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GEOMORPHIC EFFECTS OF LAND USE CHANGES (A CASE OF THE GUTANÓW LOESS CATCHMENT, POLAND)

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The study discusses the influence of land use changes on relief development in a small loess catchment with medium denivelations, located in the Lublin Upland (SE Poland). The denudation rates in the past were determined by field analysis of the soil profiles, and its present-day rate was calculated by the caesium-137 method. An attempt to determine the changes of the soil erosion rate during the 620 year period of land cultivation was undertaken. The mechanism of development of the anthropogenic relief forms and their influence on the changes in intensity of the episodic surface runoff was also analysed. A considerable influence of the field pattern, tillage direction and location of country roads on the intensity of geomorphological phenomena was observed.

Key words: SE Poland, loess catchment, soil erosion, anthropogenic relief, denudation balance, episodic processes

INTRODUCTION

Eolic loess covers with diversified relief cover 30 % of the Lublin Upland area (SE Poland). In the areas where the relative height is up to 30 m, they are

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further diversified with shallow closed depressions and denudation troughs. In the areas with bigger denivelations, dry erosion-denudation valleys are predominant (Maruszczak 1961). The natural plant communities there is a mixed forest with underlying podzolic soils with a O-Ah-Eet-Eetg-Bt_1-Bt_2-C-C_{Ca} profile, 150-160 cm deep (Turski and Słowińska-Jurkiewicz 1994). These relatively fertile soils were taken over for plant breeding. At the moment, forests cover only about 10 % of their surface area. The period of intense settlement and agricultural activities in this area dates back to the 15th century when, directly after the union between Poland and Lithuania, these border areas became safe (Myśliński 1958). When the first granges were founded in the 16th century, the cultural landscape already covered 40-50 % of this region (Maruszczak 1988).

Climatic conditions are typical for the temperate zone. The mean annual air temperature is about 7.5°C; temperature of the hottest month, July, is about 18°C, and the coldest month, January, about -4°C. Total annual precipitation ranges from 550 to 600 mm; the mean monthly precipitation sum is the highest in July (80-90 mm). However, the highest monthly totals can be observed from April to October (Kaszewski et al. 1995). Snow cover lasts for 70-80 days on the average; and every few years snowy winters give rise to runoff and erosion due to spring thawing. Torrential rains resulting in considerable erosion damage are less frequent (Maruszczak 1968, Rodzik et al. 1998).

Natural conditions and agricultural land use made the loess upland areas in the Vistula and Bug interfluve the most susceptible to soil erosion in Poland. A special predisposition for the development of anthropogenic forms of relief such as agricultural terraces and road gullies can be observed there (Reniger 1950; Ziemnicki 1968). In the places where denivelations exceed 60 m, bottoms and sides of many valleys are cut by gullies that are also considered effects of human intervention into the natural environment (Maruszczak 1961 and 1968). Neither the mechanism of development of anthropogenic forms, nor their role in the functioning of the geographical environment, has been sufficiently studied yet.

STUDY AIMS AND METHODS

The studies undertaken by the authors aimed at determining the influence of land use changes on the functioning of the catchment as a geosystem. A direct impulse to undertake geomorphological research in the Gutanów catchment was a heavy rainfall that took place close to Garbów on September 16 1995. It was found that due to anthropogenic conditions, erosion was the biggest in this region and the eroded material was accumulated in the valley bottom in the form of fanes and accumulation covers. Mapping of erosion and accumulation forms in a small catchment of about 20 ha, allowed balancing of erosion effects (Rodzik et al. 1996). Development of the erosion forms that were then created, was observed in the following years after periods of thawing and heavy rains.

In order to determine geomorphological predisposition in the development of the contemporary erosion processes, mapping of the natural and anthropogenic forms was carried out. Analysis of evolution of the anthropogenic relief forms allowed assessment of changes in the directions of the surface runoff. Changes in the geological-soil conditions were evaluated by determining soil erosion degree in 30 representative soil profiles which allowed us to calculate the mean rate of erosion from the very beginning of the agricultural utilization period. A field method of soil profile analysis was applied (Zachar 1982).

In order to evaluate dynamics of the contemporary slope processes, especially of the surface erosion of soils in the studied catchment, a method with isotope application was used; ^{137}Cs redistribution is related to the physical side of erosion processes (Richie and McHenry 1990). Applying a modified, simplified model of mass balance (Zhang et al. 1990), quantitative characteristics of the slope processes in various morphodynamic zones of the catchment were determined. Only the caesium-137 coming from Chernobyl was used. It made assessment of denudation intensity in the period from 1986 to 1998 possible.

Analysis of the historic geodetic plans supplemented with interviews with field owners was also carried out. It allowed us to learn about changes in the land use, and pattern of country roads, baulks, fields and directions of tillage in the last several decades. It allowed us to assess their influence on the surface runoff conditions, intensity of geomorphological processes and relief transformations. The studied catchment was treated as a model of a loess area with a medium relief in the Lublin Upland.

CHARACTERISTICS OF THE STUDIED CATCHMENT

The studied catchment is located in the northern part of the loessy Nałęczów Plateau, which is a mesoregion situated in the north-west corner of the Lublin Upland (SE Poland). The loess cover, formed mainly during the last glaciation (the Vistulian glaciation), is 10 m thick (Harasimiuk and Henkiel 1976). This part of the Plateau has a rolling loess relief with average denivelations of up to

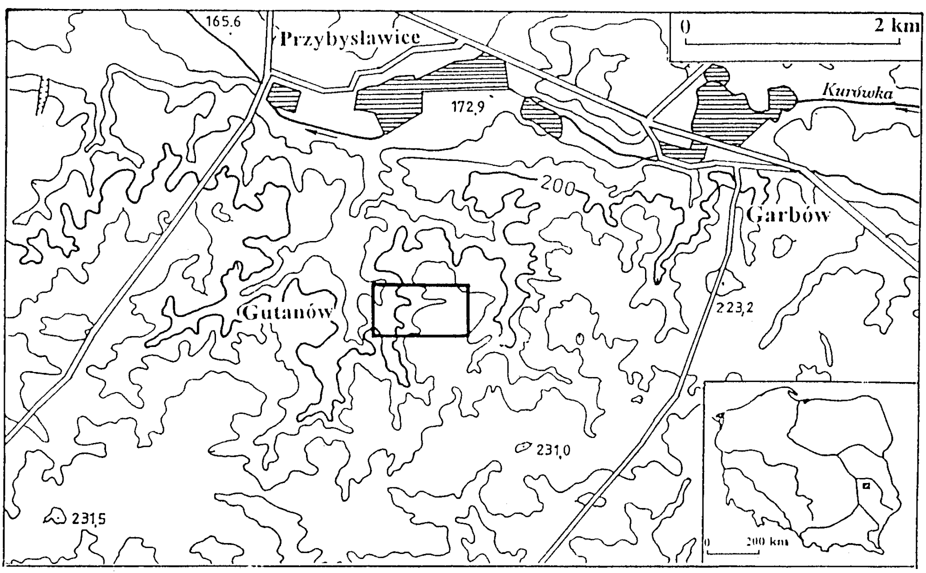

Fig. 1. Localisation of the area under investigation

50 m (Fig. 1). Its main forms are complicated systems of dry erosion-denudation valleys with the side inclinations of up to 15°, diversified with slope troughs.

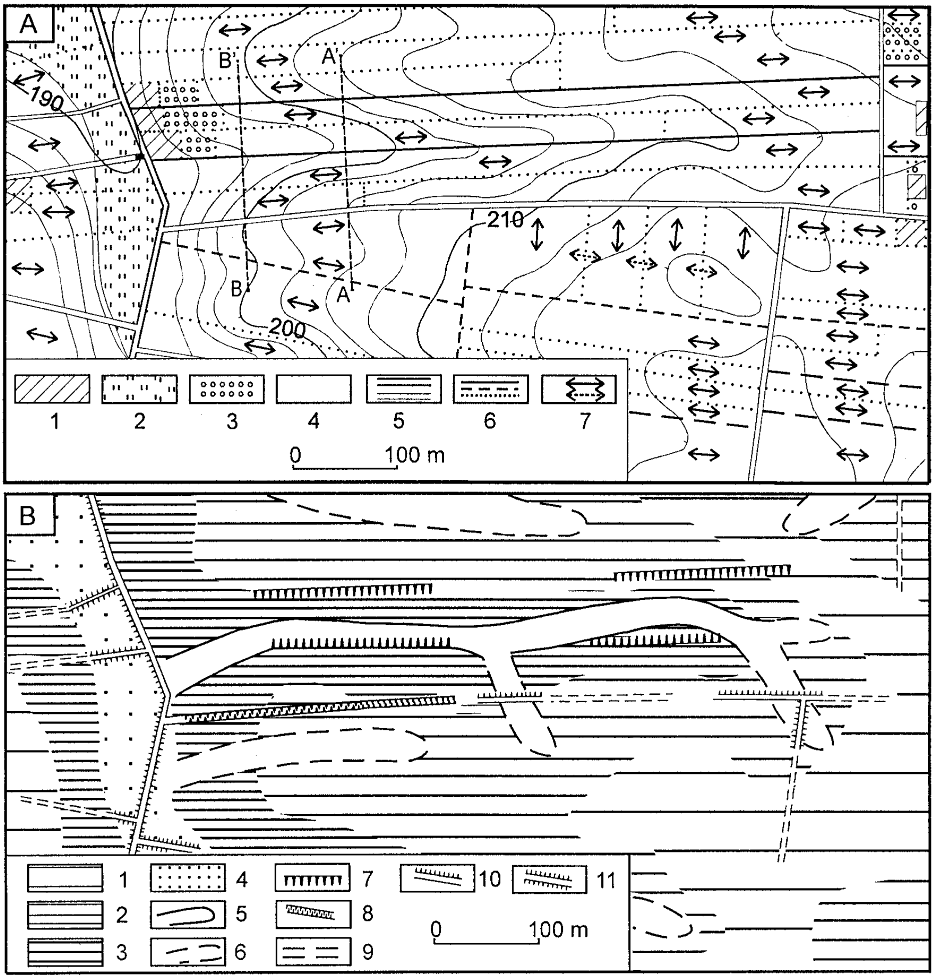

Fig. 2. Contemporary conditioning of the geomorphological processes development in loess catchment at Gutanów

A. Land use and changes of the agrarian structure in the Gutanów catchment in the XX century

1 – built-up areas, 2 – green lands (meadows), 3 – orchards, 4 – arable fields, 5 – roads used: a) for several hundred years, b) for tens years, 6 – borders of the agricultural parcels: a) after integration of lands in 1931, b) after agricultural reforms in 1945, c) after division of succession in 1962 years, 7 – tillage direction: a) before division of succession, b) after division of succession

B. Geomorphological sketch of the study area

A. Natural elements of the relief: 1 – interfluves (< 5%), 2 – slopes of interfluves (5-10 %), 3 – sides of valleys (> 10%), 4 – bottom of the main valley, 5 – bottom of the trough-like valleys, 6 – denudative troughs; B. Anthropogenic elements of the relief: 7 – agricultural scarps, 8 – road gullies, 9 – road troughs, 10 – road terraces, 11 – road dikes

The study area included a natural catchment of a trough-like valley and slope denudation trough (Fig. 2B). These forms cut the slopes and the system of flat interfluves that tower above the flat bottom of the main valley located at the height of about 190 m a.s.l. The inclination of the valley sides is 5-13^0, and of the slopes of the interfluves 3-5^0; the slightly rolling interfluves situated at the level of 213-220 m a.s.l. are diversified by low hills and closed depressions. Denivelations in the area of the studied catchment reach up to 30 m. Such conditions do not favour development of gullies. Agricultural treatment made soil cover diversified as a result of erosion. The typical arable podzolic soils of the region with a characteristic A_p-Et-Bt_1-Bt_2-BC-C-C_{Ca} profile were preserved on the flat interfluve area (Turski and Słowińska-Jurkiewicz 1994). On the slopes they have undergone considerable erosion. Hence, their profiles are reduced to the lower horizons. In the terrain depressions, they were built up with diluvia.

The studied catchment is an agricultural one. Arable land covers 98 % of the surface area. The remaining part is covered with buildings and communication tracks. Cultivated fields cover 96 % of the catchment; permanent greenland (meadows) 1.5 %, and orchards only 0.5 % (Fig. 2A). Winter cereals, spring cereals and root crops (i.e. potatoes and sugar beets) occupy an equal share of the cultivation area. In crop rotation, individual fields are often sown with grass and function as greenland for a few years. During the study period, berry plantations were founded on some of the plots (currant, aronia).

Only small individual farms with the mean area of about 5 ha can be found in the above area. They are divided into plots of 0.2 to 1.0 ha. Such an agrarian structure favours a dense net of baulks and ground service roads. The fields are lined perpendicularly to the main valley which results in the downslope tillage on its sides, and contour tillage on the sides of the trough-like valley that enters the main valley (Fig. 2).

Taking into account scarce population in this area before the 15th century, we can assume that the catchment has been utilized for agriculture for about 600 years. Gutanów was mentioned in the 15th century Długosz's chronicle under the year 1380 (Myśliński 1958). Also the village and the grange were described in some later historical documents (Sulimierski and Chlebowski 1880-1902). The location of the oldest part of the village buildings and the grange makes us believe that cultivation direction was similar to today's (W-E) and, apart from a few details, it has not undergone any significant changes until today. However, the field pattern of today was formed as late as the 20th century when a lot of bigger fields were broken up into smaller units. In the part of the catchment located on the peasants' plots north of the road, the field pattern was formed as a result of field integration in 1931. In the southern part located in the grange area, the fields were delineated during the land reform of 1945. The fields that were then formed were afterwards divided as a result of bequest divisions. The current pattern (Fig. 2B) has been functioning without any changes since the beginning of the 60-ties.

CONTEMPORARY INTENSITY OF SOIL EROSION

The highest intensity of soil erosion was observed on the convex and divergent slopes of the valley and above these slopes in the area of similarly exposed fragments of watershed ridges (Fig. 3). Total soil erosion and uncovering of carbonate loess occurred in the places where downslope cultivation was practiced, already at the inclination of 5°. Whereas in the places where contour cultivation was applied, it occurred only when the inclination was 10°. Since decalcification depth in the natural conditions is 1.6 to 1.9 m on the slopes, it can be assumed that in the border cases, the thickness of the removed soil layer is bigger than 2 m. The remains of the soil profile were preserved on the less exposed valley sides and in the area of the watershed ridges and exposed elements of the interfluve slope. Erosion is slightly smaller on the slopes and culminations of the interfluve area, that is 0.5 to 1.0 m (Tab. 1). Soil erosion degree is also reflected in the content of clay fractions (<0.02 mm) in the arable layer. In the podzolic soils, it is the highest in the Bt_1 horizon and gradually decreases with depth. A considerable or total reduction of the soil profile took place on the 30-40 % of the total area of the studied catchment which is typical for the small loess catchments of the Nałęczów Plateau (Maruszczak et al. 1984, Turski et al. 1991).

It has been assumed that the remaining part of the catchment (located outside the main valley) where denudation was weaker, has a levelled balance. The area where accumulation is not so intense corresponds approximately to the area

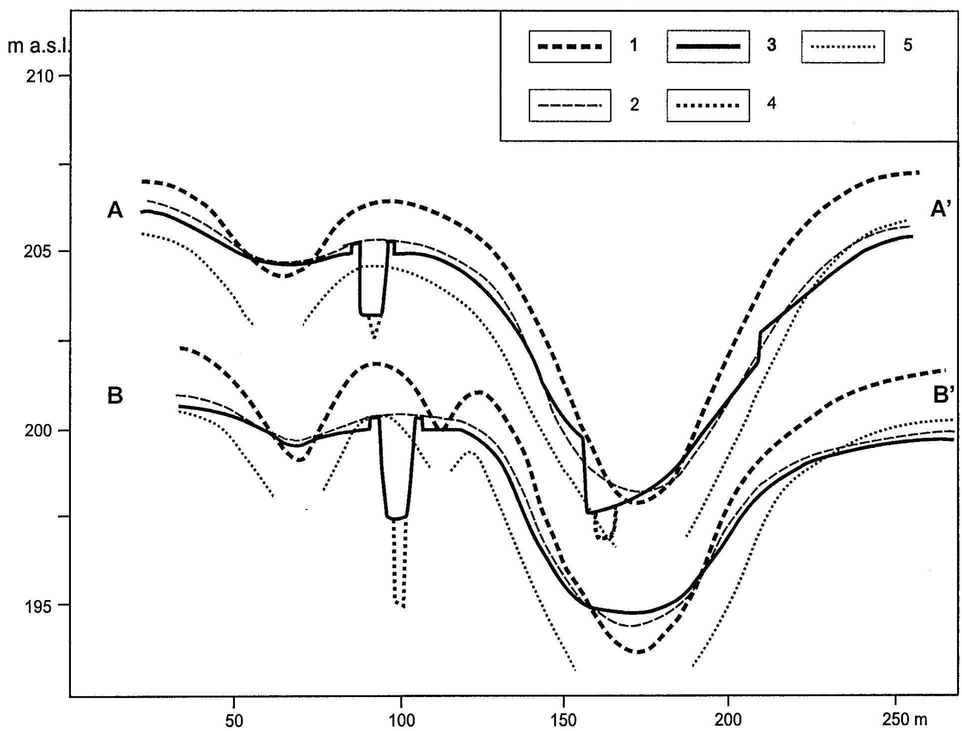

Fig. 3. Examples of changes of the topographic surface in "Gutanów" catchment caused by land use (A – A', B – B' – cross-sections localised in Fig. 2A)

1 – primary surface, 2 – surface ca. 50 years ago, 3 – recent surface, 4 – ravines and evorsive potholes, 5 – decalcification soil horizon

where erosion is characterized as weak. Bulk material removed from the catchment was estimated at 80 000 m^3 (about 136 000 tons), and lowering of its surface at > 40 cm. The mean annual denudation in the studied catchment is 0.65 mm for the whole period of agricultural utilization (620 years), whereas in the area of the most eroded slopes, it is 3.3 mm on the average, with a maximum of 4 mm/year (Tab. 1).

Tab. 1. The denudation intensity in the agricultural loess catchment at Gutanów

Degrees of erosion		Landforms	Fraction < 0.02 mm in plough soil horizon [%]	Area [%]	Denudation		
					Contemporary ^{137}Cs method [mm*year^{-1}]	Mean (620 years) [mm*year^{-1}]	Sum [m]
Erosion	very strong	side of valley and ridge-like watersheds	38	5 - 10	-5.5	-3.3	-1.5 ÷ 2.5
	strong	ridge-like watersheds and side of valley	43	10 - 15	-4.0	-2.0	-1.0 ÷ 1.5
	moderate	slope of interfluves and tops	46	10 - 15	-3.0	-1.2	-0.5 ÷ 1.0
	weak	interfluves and slope of interfluves	55	15 - 20	-1.5	-0.5	- < 0.5
	lack of erosion	interfluves	53	25 - 30	–	–	–
Deluvial accumulation		bottom of the trough	46	15 - 20	–	+0.5	+ < 0.5
Average for catchment		deluvial catchment	46.8	95	-1.5	-0.65	-0.4
Proluvial accumulation		main valley bottom	42	5	+15.0	+3.0 ÷ 5.0	+2.0 ÷ 3.0

Intensity of present-day denudation in the described catchment in the period 1986-1998 was evaluated using the caesium technique. On the basis of the spatial variability in total ^{137}Cs activity mass balance of soil material within the catchment has been established (Ritchie and McHenry 1990, Klimowicz et al. 2001, Zgłobicki 2001). The simplified mass balance model (Zhang et al. 1990) was applied for the quantitative analysis. The mean rate of lowering of the exposed interfluve parts reached 1.5 mm, slopes of interfluves – 3.0 mm, watershed ridges – 4.0 mm, and valley sides – 5.5 mm per year (Tab. 1). Thus, the contemporary denudation rate of the cultivated loess slopes in this region (about 5 mm/year) is similar to that obtained by the geodetic measurements (Mazur 1972, Pałys and Mazur 1998). It is 66 % higher than the multi-year mean. The contemporary denudation rate of the whole catchment is 130 % higher than the multi-year mean; average lowering of the surface of the catchment was 1.5 mm/ year in the years 1986-1998. Acceleration of the erosion rate in the whole catchment in relation to the slopes results from a bigger surface area covered by erosion nowadays, mainly due to the levelling and eroding of some small concave forms that gathered diluvia before (Fig. 3). Erosion of the diluvia on the slopes with a long cultivation history was also observed by Klimowicz (1993); conclusions by the latter author on the decreasing rate of soil erosion with the increasing soil cultivation time were not confirmed.

It can be assumed that such a high soil erosion rate had lasted for about 30 years when a fundamental change in the soil cultivation methods took place. Agricultural mechanization in this area was delayed compared to the state owned farms. However, despite the broken-up field structure, horses was replaced by tractors, and machines took over sowing and harvesting. Application of machines causes considerable soil shifting also during contour cultivation (Orzechowski 1962). By taking into consideration land use and cultivation conditions, the future denudation rate can be assessed on the basis of the multi-year mean and current denudation.

Soil erosion rate lower than the average certainly occurred in the first period of soil cultivation. The latter period was characterized by a three-field cereal crop rotation (winter, spring and fallow) and development of a grange type of economy. Simple tools were primarily used for soil cultivation in this area (plough, lister). These tools did not turn the furrow-slice (Myśliński 1958). This period lasted from around 1380 to the end of the 16th century. With an extensive tillage and relatively good soil protection cover made by cereals, stubble, and weeds in the fallows, soil erosion was not very intense. It can be assessed at < 0.5 mm /year for the whole catchment and > 2.5 mm per year for the most denuded slopes.

In the next period, from the beginning of the 17th century to about 1830, soil erosion developed at a similar rate. Destructive wars and frequent by armies passages together with a general economic stagnation, stopped implementation of new systems and techniques of soil cultivation in agriculture (Maruszczak 1988).

A considerable increase in the soil erosion rate took place in the 19th century due to the implementation of new cultivations (root plants) and application of crop rotation and generally improved agricultural tools. In the studied region, the above changes started about 1830, with a delay in relation to the western parts of the country (Willaume 1964). In intense soil cultivation, a plough with a mouldboard started to become popular, then a cultivator and an iron harrow. Frequency of cultivation treatments increased as root crops that substituted previous fallows required soil loosening even a few times a year. It considerably increased cultivation erosion as well as washing. We may estimate that the denudation rate was then doubled up to 1 mm per year for the whole catchment and almost 5 mm per year for the most denuded slopes. The above confirms the studies by Ziemnicki (1949) who assessed the mean multi-year erosion rate for 4-5 mm per year for the whole loess slope. In the above period, carbonate loess was exposed on the slopes that were most susceptible to erosion.

DEVELOPMENT AND FUNCTIONING OF THE ANTHROPOGENIC FORMS OF RELIEF

The last period in the studied catchment is characterized not only by the accelerated rate and extension of denudation, but also by the qualitative changes. They were conditioned by the overlapping of some unfavourable features of the field and country road pattern and such factors as: total soil erosion on some of the slopes (Fig. 3), intensification of slope processes, and an increase in the intensity of road usage. New, dynamically developing forms of relief were generated (Fig. 2B). They influenced contemporary functioning of the geosystem of the studied catchment mainly by the changes in the direction of the surface runoff (Rodzik et al. 1996).

Quick scarp formation on the oldest baulks parallel to the contour lines and cutting the gentle slope forms on the sides of the trough-like valley can be observed. In the upper part of the valley, on the convergent slopes, these are cultivation scarps where accumulation predominates, and in the lower part of the valley, where the scarps undercut the divergent slopes, erosion is predominant. Uncovering of the carbonate loess appeared to be especially important in the place where the scarp undercuts the convex form in the left valley side, above its bottom. Runoff along the furrow under the scarp shifted the valley axis just near the scarp (Fig. 3) which resulted in the formation of a small step in the longitudinal profile of the valley bottom. It is a well predisposed place for strong erosion as a few erodogenic factors overlapped here, that is exposition of the carbonate loess, increase of inclination and concentration of the surface runoff (Fig. 4A).

Country roads are also quickly transformed as they are more and more often used. Already in the previous period the number of new farms and fields in this area increased. The number of road passes also increased as a result of yield increase due to the application of artificial fertilisers. The number of vehicles also increases continuously, especially passenger vehicles. It resulted in an increase of erosion intensity in the country roads and formation of some new forms of not only erosion but also accumulation, such as diluvial causeways and road terraces (Fig. 2B), which forced deposition of material delivered on the bottom of the main valley from its sides and tributary valleys (Fig. 4B). These diluvial forms are formed as a result of accumulation of material washed off the roads located on the slopes onto the road sections located in the valley bottoms (Rodzik 1998).

The most important factor in the influence of the road formations in the studied catchment, is creation of a new partial catchment C that is drained by the road running parallel to the axis of the trough valley and cutting through the slope of the main valley. There was also a change in the direction of drainage of the slope trough cut through by this road. The above phenomenon was influenced by the crosswise division of the field next to the trough and road, and the change in the direction of its cultivation to perpendicular to the road that took place in the 50-ties (Fig. 2A). As a result, a road trough was formed (Rodzik 2000). It was accompanied by the intensification of accumulation on the road in the slope trough axis. The quickly growing road terrace (Fig. 2B) directed the runoff from the trough along the road to the main valley side (Fig. 4A). The concentrated runoff from this catchment resulted in a quick development of a road gully with the length of about 250 m and up to 3 m depth.

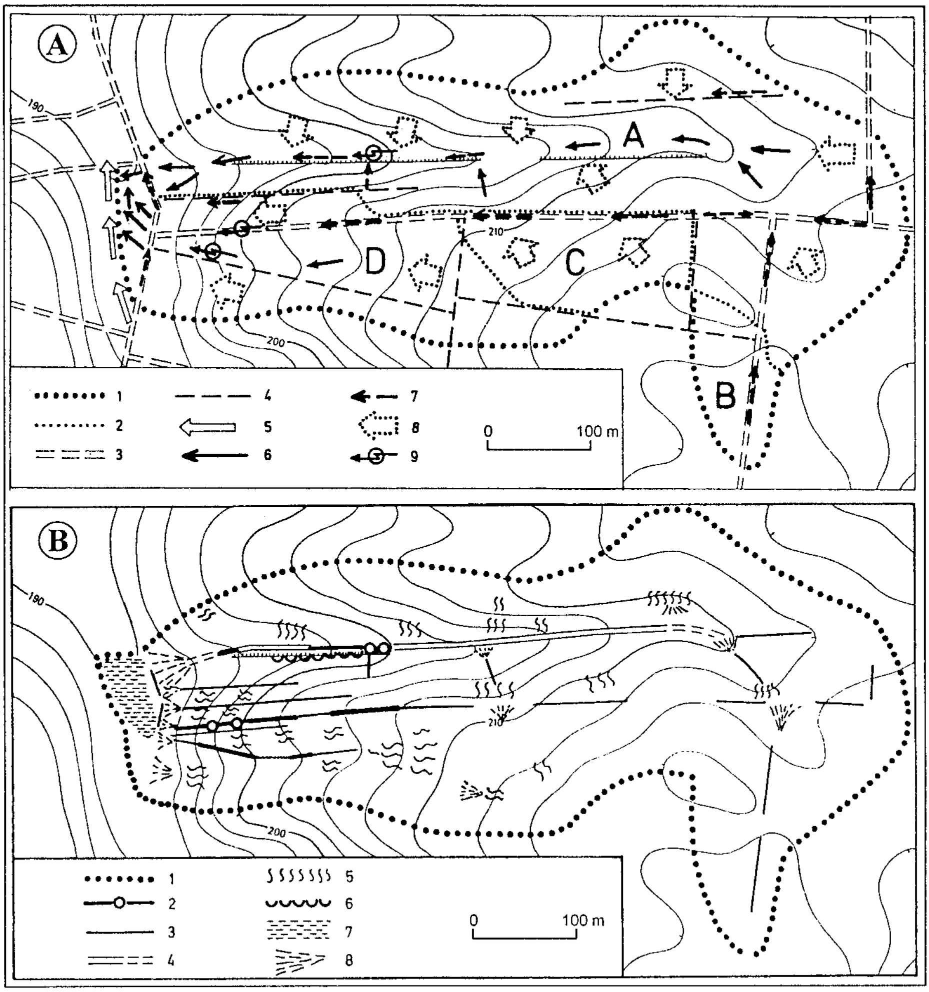

Fig. 4. Influence of the agriculture on the effects of torrential rain on 16 September 1995 in the Gutanów catchment (after Rodzik et al. 1998)

A. Direction of the overland flow: 1 – watershed of the examined catchment, 2 – watersheds of partial catchments, 3 – ground roads, 4 – balks and rills directing overland flow, 5 – major flow along the main valley bottom, 6 – concentrated flow conditioned by the surface relief, 7 – concentrated flow conditioned by the anthropogenic factors, 8 – main directions of the sheet flow, 9 – coupling of the erosion factors (complete soil erosion, big linear flow, increase of the slope); A – catchment of the trough-like valley, B – area „added" by the road flow, C – catchment of the road gully, D – catchment of the slope trough

B. Distribution of the erosion and accumulation processes: 1 – borders of the catchment, 2 – ravines and erosional-evorsive potholes, 3 – erosive rills, 4 – erosive and transport episodic channels, 5 – fields of erosive rills, 6 – detachments and rockfalls on the escarpments, 7 – proluvial covers, 8 – deluvial fans

Probably since 1945, when the road was built, the process of its incision into the slope with no soil on it, has been taking place. The rate of road incision was not very high in the beginning as the road was partially sodded, and the catchment was limited to this road only. In the topographic map from 1974, the gully does not appear. Its depth then probably did not exceed 1 m which determines the upper limit of the annual deepening for 3.5 m. It is marked on the 1986 map, which suggests that during this period it underwent a considerable development. It dates formation of the C catchment to the 70-ties and relates it to the development of mechanization in agriculture. The rate of the gully incision was then doubled in the deepest sections to 7.5-8 mm a year. Such a development scheme of the road gully was confirmed by the interviews with the locals.

Detachment of the C catchment from the catchment of the trough valley (A) did not decrease erosion in its bottom as the B catchment occurring on the interfluve was attached to it by the runoff through the road trough (Fig. 4A). It should be stressed that in the natural conditions, the runoff on the interfluve is stopped by small depressions. It can be supposed that the way roads and baulks direct the runoff, influences intensification of the soil erosion on the interfluve areas. A significant change in the runoff took place in the recent period in the area of the D catchment. The baulk that intersects the slope trough diagonally in this place, collects the runoff form its upper parts. It results in a diagonal intersection (along this baulk) of the concave form on the valley side (Fig. 4).

INFLUENCE OF ANTHROPOPRESSION ON THE EPISODIC PROCESSES

During the study period, surface runoff was observed a few times in a year during thawing, torrential and heavy rains, or even hail. Three episodes of runoffs were so intensive that special treatment was necessary to remove the results of erosion caused by them. The biggest erosion was caused by a torrential rain with the total precipitation sum of > 50 mm on September 16th 1995 (Rodzik et al. 1996). Slightly less damage resulted from the thaw of 1996 and a torrential rain of 1999 as they took place before the harvest. Country roads and the soil loosened by the skimming or scarifying appeared to be especially susceptible to all the erosion processes. Only the sodded areas and stubble appeared to be resistant (Tab. 2).

On the interfluve, torrential rains did not cause any substantial damage, even in the loosened soil. On the slopes of the interfluves, soil particles were detached by the rainsplash and underwent surface washing. It is difficult to estimate the extent of this phenomenon. In the places where runoff was intense, a net of rills with the width and depth of usually a few centimetres was formed. Strong rainsplash, intensive linear and sheet wash were observed on the valley sides, and a dense net of rills was formed. After the torrential rain of September 1995, the total volume of rills in the studied catchment was 59 m^3 (Tab. 3).

Concentrated runoff in the bottom of the trough valley built a form with a considerable width of 1-2 m and small depth defined as an episodic channel (Teisseyre 1991) or an ephemeral summer gully (Nachtergaele and Poesen 1999). The layer of arable soil from the first ploughing carried out earlier, with the total volume of 60 m^3, was then torn away. With a short-term runoff, bottom erosion was limited by the “ploughing feet”. This barrier was only overcome in the place where all the erodogenic factors were combined under the scarp (Fig. 4) where evorsion hollows with depths of 1.5 m and widths of up to 3 m and the total volume of 32 m^3 developed as a result of headward erosion. Outside the trough valley bottom, an intense linear erosion and evorsion occurred in the bottom of the road gully that was strongly cut along almost all its length. The strongest cut was observed in the lower section with the bottom inclination of about 7-8°, where one of the potholes reached the depth of over 3 m (Fig. 3). It should be stressed that on the pothole walls in the bottom of the valley and the gully, traces were visible of previous erosion in the form of pockets filled with diluvial material.

Tab. 2. Influence of plant cover and relief on the geomorphological processes within the model “Gutanów” catchment during heavy rainfall 16.09.1995 (modified from Rodzik et al. 1998)

Plant cover / Relief forms	Grassland	Stubble field		Sugar beats	Potatoes	Scarified soil	Ground roads
		winter crop	spring crop				
Interfluve	—	—	rainsplash	—	rainsplash	**rainsplash**	**rainsplash, washing**
Slope of the inter-fluve	—	—	rainsplash, washing	washing	rainsplash, washing	**rainsplash, washing**	**rainsplash, washing, rill erosion**
Sides of the valleys	**transport, landslide*)**	transport, washing	x	washing, rill erosion, piping*)	rainsplash, rill erosion	**rainsplash, washin, rill erosion**	**washing, head-cut and rill erosion**
Denudative troughs	transport	washing	x	washing	x	**rainsplash, washing, rill erosion**	washing, accumulation
Bottom of the trough-like valley	**transport**	**transport**	x	transport, **washing**	x	**transport, head-cut and chan-nel erosion**	x
Bottom of the main valley	**transport, accumula-tion**	x	x	accumula-tion	x	x	rill erosion, transport, accumulation

intensity of the process (**big** and moderate) is marked by print: (—) lack or low intensity of processes, (x) not registered within the described catchment, (*) process on the scarps

With high frequency of surface runoff, cultivated scarps or gully scarps can undergo piping. The above process is usually initiated by the tunnels made by rooting animals. Water falls into them by the grooves ploughed out parallel to the scarp. If the field above the scarp is sodded, intensive infiltration starts development of minute landslide forms – soil slips. During the present research, a change in the utilization of the field above the highest scarp in the catchment took place. This caused a change in the type of processes on the scarp (Fig. 5).

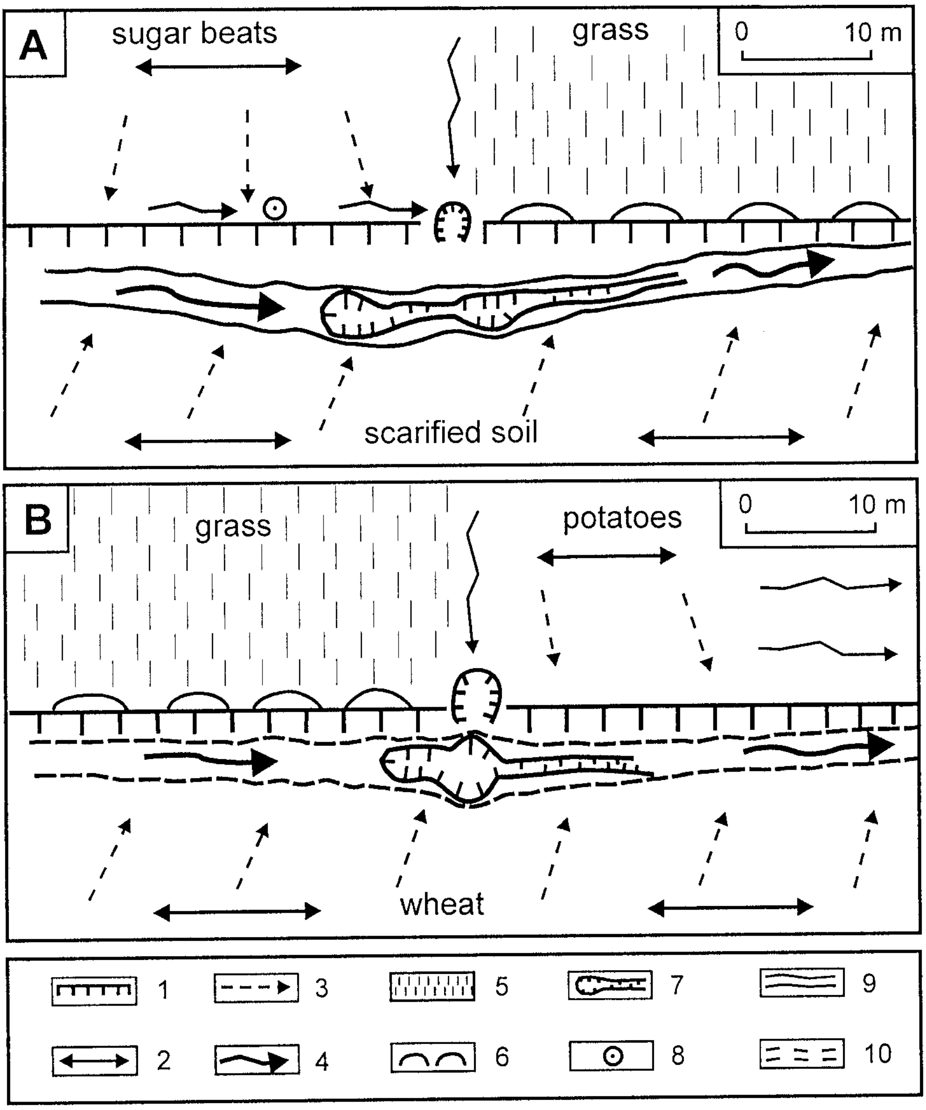

Fig. 5. Influence of the changes of tillage on geomorphological processes during torrential rains: A. September 1995, B. July 1999

1 – agricultural scarps, 2 – tillage direction, 3 – sheet flow, 4 – concentrated flow, 5 – infiltration, 6 – detachments and rockfalls, 7 – evorsive potholes, 8 – pipes, 9 – erosive episodic channels, 10 – transport episodic channels

Material eroded from the catchment is deposited in the bottom of the main valley. Below the outlet of the erosion forms, alluvial fans dammed by the road causeway running along the bottom of the valley, are formed at the foot of the slope. Together they build a diluvial road terrace. During the biggest runoffs, most of the material is deposited in the very bottom of the valley in the form of covers dammed by the transversely located diluvial road causeways and main longitudinal runoff (Fig. 4I). The thickness of the covers exceeds 20 cm at places, and their volume reaches 300 m^3, as in September 1995.

Tab. 3. Denudative balance of the model Gutanów catchment after heavy rainfall on 16 September 1995 (after Rodzik et al. 1998)

Catchment (see Fig. 4 A)	A + B (14.5 ha)	C (1.9 ha)	D (3.3 ha)	Main valley bottom (0.6 ha)	Total (20.3 ha)
Erosive channels [m^3]	60	—	—	—	60
Ravines and potholes [m^3]	32	84	10	—	126
Rills [m^3]	28	8	22	1	59
Total linear erosion [m^3]	**120**	**92**	**32**	**1**	**245**
Surface wash [a] [m^3]	55	2	29	1	87
Total erosion [m^3]	**175**	**94**	**61**	**2**	**332**
Accumulative covers [m^3]	—	—	—	300	300
Fans [m^3]	5	1	1	25	32
Total accumulation [m^3]	**5**	**1**	**1**	**325**	**332**
Balance [m^3]	-170	-93	-60	+323	0
Mean denudation [mm]	-1.2	-4.8	-1.8	+54.0	-1.7 [b]
Real denudation [mm]	-3.0 [c]	-152.0 [d]	-2.0 [c]	+108.0	

a) calculated from balance of erosion and accumulation, proportionally to denudated areas, b) recalculated by area of A+B+C+D (19.7 ha), c) recalculated by valley sides and bottoms of trough-like valleys, d) recalculated by road gully bottom area

Occurrence of ^{137}Cs was found in the profile of the proluvial deposits up to the depth of 60 cm. The above isotope occurred in the atmosphere from the trial nuclear explosions at the beginning of the 60-ties (Richie and Mc Henry 1990). Taking into consideration the rate of vertical migration, it can be calculated that the average rate of accumulation in the bottom of the valley is about 1.5 cm/year in the last 35 years. In the very catchment, accumulation is only small. Only in the axes of the troughs, small fans are formed as a result of the runoff blocked by the roads and baulks. The fans make the cultivated scarps and road terraces higher. In the bottom of the trough valley, high longitudinal depression, and direction of cultivation together with the pattern of boundary strips do not favour accumulation, and condition strong erosion (Fig. 4). The size of scattered accumulation in the catchment area as such is difficult to evaluate.

In the denudation balance of the studied catchment during the torrential rain mentioned above (Tab. 3), the volume of accumulation forms was determined as a sum of the total material eroded from the catchment (325 m^3). If this material was then evenly distributed over the whole surface of the catchment, it would form a layer 1.7 mm thick, i.e. slightly more than the average annual denudation calculated by the caesium method. When calculated as a unit denudation, the value reaches 28 t/ha (2800 t/km^2). The fact that more than half of the eroded material was removed from the road gully and the bottom of the trough valley makes the authors draw a conclusion that during episodic phenomena, the process of material removal from the catchment, that is longitudinal transport is predominant. Continual processes, first of all tillage erosion, are mainly responsible for the transverse transport of the material from the slopes to the valley bottom.

CONCLUSIONS

When the loess areas of the Lublin Upland were deforested and started to be cultivated, a considerable intensification of geomorphological processes occurred in the conditions of a transient climate of the temperate zone. Surface soil erosion that reduces soil profile at the slopes and builds them up in depressions and valley bottoms, is predominant. After a few hundred years of cultivation, the soil became totally eroded on the divergent and convex slopes, and carbonate loess was exposed. With contour cultivation, the above process was observed on the slopes with the inclination of > 10°, but in the places where cultivation was downslope, at the inclination of > 5°.

Soil erosion leads to a gradual levelling of the relief and makes the slopes more gentle. The most exposed slopes were lowered by over 2 m (3.3 mm a year), and the bottom of the dry erosion-denudation valley was built up by 2-3 meters. Differences in height in the studied catchment, decrease by more than 10 %. In total, the average lowering of the slopes and interfluves reached 0.4 m, and the rate of annual denudation – 0.65 mm.

With an increase in the intensity of soil cultivation and application of more and more modern techniques of tillage, the rate of soil erosion was also increasing. For a long time, the mean denudation rate of the slopes and interfluves was kept at the level of 0.5 mm per year. Only in the 19th century, it doubled when the modern crop rotation method was applied together with the introduction of root plants and improved tools. Further denudation increase was due to mechanization in agriculture. A changed pattern of fields and more intensive utilization of country roads also favoured erosion. When the microforms of relief were smoothed out, considerable erosion covered bigger and bigger areas. The results of application of the ^{137}Cs technique showed that in the last 15 years mean annual denudation of the catchment was 1.5 mm. Lowering of the most eroded slopes has been calculated at 5.5 mm.

Changes in the land use as well as field and country road patterns resulted in the qualitative changes in relief. Erosion within the country roads on the slopes cause formation of troughs and road gullies. Accumulation on the roads in the bottoms of depressions results in the formation of diluvial terraces and road causeways. Accumulation road forms force deposition of the material that is transported along the axes of the valleys. Changes of the fields above the cultivation scarps into greenland may cause dangerous sliding of the scarps that are usually endangered with piping. Human activities may cause overlapping of such erodogenic factors as: exposure of the carbonate loess, runoff concentration, runoff direction towards the slopes with an increased inclination. The effect of the above is intensification of the linear erosion and evorsion during episodic runoffs which, in turn, results in gully development.

During extreme phenomena, the process of material removal from the catchment by the longitudinal transport is predominant. Almost 40 % of the material that is then moved, comes from the dissections and evorsion hollows. Their development is conditioned by the course of country roads and baulks. With a more favourable location of roads and baulks, spectacular erosion forms could not have been formed. If an additional, simple protective treatment of sodding was applied to the trough valley bottom, the episodic channel that functions there, would have a transport and not an erosion character. Such treatments would decrease erosion by a total of as much as almost 60 %, and transverse transport would be dominant in the catchment.

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GEOMORFOLOGICKÝ EFEKT ZMIEN VYUŽÍVANIA KRAJINY (PRÍKLAD SPRAŠOVEJ OBLASTI V OKOLÍ GUTANÓWA)

Výskum denudačných procesov sa uskutočnil v sprašovej oblasti, využívanej poľnohospodársky 620 rokov. Študované územie je situované na okolí Gutanówa v Lublinskej vrchovine (obr. 1). Pre účely štúdia danej problematiky bolo vybrané malé povodie s rozlohou 20 ha. Povodie predstavuje suchú erózno-denudačnú dolinu s korytovým zárezom na jednom z jej svahov. Reliéf povodia je zvlnený, s energiou do 30 m a sklonmi do 13°. Pôdy reprezentujú podzoly s rôznym stupňom postihnutia eróziou.

Polia v študovanom povodí patria malým súkromným farmám. Ich veľkosť je 0,2 – 1,0 ha. Súčasná textúra polí a ciest vznikla v období 1930-1960 ako výsledok sceľovania polí, pozemkovej reformy a dedičného delenia. Svahy hlavnej suchej doliny sú kultivované po spádnici, svahy bočnej korytovej doliny po vrstevnici. Medze na vrstevnicovo obhospodarovaných svahoch majú podobu kultivačných stupňov. Koncentrácia odtoku na poľných cestách, podliehajúcich zmyvu a erózii, vedie k vzniku úvozov a výmoľov na svahoch a akumulačných terás a vyvýšených ciest v dnách dolín (obr. 2).

Stav pôdnej pokrývky, ktorá je miestami úplne erodovaná, svedčí o značnej intenzifikácii eróznych procesov (obr. 3). Pôdne profily v povodí ukazujú, že najexponovanejšie svahy boli znížené o viac ako 2 m (3,3 mm ročne). Dno suchej erózno-denudačnej doliny bolo pokryté niekoľko metrov mocnou vrstvou sedimentov. Denivelácie v povodí sa takto znížili o viac ako 10 %. V priebehu celého hodnoteného obdobia zníženie svahov a chrbtov predstavovalo 0,4 m, a teda priemerná hodnota ich denudácie za rok vykazovala 0,65 mm (tab. 1).

Merania koncentrácie izotopu ^{137}Cs ukázali, že v priebehu posledných 15 rokov došlo k zvýšeniu priemernej intenzity denudácie v povodí až na 1,5 mm ročne, pričom najvyššie hodnoty znižovania povrchu vykazovali rozvodné chrbty (4,0 mm) a svahy dolín (5,5 mm) (tab. 1). Uvedené údaje sú v súlade s hodnotami intenzity denudácie obrábaných svahov na spraši, nameranými geodetickými metódami v podobných územiach. Následkom mechanizácie poľnohospodárstva a zvýšenia intenzity využívania ciest bola akcelerácia erózie. V skoršom období, konkrétne v 19. storočí, bol nárast intenzity denudácie podmienený prechodom od trojpoľného systému k striedaniu plodín, zavedením okopanín a používaním novej, kvalitnejšej poľnohospodárskej techniky.

Priebeh ciest a medzí značne pozmenil prirodzené podmienky povrchového odtoku počas extrémnych zrážok a topenia snehu. Je to zvlášť viditeľné počas takých lejakov, aké sa vyskytli v septembri 1995, kedy koncentrácia odtoku na cestách a na medziach presiahla kritickú hranicu. Kombinácia viacerých erodogénnych faktorov zapríčinila silnú eróziu a vznik erózno-evorzných depresií o hĺbke viac ako 1 m. Najsilnejšia erózia, zapríčinená pripojením ďalšieho parciálneho povodia následkom zmeny textúry susediacich polí, sa vyskytla na dne úvozu (obr. 4), kde hĺbka krútňavových hrncov dosahovala do 3 m.

Výskyt a intenzita takých eróznych procesov, akými sú napr. plošný splach a stružková erózia, boli podmienené najmä pôdnymi pomermi, rastlinnou pokrývkou alebo agrotechnologickými postupmi. Poľné cesty sa ukázali ako veľmi náchylné na erózne procesy, podobne ako to bolo v prípade plôch s odstránenou drnovou pokrývkou, či plôch rozrytých. Iba zatrávnené partie alebo strniská po oziminách sa ukázali rezistentné (tab. 2). Na skladoch vrstevnicových polí sa v podmienkach častého povrchového odtoku zvykne vyskytovať sufózia. Ak sa pole nad skladom zatrávni, sklad sa zosunie (obr. 5).

Väčšina materiálu vynášaného z povodia sa uložila na dne hlavnej doliny v súvislosti s prehradením odtoku vertikálne narastajúcimi telesami poľných ciest. Objem kužeľov a proluviálno-deluviálnych pokrovov predstavuje 225 m^3. Keby bol uvedený materiál rovnomerne rozložený po celom území povodia, vytváral by 1,7 mm mocnú vrstvu (tab. 3), t. j. trochu mocnejšiu ako je priemerná ročná hodnota denudácie, stanovená na základe céziovej metódy. V prepočte na jednotku plochy to znamená odnos 28 t/ha (2800 t/km^2). Skutočnosť, že viac než polovica materiálu bola vynesená z úvozov a dna bočnej korytovej doliny, umožňuje vysloviť záver, že počas epizodických udalostí dominuje v povodí pozdĺžny transport. Priečny transport materiálu zo svahov na dno doliny je prevažne výsledkom sekulárnych procesov, akým je erózia z orania (tab. 1).