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The intensity of soil erosion in agricultural areas in North-Eastern Poland

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Abstract: Investigations in to the intensity of soil erosion have been conducted by measurements of rill capacities on selected hillslopes in agricultural areas of North-Eastern Poland. The intensity of interrill erosion has been measured by using sediment traps.

Owing to the interrill erosion, it is the convex parts of the slopes which have been eroded the most intensively. On gentle slopes (<9 degrees), the most intensive erosion has been observed in the upper convex part (0,3–7 t/ha/yr.) and a zone of temporary deposition has been identified just below the zone of erosion i.e. in the middle and the lower parts of a convex-concave slope. On steeper slopes (those steeper than 9–10°) the upper and middle part of the slope are also part of the zone of erosion. The highest rates of erosion occur in those middle parts of the slope witch have the steepest inclination (3–11 t/ha/per yr.). Soil deposition takes place in the upper concave part of the slope. The rill erosion is the effect of ploughing parallel with the slope. The highest rate of denudation is in the middle and the lower parts of the convex-concave slope (3,3–16,6 t/ha/yr.). The areas of micro-catchment are a very important factors in the determination of the effectiveness of rill erosion. The efficient operation of the process was observed in the zone making 10–21% of the total area of micro-catchments. Rill erosion only takes place in plough lands. On slopes used as pastures the intensity of sheet wash was very small, averaging 16–58 kg/ha/yr. On slopes which were not in use and had a natural vegetation, it was only 2–10 kg/ha/yr.

Volumetric measurements of covers at the bases of the slopes show that the thickness of the anthropogenic accumulation (either from run off or agrotechnical practice) formed as an agricultural diamicton is 40–100 cm in Suwałki Lakeland. In the northern part of Mazowiecka Lowland these diamictons are thicker, locally exceeding 2,5 m.

Key words: wash, inter-rill and rill erosion, tillage erosion, deposits, agricultural diamicton

Introduction

Identification of the modern processes which shape the relief of the Polish Lowlands indicates that water erosion is the main slope-forming process, particularly in agricultural areas. Water erosion in the degradation of slopes in the area covered by the last glaciation is particularly important (Niewiadomski & Skrodzki, 1964; Chudecki & Niedźwiecki, 1983; Uggla *et al.*, 1998).

The aim of the present study was to determine the intensity of surface wash. This was established by quantitative measurements of the process on slopes characteristic of the local relief and specially chosen in respect of their structure and use.

The main tasks undertaken were: quantitative examination of water erosion on the selected slopes, both rill and interrill erosion and the identification of the erosion and accumulation zones on these slopes.

The investigations were carried out in two regions of North-East Poland (Fig. 1):

1) the area of the Würmian Glaciation in the Suwałki Lake District (the western part of the Lithuanian Lake District) in the years 1987–1989 (Smolska, 1993; Smolska, Mazurek & Wójcik, 1995) and also the period 1998–1999;

2) the area of the Riss Glaciation in the northern part of Mazowiecka Lowland near Różan over the period 1995–1996 (Smolska, 1998) and Łochów in the years 1991–1992 and 1997.

Fig. 1. Location of the study area; the maximum limits of the Würm Glaciation (W) and the Riss Glaciation (R)

The weather conditions at the time of the investigations

The period of the field-investigations was characterised by an annual precipitation approximating to the long-term mean (550 mm). The year 1996 was relatively dry (471 mm) whereas the year 1997 was more humid. In Autumn, Winter and early Spring, the precipitation was of low or moderate intensity. In late Spring and in Summer, heavy rain-falls occurred one to three times per month, their daily sum oscillating usually from 8 mm to 30 mm. In the Suwałki region the maximal daily precipitation was 54 mm whereas in the Mazowiecka Lowland, it was 32 mm. The characteristic climatic features of the period of investigations were mild Winters with a little or no snow cover.

Experimental methods

The geomorphological mapping of contemporary processes (and forms) was carried out seasonally. The mapping began before the quantitative measurements and were made after wards.

The measuring of interrill erosion was conducted using modified Słupik traps (Słupik, 1973). The trap consists of a frame of thick steel wire with a piece of sheet zinc attached to it. To the frame is attached a sack of thick plastic foil in which the soil is collected, together with water flowing downslope. In order to obtain information about erosion on particular parts of the slope, the sampling sites were distributed according to the method proposed by Gerlach (1976). The catchers were placed on the slopes at places where the inclination and form changed. This was done in such a way that the trap collects the soil material from the watershed to the position of the trap. Each sampling site was composed of three traps which had 50 cm wide inlets. The traps were unloaded once a month except during periods of agricultural activity.

The evaluation of rill erosion required measurements of the depth, width and length of the rills. Thus their volume and an estimation of the amount of washed out material could be calculated. Similar measurements were carried out in the case of the proluvial fans: the surface area and thickness of the alluvia were measured in a network of squares of side length 0.5 m for smaller microforms and 1 m for larger ones.

Study area

The area of the Würmian Glaciation – the Suwałki Lake District, exhibits a strongly diversified relief. The hillslopes are short and have varied inclinations (6–24°), mostly convex-concave. Local denivelations do not exceed 20 m. Only the slopes of the vast Szeszupa valley, of an exharation (a melt-out) origin, are longer, up to 150 m, and show greater relative heights, 50–70 m. In this area, the investigations were carried out on 9 different slopes although on only three was the intensity of rill erosion measured.

The area of Riss Glaciation is represented by the region of Różan and Łochów. Here there is a flat, locally rolling landscape with denuded hillocks of frontal moraines, terraces of marginal glacier valleys and of river valleys, covered with dunes. The slopes are short, about 10–15 m height, of 3–9 degrees inclination and of convex-concave shape. Greater denivelations (up to 30 m) and inclinations (9–24 degrees) occur along the sides of Narew valley. The sides of this valley are intersected by deep dry valleys, locally with deep ravines in their lower parts and with periodic or permanent streams. In the region of Różan, two slopes of a moraine hillock and the bottom of a dry valley used as arable land cutting the side of river Narew were chosen for investigations, as well as a steep grassy slope in this dry valley. In the region of Łochów this was the slope of a ground moraine, used as arable land and two slopes of a dune, one wooded, the other deforested.

Results

The examined slopes were modelled at various intensities. They are characterised by the occurrence of erosion and accumulation zones and of short zones of accumulation at the latter being of limited extent near to the slope base.

Table 1. The intensity of wash-mean annual values on the slopes investigated

Region of Poland	Morphology	Lithology	Sheet wash	Linear wash
Suwałki Lakeland	Convex sector of slope		Erosion	
		Loam	30–124 kg/ha	0–300 kg/ha
		Sandy Sandy silty	60 kg – 7,2 t/ha	0–670 kg/ha
	Uniform sector of slope	Loam	17–50 kg/ha	0,6–16,6 t/ha
		Sandy Sandy silty	58 kg – 3,9 t/ha	0,2–4,7 t/ha
	Concave sector of slope		Accumulation	Erosion
		Loam	26–174 kg/ha	3,3– 10,4 t/ha
		Sandy Sandy silty	160–330 kg/ha	0,2–4,5 t/ha
Mazowiecka Lowland	Convex sector of slope		Erosion	
		Loam	16–93 kg/ha	0
		Sandy Sandy silty	12–92 kg/ha	0
	Concave slope		Accumulation	Erosion
		Loam	16–93 kg/ha	0
		Sandy Sandy silty	40–920 kg/ha	0

The average annual erosion resulting from sheet wash is insignificant whereas the annual erosion of slopes resulting from linear wash was much more intensive (Table 1).

The distribution of erosion and accumulation zones on slopes is distinctly related to the slope inclination and shape, the weather regime and the land use.

On convex-concave slopes of less than 9°, the most intensive erosion results from the sheet wash and occurrs on convex parts (0,3–7 t/ha); the deposition zone is situated immediately below the erosion zone, i.e. in the middle and the lower parts of the slope (Fig. 2a). On steeper slopes, i.e. those over 9°, the erosion zone comprises the upper and the middle parts of the slope, the middle part, that with the greater inclination being the most intensively degraded (the upper fragment of the uniform inclination sector; 3–11 t/ ha/ yr). The soil deposition takes place in the upper concave section of the slope (Fig. 2b). Only small part of the transported material was transferred beyond the slope base. A similar situation has been described many times previously (e.g. Selby, 1982; Govers & Poeson, 1988; Govers, 1991a; Kostrzewski *et al.*, 1992).

A straight slope (that a uniform inclination) is characterised by the occurrence of erosion zones in the upper and lower parts, being situated in the middle part of the accumulation zone (Fig. 2c).

Measurements of the distribution of the wash intensity throughout the year allows us to define periods of greater and lesser activation of the process. The Winter – thaw period is characterised by low intensity (up to 10% of the annually eroded material). The thaw period in north-eastern Poland is usually characterised by slow snow melting and limited precipitation. During the Autumn extensive rains give rise to more intensive sheet erosion (20–30% of annual value). The slopes are modelled mainly in late Spring and early Summer, i.e. May to the beginning of July. Precipitation of high intensity may occur at that time. Usually there are 2–3 heavy rains per month at times when the vegetation on slopes used as arable land is not yet mature. In Summer the intensity of process is at an average despite the occurrence of heavy rainfall. The soil is protected by rich vegetation at that time.

Modelling of the ploughed slopes is clearly dependent on the rainfall regime in the late Spring and early Summer. Short, but intensive rainstorms falling on a dry soil surface, results in the erosion of the upper convex part of the slope and the deposition of the material just below the convex sector. However rain falling on moist soil generates erosion on individual parts of the slope with an intensity commensurate with to its inclination (Fig. 3a).

Linear erosion has occurred on 4 of the 9 investigated slopes in the Suwałki Lake District and on 1 of the 4 slopes and at the bottom of a dry valley in the Mazowiecka Lowland. The maximum rate of destruction (3.3–16.6 t/ha – annual averages) was observed in the middle and lower sections of the concave – convex slopes, especially on the convergent slopes which are used as arable land.

Various spatial patterns of rills and terminal fans were observed. Small, 5 cm-deep rills begin to form on the slopes, below concave slopes. The density of these forms reached 18/100 m² in convergent sections of the slopes and e. 4–6/100 m² in divergent or uniformly inclined slopes. Small rills usually merge and form larger ones, reaching depths of 10–20 cm, in the middle parts of the slopes. Densities of the rills in the middle and upper parts of the convex sections were lower (6–10 rills/100 m²). The accumulation of sediments begins in the convex areas – initially at the bottom of the rills

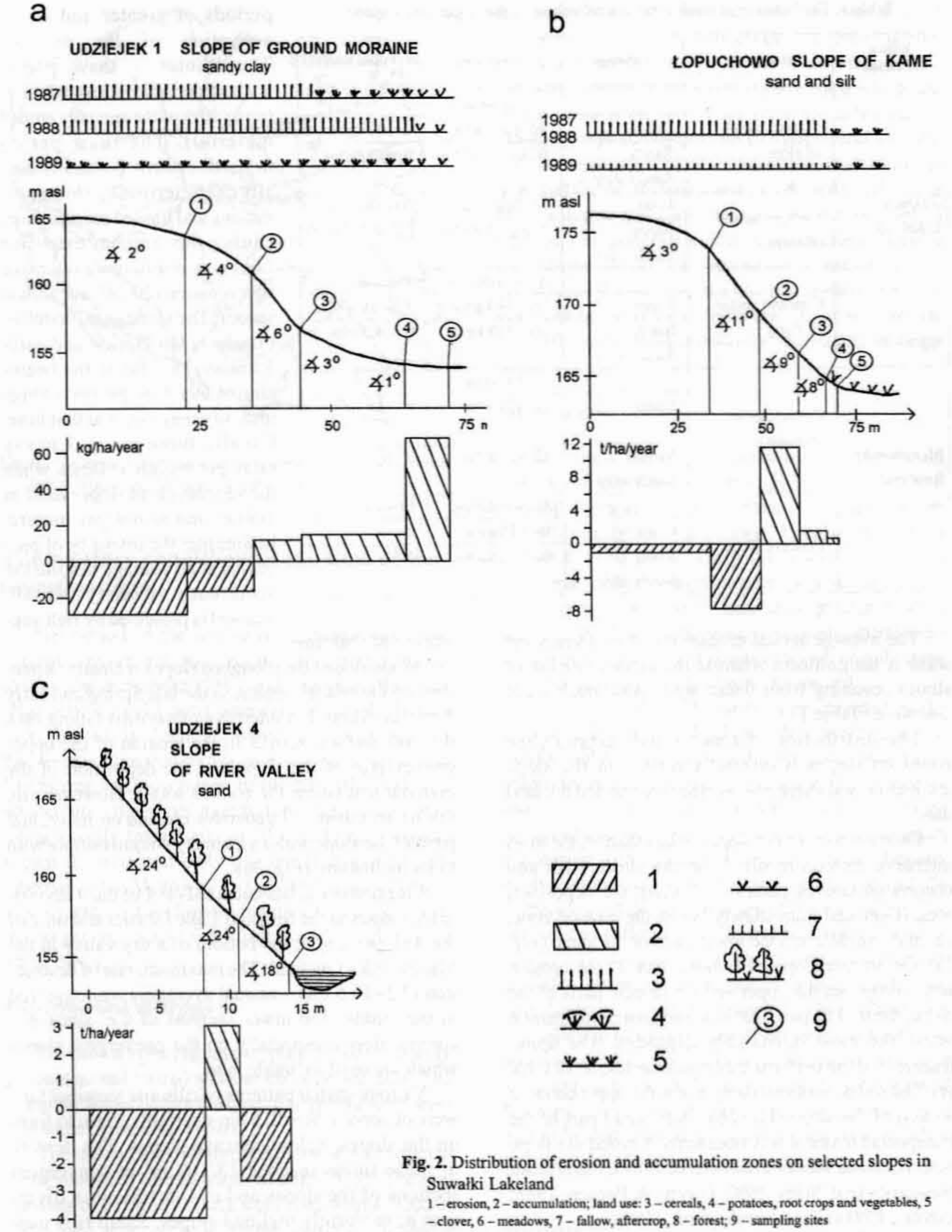

Fig. 2. Distribution of erosion and accumulation zones on selected slopes in Suwałki Lakeland

1 – erosion, 2 – accumulation; land use: 3 – cereals, 4 – potatoes, root crops and vegetables, 5 – clover, 6 – meadows, 7 – fallow, aftercrop, 8 – forest; 9 – sampling sites

and then as proluvial fans (19 – 100% of transported material). Accumulation at the base reaches on average 4,13–11,4 t/ha annually. A similar distribution of erosion and accumulation zones resulting from linear wash was observed by Gerlach (1976) and Zachar (1980). In the loess area, the rills are also found in the convex parts of hillslope but the range of material accumulation extends far beyond the base of slope (Ziemnicki, 1978; Govers, 1991b; Teisseyre, 1994).

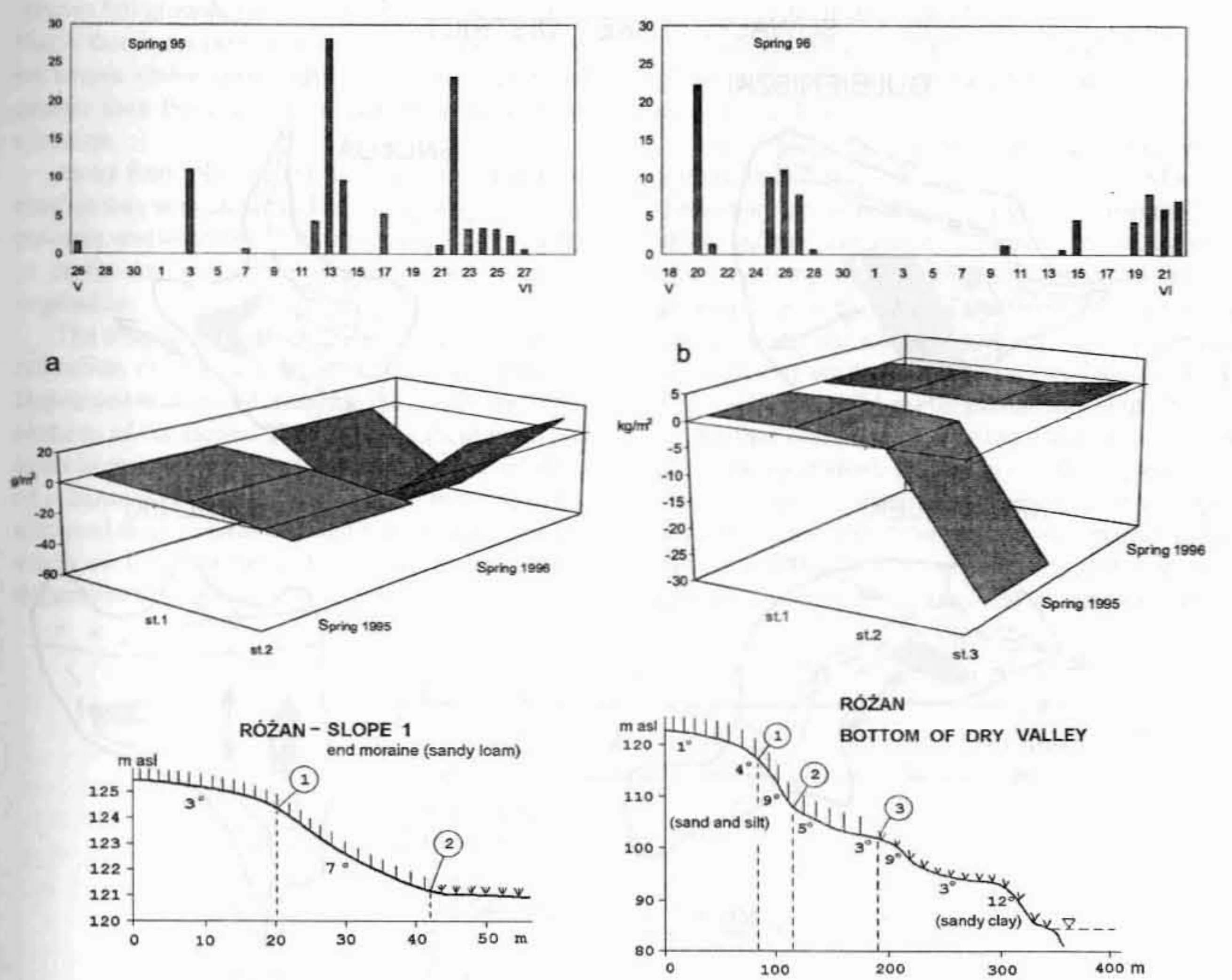

Fig. 3. Modelling of slopes resulting from sheet (a) and linear wash (b) depend on regime rainfall on example chosen slopes; explanation on text

Clearly, the size of the micro-catchment and divergence of the ploughing direction relative to the slope play an important role in the intensity of the rill erosion (Kostrzewski *et al.*, 1989). The effectiveness of the process was observed in an area which represents 10–21% of the total micro-catchment (Fig. 4). Intensification of the process on the investigated slopes does not necessarily occur in consecutive years; this is characteristic of the linear wash process. Intensification of the rill erosion was usually observed only in a particular season of the year. For instance, in Krejewelek, micro-catchment rills formed solely in the Spring of 1988. Erosion reached over 31 t/ha, and accumulation in the form of a cover – around 22.5 t/ha. Subsequently, the process occurred at a lesser intensity or not at all. Long slopes were being destroyed only in their lower parts with a steady, significant intensity, as in Gulbieniszki and in the vicinity of Rożan (Fig. 4). Clearly, the catchment area of the water flowing into the region where the process was observed and western (precipitation exposition) slope played a significant role.

Rills form mainly during Spring thaw and/or in May and June during heavy rainstorms. In the absence of a protective vegetation layer, a network of rills forms with alluvial fans at their base. Up to 7–95% of yearly-eroded soil was being removed at that time. During summer storms the intensity of linear wash is modest (around 10–25% of annually eroded soil) because the soil is well protected by vegetation. Rills formed in the Spring are functional, while the new ones rarely develop. In the Autumn, rill erosion is minimal (around 2–5% of the yearly value). The microrelief on the slopes is being destroyed due to farming and new rills form sporadically.

Modelling of the slopes being modified by rill wash, as in the case of sheet wash, is dependent on Spring and early Summer precipitation. During short but intensive rainstorms only a short transport of material takes place on a dry soil – deposition starts in the lower part of a concave section of a slope (Fig. 3b). Only a small amount of material is carried out beyond the base of the investigated slopes. On a moist soil intensive rainstorms (above 20 mm/day) cause erosion

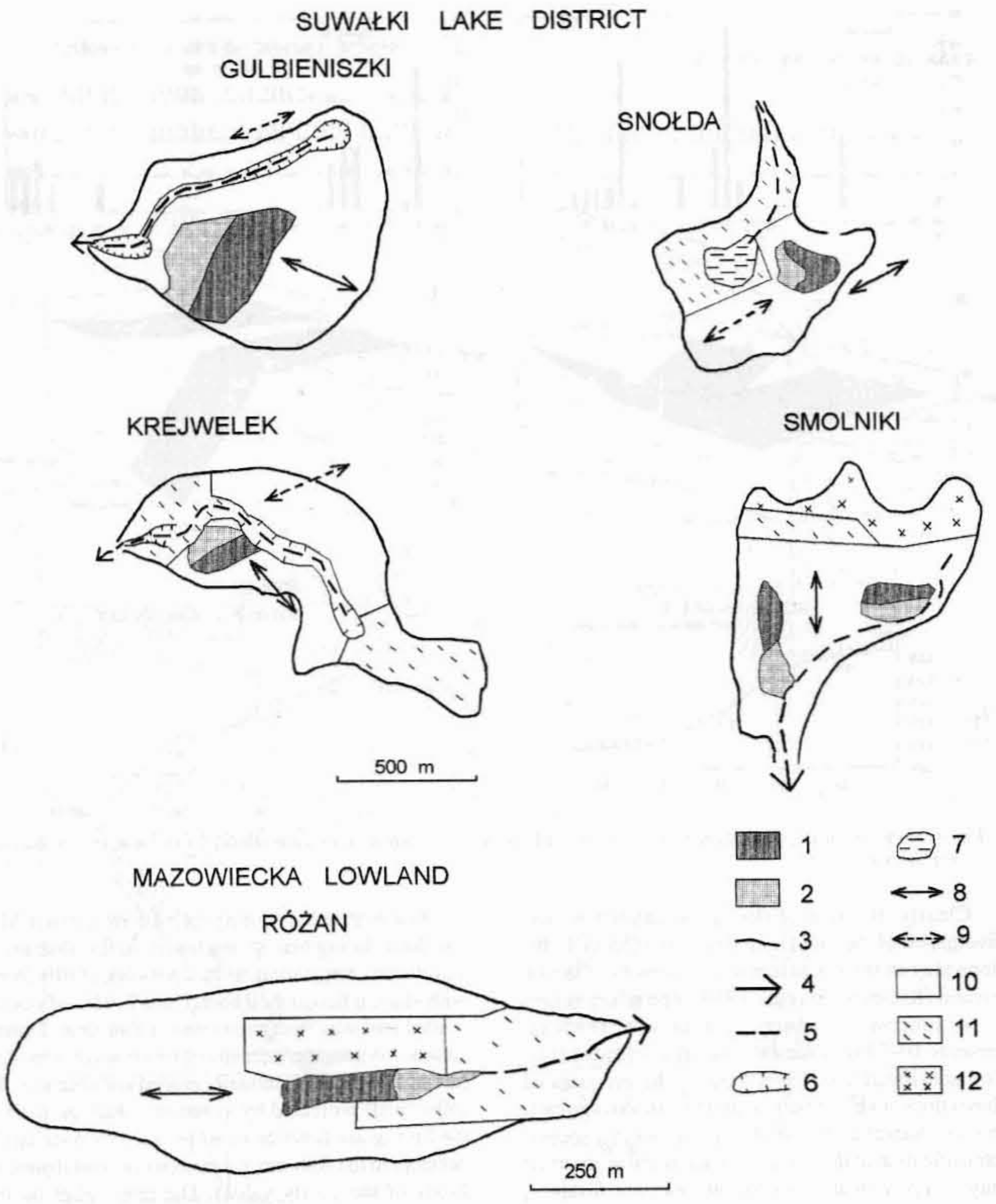

Fig. 4. Location of rills and deposition zones in observed micro-catchments
1 – erosion zone, 2 – deposition zone, 3 – watershed, 4 – permanent stream, 5 – episodic stream, 6 – gully, 7 – swamps, 8 – ploughing along slope, 9 – ploughing across slope, 10 – arable land, 11 – pastures, 12 – forest

of the middle and lower sections of the slopes. The accumulation zone occurs in the lower part of the concave sections of the slopes and below their base. Transport of material was significantly longer then in the case of short rainstorms.

Land use is crucial to the development and intensity of the process. Rills do not form in the areas permanently grassy or forested. On ploughland, maise was especially promoting rill erosion, among the observed crops, whereas trefoil protected soil from rain-wash, as did a grass cover. In the case of potatoes planted in the furrows parallel with slope inclination, erosion is 150 times greater than on the same slope covered by grain-crops. On slopes where vegetables

were in full growth, erosion values were 20–70 times bigger than in the case of trefoil or grass. Water erosion on slopes under grain cultivation was 4–10 times greater then those grassy slopes, regardless of inclination.

Away from ploughland, the intensity of interrill erosion was very small and on grassy slopes used as pastures was up to 16–58 kg/ha/yr. and 1.6–10 kg/ha/yr. on the non-agricultural slopes covered by natural vegetation.

The shape of the investigated slopes is clearly a reflection of the very limited transport distance. Deposition is observed mainly in the middle and lower sections of the slopes. This is due to sheet wash and in the lower sections, also to linear wash. The intensity of accumulation due to sheet wash at the base of the analysed slopes is 42–260 kg/ha/yr. It can extend as much as 1.5–9 m beyond the base and is clearly dependent on vegetation type (Fig. 5a). In the alder forest, with dense undergrowth, the accumulation zone is narrower whereas on the wet meadows, hay-growing meadows and on the pastureland, it tends to be wider: 3–9 m.

Accumulation under slopes subject to linear wash is more intense, than on slopes which have sheet wash; the former amounts to 0.25–11 t/ha/yr. (average). Its extent and thickness depend on precipitation, the type of cultivation, the ploughing direction, and the vegetation type at the base of the slope. The narrowest zones are formed when natural vegetation is present (4–6 m); they are wider on meadowland and pastures, and widest (up to 24 m) on ploughland (Fig. 5b).

Further mass transport takes place on the floors of the valley studied. Depending on the degree of the vegetative growth transported material from the upper agricultural section of the valley was deposited in the middle section of its grassy floor. The transport zone (periodical deposition) was 7–34 m wide during the

Fig. 5. Ranges of the accumulation due to inter-rill (a) and rill erosion (b) at the slope base in the Suwałki Lake District
1 – width of accumulation zone, 2 – annual accumulation; land use: 3 – arable land, 4 – hay meadow, 5 – wet meadow, 6 – thickets, 7 – alder-wood swamp

height of the growing season, and >100 m during the early Spring thaws.

The age of the organic sediments (peat and mineral-organic silt) at the base of the two slopes studies was determined by the ^{14}C-method to be 860 and 600 years BP. This shows the rate of deposition to be, on average, 0,8 and 1,2 m annually. A comparison of these values with the intensity of the present-day deposition of 0,02–0,1 mm due to sheet wash and 0,5–0,7 mm (annual average) due to linear wash, shows that a significant amount of the material at the base of the slope must originate in soil tillage. A significant destruction of the slopes due to tillage erosion in the middle part of the North Poland was noted by Sinkiewicz (1998). On the basis of radiocarbon dating of fossil soils at the foot of slopes, he assumed that the rate of aggradation in the base of slopes is about 0,4–0,8 mm/yr. during the last millennium and 2–2,5 mm/yr. during the last 150–300 years.

Conclusions

Measurements of the intensity of water erosion allow us to assess the effectiveness of the process under normal weather conditions. Both thaws and an average precipitation characterised the research period. The convex and middle sections of the slopes of the ploughland are degraded by interrill erosion. They are lowered, on average, 0.1–0.7 mm annually in the Suwałki Lake District (area of Würm glaciation) and to 0,5 mm on the Mazowiecka Lowland (Riss glaciation), which is equivalent to soil erosion of 20 kg/ha/yr – 7 t/ha/yr. The maximum interrill erosion intensity during one season reached over 13 t/ha. The process is characterised by a short mass transport, because deposition occurred directly under the erosion zone–usually in the middle section of the slope, even those significantly inclined. In the middle sections of the slopes both transport but, mainly during the study period, deposition of soil takes place. The deposition zone occurrs in the lower concave slope sections and only a small part of the transported material is carried beyond the base of the slope. Rill erosion causes degradation of the middle sections of the slopes, mainly those which are convergent, through recession on average from 0.5 mm to 1.2 mm yearly. The maximum observed seasonal erosion intensity on the slope was over 30 t/ha.

The maximum values of slope annual erosion noted in the Mazury Lake District (northern Poland) are 50 t/ha. By comparison, they are 61 t/ha in the Pomorski Lake District (NW Poland) and the average rate of slope degradation is 30–15 kg/ha (Niewiadomski & Skrodzki, 1964; Kostrzewski *et al.*, 1992). Analyses of the covers formed at the base of the slope indicate that thickness of the anthropogenic accumulation (from water erosion and tillage translocation) of the agricultural diamicton in the Suwałki Lakeland is 40–100 cm, in the northern part of the Mazowiecka Lowland it is higher, locally exceeding 2,5 m.

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