizons, the stagnic colour pattern subsequently replaces the formerly dominant gleyic colour pattern (Kawałko et al., 2021) (Fig. 2b-c). Also, the decrease of groundwater level allows deeper penetration of plant roots, extending the range of biochemical processes occurring in the rhizosphere (Ellis and Atherton, 2003; Makeschin, 1997; Zeitz and Velty, 2002), thus leading to the development of morphological and structural features of B horizon (Strzemski, 1955) (Fig. 2a). In Poland they have designation of Bw or Bv, in fine-textured or sandy soils, respectively (Kawałko et al., 2021; Systematyka gleb Polski, 2019). Pedogenic processes, including the bioturbation, lead to the blurring of initial stratification of alluvial material, homogenization of the brownish or rusty colours, and development of pedogenic structure, that is, most commonly, strong subangular blocky (with transitions to angular blocky) in fine-textured soils, and weak, fine subangular blocky in sandy soils (Kawałko et al, 2021). The subsurface B horizons occur in many varieties, differing in thickness, texture, colour, structure and physicochemical properties. If enough thick, it meets typically the criteria of loamy/silty kambik (Bw) or sandy siderik (Bv) horizon. The distinction between Bw and Bv horizons may not be obvious in case of texture variability within B horizon, inherited from initial macro-stratification of the fluvial material (Kawałko et al., 2021). Among the phenomena mentioned above, the formation and properties of topsoil A horizons in the alluvial soils are directly affected by human activity and often have recognisable anthropogenic features (Łabaz and Kabała, 2016; Rytelewski, 1965; Żyromski et al. 2016), whereas the subsurface Bw/Bv horizons develop naturally, under indirect human impact only (Chojnicki, 2002; Strzemski, 1955).

Initial stratification of the parent material, blurred by pedogenic processes in the upper layers of alluvial soils, is typically still preserved in the middle and bottom parts of soil profiles and is a diagnostic feature for a recognition of alluvial soils ('mady') (Fig. 1–3). In the drained, well developed soils, having especially thick Bw/Bv horizons, recognizable stratification may start deeper than 100 cm from the soil surface (Żyromski et al., 2016) or below the groundwater table in case of its high mean level (Roj-Rojewski and Walasek, 2013). Also, the recognition of

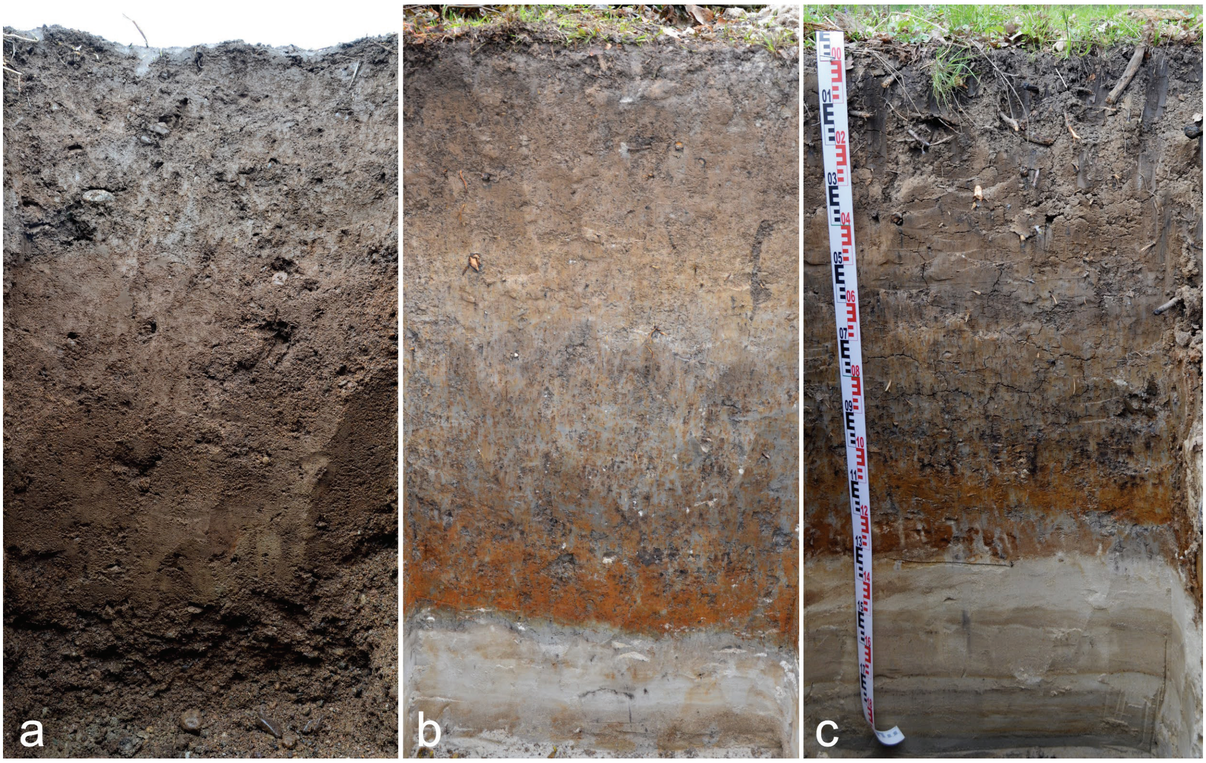

Fig. 2. Brown alluvial soils of Poland: (a) humic brown alluvial soil (SGP: 'mada brunatna próchniczna') – WRB: Eutric Endoskeletic Cambisol (Anoloamic, Endoarenic, Aric, Ochric, Bathyfluvic); (b) stagnogleyic brown alluvial soil (SGP: 'mada brunatna opadowo-glejowa') with gleyic properties in the deep subsoil – WRB: Eutric Stagnic Cambisol (Pantoloamic, Ochric, Bathyarenic, Bathyfluvic, Bathygleyic); (c) stagnogleyic humic brown alluvial soil (SGP: 'mada brunatna próchniczna opadowo-glejowa') – WRB: Cambic Fluvic Stagnic Phaeozem (Pantoloamic, Bathyarenic, Bathygleyic). Abbreviations: as in Fig. 1.

the diagnostic fluvic material may be difficult if the macro-stratification occurs, with single sandy/loamy strata thicker than 30–40 cm (Latocha, 2007; Ligęza, 2008; Mazurski, 1976; Myślińska et al., 1982) (Fig. 3 and 4b).

3. Development of the definition and classification schemes of alluvial soils in Poland

Alluvial soils, due to their specific location, parent material and properties, were traditionally distinguished as a single, separate high-level category in soil classifications and maps in Poland. Miklaszewski (1930) distinguished the sub-groups of alluvial soils based on their texture, water regime and location within the river valley, and did not recognise subunits related to development stage. It must be, however, stressed, that Miklaszewski did not agree with Ramann's concept of Braunerden, thus he did not recognise the brown horizon in any Polish soils, including the alluvial ones.

The position of alluvial soils in Polish classification schemes published in 1950s was vawing. They were listed as separate landscape-related category at the highest level with various subcategories, initially related to their texture (Białousz, 2022). The range of further derived subcategories, such as 'ordinary alluvial soils' (mady właściwe), 'brown alluvial soils' (mady brunatne) and 'humus-rich alluvial soils' (mady próchniczne) was not clearly stated as the soil type or subtype (Przyrodniczo-genetyczna klasyfikacja gleb Polski, 1956; Genetyczna klasyfikacja gleb Polski, 1959). The 3rd and 4th editions of the Polish soil classification (Systematyka gleb Polski, 1974, 1989) merged all three above mentioned units as subtypes of the 'river-alluvial soils' (mady rzeczne) type, combined in an order of 'fluvial soils' (gleby napływowe) together with the 'marine-alluvial soils' (mady morskie) and 'colluvial soils' (gleby deluwialne) types. The alluvial soils at the initial development stage were placed in 'regosols' type (gleby inicjalne luźne') together in other raw soils developed of loose sediments. An introduction of diagnostic horizons (Systematyka gleb Polski, 1989), that allowed recognitting the cambic and mollic horizons in 'brown alluvial soils' and "humus-rich alluvial soils', respectively, did not change their placement as subtypes of the 'river-alluvial soils' type. Such a classification of alluvial soils in Poland was consistent with the early FAO and WRB schemes, where all soils with fluvic material were merged into Fluvisols group, placed at very high position in the key, irrespectively of the presence of other mineral diagnostic horizons or properties (World Reference Base for Soil Resources, 1998).

The fundamental change in alluvial soil classification in Poland was launched after Fluvisols' shifting to a distant position in the WRB key to soil reference groups (IUSS Working Group WRB, 2006). After this change, soils having fluvic properties, but also having mollic, umbric, cambic or other diagnostic horizons, or gleyic/stagnic properties, are classified in reference groups respective to particular diagnostics (e.g. Gleysols, Stagnosols, Phae-

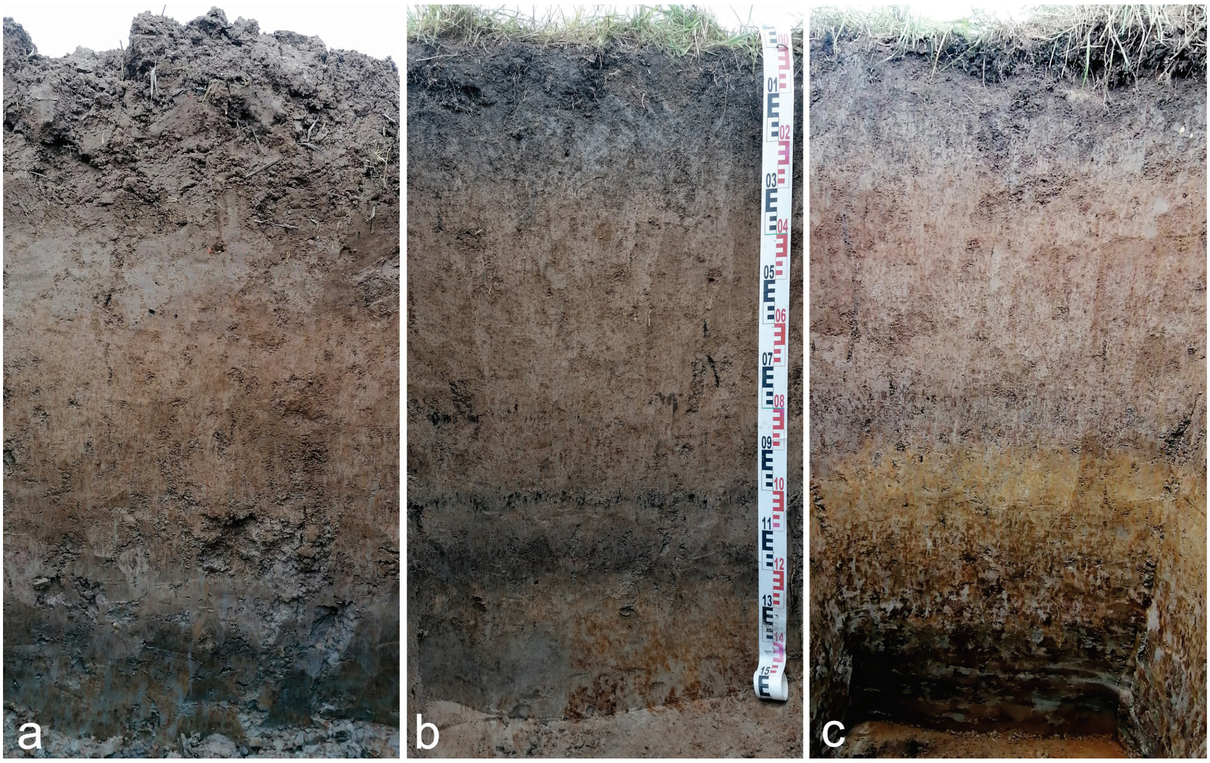

Fig. 3. Brown alluvial soils of Poland: (a) stagnogleyic humic brown alluvial soil (SGP: 'mada brunatna próchniczna opadowo-glejowa') – WRB: Eutric Stagnic Cambisol (Pantoloamic, Aric, Ochric, Panpaic); (b) stagnogleyic humic brown alluvial soil (SGP: 'mada brunatna próchniczna opadowo-glejowa') – WRB: Cambic Stagnic Phaeozem (Pantoloamic, Bathyarenic, Bathyfluvic, Bathypanpaic); (c) stagnogleyic humic brown alluvial soil (SGP: 'mada brunatna próchniczna opadowo-glejowa') – WRB: Cambic Fluvic Stagnic Phaeozem (Pantoloamic, Bathyarenic, Bathypanpaic). Abbreviations: as in Fig. 1.

ozems, Umbrisols, Cambisols, etc.), i.e., reflecting the stage of soil development. This change made WRB more consistent with Soil Taxonomy, where soils developed from alluvial sediments, but having the diagnostic horizons, are respectively classified to Mollisols, Inceptisols, or other orders (USDA-NRCS, 2014). Following this concept, the alluvial soils in the 5th edition of Polish soil classification were placed in different orders, respectively to their developments stage and diagnostic horizons and properties identified in their profiles (Systematyka gleb Polski, 2011), still retaining their traditional Polish names (Kabała et al., 2016; Świtoniak et al., 2019). Unfortunately, due to the lack of the key to orders/types, the distinction between variably gleyed alluvial soils and Gleysols was still imperfect (Kabała, 2014). The position of alluvial soils in the recent, 6th edition of the Polish soil classification (Systematyka gleb Polski, 2019) is as follows:

(a) mineral soils developed from recently settled alluvia, having the joint thickness of O, A, and B horizons (if present) up to 10 cm, belong to 'loose raw soils' type (gleby inicjalne luźne) in the order of 'poorly developed soils'

(b) mineral soils (i) located on the Holocene age terraces, (ii) developed from alluvial sediments and retaining fluvial stratification within their profiles, (iii) having the joint thickness of O, A, and B horizons more than 10 cm, but (iv) not having any mineral diagnostic horizon and (v) not having gleyic or stagnic properties starting at shallow depth, belong to 'ordinary alluvial soils' type (mady właściwe) in the order of 'poorly developed soils' (Fig. 1);

(c) mineral soils (i) located on the Holocene age terraces, (ii) developed from alluvial sediments and retaining fluvial stratification within their profiles, (iii) having a kambik (fine-textured) or siderik (sandy-textured) horizon, and (iv) not having mollik/umbrik horizon or gleyic/stagnic properties starting at shallow depth – belong to 'brown alluvial soils' type (mady brunatne) in the order of 'brown earths' (Fig. 1–3);

(d) mineral soils (i) located on the Holocene age terraces, (ii) developed from alluvial sediments (fluvic material) and still retaining fluvial stratification within their profiles (i.e., starting no deeper than 150 cm from the soil surface), and (iii) having mollik or umbrik horizon – belong to 'chernozemic alluvial soils' type (mady czarnoziemne) in the order of 'chernozemic soils' (Fig. 4).

As stated above, the alluvial soils are in four types in three soil orders. The common required features of the alluvial soils are their location on Holocene terraces and the presence of fluvial stratification starting within 150 cm from the soil surface. However, as signalised previously, some soils located on alluvial sediments are intentionally excluded from the concept of 'mady'. In particular soils with organic layer of any origin, thicker than 30 cm, irrespectively of the kind and origin of underlying mineral layers, belong to the order of 'organic soils'. Furthermore, a transitional position is occupied by soils with arenimurszik horizon, defined as a thick (>30 cm), very dark topsoil layer, having a sandy texture. Arenimurszik horizon has high content of or-

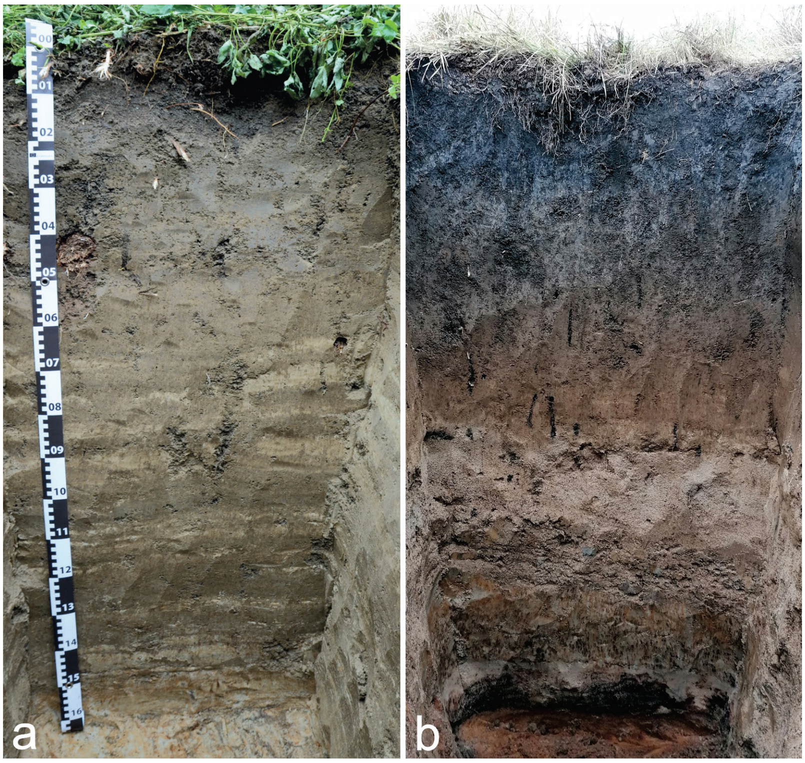

Fig. 4. Chernozemic alluvial soils of Poland: (a) typical chernozemic alluvial soil (SGP: 'mada czarnoziemna typowa') – WRB: Fluvic Phaeozem (Pantoloamic, Pachic; Bathystagnic); (b) brown chernozemic alluvial soil (SGP: 'mada czarnoziemna zbrunatniała') over buried brown alluvial soil – WRB: Cambic Endostagnic Phaeozem (Anoloamic, Endoarenic, Bathyfluvic). Abbreviations: as in Fig. 1.

ganic matter (but no more than 20% of soil organic carbon) derived from the degradation of peat or similar organic material, responsible for a specific structure and moist/dry behaviour of the horizon (Łabaz and Kabała, 2016). Soils with arenimurszik horizon belong to 'post-mursh soils' (gleby murszowate) in the 'chernozemic order', even if they have fluvic material in the subsoil. And finally, soils located in the river valleys, featured by strongly marked gleyic or stagnic properties starting close to soil surface, but lacking the mollik/umbrik/arenimurszik horizons, are placed in the order of 'gleyed soils'. Theexclusions mentioned above result from the positioning of particular soil orders and types in the key to Polish soil classification (Kabała et al., 2019).

The units/subunits of alluvial soils named after Polish soil classification correlate well with the units of WRB and Soil Taxonomy (IUSS Working Group WRB, 2022; Kabała et al., 2016, 2019). 'Chernozemic alluvial soils' (mady czarnoziemne) with mollik/mollic horizon belong in majority to Fluvic Phaeozems (WRB) and Fluventic/Fluvaquentic Hapludolls (Soi Taxonomy). 'Brown alluvial soils' (mady brunatne) are easily correlated with Fluvic Cambisols (Fluventic/Fluvaquentic Eutrudepts) if they have a kambik/cambic horizon, or with Brunic Fluvisols (Udipsamments) if they have a sandy siderik horizon. The 'ordinary alluvial soils' (mady właściwe) are in majority correlated with Eutric Fluvisols (Udifluvents if silty/loamy or Udipsamments if sandy). The 'loose raw soils' consisting of fine-textured alluvial material starting from the soil surface belong to Pantofluvic Fluvisols (Udifluvents/ Udipsamments), while the 'loose raw soils' consisting mostly of gravelly/stony alluvial material belong to Coarsic Leptosols (Udifluvents) (IUSS Working Group WRB, 2022). However, the alluvial soils, classified according to WRB as Cambisols or Phaeozems receive the principal qualifier Fluvic if the fluvic material starts no deeper than 75 cm from the soil surface. If the alluvial stratification occurs deeper, the Bathyfluvic may be applied among the supplementary qualifiers (Fig. 2b). Furthermore, some alluvial soils classified as Fluvic Phaeozem, having a mollic horizon 20–30 cm thick, are in Poland classified as brown or ordinary alluvial soil rather than chernozemic alluvial soils because Polish soil classification (Systematyka gleb Polski, 2019) recognizer the mollik horizon if it is at least 30 cm thick.

4. Crucial properties of alluvial soils in Poland

Alluvial soils are among the most diversified soils in terms of their morphology, texture and physicochemical properties, which may variate in three 'dimensions' in the river valley: horizontally along river course and in the valley cross-section, and vertically within each soil profile (Myslińska et al., 1982; Strzemski, 1955). The differentiation of soil texture between the upper, medium and lowermost sections of the river valley is affected by water flow energy related to general inclination of the landscape and relative differences in an altitude, as well as the abruptness of the floods (Teisseyre, 1988). As a result, stony/gravelly alluvial soils occur mainly in the mountainous sections of the valleys (Kabała et al., 2013; Mazurski, 1976; Niemyska-Łukaszuk et al., 2004; Skiba and Drewnik, 2001), sandy- and sandy-loamy-textured soils prevail in the middle parts of valleys (Kabała et al., 2015; Kawałko et al., 2021; Ligęza, 2016; Pranagal and Ligęza, 2011), while silty-clayey textures prevail in the lowermost sections of the long river valleys (Brandyk, 1988; Malinowski et al., 2004; Orzechowski and Smólczyński, 2010b; Piaścik et al., 1998). However, it is only a general rule, because the local sources of eroded material may greatly affect the texture of soils in neighbouring valleys, in particular of smaller rivers (Jonczak, 2015; Kabała et al., 2002, 2011; Kacprzak et al., 2012; Niedźwiedzki et al., 2010a). Textural soil differentiation along the valley cross-section was early characterized e.g. by Miklaszewski (1930), who indicated that the soils on the natural flood dikes developed along the river channel typically have sandy texture (so-called Naspa soils), while the soils in more distant positions on the flooding terrace have finer texture due to 'trapping' of the flooding water and dispersed fine particles. This general rule is blurred in meandering river valleys, where many series of the arc-shaped sandy bands occur parallely (Fig. 5).

Similarly important in terms of local land use planning and crop selection is the vertical differentiation of the texture within soil profiles. It is observable in all sections of the river valley, but it is most prominent probably in the upper and middle valleys, where the dominant sandy deposits are commonly interbedded or covered with finer sediments. It is accepted that the primary reason of the development of loamy and silty topsoil strata is a human-triggered erosion in the highland areas, in particular in the loess-covered south Poland (Latocha, 2007; Zawadzki, 1980). Originally, the term 'mada' was applied to fine-textured alluvial topsoil sediment only, that excluded alluvial sands (Miklaszewski, 1930; Strzemski, 1955; Tomaszewski, 1959). This point of view was applied in the classification of alluvial soils for agricultural purposes into thin, medium, and thick, which reflected the thickness of the silty/loamy-textured topsoil layer (to the contact with underlying sandy sediments) (Strzemski et al., 1973). The highest agricultural value (1^{st}–2^{nd} class of arable lands in a nine-class scale) have soils with the silty texture throughout the profile or in at least 100–120 cm thick topsoil layer (and drained). Whereas the alluvial soils with 40–50 cm thick loamy/silty topsoil layer (and drained) belong to the 4^{th} class at maximum (Strzemski et al., 1973).

Such a variable evaluation of alluvial soils, reflecting their different potential productivity, and its close relation to soil texture results from huge impact of the texture on soil properties, well documented in many research papers. The higher content of clay and silt fractions, as well as larger thickness of fine-textured topsoil layer clearly improves the water retention and decides, by capillary rise, about soil reaction on the drainage and groundwater drop (Borek and Bogdał, 2018; Brandyk, 1988; Brandyk and Skąpski, 1993; Malinowski, 2007; Owczarzak et al., 2007; Piaścik et al., 1998; Pranagal and Ligęza, 2011; Witkowska-

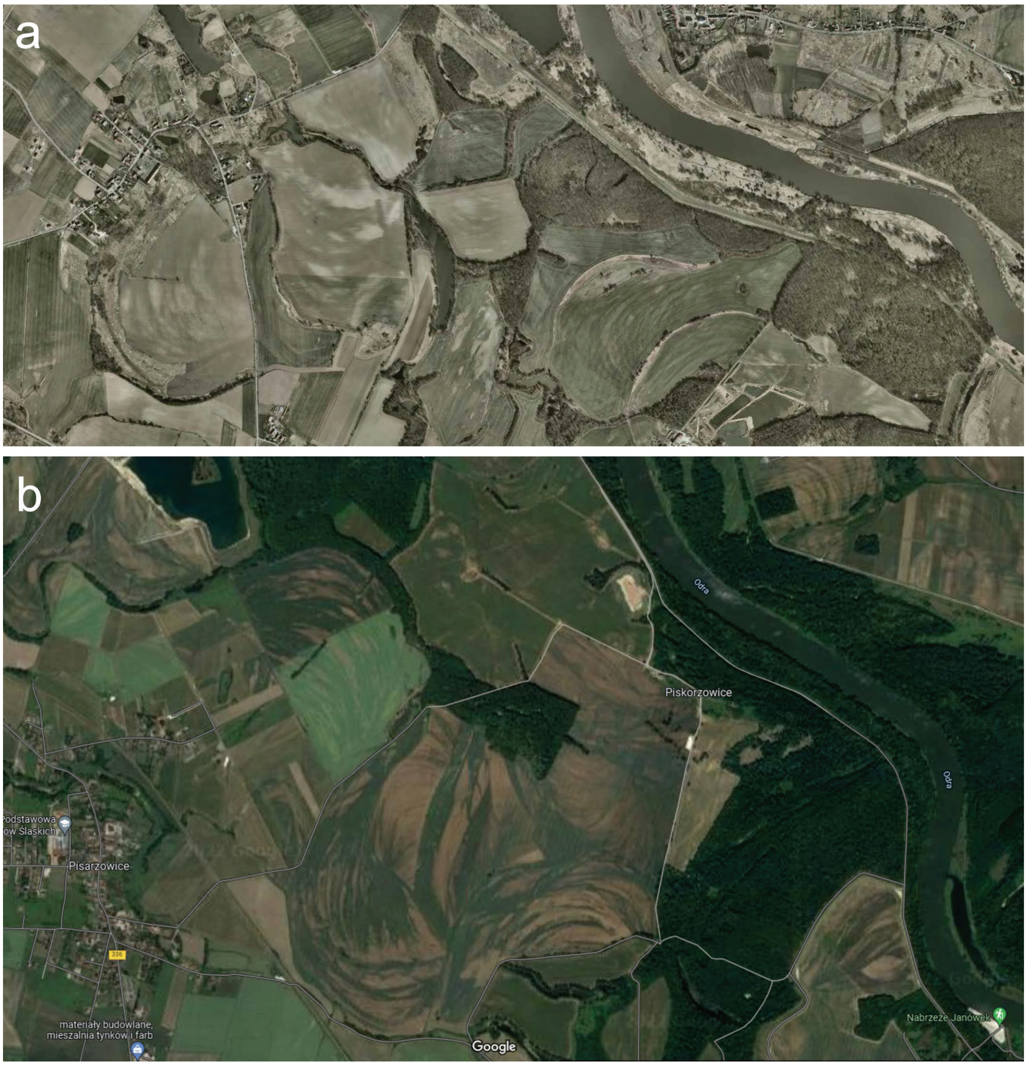

Fig. 5. Spatial variability of alluvial soils in the valley of the large meandering lowland river (Odra river below Wrocław, SW Poland): (a) lighter and darker arc-shaped stripes within former meanders indicate differences in soil moisture related to sand- and loam/silt-dominated topsoil texture, respectively; (b) brownish and greenish stripes/sections indicate differences in soil moisture related to higher and lower microrelief, respectively.

Walczak et al., 2000). These reports have documented large water capacity of heavy-textured alluvial soils, particularly in the Wisła delta, while susceptibility for drought (after drainage) of coarse-textured soils in the valleys of central and southern Poland. Fine-textured topsoil horizons of alluvial soils have high exchange cation capacity and ability to adsorb macronutrients, as well as support stabilisation of organic matter (Banach-Szott et al., 2018; Brogowski and Okołowicz, 2008; Brogowski and Kwasowski, 2014; Dąbkowska-Naskręt, 1990; Długosz et al., 2018; Kabała et al., 2002; Kalembasa and Becher, 2010; Kobierski and Banach-Szott, 2022; Kobierski et al., 2010; Malinowski, 2008; Malinowski et al., 2004; Niedźwiedzki et al., 2011; Orzechowski et al., 2005; Woźniak, 1998). Strzemski et al. (1973) have concluded that the thickness of the fine-textured topsoil (above the sandy subsoil), along with the depth of mean groundwater table, decide about the productivity of arable alluvial soils in Poland.

Particularly high impact of clay fraction in alluvial soils in Poland on the cation sorption capacity has its explanation in the composition of the clay fraction, i.e., in a predominance of smectites and their interlayers with illite. The other minerals, such as 'pure' illite, chlorite, vermiculite and kaolinite have a minor importance, irrespectively of geographical location of the valley and soils under investigation (Chodak and Perlak, 1999; Cieśla et al., 1988; Dąbkowska-Naskręt and Długosz, 1996; Kabała et al., 2009).

In contrast to arable soils, the texture and physicochemical properties of alluvial soils seem to have lesser importance for the quality and differentiation of the forest habitats (Andrzejczyk and Sewerniak, 2016; Łabaz et al., 2016). The hydrological conditions, such as the depth and quality of groundwater and the occurrence and regularity of flooding (Cieśla, 2009; Kowalska et al., 2019) have primary importance and decide about the differentiation of forest habitats and forest communities into wet alder forests, alder-ash riparian forests, and transitional oak/oak-hornbeam forests (Wanic et al., 2011). In general, the habitats on the alluvial soils are among the most fertile forest habitats, if considering the soil quality indexes, biological activity, rates of organic matter decomposition, and the composition of the forest floor vegetation (Błońska et al., 2019; Kaczmarek et al., 2010; Kawałko et al., 2017).

After the great floods in Odra and Wisła valleys in 1997–2000, the contamination of the river sediments and alluvial soils with trace elements and organic xenobiotics got a particular attention (Cebula and Ciba, 2005; Ciszewski et al., 2008; Maliszewska-Kordybach et al., 2013). Numerous investigations, launched in the valleys of both large (Bartkowiak et al., 2013; Czarnowska et al., 1995; Czarnowska and Turemka, 1997; Dąbkowska-Naskręt and Kędzia, 1996; Gambuś and Grabowski, 1996; Kobierski, 2015; Kobierski and Piotrowska, 2010) and smaller rivers (Glińska-Lewczuk et al., 2014; Kabała et al., 2008; Kalembasa et al., 2007; Kawałko et al., 2007; Kud and Woźniak, 2000; Malinowski, 2007; Orzechowski and Smólczyński, 2010a; Zgłobicki et al., 2016) have reported raised concentrations of Zn, Cu, Pb, Cd, As, Ni, and Hg in many sites; however, the contamination exceeding the legal limits was reported rarely, in a close vicinity of large towns or metal mining and smelting facilities (Krysiak and Karczewska, 2007; Lewandowski et al., 1998; Pisarek and Żarczyńska, 2002; Szerszeń et al., 1983). The fractionation studies indicated prevailing binding of trace elements to iron oxides and organic matter among mobile forms, but in general strong binding with clay minerals in immobile forms (Bartkowiak, 2012; Chojnicki, 2001; Czarnowska and Szymanowska-Sienczewska, 1999; Kobierski, 2013; Różański, 2013).

5. Spread, land use and threats for alluvial soils in Poland

Although the area covered with alluvial soils in Poland is estimated at ca 15,600 km^2 that makes ca 5% of total territory only (Bednarek and Prusinkiewicz, 1997), the soils are well marked on the soil maps due to their linear continuity along the river valleys (Białousz, 2022). The largest areas of alluvial soils were recognised in the lowland valley sectors of the great rivers such as Odra and Wisła, in particular in the lowermost deltaic section of Wisła valley, known as Żuławy Wiślane (Orzechowski and Smólczyński, 2010b; Piaścik et al., 1998; Witek, 1965). As long as till 1950s, nearly 70% of alluvial soils in Poland were utilized as extensive, flooded meadows and pastures, but the percentage of arable lands rapidly increased since 1960s due to flood protection dikes construction and large-scale soil drainage (Strzemski et al., 1973). Whereas, the area covered with forests in the river valleys seems relatively stable due to legal protection of the existing stands and avoiding of new afforestation in the flooding zone (Danielewicz, 1993).

More detailed information on the alluvial soil distribution and land use are available for few regions only, where the information from forest and agricultural soil maps and databases was compiled. Such a compilation for the Lower Silesia region (SW Poland) was done by Kabała et al. (2015) based on digital forest habitat maps (on a scale 1:10,000), digital agricultural soil maps (scale 1:25,000), and digital soil maps for the Karkonosze Mountains and Stołowe Mountains National Parks (scale 1:5,000). The soil subtypes missing in the agricultural soil maps were approximated based on the suggestions of Świtoniak et al. (2019), expert knowledge and controlled soil profiles. The alluvial soils cover 11.1% of the Lower Silesia territory, mainly in the Odra and Barycz valleys (Kabała et al., 2015). Only 15% of these alluvial soils is covered with forests, while the other 35% is arable and 50% in the meadows and pastures. The latter two numbers seem outdated, probably reverse, due to large decrease in livestock production and ploughing of the former meadows/pastures after Poland joined the European Union, but still are not updated in the databases (Woźniak-Kostecka et al., 2019). If compared to the total area of particular land use types in the Lower Silesia, alluvial soils create 6.5% and 12.8% of the afforested and agricultural areas of the region, respectively. Approximation of the subtypes (joint data for arable, afforested and grassland areas) suggests, that up to 85% of soils may belong to brown alluvial soils (including 82% as loamy/silty-textured typical brown alluvial soils – 'mady brunatne' and 3% as sandy-textured rusty alluvial soils – 'mady rdzawe'), 10% – to chernozemic alluvial soils ('mady czarnoziemne') and 5% – to ordinary alluvial soils ('mady właściwe'). The latter findings confirm the widely known trends (Chojnicki, 2002; Kawałko et al., 2021; Ligęza, 2016; Strzemski et al., 1973), but the specified numbers should be further confirmed in the larger number of profiles.

The spread of alluvial soils on the Polish maps and in the Soil Atlas of Europe (Jones et al., 2005) is similar, because the latter was prepared based on older version of WRB classification featured by high position of Fluvisols in the key (World Reference Base for Soil Resources, 1998). Whereas, the international soil maps expectedly prepared in the future will base on the recent WRB classifications, where soils with diagnostic horizons (mollic, umbic, cambic) and diagnostic properties (gleyic and stagnic) precede Fluvisols in the key to reference groups (IUSS Working Group WRB, 2006, 2022). Therefore, a 'disappearance' of Fluvisols must be expected in favour of Cambisols and Phaeozems. Only the ordinary alluvial soils ('mady właściwe') have a chance to persist as Fluvisols, but their share in the soil cover of Poland will be insignicant, i.e., at 0.5–1%.

The mentioned above uncertainty about the future persistence of alluvial soils on the maps is a challenge for researchers. The arable alluvial soils have been mapped in Poland on a detailed scale (typically 1:5,000); however, the emphasis has been placed on their texture and the information about their pedogenic transformation, reflected in genetic soil type/subtype is basically missing (Świtoniak et al., 2019). The moisture status, considered during agricultural evaluation and mapping in 1950s–1960s, have changed in many sites, thus the current soil value and utility may greatly differ (Ligęza, 2016; Łabaz and Kabała, 2012; Markiewicz et al., 2017; Owczarzak et al., 2007). The spatial variability of alluvial soils in many areas is much larger than presented on the 'detailed' maps, makes them unsuitable for 'precise agriculture' and requires a new approach to approximate the soil properties crucial for soil productivity (Gałka et al., 2016). As, in general, eutrophic and moist soils, alluvial soils have high potential for carbon sequestration, supported by plow deepening after soil drainage (Mendyk et al., 2016; Niedźwiedzki et al., 2010b; Żyromski et al., 2016). However, the carbon sequestration potential and its variability in alluvial soils has been poorly studied (Kawałko et al., 2021; Łabaz and Kabała, 2016; Łabaz et al., 2016; Markiewicz et al., 2016; Smólczyński et al., 2011).

Due to location of alluvial soils in the geomorphologically active river valleys, their mechanical transformation is considered a natural phenomenonon, even if combated by river regulation (Plesiński, 2018; Roj-Rojewski and Banszuk, 2004; Teisseyre, 1988). Plain topography of the river terraces makes the alluvial soils insusceptible for sheet erosion (Myślińska et al., 1982). The lowering of ground-water table is considerd in these soils necessary to ensure agricultural usefulness and productivity (Olszewska and Pływaczyk, 2013; Rytelewski, 1965). However, excessive drainage, in particular in sandy soils, may lead to lowering the soil productivity (as arable field, meadow or pasture) and to the degradation of natural ecosystems (Borkowski and Mikołajczak, 1993; Cieśla, 2009; Dyderski and Wrońska-Pilarek, 2015; Kaczmarek et al., 2010; Niedźwiedzki et al., 2010b). Therefore, the threats for degradation of alluvial soils are not the same as for 'highland soils'. However, river valleys are increasingly threatened by urbanization, commonly connected with soil transformation to human-affected 'technogenic soils' (Uzarowicz et al., 2020). Alluvial soils have always been affected by contamination from industrial, municipal, and agricultural sources (Krysiak and Karczewska, 2007; Kabala and Singh, 2001; Kabala et al., 2011b). Although, as mentioned above, the pollution exceeding the intervention limits is relatively uncommon (Cebula and Ciba, 2005; Czarnowska et al., 1995; Dąbkowska-Naskręt and Kędzia, 1996; Kalembasa et al., 2007; Szerszeń et al., 2000), the quality of alluvial soils must be regularly monitored, as any uplifted concentration of xenobiotics may create risk and negatively influence soil biodiversity and productivity, and ground-water quality (Furtak et al., 2019, 2021; Maliszewska-Kordybach et al., 2013).

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Geneza, transformacja i klasyfikacja mad w Polsce – gleb roku 2022

Słowa kluczowe

Mady właściwe
Mady brunatne
Mady czarnoziemne
Systematyka gleb
Funkcje gleb

Streszczenie

Polskie Towarzystwo Gleboznawcze wybrało mady jako gleby roku 2022. Choć mady pokrywają mniej niż 5% powierzchni Polski, mają duże znaczenie dla rolnictwa i leśnictwa wskutek ich specyficznego położenia w dolinach rzecznych, dużej wilgotności oraz dzięki wysokiej potencjalnej produktywności. Mady odgrywają też specjalną rolę w funkcjonowaniu niektórych chronionych siedlisk naturalnych i półnaturalnych. Jednocześnie, warstwowane gleby aluwialne, często w swoich profilach zawierające pogrzebane poziomy próchniczne, są też istotne dla rekonstrukcji zmian zachodzących w środowisku (w tym zmian klimatycznych i hydrologicznych) a także wpływu człowieka na środowisko. W niniejszym artykule zaprezentowano: (a) koncepcję mad w Polsce, rozróżniającą między różnymi glebami mineralnymi i organicznymi w dolinach rzek, (b) przegląd poglądów na temat tworzenia się i przeobrażenia gleb aluwialnych (mad) w kontekście dynamiki dolin rzecznych i wpływu człowieka, (c) historycznych i współczesnych schematów klasyfikacji mad w Polsce oraz ich korelacji z międzynarodowymi systemami (WRB i Soil Taxonomy), oraz (d) użyteczność mad dla rolnictwa i leśnictwa w nawiązaniu do ich właściwości fizykochemicznych i reżimu wodnego.