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Spatial diversity of gully density of the Lublin Upland and Roztocze Hills (SE Poland)

Zróżnicowanie przestrzenne gęstości wąwozów na Wyżynie Lubelskiej i Roztoczu (Polska południowo-wschodnia)

ABSTRACT

Compared to other regions in Poland, the Lublin Upland and Roztocze Hills are distinguished by the density and size of gully systems. In this area, morphometric analyses using GIS tools were performed based on digital data processed from 1:10 000 topographic maps and the Digital terrain Model. The results obtained allowed distinguishing of 17 "gully regions", i.e. areas characterized by a high concentration of gully forms. The analysis of distribution of gullies in relation to other environmental elements demonstrated that the particularly intensive development of gullies in specific areas was associated with geomorphological, geological, hydrogeological, and paleogeographical factors. The anthropogenic impact, i.e. intensive, long-term agricultural management and consequent deforestation, was of great importance as well. The gully regions identified are characterized by a varied surface area and dissection density that in extreme cases reaches over 10 km/km^2. From the economic point of view, the phenomenon is unfavourable, as it leads to fragmentation of arable land and intensification of erosion processes. On the other hand, gully regions offer attractive landscape and natural values, therefore some areas have been included in various protection programmes.

Key words: gullies, road gullies, odra glaciation, Lublin Upland

INTRODUCTION

1. Young erosion landforms (gullies and road gullies) occur in approximately 18% of the area of Poland, both on agricultural and forested lands. Their countrywide density is highly diverse; it is the highest in the Carpathians, where it reaches or even exceeds the value of 2 km/km^2. On the Lublin Upland and Roz-

tocze Hills, the dissection density is similarly high with values close to those in the Carpathians, although the dissected areas occupy a smaller space, likewise on the uplands of Central Poland, where gullies and road gullies are concentrated on the Sandomierz and Miechów Upland. The Sudety Mountains and their Foreland are a prominent region with lower gully densities (typically 0.1–0.5 km/km^2) but considerably larger areas covered by these landforms. In other regions of Poland, gullies occur only sporadically and only in the north; in the South Baltic and East Baltic Lakelands, there are large areas with the dissection density of 0.1–0.5 km/km^2, and less frequently 0.5–1.0 km/km^2 (Józefaciuk, Józefaciuk 1992).

2. In the Polish literature, the term ”gully” usually refers to young valleys having no permanent runoff and exhibiting specific morphological features. The differences between gullies and river valleys include absence of a permanent river-bed, an unlevelled longitudinal slope, and steep and frequently precipitous slopes with a distinct knickpoint at the top; this is the evidence for their young age and episodic nature in terms of geological time (e.g. Maruszczak 1958, Buraczyński 1968, Klimaszewski 1978, Migoń et al. 1997/98, Migoń 2006). Gullies can be single and reach a depth of 100 m and a length of a few kilometres, although very complex systems with a total length of even up to several tens of kilometres have also been reported. As these landforms evolved and aged, their characteristics changed, hence a few developmental stages have been distinguished (Maruszczak 1961, 1973). Gully development is promoted by specific substrate properties, i.e. low resistance to linear erosion accompanied by compactness, which contributes to formation of steep slopes or sometimes vertical walls. The term “gully” sometimes refers to short, dry valleys that dissect slopes. They are characterized by a narrow bottom**,** unlevelled longitudinal slope, and a transverse V-shaped profile. They differ from gullies in their vertical and horizontal sizes, which are an order of magnitude smaller. They are referred to as “dells” in the Polish geomorphological literature (Klimaszewski 1978). Both gullies and dells develop mainly as a result of natural processes, in contrast with the so-called road gullies, where a pivotal role is played by destruction of the natural vegetation cover, the mechanical impact of vehicles on the substrate and, consequently, accelerated erosion processes.

3. In the West-European and American literature, the term “gully” refers to landforms developing as a result of periodic runoff in episodic river-beds from which the soil layer is discharged. Two types of these landforms are distinguished: permanent 25–30 m deep gullies, and ephemeral gullies, which are formed in the same way, but exhibit smaller sizes and are larger than erosion rills. Ephemeral gullies are typically eradicated by common agricultural practices. Both types are characteristic of agricultural areas located on slopes (Soil Science Society of America, 2001; Poesen et al. 2006). Ephemeral gullies accompany rills; they can be distinguished by their morphometric parameters, i.e. ephemeral gullies have a cross section exceeding ca. 1000 cm^2 (square foot) (Hauge 1977, Poesen 1993)

or are larger than 0.3 in width and 0.5–0.6m in depth (Brice 1966, Imeson and Kwaad 1980). Landforms that have developed within morphological escarpments are referred to as bank gullies dissecting the edges of terrace levels in river valleys and other forms with large slope gradients. In North America, they are called "edge-of-field gullies" (Dabney et al. 2004). These landforms develop primarily due to backward erosion, reaching higher areas even when the catchment area is small (Poesen, Govers 1990).

CURRENT STATE OF KNOWLEDGE

The issue of the distribution and density of the gully systems and their development conditions on the Lublin Upland and Roztocze Hills has been a subject of extensive cartometric, geomorphological, and application research focused on single gullies or gully systems, as well as entire sub-regions or the whole macroregion. The investigations were based on different methods and highly diverse cartographic material; therefore, their results are not strictly comparable.

The first report presented a research of the young erosion dissections on the Lublin Upland (Królik 1959) performed on the basis of cartometric measurements in fields that were too large for a detailed analysis of regional diversity. A thorough analysis of the western part of the Nałęczów Plateau based on 1: 25 000-scale maps (Kęsik 1961) facilitated elaboration of a density map in 2 km^2 fields. Another research (Buraczyński 1968, 1972, 1977) was carried out in Goraj Roztocze on the basis of measurements done in 1 km^2 fields with the use of 1:25 000 topographic maps. The first fairly detailed regional study in the upland regions in eastern Poland (Maruszczak 1973) was conducted in 10 km^2 hexagon measurement fields using 1:100 000 topographic maps. The study presented the spatial diversity of gully density and indicated the relationship between gully distribution and diverse relative altitudes and occurrence of loess patches. The survey of the density of all forms of land dissections in the physiographic regions of Poland (Józefaciuk, Józefaciuk 1990a, 1990b, 1992, 1996) determined the position of the Lublin and Volhynia Uplands and Roztocze Hills among other macroregions with gully erosion landforms. The map was elaborated to show, in a very general way, the areas of gully erosion. The region analysed is dominated by areas that are moderately (0.5–1 km/km^2) and strongly (1–2 km/km^2) dissected. Very strongly dissected areas (over 2 km/km^2) are distinct on the Nałęczów Plateau, near Dzierzkowice, and in the Goraj Roztocze region.

The occurrence of road gullies in the region is the subject of another study, which addresses the issue of the distribution of these landforms and the problem of protection thereof against destructive processes (Kołodyńska-Gawrysiak et al. 2011). Attempts at estimation of their density in the country scale (Józefaciuk,

Nowocień 1991) and the rate of development of some of these landforms have also been undertaken (Nowocień 1996, Zgłobicki 1998).

METHODS

The present work is based on data provided by digital processing of 1:10 000 topographic maps in the PUWG1965 coordinate system elaborated in the 80's of the 20th century, which facilitated generation of digital maps (layers) of the distribution of natural gullies. Morphometric analyses of the geomorphological subregions (the density of the gully system, relative altitudes) were performed in 10 km^2 hexagon basic fields using the ArcGIS program. The analyses were carried out for 1, 262 fields (12, 620 km^2) on the Lublin Upland and Roztocze Hills. The indices for the geomorphological regions were calculated using a digitalized geomorphological map of the Lublin Province (Maruszczak 1964), with focus on analyses of the areas of the Lublin and Volhynia Uplands and Roztocze Hills (ca. 11,440 km^2). The analysis of the topographic factors of gully distribution was performed using the DTED Level 2 elevation data (resolution ca. 30 m), which allowed mapping the relative altitudes and mean slope reduction in the same basic fields.

GULLY DENSITY AND DISTRIBUTION

The study material allowed a detailed analysis of the distribution of gullies and their relationships with the particular elements of the environment. The total length of the gullies in the study area is approximately 3,880 km, which corresponds to the mean density of 0.34 km/km^2. However, the spatial distribution of the gullies exhibits very high regional variation (Fig. 1, 2, 3). Gullies occur in roughly half of the basic fields analysed (51.81%). Areas with no gullies dominate in "flat" regions where the relative altitude within the basic fields does not exceed 30 m. Such areas include the Świdnik and Bełżyce Plateaus, Chodel, Zamość, and Pobuże Basins, and Chełm Hills, where considerable denivelations (30–60 m, sometimes exceeding 60 m) are not accompanied by any deposits that would contribute to development of gullies. Vast areas without gullies also occur in regions with a richer terrain relief, i.e. in the eastern part of Grabowiec Heights, on the Horodło Range, in the central part of the Nałęczów Plateau, and the eastern part of the Sokal Plateau-ridge. Poorly dissected areas (up to 0.5 km/km^2) represent 36.45% of the basic fields. Fields of this category are predominant on the Giełczew and Urzędów Heights, in the western part of the Bełżyce Plateau and at the edge of the Nałęczów Plateau, in the northern and western part of the Grabowiec Heights, in the Tomaszów Roztocze region, and in the western part of the Sokal Plateau-ridge. Other areas with a density exceeding 0.5 km/km^2 cover a total of 15.46% of

the region. It is characteristic that the gully landforms are concentrated in compact areas, where both single and complex gully systems sometimes cover large areas. Areas where the dissection density exceeds, sometimes to a large extent, 2 km/km^2, can be referred to as "gully regions" (Fig. 3, Tab. 2). As indicated, the spatial distribution of gullies shows a clear correlation with the morphometric features of the relief and close relationships with substrate lithology. Most gullies (80.2% of the length) developed within thick loess covers (Fig. 1). At small denivelations (0–30 m), gullies occur only occasionally, and when denivelations reach 30–60 m they occur more frequently and their density is much higher (0.22 km/km^2). Denivelation reaching 60 m seems to be the threshold value, beyond which gullies are fairly common within the loess cover. In the range of 60–90 m, the mean gully density reaches 0.63 km/km^2 and is significantly lower than the density at denivelations of 90–120 m (2.0 km/km^2). Gullies in the denivelation range of 60–120 m constitute 83.7% of the total gully length in the study area.

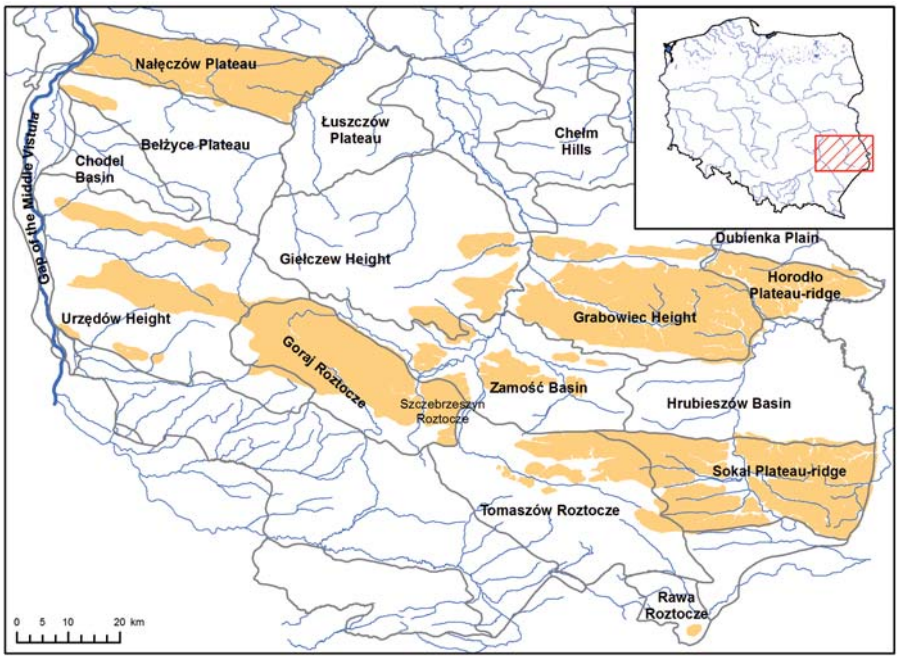

Fig. 1. Gully distribution in geomorphological regions and loess patches of the Lublin and Volhynia Uplands and Roztocze Hills

The Goraj Roztocze region has been reported to be the most strongly dissected geomorphological region (1.84 km/km^2). As many as 5 compact areas with gully density exceeding 2.5 km/km^2 (Fig. 2) have been identified in this region. They cover a total area of nearly 290 km^2. A particularly high density with the

mean value of 4.57 km/km^2 is characteristic of the Gorajec and Wieprz interfluve (Szczebrzeszyn Roztocze).

Another highly dissected region is the western part (2.48 km/km^2) of the Nałęczów Plateau (1.37 km/km^2), where erosion takes place on the bottom of deeply incised valley of the Vistula River located at the altitude of 120 m a.s.l. at the absolute height of the plateau top reaching 220 m. The highest density of the gully system (max. 10.46 km/km^2) in the Upland and Roztocze regions is found near Parchatka. Concurrently, this is the highest gully density in the European uplands. The area of the Bystra River catchment is particularly remarkable (within the Plateau) with its mean density of 2.89 km/km^2. There are no gullies in the central part (the upper Ciemięga River), and the eastern part is more poorly dissected (0.19 km/km^2).

The gully densities in the other geomorphological regions do not exceed 0.6 km/km^2. Two groups can be distinguished: the first one (density of 0.2–0.6 km/km^2) includes the Bełżyce Plateau, Sokal Range, Tomaszów and Rawa Roztocze, and Urzędów, Giełczew, and Grabowiec Heigths. Poorly dissected areas (0.1–0.5 km/km^2) are predominant, although there are fields with density exceeding 2 km/km^2, or even 3.58 km/km^2 (the escarpment in Dobre). The density in the other regions (Chodel, Zamość and Hrubieszów Basins, Chełm Hills, the Łuszczów Plateau, Horodło Plateau-ridge, Gap of the Middle Vistula, and the Dubienka Plain) is lower than 0.08 km/km^2. Non-dissected areas dominate, and gullies occur only sporadically.

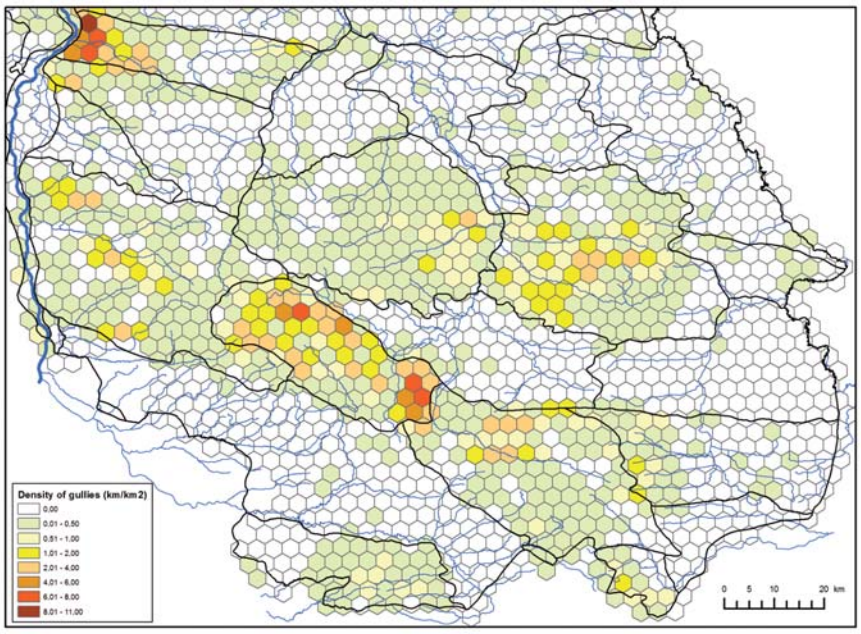

Fig. 2. Gully density in basic fields in geomorphological regions of the Lublin and Volhynia Uplands and Roztocze Hills

The main criterion for identification of the "gully regions" was the density of gully dissections, which form distinct clusters or systems. The areas analysed comprise 17 such regions (Tab. 2, Fig. 3) of a total area of 644.68 km^2 (5.64% of the entire area). Their names originate from the major towns located in the areas or in their immediate vicinity. The regions contain 2544.2 km of gullies, which represents 65.58% of the total length of these landforms in the study area. The surface areas of these regions are highly diverse – from 8 km^2 (Dobre, Teodorówka) to over 100 km^2 (Godziszów). The values of the gully density within these regions range from nearly 2 km/km^2 (Sitaniec) to over 9 km/km^2 (Parchatka). The gully regions are rather unequally distributed; they occur both within geomorphological regions characterized by a high general dissection index (Goraj Roztocze, the Nałęczów Plateau) and in regions exhibiting local clusters of gullies with a lower mean density, i.e. (Urzędów, Giełczew, and Grabowiec Hills, the Bełżyce Plateau, and Tomaszów Roztocze).

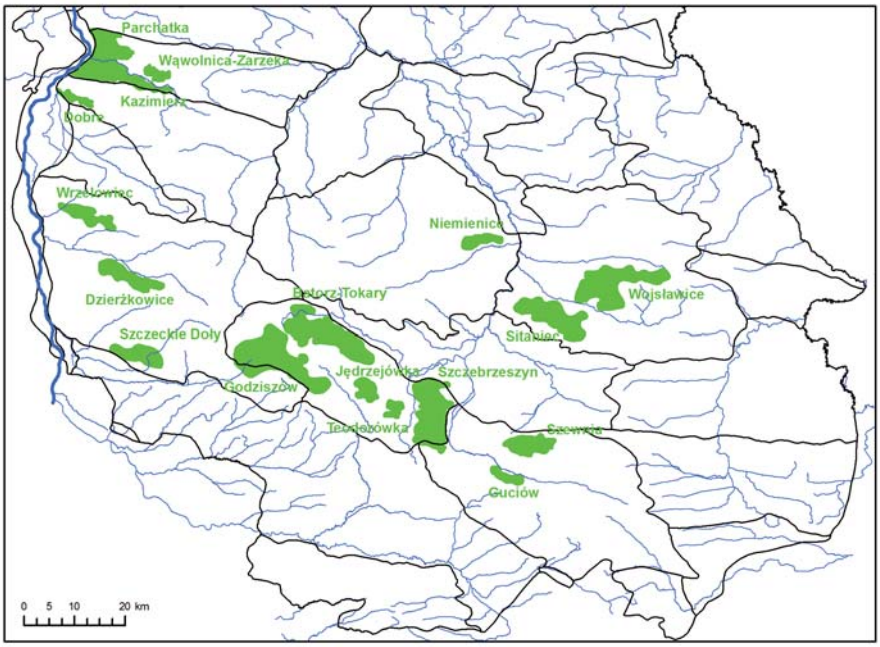

Fig. 3. "Gully regions" in the Lublin and Volhynia Uplands and Roztocze Hills

Parchatka – a region characterized by the highest gully density (mean 9.08, maximum 10.46 km/km^2). It comprises gully systems (Fig. 4) dissecting the right slope of the Vistula River valley between Bochotnica and Włostowice, the lower section of the right slope of the Bystra River valley in the east, and the escarpment zone of the Nałęczów Plateau near Skowieszyn in the north (the Kurówka

River catchment). Denivelations in this area reach 90 m. Almost the entire area is covered by loess, whose thickness reaches 30 m in the valley zones and 20 m on the plateau top. The loess substrate consists of a complex of glacial sediments of the marginal zone of the odra glaciation as well as opokas and gaizes of the Upper Cretaceous and Palaeocene. The loess cover is also characterized by considerable denivelations. Therefore, the combination of geological, hydrogeological, and paleogeographic factors as well as the high relative altitude values determine the high gully density in this region. The presence of impermeable glacial till deposits in the loess substrate contributes to intensive suffosion processes, which in turn initiate gully erosion. Great significance for such substantial erosive dissection of this area is attributed to intensive agricultural management and consequent deforestation regarded by archaeologists to have taken place in several phases since the Neolithic (since ca. 5000 years) as well as the specific layout of fields promoting accumulation of surface water runoff .

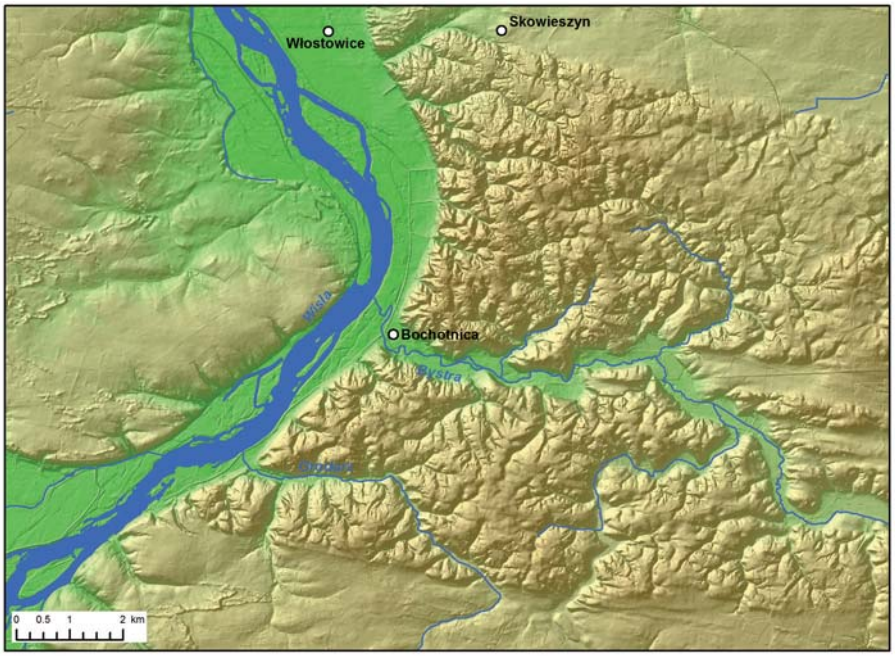

Fig. 4. Gullies in the western part of the Nałęczów Plateau

Kazimierz – Nałęczów – a region that covers the left side of the Bystra River catchment from Nałęczów to the river estuary in Bochotnica and a fragment of the Grodarz River catchment. The region is characterized by similar features as the Parchatka region. They are separated by the deeply incised Bystra River valley.

Wąwolnica – Zarzeka – a small (8.81 km^2) region covering a compact system of gullies that developed on the right slope of the Bystra River valley below Nałęczów. The determinants of the intensive dissection in the region are similar to those described in the aforementioned regions.

Dobre – a small, strongly dissected (7.10 km/km^2) region covering the gullies located within the escarpment of the Vistula River valley and the Bełżyce Plateau inclined towards the Chodel Basin. The 110 m high cuesta escarpment is formed of opokas and marls from the Upper Maastricht and its course coincides with an important active tectonic zone (Żelichowski 1983). The escarpment is overlaid by a 10–15 m thick loess cover partially overlapping the steep cuesta slope. V-shaped gullies, typical of the escarpment, dissect the bedrock in the central and lower part; in the upper part, where they dissect the loess cover, they have a typically loessial character. Gullies of this type are characterized by very large bottom declines and substantial depth.

Wrzelowiec is a gully region in the central part of the left slope of the Wrzelowianka River valley and the right slope of the Podlipie River valley (the right tributary of the Urzędówka River). A narrow, ca. 15 m thick watershed loess patch is more strongly dissected by gullies (ca. 3 km/km^2) in the eastern part, which belongs to the catchment of the deeply incised Urzędówka River valley characterized by denivelations exceeding 60 m. The western part, with its denivelations ranging from 40 to 50 m, is definitely dissected more poorly (gully density below 2 km/km^2).

Dzierzkowice is a region located on a fragment of the left slope of the Wyżnica River valley between Kolonia and Dzierzkowice. Denivelations in this region exceed 60 m, and the 20 m thick loess cover lies on a steep fossil slope of the Wyżnica River valley formed of Cretaceous rocks. In the 60s of the 20th century, torrential rain resulted in revival of large-scale erosion activity in the gullies of this region (Buraczyński, Wojtanowicz 1971).

Szczeckie Doły – a region comprising gullies in the escarpment zone of the Lublin Upland and the slopes of the Karasiówka River valley near Wólka Szczecka. The escarpment is an active morphotectonic zone separating the Lublin Upland from the tectonic Pre-Carpathian Trough (the macroregional tectonics scale). This zone has exhibited a long-term tendency towards raising movements between the Miocene and the Quaternary. The lithological complex of Cretaceous and Miocene carbonate rocks is covered by loess and loess-like deposits. Denivelations exceed 100 m in this zone. The gullies dissect the loess cover and the bedrock. A characteristic feature is the directional arrangement of the gullies corresponding to secondary faults and the network of fractures in carbonate rocks.

Godziszów – the largest of the study regions (102.45 km^2) situated primarily in the western part of the escarpment zone of Goraj Roztocze from Wierzchowiska to Kocudza Górna. In terms of hydrography, the region comprises the upper

sections of the catchments of the Sanna, Biała, and Branew Rivers as well as small fragments of the Ład and Por Rivers. Denivelations in the region exceed 60 m. The upper sections of the catchment of the Sanna and Branew valleys are characterized by a clearly higher degree of gully dissection. The region is subject to current raising movements, likewise almost the entire area of the Roztocze Hills.

Batorz-Tokary – the region covers the upper part of the Por River catchment in Roztocze and a broad northern tectonic escarpment zone of Roztocze. Loess thickness reaches up to 20 m in this area and denivelations exceed 100 m. The northern slope of Roztocze in this fragment is dissected by a system of dry valleys that are oblique in relation to the main escarpment dislocation formed in the Pleistocene before the main stage of loess accumulation during the last glaciation. A dense gully system dissects the slopes of these landforms.

Jędrzejówka (14.85 km^2) and **Teodorówka** (8.62 km^2) are regions located in the south-eastern part of Goraj Roztocze. The considerable thickness of the loess cover in the inner ridge of the loess patch and substantial denivelations associated with the deeply incised valleys of the Łada (Jędrzejówka) and Gorajec (Teodorówka) Rivers have contributed to the very intensive dissection of these areas by gullies.

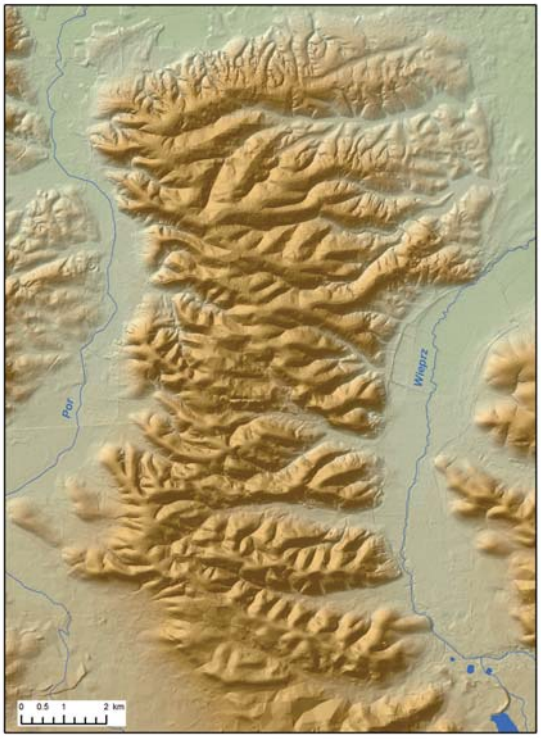

Fig. 5. Gullies in Szczebrzeszyn Roztocze

Szczebrzeszyn – one of the largest regions (76.77 km^2) covering a total of over 403 km of gullies dissecting the so-called Szczebrzeszyn Hump in the interfluve of the Wieprz, Gorajec, and Por Rivers (Fig. 5). Spatial diversity of the dissections is a characteristic feature of this distinct gully region, which is a tectonic horst located between the tectonic grabens of the Gorajec River valley and the Wieprz River valley. Denivelations reach 120 m in the eastern part of this region. Nearly the entire the region is covered by 20 m thick loess. A major part of this area belonging to the Wieprz River catchment is dissected more intensively (5.29 km/km^2) than its western (the Gorajec River catchment 3.32 km/km^2) and northern (the Por River catchment 2.77 km/km^2) parts. The gullies in the Por River catchment are typical branching escarpment landforms dissecting the steep northern slope of the Roztocze escarpment. The western escarpment of Szczebrzeszyn Roztocze, which is consequent to the dip of Upper Cretaceous rocks and declines toward the Gorajec River valley situated in a tectonic graben (Harasimiuk 1980; Brzezińska-Wójcik et al. 2002; Brzezińska-Wójcik et al. 2003), is dissected by numerous relatively short dry valleys with many gullies dissecting their slopes. The eastern part appears to be different. The watershed between the Gorajec and Wieprz Rivers valleys runs asymmetrically in relation to the longitudinal axis of the region. Approximately 2/3 of the area constitutes the Wieprz River catchment. There are numerous large dry valleys, consequent to the Cretaceous rock dip, whose slopes are dissected by an extremely dense system of gullies; these sometimes display characteristics of a typical "bad land", where secondary watersheds have the form of only narrow ridges separating the particular gullies. The region exhibits a particularly distinct impact of the primary subloessial relief determined by the bedrock structure on the distribution and dynamics of the gully landforms. A key role is also ascribed to the long-term agricultural management of the area (Buraczyński 1972, 1977).

Guciów – a small (10.31 km^2) region comprising gullies located on the left slope of the Wieprz River valley near Guciów. Small 10–15 m thick loess patches occur in the region and denivelations exceed 100 m. The gully density exceeds 5 km/km^2. The gullies dissect the loess cover and the bedrock.

Szewnia is a 28.80 km^2 region in the northern escarpment zone of Tomaszów Roztocze, in the catchment of the upper Topornica River at the western edge of the loess patch.

Niemienice – a small (14.17 km^2) region on the left slope of the Żółkiewka River associated with a narrow loess belt on the slope of the Giełczew Heights descending towards to the deeply incised Żółkiewka River valley; hence, the denivelations exceed 60 m in the region.

Sitaniec – one of the largest (57.09 km^2) and most poorly dissected (1.86 km/km^2) regions comprising the left side of the lower Wolica River valley.

Wojsławice – the second largest region (77.28 km^2) comprising the upper Wojsławka River valley and a fragment of the upper Wolica River valley. Loesses occur in the watershed zone descending onto the slopes of the valleys characterized by an almost latitudinal course. Denivelations in the region reach ca. 90 m. The slope falling towards the Wojsławka River valley is slightly more dissected.

Besides the distinguished regions, smaller clusters and areas of dispersed gullies are noteworthy. These areas include the lower Ciemięga River valley (the Nałęczów Plateau, the valleys of the upper Urzędówka, Wyżnica, Tuczyn and Karasiówka (the Urzędów Heights) Rivers; the interfluve of the upper Bystrzyca and Por Rivers, the vicinity of Jędrzejówka (the eastern part of Goraj Roztocze), the northern escarpment zone of Tomaszów Roztocze and Sokal Range (between Ruszów and Komarów), and the watershed of the Sołokija and Huczwa Rivers (to Justynówka/Biała Góra). In Rawa Roztocze, the section of the Sołokija River valley between the Żyłka and Prutnik Rivers is a remarkable gully area. In Grabowiec Heights, larger clusters of gullies are found on the slopes of the lower Wolica River valley and on the left slope of the Wojsławka River valley, particularly near Brzeziny and Zastawie. The density of the gully system within the Giełczew Heights is inconsiderable; a higher density has been reported only on the right slope of the central and lower Żółkiewka River valley.

Table 1. Gully density (km/km^2) in geomorphological subregions of the Lublin Upland, the Volhynia Upland, and Roztocze Hills

Subregion	Density (km/km^2)	Length (km)
The Lublin Upland		
Dubienka Plain	0.00	0.12
Chełm Hills	0.01	4.71
Gap of the Middle Vistula	0.02	4.63
Zamość Basin	0.02	12.41
Chodel Basin	0.02	4.98
Łuszczów Plateau	0.01	6.01
Bełżyce Plateau	0.12	82.00
Urzędów Height	0.33	457.10
Giełczew Height	0.26	331.25
Grabowiec Height	0.41	509.69
Nałęczów Plateau	1.37	678.32
– western part	2.48	
– eastern part	0.19	
– in the Bystra River catchment	2.89	

The Volhynia Upland		
Sokal Plateau-ridge	0.13	96.70
Hrubieszów Basin	0.00	1.33
Horodło Plateau-ridge	0.01	2.20
Roztocze		
Goraj Roztocze	1.84	1253.28
– Szczebrzeszyn Roztocze	4.57	
– in the Wieprz River catchment	5.29	
– in the Gorajec River catchment	3.32	
– in the Por River catchment	2.77	
Tomaszów Roztocze	0.37	381.35
Rawa Roztocze	0.39	53.17

Table 2. Characteristics of the "gully regions"

NAME	**Density (km/km^2)**	**Area (km^2)**
Sitaniec	1.86	57.09
Szczeckie Doły	2.01	27.25
Wojsławice	2.18	77.28
Godziszów (Roztocze)	2.53	102.45
Szewnia	3.20	28.80
Dzierzkowice	3.36	31.35
Niemienice	3.71	14.17
Jędrzejówka	3.95	14.85
Wrzelowiec	4.00	23.84
Batorz–Tokary (Roztocze)	4.53	81.59
Teodorówka (Roztocze)	4.69	8.62
Guciów (Roztocze)	5.46	10.31
Szczebrzeszyn (Roztocze)	5.49	76.77
Wąwolnica–Zarzeka	6.27	8.81
Kazimierz–Nałęczów	6.28	41.02
Dobre	7.10	8.27
Parchatka	9.08	32.19
Total		**644.68 (5.64%)**
Total length of the gullies	2 544.2 km	65.58% of the length of the gullies

GEOLOGICAL AND GEOMORPHOLOGICAL FACTORS OF GULLY EROSION

In the analysis of gully distribution using maps of relative heights and loess patch ranges, Maruszczak (1961) indicates orographic and lithographic factors of the development of these landforms. Gullies are mainly formed in loess at denivelations ranging between 30 and 60 m; however, a greater density of the dissections can be found at denivelations exceeding 60 m (Fig. 2).

The intensity of gully erosion is affected by other factors as well, which is evidenced by clear exceptions to the rule found by Maruszczak (1961). In Goraj Roztocze, there are almost no gullies in some fields, where denivelations exceed 90 m. The vicinity of Biała Góra (Tomaszów Roztocze), where denivelations are the greatest, is characterized by as low gully density as 1.31 km/km^2. A similar area in this respect is the western loess part of the Sokal Plateau-ridge, where the gully density only infrequently exceeds 1 km/km^2. Another "puzzling" area is the upper Wolica River catchment, where considerable relative heights (over 60 m) are accompanied by a relatively low number or even absence of gullies. Interestingly, the left slope of the Wieprz River valley between Izbica and Krasnystaw with denivelations exceeding even 90 m is dissected by only few gullies. In Horodło Plateau-ridge, gullies have developed only sporadically despite thick loesses and denivelations reaching 60 m. The examples presented above demonstrate that denivelations are not strict determinants of gully erosion, which is evidenced by the correlation coefficient 0.469. It should be emphasized that a higher gully density can be found in regions that exhibit a distinct tendency to neotectonic raising movements. This applies particularly to the strongly dissected areas of Goraj Roztocze as well as smaller areas such as the escarpment in Dobre, the surroundings of Dzierzkowice, or Szczecyn.

Dense gully systems constitute particularly attractive landscapes characterized by high bio- and geodiversity. Therefore, a substantial proportion of gully areas have been included in various environmental protection programmes. The strongly dissected areas of the Nałęczów Plateau have been protected as the Kazimierz Landscape Park since 1979. A landscape reserve was established in 1991 in the area of the highly eroded escarpment of the Bełżyce Plateau descending towards the Vistula River valley and Chodel Basin. The gully system in the area of Wrzelowiec is protected as the Wrzelowiec Landscape Park as well as the gullies in the catchments of the Wolica and Wojsławka Rivers within the Skierbieszów Landscape Park. Goraj Roztocze, strongly dissected by gullies, is almost fully protected as a landscape park. Reserve protection has been established for the "Szczeckie Doły" gully and a gully system near Niemienice in the Żółkiewka River valley. Some of the gullies have a status of documentation localities.

Investigations of erosion landforms (mainly gullies) have an important application aspect. In recent years, the Lublin Upland and Roztocze Hills have witnessed considerable changes in the land management and land ownership structure. In regions with a high gully density, the proportion of fallow land has increased; also, the field road infrastructure has been rebuilt, and the average farm size has risen. These processes pose new challenges for spatial management associated with agricultural restructuralization. In areas that are susceptible to erosion, changes in the field and road network may trigger the process. It is advisable that work should be undertaken to develop model solutions for agricultural land consolidation. This is particularly important in the Roztocze region, where 5 high-density gully regions with a total area of ca. 300 km^2 were distinguished, and in the Nałęczów Plateau (3 regions with a total area of ca. 100 km^2).

Simultaneously, there is a tendency in the high-density gully regions to take advantage of the gully systems and develop new tourism products based on the landscape and geotouristic values of these areas (designed geoparks partly covering the Nałęczów Plateau and Roztocze Hills).

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STRESZCZENIE

Erozja wąwozowa stanowi istotny problem gospodarczy w regionach, gdzie występuje, ograniczając lub utrudniając racjonalne użytkowanie gruntów. Procesem tym zagrożonych jest około 18% powierzchni Polski. Wyżyna Lubelska i Roztocze wyróżniają się zarówno gęstością form erozyjnych, jak i wielkością systemów wąwozowych.

Analizy morfometryczne (gęstość wąwozów, średnie spadki i wysokości względne) wykonano dla subregionów geomorfologicznych na obszarze 1260 km^2, w sześciobocznych polach podstawowych o powierzchni 10 km^2, na podstawie danych z cyfrowego przetworzenia map topograficznych w skali 1: 10 000 w środowisku programu ArcGIS. Do analizy uwarunkowań występowania wąwozów wykorzystano numeryczny model terenu DTED Level 2 o rozdzielczości około 30 m.

Łączna długość wąwozów w badanych regionach wynosi 3880 km, co daje średnią w skali Wyżyny Lubelskiej i Roztocza łącznie 0,34 km/km^2. Obszary o gęstości wąwozów przekraczającej 0,5 km/km^2 zajmują łącznie 15,46% powierzchni. W skali subregionalnej wyróżniają się: Roztocze Gorajskie (1,84 km/km^2) i Płaskowyż Nałęczowski na Wyżynie Lubelskiej (1,37 km/km^2). Charakterystyczne jest duże przestrzenne zróżnicowanie wskaźnika gęstości wąwozów. Wydzielono 17 „regionów wąwozowych" (ryc. 3, tab. 2), w obrębie których wąwozy tworzą wyraźne skupiska lub rozbudowane systemy. W wydzielonych obszarach znajduje się 2 544,2 km wąwozów, co stanowi 65,58% całkowitej długości form na całym analizowanym obszarze. Powierzchnia wydzielonych obszarów jest zróżnicowana – od 8 km^2 do ponad 100 km^2.

Obszarem wyróżniającym się jest północno-zachodnia część Płaskowyżu Nałęczowskiego (Parchatka – powierzchnia około 32 km^2), gdzie gęstość średnia wąwozów wynosi 9,08 km/km^2, w tym też obszarze występuje pole o maksymalnej wartości tego wskaźnika osiągającej 10,46 km/km^2, co prawdopodobnie jest najwyższym wskaźnikiem gęstości wąwozów w skali europejskiej. Intensywnemu rozwojowi erozji wąwozowej w tym obszarze sprzyjają: wysokości względne dochodzące do 90 m, prawie pełne pokrycie obszaru lessem, którego miąższość dochodzi do 30 m, występowanie w podłożu lessu nieprzepuszczalnych glin zwałowych i tendencja do neotektonicznych ruchów podnoszących. O niezwykłej gęstości wąwozów w tym obszarze decyduje więc zespół czynników geologicznych, hydrogeologicznych i paleogeograficznych. Nie bez znacznia jest tu intensywna, długotrwała gospodarka rolnicza i związane z nią wylesienie obszaru. W obrębie Płaskowyżu Nałęczowskiego występują jeszcze dwa obszary o dużej gęstości wąwozów o podobnych uwarunkowaniach środowiskowych.

W obrębie grzbietu Roztocza wyróżniono 7 obszarów wąwozowych, gdzie gęstość wąwozów waha sie od 2,53 do 5,49 km/km^2. Szczebrzeszyn (ryc. 5, tab. 2) to jeden z największych regionów (76,77 km/km^2), najwyraźniej wyodrębniający się, obejmujący łącznie 403 km wąwozów. Jest to współcześnie dźwigany zrąb tektoniczny obrzeżony od wschodu i zachodu dolinami rzecznymi położonymi w rowach tektonicznych, przy deniwelacjach do 120 m. W tym regionie szczególnie wyraźny jest wpływ pierwotnej – podlessowej rzeźby uwarunkowanej strukturą podłoża skalnego na rozmieszczenie i dynamikę form wąwozowych.

Podstawowymi czynnikami warunkującymi intensywne procesy erozyjne w badanym obszarze są: pokrywa lessowa, duże deniwelacje (powyżej 60 m), subregionalne przestrzenne zróżnicowanie współczesnych ruchów podnoszących i intensywne, długotrwałe użytkowanie rolnicze.

Gęste sieci wąwozów tworzą niezwykłe, atrakcyjne krajobrazy o bardzo dużej bio- i georóżnorodności. Dlatego znaczna ich część została objęta różnymi formami ochrony środowiska. W większości są to parki krajobrazowe. Trzy spośród obszarów wąwozowych mają status rezerwatów przyrody. Są to: Krawędź w Dobrem, Szczeckie Doły na południowej krawędzi Wyżyny Lubelskiej i Niemienice w dolinie Żółkiewki.

Gęste sieci wąwozów stanowią także istotną barierę w rozwoju nowoczesnych form gospodarki rolnej na obszarach o wysokiej jakości gleb. Zachodzące przemiany układu pól i sieci drogowej mogą być w tych obszarach czynnikiem stymulującym ożywienie procesów erozyjnych.

Słowa kluczowe: wąwozy, głębocznice, zlodowacenie odry, Wyżyna Lubelska, Roztocze