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Geomorphological record of transformations of upland river valley bottoms at variable rate of gully erosion (case study: Wieprz River valley in Roztocze)

Geomorfologiczny zapis transformacji den dolin rzek wyżynnych w warunkach zróżnicowanego natężenia erozji wąwozowej na przykładzie roztoczańskiej doliny Wieprza

Keywords: river valley relief, gully erosion, alluvial fans, Wieprz River catchment, Roztocze region

Słowa kluczowe: rzeźba dolin rzecznych, erozja wąwozowa, stożki napływowe, dorzecze Wieprza, Roztocze

INTRODUCTION

In the upland geosystems of the moderate climate zone, any change in the conditions of functioning of a catchment causes a response of the system involving variable dynamics of fluvial processes (Gregory, Walling 1973; Schumm 1977, 1981; Kostrzewski, Szpikowski 2003; Świeca, Kociuba 2007). In the conditions of low anthropopressure, the direction and intensity of the processes modelling the valley bottom are determined by environmental factors, i.e. the geology and lithology of sediments, and land relief, and climate-driven factors, i.e. precipitation and groundwater supply determining water and sediment discharge rate (Froehlich 1982; Kostrzewski et al. 1994; Krzemień 1999; Dearing, Jones 2003, Meybeck et al. 2003; Kociuba et al. 2003; Świeca, Kociuba 2007; Rodzik et al. 2008). In the conditions of strong anthropopressure, the processes of transformation of the valley bottom can be largely accelerated due to disturbances in the stability of the catchment's environmental conditions. Their geomorphological effects are manifested in changes in the channel shape (in the plan and cross profile), and in the modelling of the zone outside the channel, as a result of both flood and delluvial sediment deposition, particularly in the mouth zones of dry valleys and erosional dissections (Bork 1989; Rodzik et al. 2008; Brown 2009).

Transformations of valley landforms resulting from changes in natural conditions and anthropopressure on the valley system can be traced based on the example of the meridional part of the Roztocze section of the Wieprz River valley (Fig. 1) – a typical medium-sized upland river of the moderate climate zone (Rodzik et al. 2008).

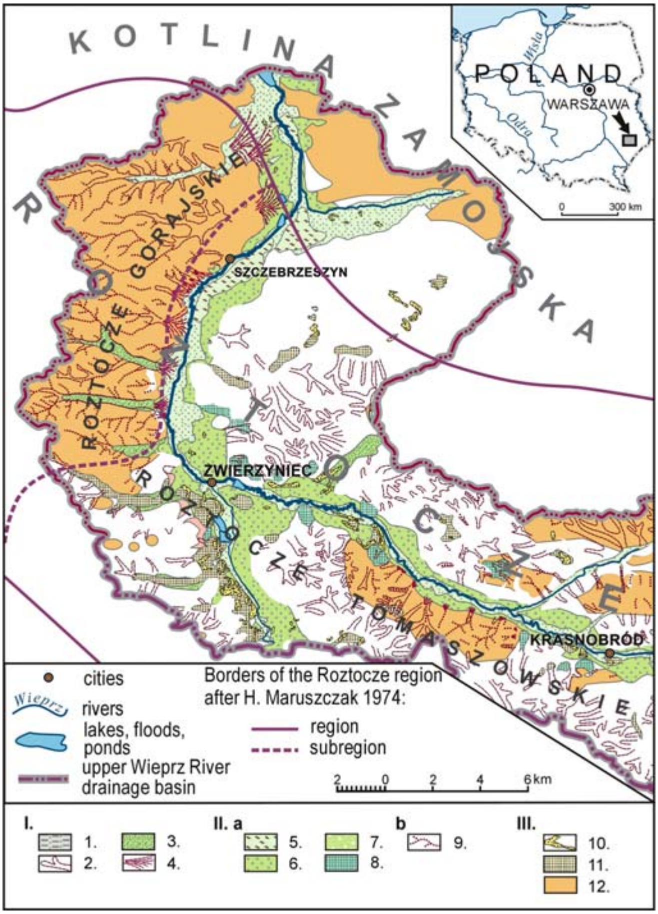

Fig 1. Location of the study site in relation to the basic types of land relief in the upper Wieprz River catchment. I. denudational landforms: 1. denudational plains, 2. dry valleys, 3. dry valley bottoms, 4. alluvial fans; II. fluvial landforms: a) river valley bottoms: 5. accumulative flood terraces, 6. accumulative non-flood terraces, 7. elevated accumulative terraces, 8. erosional terraces; b) erosional landforms: 9. erosional dissections, gullies; III. aeolian landforms: 10. dunes, 11. aeolian sands plains, 12. loess covers

The modern relief of the alluvial plain of the Roztocze fragment of the Wieprz River valley results from complex morphogenetic processes (Kociuba, Brzezińska-Wójcik 2002; Kociuba, Superson 2004). The primary morphostructural features developed with the contribution of tectonic movements in the Neogene and Early Pleistocene. In the Middle Pleistocene, fluvioglacial accumulation was of particular importance. The current course of the valley along the analysed section developed in the conditions of periglacial climate in the Upper Pleistocene. The lithological conditions and location in the zone of loess deposition (in the Late Glacial) determined the alternate occurrence of natural narrowings and bottom widenings with a shape of a basin. In the Holocene, the flat flood bottom developed, with numerous traces of lateral migration of the channel (Kociuba, Superson 2004).

OBJECTIVES, METHODS AND STUDY AREA

The objective of the paper was the reconstruction of the transformation of the meridional part of the bottom of the Roztocze section of the upper Wieprz River valley in the conditions of changing intensity of gully erosion initiated by anthropopressure in the catchment area.

The course of development of the valley bottom was determined based on field research (mapping of landforms and drilling up to a depth of 5 m), laboratory analyses (dating of the age of organic sediments by means of the ^{14}C radiocarbon method), and desk studies (interpretation of aerial photographs and oblique photographs from low altitude). The study involved the analysis of five series of standard aerial photographs (for topographic purposes) taken in the years 1964-1999 (including three panchromatic and two multispectral series) from an altitude of approximately 5,000 m a.g.l. The interpretation of the course of palaeochannels was largely based on the interpretation of the content of aerial and oblique photographs taken from low altitude (100–500 m a.g.l.). The oblique photographs were taken in two series in early and mid-April 2000, before the commencement of plant vegetation. The information obtained as a result of photointerpretation, verified in the scope of terrain mapping, permitted detailed cataloguing of landforms related to horizontal changes in the channel. Oxbow lakes and traces of their development (developing distinguishable systems in the valley bottom), whose period of exclusion from discharge was determined based on radiocarbon datings, provided the basis for the reconstruction of the directions and range of migration of the channel, and the determination of the development tendencies. Transformations of the valley bottom in the conditions of variable rate of gully erosion were analysed along the Roztocze section of the Wieprz River catchment, distinguished by a relatively low level of anthropopressure (Świeca 1998; Świeca ed. 2004).

The detailed analysis was performed in the meridional part of the Roztocze section, subject to the highest degree of transformations as a result of human activity. The analysed part of the Wieprz River catchment represents environmental conditions typical of upland areas. It particularly covers the area of Roztocze Gorajskie and Roztocze Tomaszowskie (Maruszczak 1974) (Fig. 1). The meridional section of the valley has a length of 16.7 km. The valley is wide here, and the river channel has an inclination (1.16‰) lower than in its upper and middle course (1.36‰) (Kociuba 2002; Kociuba, Superson 2004). As a result of anthropopressure, the channels of the Wieprz River and its tributaries lost their original character along many sections. In the analysed area, it was regulated in a number of places, but on some of the transformed sections, a secondary increase in the tendency for lateral erosion is observed, manifested in an extensive channel width (1.5 m–25 m).

In the vicinity of Zwierzyniec, the valley has a NW-SE orientation, and the floodplain reaches a width of up to 600 m. Below Wywłoczka, with the change of orientation to N–S, the valley becomes considerably wider, and the floodplain reaches a width of up to 1,500 m (Fig. 2 A, B). This section is distinguished by a varied relief of the Holocene bottom. The variety of the sediment cover of the asymmetric valley slopes (left – loesses, and right – sands), as well as the aeolian processes in the Late Glacial, determined the varied character and lithology of sediments filling the floodplain.

RECORD OF EFFECTS OF INTENSIFIED GULLY EROSION IN THE RELIEF OF THE WIEPRZ RIVER VALLEY BOTTOM

Along with changing anthropogenic conditions, i.e. intensity and structure of management of the floodplain, non-flood terraces, slopes, and plateaus, the majority of elements of the natural environment were largely transformed. Such transformations are reflected in among others: varied lithology of sediments deposited in the valley bottom, and morphological variability. The human interference in each of the mentioned elements causes changes in the remaining ones, and therefore the transformation of the valley bottom.

VARIABILITY OF SEDIMENTS OF THE FLOODPLAIN

The meridional section of the valley, in the eastern part of the floodplain, is dominated by sandy sediments, particularly of alluvial origin, and to a certain extent originating from washing out of sandy covers and dunes, causing aggradation of the non-flood terrace in the vicinity of the Bagno settlement (Fig. 2A, B). The mean thickness of the Holocene sediments of the floodplain varies from 3 to 5 m,

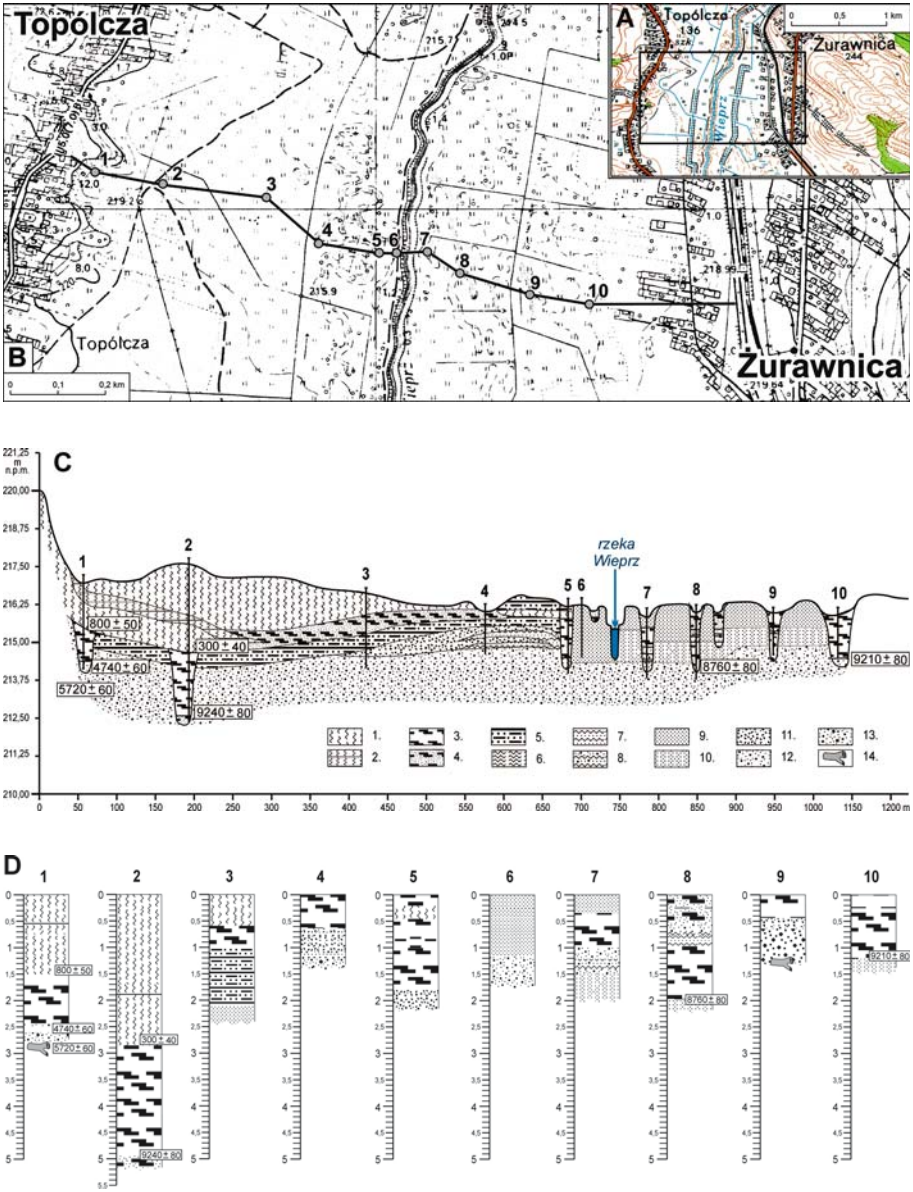

Fig. 2. Cross profile through the Wieprz River valley bottom between Topólcza and Żurawnica; A. location of the study area; B. location of the particular measurement sites on the topographic map; C. cross profile through the alluvial valley bottom: 1. proluvial silts, 2. varved proluvial silts, 3. peat, 4. peat with sands, 5. varved proluvial silts with sands, 6. silts, 7. silts with sands, 8. silts with medium- and coarse-grained sands, 9. fine-grained sands, 10. fine- and medium-grained sands, 11. coarse-grained sands, 12. medium- and coarse-grained sands, 13. sands of various grain sizes, 14. trunks and plant remains; D. profiles of cores with radiocarbon dates

and reaches a maximum of 6.5 m (Fig. 2 C, D). As a result of erosion of the left slope of the valley covered with loess, the western part of the floodplain is supplied with a high amount of silty material. It is deposited in the form of delluvial fans and banks (Fig. 3) on the plain surface. During downpours, it is also supplied to the river sediment by dirt roads and melioration ditches. This results in a substantially higher contribution of silty and sandy-silty sediments along this section in the western part of the Holocene valley bottom (Kociuba 2002).

Due to the low inclination of the long profile, resulting in a decrease in the discharge rate, peats and the accompanying peaty muds, as well as mineral-organic aggradate muds, have a high contribution in the development of the floodplain (Fig. 2 C, D). Good conditions for their development also occur in the abandoned fragments of palaeochannels, local depressions in the valley bottom, mouth sections of lateral valleys, and closed-drainage basins. Peats with a thickness of up to 2.5 m occur between Topólcza and Żurawnica both in the form of a peat plain (covered with the delluvia from fans), and in oxbow lakes (Fig. 2 C, D). The analysis of the age of the uppermost and bottom peat layers filling palaeochannels permitted the determination of the mean rate of their growth in this part of the valley from 0.1 mm to 0.3 mm/year.

RECONSTRUCTION OF THE CHANNEL MIGRATION AND DEVELOPMENT OF FLOODPLAIN LANDFORMS

Due to a double increase in the width of the floodplain below Wywłoczka, and a simultaneous decrease of the channel inclination (resulting in a decrease in the discharge rate), this section is distinguished by increased sinuosity (Kociuba 2002). During floods, water stays in the river channel, and its excess is distributed to flood basins, largely limiting the erosional action of flood discharges. This affected the functioning of fragments of palaeochannels together with systems of landforms outside channels developed throughout the Holocene (Fig. 2 C, Fig. 3). Organic sediments filling the abandoned fragments of palaeochannels permitted the determination, by means of radiocarbon dating, of the beginning of deposition of the overlying banks and fans narrowing the valley bottom and the meander belt in the second half of the Sub-Atlantic period (Fig. 2 C, D, Fig. 3). An increase in the activity of slope processes in the period is confirmed by delluvial sediments (dusty silts) in the vicinity of Topólcza, covering the "Atlantic" palaeochannel filled with organigenic sediments. These landforms are distinguished by a low thickness of covers from 0.7 m to 1.0 m (Fig. 2 C, D). This suggests that the processes developing the landforms were of moderate intensity (Kociuba, Brzezińska-Wójcik 2002). The age of peats in the uppermost layer of sediments filling the palaeochannel is determined as $800^{\pm}50$ years BP (Fig. 2 C, D, Fig. 3). An increase

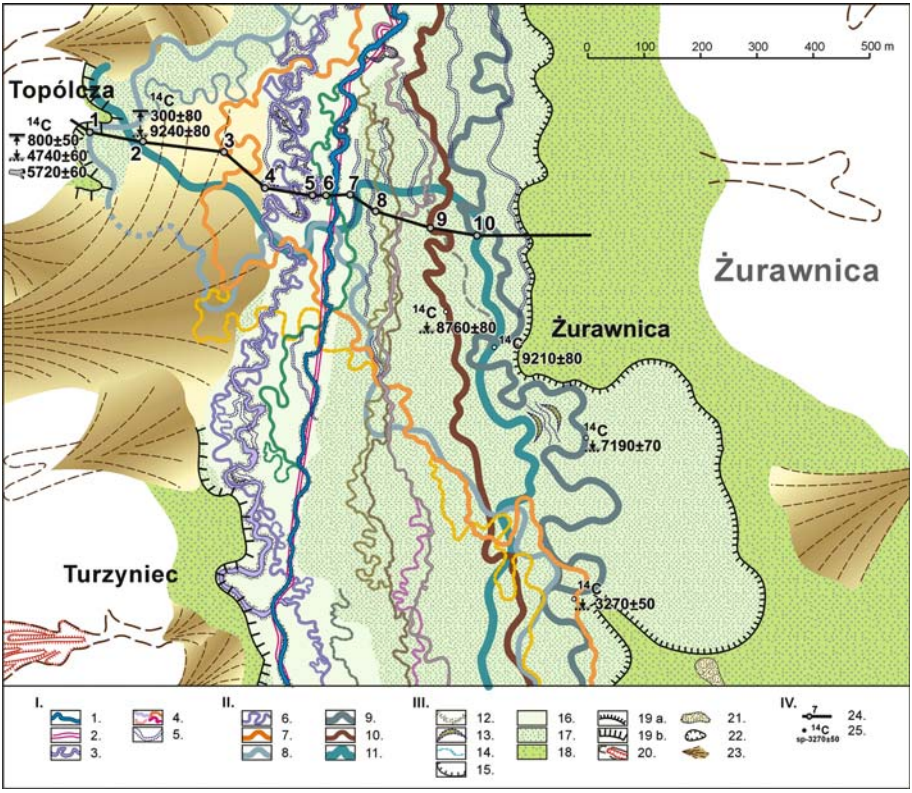

Fig. 3. Geomorphological draft of the meridional part of part of the upper Wieprz River valley bottom between Topólcza and Żurawnica. I. course of the river channel: 1. in 1999, 2. channel regulated in the 19th century, 3. channel in the early 19th century, 4. free migration of meanders, 5. out of channel flows; II. reconstructed course of the channel: 6. in the 19th century, 7. in the Subboreal, 8. in the Late Atlantic, 9. in the Atlantic, 10. in the Boreal, 11. in the Preboreal; III. landforms of the valley bottom and slopes: 12. natural levees, 13. meander scroll banks, 14. overbank sedimentation basin, 15. meander erosional banks, 16. proximal floodplain, 17. distal floodplain, 18. non-flood terrace, 19. edge of terrace: a) 1-2 m above average river level, b) 3–5 m above average river level, 20. slopes, denudational valleys, gullies, road gullies, 21. dunes, 22. deflation depressions, 23. alluvial fans, IV. other: 24. geological profile, 25. radiocarbon dates of organic material filling palaeochannels

in the rate of the processes of surface and linear erosion on the valley slopes (Schmitt et al. 2006), as well as increased deposition on the floodplain surface, occurred at the end of the period of exceptionally high climate humidity (Ralska-Jasiewiczowa, Starkel 1991).

Another stage of intensive transformations of the valley bottom corresponds to the period of global climate cooling, lasting from the mid-16th to the second half of the 19th century (Lamb 1984, 1984a). According to Maruszczak (1998), the increasingly continental climate caused a decrease in discharge rates with a simultaneous increase in their seasonal character. A substantial growth of the population of the Wieprz River catchment in the 16th century was followed by the development of agriculture, breeding, and industry (Skowronek 1999), contributing to the activation of erosion processes in the catchment. The proceeding fragmentation of settlements and fields, and therefore field ploughing along the slope inclination, contributed to an increase in the rate of erosion processes in fields and access roads. This caused a substantial increase in the volume of clastic material deposited in the valley bottom and transported by the river. In the conditions of an increased climate humidity 300–100 years BP (Ralska-Jasiewiczowa, Starkel 1991), high rate of surface and linear erosion of the valley slopes devoid of a vegetation cover resulted in the intensive development of the youngest generation of delluvial landforms narrowing the valley bottom and meander belt (Fig. 3). During the time, the development of delluvial fans and banks commenced on the eastern side of the meridional section of the upper Wieprz River valley. The supply of loess delluvia to the surface of the peat plain, occupying the peripheral areas of the discussed section of the Holocene valley bottom, resulted in a discontinuation of the peat-forming process commenced in the Preboreal. Peats in the uppermost layer of sediments filling the palaeochannel, documented under the delluvial bank, were dated for $300^{\pm}50$ years BP (Fig. 3).

A considerable thickness of dusty silt covers, reaching up to 2.5 m (Fig. 2 C, D), suggests high dynamics of deposition processes (Kociuba, Brzezińska-Wójcik 2002). Increased deposition in the valley bottom correlates well with periods of intensified erosion in the gully system (e.g. Jedliczny Dół, Schmitt et al. 2006). A part of products of erosion deposited in the valley bottom was subject to redeposition, and was shortly supplied to the river sediment. In periods of stabilisation (e.g.: the La Tene period, the Migration period, the 13th and 15th century, after 1974), within the channel, sediments were deposited in the form of bars and scroll ridges. During floods, overbank sandy and dusty silts (younger alluvial soil) were deposited on the floodplain. Their deposition was related to an increased supply of sandy-silty material from dissected slopes. This was caused by an increasing impact of the anthropogenic factor, and particularly deforestation of the area (Maksiak 1966; Nakonieczny 1971; Kociuba 2002). The floodplain is currently developed by fluvial processes with low dynamics. The alluvial fans developing on both sides of the floodplain cause the narrowing of the bottom, and local increase in inclination (Kociuba 2002).

FUNCTIONING OF THE VALLEY BOTTOM IN THE CONDITIONS OF VARIABLE ANTHROPOPRESSURE

Transformations of the valley bottom in the conditions of dispersed settlement

Transformations of the valley bottom in the period of Palaeolithic and Mesolithic settlement were insignificant. Valleys were overgrown by dense forest formations, and the peoples inhabiting them had a nomadic lifestyle. The human pressure on the valley environment increased considerably in the Neolithic along with the appearance of farming cultures in the area. The Neolithic peoples established settlements, and practiced hoe-farming on the surrounding deforested (slash-and-burn) areas (Ostoja-Zagórski 1998). Traces of Neolithic settlements were found in the analysed section of the Wieprz River valley in the vicinity of Szczebrzeszyn (Gurba 1961). The effects of the Neolithic stage of the valley anthropogenation include substantial deforestation (Skowronek 1999). It contributed to the initiation (activation) of erosion processes on deforested parts of slopes, and increased deposition of flood sediments in the valley bottom (Kociuba 2002). This resulted in the transformation of a network of dry valleys, and the appearance of initial erosional landforms – gullies – on the loess slopes.

In the Bronze and Iron Ages, the cultures inhabiting the Wieprz River valley specialised in land cultivation, breeding, and primitive craftsmanship. Rodzik and Zgłobicki (2010) mention wood exploitation for the purpose of iron smelting from bog iron at the turn of the Bronze and Iron Ages (Lusatian culture) as a probable cause of the development of gullies. Between the La Tene and Roman Periods, a regress of settlement occurred, resulting in the succession of forest assemblages in the valley bottom. The intensification of settlement in the Roman Period, supported by the application of iron tools and improvement in land cultivation techniques (fallow system of farming) and breeding, once again resulted in deforestation, and the development of agricultural landscape in deforested areas (Skowronek 1999). Further changes in the environmental conditions of the valley bottom, resulting from the regress of settlement in the Migration period, are reflected in the repeated succession of forest assemblages. From the Early Medieval Ages, a gradual increase in anthropopressure occurred as a result of the development of a settlement network. The hydro-climatic conditions (warm and dry climate and a decrease in the groundwater level) permitted the management of the flood bottom of the valley. The dispersed character of Early Medieval settlement, however, caused no considerable changes in the valley's environment. Another renaturisation process occurred in the 13th century, after the destruction of the settlement network existing in the valley as a result of numerous raids.

Transformations of the valley bottom in the conditions of increased intensity of settlement development

Another stage of the valley anthropogenation involved the development of a settlement network in the early 14th century. It resulted in the first deforestations in the modern period (Skowronek 1999; Kociuba 2007). Beginning from the second half of the 14th century, anthropogenic transformations of the catchment intensified as a result of climatic changes unfavourable for settlement (Dobrowolska 1961). Further increases in the settlement activity corresponded to the period of further cooling of the climate (Little Ice Age). This contributed to the magnification of their morphological effects (Kociuba 2002; Kociuba, Brzezińska-Wójcik 2002; Kociuba, Superson 2004; Schmitt et al. 2006). A considerable growth of the population of the Wieprz River catchment, recorded in the 16th century, involved the development of agriculture, breeding, and industry, largely based on local natural resources, and particularly wood (Skowronek 1999). A change in the natural and anthropogenic conditions resulted in transformations of valley landforms (Schmitt et al. 2006). Further deforestation, covering substantially larger areas than those occurring in the 14th century, resulted in replacing forest assemblages with segetal vegetation, and the acceleration of the development of erosional landforms (gullies, and road gullies). In the consecutive 17th and 18th centuries, the settlement tendencies considerably decreased, but substantial changes occurred in the settlement structure. Settlements and the adjacent fields were largely fragmented (Skowronek 1999). Deforestation, changes in land cultivation techniques and manners of land management introduced in the period, and climate changes (Ralska-Jasiewiczowa, Starkel 1991), resulted in an increase in the rate of development of the slopes and bottom of the Wieprz River valley. Ploughing along the slopes, forced by a low width of plots, contributed to the intensification of erosion processes in fields and access roads. This led to changes in the morphology of valley slopes, i.e. development of gullies, and road gullies, and the development of new erosional landforms (Schmitt et al. 2006), as well as transformations of the valley bottom (delluvial fans) and the river channel (Kociuba 2002).

Transformations of the valley bottom in the conditions of intensive settlement development

The most substantial transformations of the valley bottom, resulting from the development of settlement, occurred during the last two centuries. The 19th century corresponds to a further increase in the number of settlements in the valley. It was accompanied by proceeding changes in land management, deforestation for agricultural and settlement purposes, development of the road network, and establishment of artificial water bodies (mill races) in the valley bottom (Skowronek 1999). The turn of the 19th century is distinguished by the effect of human economy on the processes occurring in the slopes (Schmitt et al. 2006) and bottom of the Wieprz River valley (Kociuba 2007). The period of the most intensive exploitation of forests, correlated with the highest population density in the valley, corresponds to the interwar period (Skowronek 1999). The 2nd World War changed the demographic and economic situation. The proceeding deforestation and agricultural management was discontinued as a result of a decrease in the size of the population. After the war, clearing of forests began again. The population gradually increased, reaching approximately the maximum state from the first half of the 20th century in 1974. The establishment of the Roztocze National Park (RPN) and its buffer zone in 1974 initiated a new stage of renaturisation of the valley slopes and bottom in areas under protection. In the park and its buffer zone, economic activity and the expansion of the settlement network were largely restricted (Skowronek 1999). Extensive areas of plateaus and valley slopes as well as non-flood terraces and the floodplain were excluded from agricultural use. This resulted in succession of herbaceous vegetation and colonisation of the slopes by forest assemblages, as well as gradual reconstruction of riverside carr vegetation in the valley bottom. As a result, the slopes were stabilised (Schmitt et al. 2006), and the amount of delluvia deposited in the valley bottom and supplied to the channel after redeposition decreased. A decrease in the volume of river bedload was compensated by increased lateral erosion of the Roztocze section of the Wieprz River valley (Kociuba 2002; Kociuba, Brzezińska-Wójcik 2002).

FINAL REMARKS

The periodical character of settlement and degree of anthropogenation of the valley environment in each of the periods of its development is reflected in the lithology of valley sediments along the Roztocze section of the Wieprz River valley. They are dominated by flood sediments, with a substantial contribution of peat plains. Periods of intensive transformations of the landforms of the valley bottom and slopes resulted in an increase in the variety of flood sediments in the vertical profile. The lower part is represented by sediments with the highest content of the silty fraction (younger alluvial soil) with a thickness rarely exceeding 1 m, particularly occurring at the bottom of oxbow lakes. The upper part of the profile of flood soils contains sediments deposited in the modern period, particularly represented by sands and dusty sands (younger alluvial soil) (Maksiak 1966; Nakonieczny 1971) with a thickness of up to 1.5 m (Kociuba 2002; Kociuba, Brzezińska-Wójcik 2002; Kociuba, Superson 2004). The thickness and lithology of particular layers of flood sediments provide a clear record of the transformation of the valley determined by natural factors, e.g. periodical increase in climate humidity (Ralska-Jasiewiczowa, Starkel 1991), and anthropogenic factors, e.g.

intensity and manner of management of the valley bottom and slopes (Schmitt et al. 2006; Kociuba 2006, 2007). The lower, older horizons of alluvial fans can be related to periods of intensive deforestation of the study area (Neolithic, Roman Period, 14th and 16th century), and the upper, younger ones – to changes in the manner of land management and introduction of hoe-farming (17th–18th century) on the valley slopes (Kociuba 2002). Therefore, changes in the lithology of sediments of the floodplain constitute a record of the activation of erosion processes determined by natural factors (increase in climate humidity), but initiated as a result of changes in the manner and structure of land use (Starkel 1983, 1988, 1991; Klimek 1987, 1988; Michno 2004; Dotterweich et al. 2012; Schmitt et al. 2006). Intensive erosion of slopes and development of deposition landforms were favoured by the established ownership structure, field structure, and ploughing along the direction of the runoff of precipitation waters.

In periods of increased anthropopressure, the importance of natural factors was marginalised. Transformations of the environment of the valley bottom particularly concerned natural (predominantly forest) vegetation, replaced with segetal vegetation. This, in turn, caused changes in the remaining components of the environment (among others water relations and soils), resulting in the activation of geomorphological processes leading to the transformation of the existing landforms (dry valleys) and initiation of new ones (dry gullies, gullies, road gullies), as well as the deposition of products of erosion in the valley bottom in the form of fans and delluvial banks (Superson ed. 2012). A decrease in anthropopressure in a catchment area results in rapid renaturisation of the environment of the valley bottom (Kociuba 2007).

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STRESZCZENIE

W artykule przedstawiono transformacje dna roztoczańskiego odcinka doliny Wieprza, determinowane czynnikami naturalnymi oraz antropogenicznymi, które miały miejsce w ciągu kilku ostatnich tysiącleci. W rekonstrukcji rozwoju wykorzystano metody fotointerpretacyjne i kartowanie geomorfologiczno-geologiczne. Datowanie wieku pobranych prób osadów organogenicznych (torfy, namuły torfiaste) pozwoliło na odniesienie rejestrowanych zdarzeń do okresów zróżnicowanej antropopresji na obszarze zlewni i jej skutków.

Okresy zróżnicowanej antropopresji skutkowały intensywnymi przekształcaniami form dna i zboczy doliny, odzwierciedlonymi zróżnicowaniem osadów powodziowych w profilu pionowym. Ich miąższość i litologia stanowi czytelny zapis transformacji pod wpływem czynników naturalnych – np. okresowego uwilgotnienia klimatu oraz antropogenicznych – np. intensywności oraz sposobu zagospodarowania dna i zboczy doliny. Starsze poziomy stożków napływowych odpowiadają okresom intensywnej deforestacji obszaru zlewni, zaś młodsze – zmianom sposobu zagospodarowania i wprowadzaniem upraw okopowych. Zmiany w litologii osadów równi zalewowej świadczą o okresowym uaktywnianiu procesów erozyjnych warunkowanych czynnikami naturalnymi (klimat), ale uruchomionych w wyniku zmian w sposobie i strukturze użytkowania. Z kolei obniżenie antropopresji w środowisku dolinnym na obszarze dorzecza skutkuje szybką renaturyzacją środowiska zlewni den dolinnych.