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EVALUATION OF THE DYNAMICS OF RAVINE EROSION IN THE GRODARZ STREAM BASIN STIMULATED BY AGRICULTURAL EXPLOITATION AND COMMUNICATION SYSTEM

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A b s t r a c t. Ravine erosion is a serious economic problem in Poland, especially in the loess uplands with high relative relief. Kazimierz Dolny, is one of the areas with the highest impendence of ravine erosion in Poland.

In this paper it is shown that: with the current cultivation structure it is not possible to limit erosion processes to the level that will not be troublesome for Kazimierz; a basic method to protect ravines against erosion should be biological construction, that is introduction of suitable plant varieties in order to fix the most active ravines; it seems that some technical solutions cannot be avoided; material carried outside the ravine catchment should be directed via a special canal and culvert under the road to the purpose-built retention reservoir; only very considerate and complex preventive measures against erosion can limit this phenomenon in any significant way.

K e y w o r d s: ravine erosion, loess area, prevention of erosion

INTRODUCTION

Ravine erosion is a serious economic problem in Poland, especially in the loess uplands with high relative relief. Ravines can take up even over ten per cent of the area at places and develop mainly at the expense of arable land [1,22]. Attempts to limit this phenomenon have been carried out for several years. Depending on the type and degree of terrain dissection and its utilisation, various methods of preventing ravine erosion have been worked out. They include mainly: phytomelioration, limitation of water outflow, technical and biological constructions at the bottom, colmatation, and even filling up. Research and implementation work were carried out mainly in the two research institutions: in the Department of Melioration and Agricultural Constructions of the University of Agriculture in Lublin [26,29,45,49] and in the Department of Soil Erosion and Design of Terrains with High Relief of the Institute of Plant Cultivation, Fertilisation, and Soil Science in Puławy [3,10,12-15,31]. A complex method of management for the terrain affected by ravine erosion have also been worked out and implemented [16,17,18]. However, the method did not cover terrains with the highest degree of dissection and assumed a considerable transformation of the natural environment, including change in the relief.

Kazimierz Dolny, is one of the areas with the highest impedance of ravine erosion in Poland [6,24]. Even though already in the Middle Ages these areas were economically well developed [43], a considerable percentage of this area was covered by forest up to the 19th century [20]. After deforestation the modern phase of ravine erosion became activated. It poses a serious economic problem. The biggest measurable economic damage is caused by the erosion of unsurfaced roads and silting up with colluvia the roads, buildings, and streets of this beautiful town [6,11,24,33,38] - a historical monument of architecture and landscape placed in the international class zero.

Intensive ravine erosion in the neighbourhood of Kazimierz has been the subject of research for a long time [34,35,38,47,48]. Necessity to counteract it has also been realised for a long time [30]. The problem of protection against erosion was manifested very strongly after two events of torrential rainfall that occurred in a short period of time, i.e. on 25.04.76 and on 24.06.81. Research aiming at the recognition of the conditions and possibilities to limit ravine erosion has been undertaken then [11,24,37]. Research work was combined with some practical undertakings. General guidelines for counteracting the effects of abrupt surface runoff were worked out. Detailed modernisation projects for the streets and the Grodarz channel within the town limits have been realised, but none of the anti-erosion projects for ravine management. They assumed costly technical constructions and did not take into consideration any specific local conditions, mainly the absolute necessity to preserve natural environment [7].

In the recent years modernisation of the road running down the Grodarz valley to Skowieszynek, where it joins the road from Puławy to Opole Lubelskie has become an urgent issue. The above road is frequently silted up during spring thaw and heavier summer rainfalls and requires clearing. It also became an route for periodical surface runoff and silt transportation route into the town limits. Detailed plotting of the geomorphological processes threatening the road has been done on the request of the Town Mayor of Kazimierz Dolny in order to work out guidelines for the road modernisation project (Fig. 1). The work has not been limited to the spatial distribution of forms resulting from the individual processes but included also recognition of all the conditions for their development, both on the general and local level.

NATURAL ENVIRONMENT AND ITS CHANGES DUE TO ANTHROPOPRESSION

The above described ravines go to the valley of the Grodarz which is a small tributary of the Wisła with the length of about 3 km and the usual discharge of about 10 l/s. The lower, loess part of the Grodarz basin is distinguished by highly configurated terrain and considerable relative relief that reach up to 80-90 m at the Wisła valley. Relatively fertile lessive' soils on loess have been agriculturally cultivated. Small forest areas were preserved almost only in the ravines and on the steepest sides of some valleys. The sides cut by ravines of the deep valley of the Grodarz have the inclination of 30 or more degrees [24].

The bedrock of the Quaternary sediments is built of the Upper Maestrichtian opokas overlain by a thin series of the Danian gaizes and opokas. Strongly fissured carbonate rocks are covered by glacial and fluvioglacial deposits up to several meters thick from the San and Odra glaciations. Locally, on the surface, directly on the gaizes and opokas there are losses with the average thickness of several meters. Intensive accumulation of loess during the Warta and Wisła Glaciations created the planation level at the height of 190-210 m a.s.l. [8,34-36]. At the end of the last glaciation this surface was dissected by a net of erosion-denudation valleys that were related to the relief of bedrock below loess [21].

In the western part of the Plateau a considerable part of the erosion-denudation valleys was subjected to the secondary cutting during the Holocene. Their lower sections could have been cut already in the older Holocene, however, most of the young forms of erosion, that are commonly called ravines, resulted from human interference in the natural environment and were probably formed in the historic times [23].

This region has been exploited by man for a long time. Already in the Neolithic (6-4 thousand years ago) settlers entered these areas and started burning out the forest to acquire farmland. Natural plant cover was

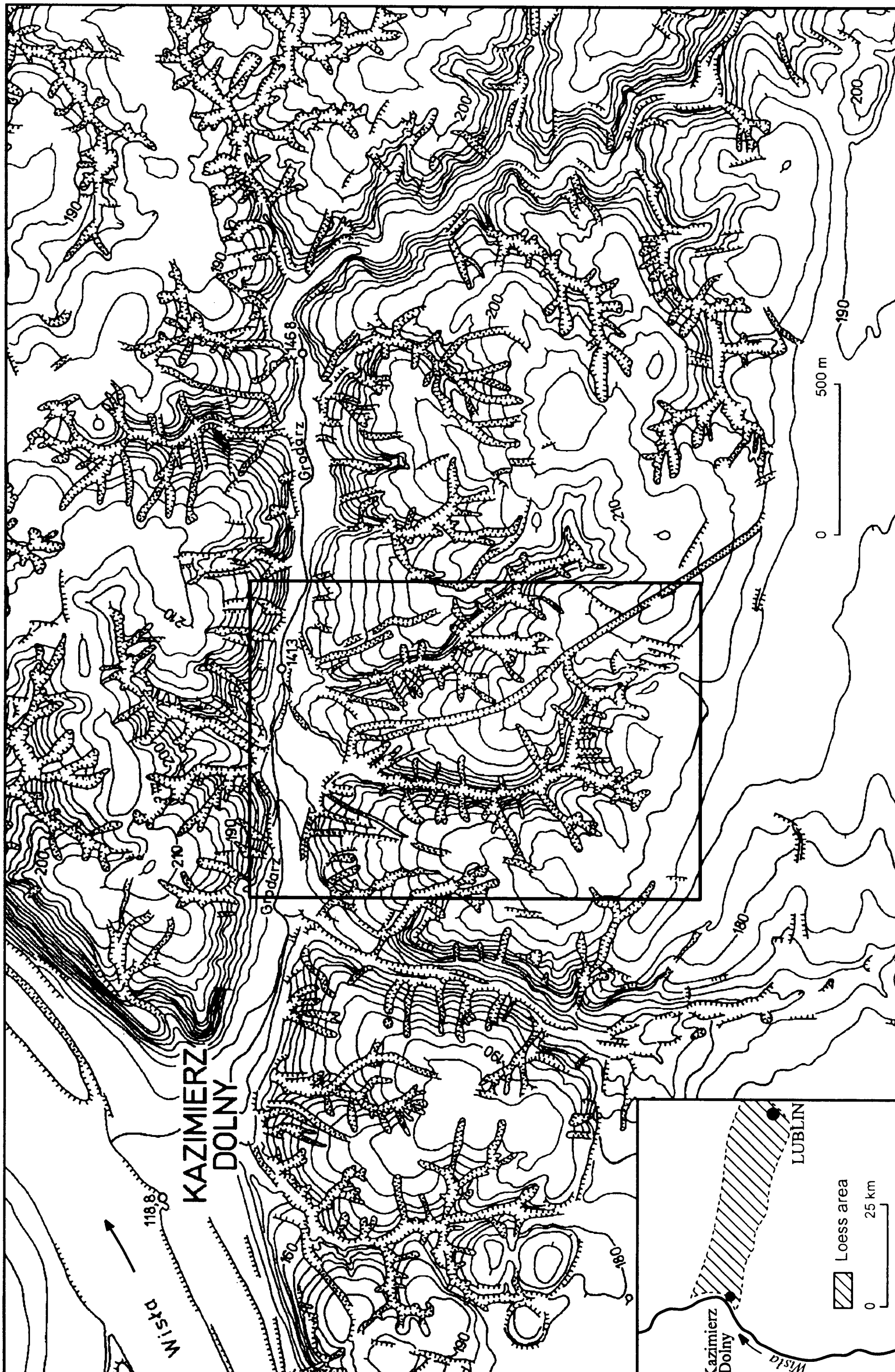

Fig. 1. Hipsometry of the lower part of the Grodarz stream basin (in the frame - the catchment of Kwaskowa Góra).

destroyed to a large extent especially in the region between Wąwolnica and Puławy. It enabled quicker surface runoff that concentrated along roads and paths and caused ravine erosion. It can be confirmed by a thick layer of muds from this period found in the bottoms of river valleys [22].

The next wave of settlers entered the fertile land of the Plateau in the Middle Ages. Already in the XII and XIII century the settlements of Skowieszynek, Kazimierz, and Wąwolnica were founded [43]. Intensification of settlement was combined with extension of arable land at the expense of forest. At the same time density of the road net - both in-between the settlements and leading to fields - was also increasing. Climatic changes expressed in periodical increase of precipitation overlapped with human activity. Probably at that time the area in the neighbourhood of Kazimierz Dolny was dissected.

It is assumed that the next period of ravine erosion took place in the XIX century. An increase in population followed by almost total deforestation and considerable diminution of farm sizes, and hence an increase in the amount of approach cart-roads took place. Deforestation started in the steep sides of the valleys (and even some of the ravines) as a result of overpopulation and „hunger for land". It intensified soil erosion processes that led to destruction of the soil profile and denudation of the loess. As a result not only the bottoms of the erosion-denudation valleys that concentrated surface runoff but also their sides and even some fragments of the planation level, got dissected.

Analyses of the maps from the period of 150 years ago allowed to investigate basic changes in the land use of the Grodarz stream basin [19,42,44]. On the basis of these maps it can be concluded that in the beginning of the XIX century the whole region was largely covered with forests and in the second half of the XIX century the forest area changed only slightly. Basic differences in the forestation of the region described here could be noticed only when the situation in the beginning of the XIX century is compared to the first half of the XX century. Probably, easement was particularly responsible for the destruction of forests, as the size of forest obligations was in that period considerably higher in the District of Lublin than in the remaining parts of the Kingdom of Poland [20]. Devastation of forests took place also during the I World War due to the wasteful exploitation by the occupants' authorities, which must have resulted in a rapid increase in the ravine erosion. Even though a considerable part of the Grodarz stream basin (including all the ravines) is covered with forests at the moment, but it is mostly the result of young afforestation.

In this latter period also the net of roads in the region of Kazimierz Dolny underwent significant changes. A lot of former communication routes lost their significance and their place was taken up by new roads. This change in the road standing is more marked in the areas located to the south of Kazimierz. However, in the region of the Grodarz stream basin a lot of ravines formed in place of former roads and generation of young erosion dissections where the new roads were started can be observed.

It should be noted that also cultivation methods applied in the areas dissected by ravines contribute to the development of ravine erosion. Direction of ploughing is especially important in this respect as it often favours surface runoff in the direction of ravines which enhances destructive activity of thaw and rain waters.

One part of the Grodarz stream basin situated in the area of the Nałęczów Plateau has the area of about 11 km^2 and a net of ravines with the total length of almost 60 km. An average density of dissections exceeds here 5 km/km^2, and reaches the level of 7-8 km/km^2 at places. The valley of Grodarz stream together with side valleys divides the loess cover of the north-west part of the Nałęczów Plateau into a few isolated, small watershed patches. It limits the spatial development of ravines; the biggest systems with the main form about 1 km long cut here relatively small basins with the area of about 0.5 km^2 (Fig. 1). It creates favourable conditions for the quick surface runoff after torrential rainfalls and water concentration in the bottom of the Grodarz valley due to overlapping of flood waves.

RESULTS OF MAPPING OF GEOMORPHOLOGICAL PROCESSES

Detailed mapping of the geomorphological processes in the area of about 3 km^2 was carried out in 1996. The mapping covered catchments of the ravines that threatened the road in the bottom of the Grodarz valley (Fig. 1). During the field studies carried out directly after spring thaw and summer heavy rainfalls special attention was paid to the mechanism and intensity of the processes that developed at that time, taking into consideration reasons and effects generated by them. All the freshly formed or activated erosion and accumulation forms were marked on the base-map in the 1 : 1000 scale, their size, level of activity, and conditions of development were determined.

The winter of 1995/96 was long, severe and full of snow. Thick snow cover (of about 30 cm) developed only in the second half of February [32]. Earlier, a deep freezing of the ground that exceeded the depth of 1 m took place. Together with the snow cover it came through up to the first decade of April when sudden warming up caused a short, rapid surface runoff of thaw water. For the following two weeks a tiny surface runoff persisted fed from the remains of the snow cover, fresh snow falls and ground thawing. These were all very favourable conditions for the development of erosion, piping (mechanical suffosion), and mass movement.

Erosion dissections in the ravines caused by the thaw water flow were not frequent and did not reach any considerable sizes. This fact can be explained by freezing of the snow cover in the bottoms of the ravines, which thus were protected against first rapid flow of thaw water. Later on an insignificant flow took place on the frozen litter. Only in some active side ravines with heavy bottom gradients quite strong erosion occurred on the steps generated by piping and mass movement.

Intense erosion was observed in the dry section in the bottom of the Grodarz valley above its spring; in the ploughed fields and unsurfaced roads episodic channels, 2-3 m wide at places, 10-20 cm deep and to several dozen meters long, appeared. Another area of strong erosion were young intensely exploited (unsodded) unsurfaced roads on the slopes. Those roads are the initial phase of the road gullies formation. They have differentiated gradients and scarps without trees or bushes. Earth falls commonly occurred at the scarps, and in the bottoms erosion trenches and potholes appeared forming combinations up to 1 m wide and deep, and up to 10 m long.

Erosion forms in the older tree-covered road gullies were of significantly smaller sizes. Litter made up by the last year fallen leaves could have served as an additional protection layer. On the vertical walls of the road gullies there were commonly earth falls and wash-outs, but of smaller sizes. Piping processes do not occur frequently in this area. However, they pose a more serious threat, because they could initiate landslips. Landslides and soil creeps appeared first of all on the natural ravine slopes. It was due to water seepage, erosion, and slope undercutting.

Piping processes developed very intensely in the spring of 1996. A important factor there was ground freezing that limited infiltration. It ensured long-lasting water flow from fields to ravines. Ground freezing conditioned development of earthslides or intense process of earth falls on the gradually thawing walls of niches and potholes. Piping forms up to several meters big developed commonly in the ravines of the Grodarz stream basin. A lot of older forms were reactivated, and a lot of new forms that could initiate development of side ravines appeared. In the natural ravines piping was the main process that started transport of material. Beside potholes and niches, pipes and underground channels developed. It was found that in many cases piping was initiated by the tunnels made by rooting animals.

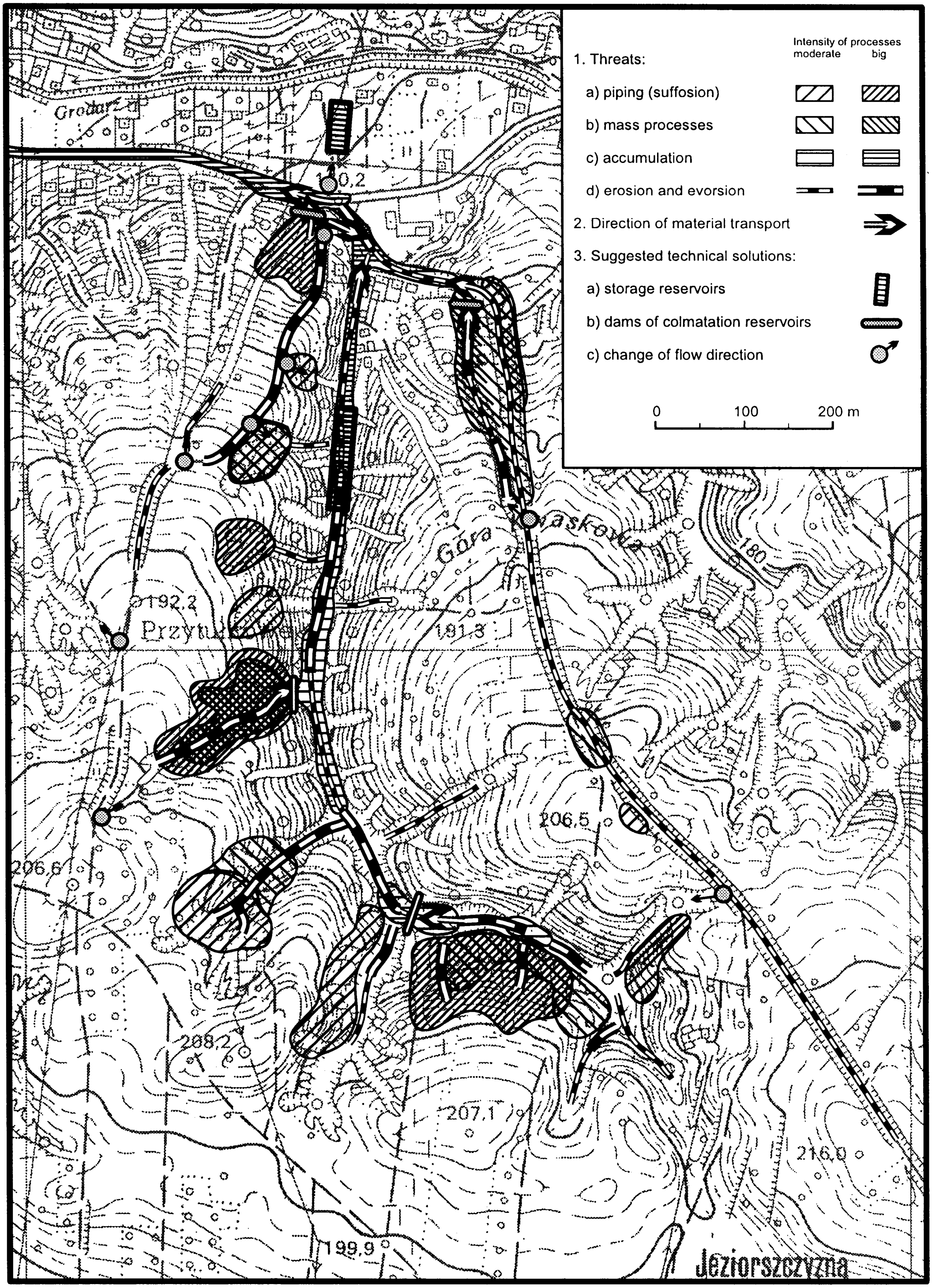

Fig. 2. Geomorphological processes endangering the catchment of Kwaskowa Góra and the suggested technical preventive measures.

Most of the materials form the spring ravine erosion was deposited on the bottom of the Grodarz valley. At the outlet of eroded ravines proluvial fans were formed. As a result of silting up ditches that were not properly maintained, roads and streets became flow routes and sites of sediment accumulation. Almost along the full length of the road in the bottom of the valley a silt cover with the thickness of a few and up to several cm at places was formed.

In August 1996 heavy rainfalls occurred three times and brought about significant geomorphological effects. Effects of intense washing out, moderate linear erosion, and evorsion were observed. Mainly roads in the ravines - both natural and road gullies - were eroded to a degree that was slightly higher than in spring. Only in relatively new unsurfaced roads, that were strongly eroded during thawing, summer erosion was smaller than the spring one. The main place of sediment deposition was the road in the bottom of the Grodarz valley.

Mapping gave basis for working out a synthetic morphodynamic map in the 1 : 5000 scale on which the most important effects of geomorphological processes were marked. First of all, zones threatened by mass processes, piping and erosion with various intensity were delineated. Moreover, main directions and routes of material transport were determined in order to distinguish possible places for its interception. Archival materials from the field research carried out earlier, among others from the geomorphological mapping after torrential rainfall of 1981, were taken into consideration while drawing the map of threats. Figure 2 presents a fragment of such a map for the chosen catchment at Kwaskowa Góra, which includes: active ravine system Chałajowy Dół, old (with Medieval foundation) road gully (Droga Opolska) young road gully and several „deserted" road gullies (some very active). The whole complex of ravines delivers significant amounts of material that reach the centre of the town at each type of surface runoff.

Field research showed that in order to construct anti-erosion safeguards that would counteract the most dangerous effects of ravine erosion processes the geomorphological mapping should be carried out during the period when these phenomena occur with high intensity. In the years of low intensity of geomorphological processes it is difficult to assess degree of danger as not all of the active forms develop and some of them can even disappear for some time.

EVALUATION OF THREATS

Geomorphological processes that endanger the town develop intensely during heavy rainfalls and spring thawing, as well as during torrential rainfalls when they become catastrophes. These phenomena - of an extreme character - result in crossing out the threshold balance of the geomorphological system [41]. If they occur often, the system has no chance to come back to the state of equilibrium; in case of the loess areas with high relative relief it leads to the development of ravines [2,23,25,39,40]. Whereas the processes that develop during continuous rains and „normal" thawing even though they do not present any major danger, can locally activate material transport and cause silting up.

In the region of the western edge of the Nałęczów Plateau the frequency of torrential rainfalls with the intensity of >1 mm/min [4], is extremely high; for example: in Kazimierz they appeared in 1936, 1976, 1981, and 1997 [39]. For sure not all of them were recorded; it is also well known that in the historical past [43] they occurred as well. Heavy summer rainfalls (<1 mm/min) that cause significant geomorphological results occur practically speaking every year or even a few times in one year [45,48]. Recently they were observed three times in 1996, and four times in 1997. Thaw flows with the intensity similar to the one in 1996 occur once in several years' time; the last ones took place in 1956, 1964, and 1979 [27]. They activate considerable amount of material; even though it is a few times less than in the case of torrential rainfalls. The effects of thawing with lower intensity that occur one in a few years time are comparable to the effects of heavy rainfalls.

During torrential rainfalls a quick flow via ravines and its concentration in the bottom of the Grodarz valley take place. Then first of all, the bottoms of natural ravines are intensely eroded where momentary flows can reach several m^3/s. High longitudinal gradients of the ravines favour erosion and material transport to the Grodarz valley [38]. Kazimierz is then exposed to the effects of rapid flows both along the valley and directly form the ravines as some of the outlets are situated in the town. It causes a local flood and silting up of the valley bottom with its communication-urban system [11,33]. A torrential rainfall of June 24th, 1981 can be given an example to illustrate the above. Precipitation sum was over 100 mm when the flow at the outlet of the Grodarz was estimated for 37 m^3/s [28]. At the relatively high gradient of the valley bottom of about 10 ‰ [22] the same amount of water transports enormous amounts of material. The volume of the accumulated material in the town itself or brought into the Wisła has been assessed for at least several thousand of cubic meters [6].

During thawing the flow is more spread in time; however snow retention can be so considerable that the runoff sum can exceed the runoff after a torrential rainfall. At the bottoms of the slope througts and dry valleys, in some road gullies, and also at the heads and in the side active arms of ravines big erosion-evorsion forms are observed. Deep freezing that destroy ground structure favour gravitational processes such as landslides and earth falls during ground thaw. First of all, however, it is a condition for long-lasting flow makes washing out easy and favours piping. The process of piping that is predominant during thawing takes place in the side arms, at the heads and on the scarps of the ravines at the outflow places from the fields. With moderate intensity of morphogenetic processes the fact that they are long-lasting causes considerable geomorphological effects. Even a small amount of water transports considerable amounts of material at high distances as suspended sediment concentration at the final stage of the thaw flow exceeds 100 g/l.

On the basis of the measurements taken, observations carried out and data obtained from the City Council on the amount of material swept down from the roads and streets, degree of danger for the communication system of Kazimierz can be evaluated for various types of flows. Surface runoff from heavy rainfall similarly to moderate thawing leaves about 100 m^3 of silt in the roads and streets. Practically every year or even a few times in one year it is necessary to remove it. Intense thawing that occurs every several years leaves at least a few hundred cubic meters similarly to a short torrential rainfall that lasts for several minutes. A torrential rainfall with the precipitation sum of about 50 mm outside the full vegetation period and up to about 100 mm during full vegetation causes a rapid surface runoff that deposits varigrained material in the amount of several thousand cubic meters in the town area [11]. Precipitation of 100 mm results in a catastrophe. Ravine bottoms are strongly eroded, basements and ground floors of the buildings get flooded, surface of the roads is torn away at places, vehicles are moved. However, rainfall of that size occurs once in several dozen years.

Attention should be paid to the immediate erosion dangers. Unsurfaced roads are the ones that are eroded most frequently. It makes frequent repairs necessary. Piping is also a serious problem that endangers farmland. It should be stressed that most of the piping forms develop in the triangles in-between the side arms of a ravine that are excluded from agricultural exploitation and undergo self afforestation. It confirms the opinion that forest is not always an efficient protection against piping [5,46]; in some cases it can even make piping easier as water migrates along the tree taproots. What is more, rooting animals find conditions very favourable there; the tunnels that they dig often initiate the process [9].

POSSIBILITIES TO LIMIT THE THREATS

On the basis of detailed mapping carried out after torrential rainfall, thawing and heavy rainfalls a map of threats for the basin by individual processes in a moderate and strong degree have been carried out (Fig. 2). Recognition of „foci" and conditions for the erosion processes is a preliminary stage for working out a design of preventive measures against erosion processes. It should be stressed that total elimination of erosion is not possible irrespective of the solution chosen or cost incurred. It is also inexpedient as ravines are valuable and protected element of the Kazimierz Landscape Park and generally speaking they should develop naturally. To achieve our target, some of the ravines that do not endanger the town should be identified and left with- out human interference.

With the current cultivation structure it is not possible to limit erosion processes to the level that will not be troublesome for Kazimierz. It is necessary to change agricultural exploitation of the basin. Permanent grassland should be introduced (pastures and meadows), and the steep slopes should be afforested. At the moment, some of the fields around ravines are excluded from the agricultural exploitation and undergo self afforestation. However, that does not inhibit piping processes as the old flow routes along balks remain. Suitable organisation of flow is needed above the ravines, and first of all, reduction of the water volume flowing along the strongly eroded unsurfaced roads. The locations where it is easy to direct flow are marked on the map (Fig. 2).

A basic method to protect ravines against erosion should be biological construction, that is introduction of suitable plant varieties in order to fix the most active ravines. Bushy plants are best suited for this purpose as they do not penetrate with their roots too deeply and do not overload the scarps of the ravines. They store snow and litter which counteract ground freezing and enriches it in water and humus. Bushes at the field-forest boundary do not shade the fields too much [30]. It is especially necessary to cover with bushes the scarps of young road gullies.

It seems that some technical solutions cannot be avoided. The most eroded sections of unsurfaced roads should be hardened using modern, ecologically acceptable means and the flow system should be organised at the same time. We should also try to intercept and retain material in the basin area. Colmatation reservoirs located at the outlets of the most eroded arms, especially the ones that are of no particular landscape value, can fulfil this task. The construction and functioning of such a reservoir requires building a earth dam in the ravine, with strengthened, underground outflow and raised inlet well. The reservoir stops material and directs excess water outside. Its silting up raises base-level of erosion and inhibits erosion [13]. Flows from fields and unsurfaced roads should be directed to the colmatation reservoirs if possible; it will lower the amount of material carried into the bottom of the Grodarz valley radically.

Material carried outside the ravine catchment should be directed via a special canal and culvert under the road to the purpose-built retention reservoir (Fig. 2) which will prevent silting up ditches along the roads, or the roads themselves, and the Grodarz channel. It should be a earth reservoir easy to make, dry or partially covered with water with strengthened outflow and a possibility for periodical mechanical silt removal. It should be noted that all the culverts should have a diameter higher than the standard. Rapid changes of direction and sharp inclination of offtake ditches should be avoided as it would cause material deposition and silting up of the ditches.

The solutions proposed have already been applied elsewhere and their efficiency was practically checked [17,18]. Carrying out the above projects should considerably influence decrease in the intensity of the geomorphological processes in the ravines, and most of all, it should significantly limit the effects of these processes, i.e. silting up streets, roads, and living yards. It must be stressed here that dangers related to the effects of erosion are mainly caused by inconsiderate human interference in the natural environment. Only very considerate and complex preventive measures against erosion can limit this phenomenon in any significant way, that is to bring it back to the level and dynamics of a natural feature.

CONCLUSIONS

With the current cultivation structure it is not possible to limit erosion processes to the level that will not be troublesome for Kazimierz.

A basic method to protect ravines against erosion should be biological construction, that is introduction of suitable plant varieties in order to fix the most active ravines.

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REFERENCES

1. **Buraczyński J.:** Gully erosion intensity and soil erosion in the Roztocze Gorajskie (in Polish). Zesz. Probl. Post. Nauk Roln., 193, 91-99, 1997.
2. **Buraczyński J., Wojtanowicz J.:** Development of loessial gullies in the vicinity of Dzierzkowice in the Lublin Upland as a result of rainstorn in June 1969 (in Polish). Ann. UMCS, B, 26; 135-168, 1974.
3. **Bury-Zaleska J., Pięta J.:** Aforestation trails in the loess gully "Mikołajec" (in Polish). Pam. Puł., 34; 79-104, 1968.
4. **Chomicz K.:** Rainstorms and nival rainfalls in Poland (in Polish). Wiad. Służby Hydrolog. i Meteorolog., 2, 3, 1951.
5. **Czeppe Z.:** Suffosion phenomena in loams of the upper part of San river catchment (in Polish). Biul. PIG, 150, 297-324, 1960.
6. **Gardziel Z., Harasimiuk M., Rodzik J.:** Dynamics of geomorphological processes in the Grodarz river catchment and related risk to Kazimierz Dolny. Polish Lowland Gorges - advantages, risks and protection (in Polish). Kazimierz Dolny, September 18-20, 21-31, 1996.
7. **Harasimiuk M., Bartoszewski S., Gardziel Z., Michalczyk Z., Rodzik J., Zgłobicki W.:** Evaluation of archives describing problems of Kazimierz protection against rain water flooding (in Polish). Archiwum UMiG w Kazimierzu Dolnym, 1994.
8. **Harasimiuk M., Henkiel A.:** Ann. Influence of geological structure and substratum relief on loess cover relief in Western part of Nałęczów Plateau (in Polish). UMCS, B, 30/31; 55-80, 1976.
9. **Jońca E.:** On the role of animals in formation of relief of the Earth's surface (in Polish). Czas. Geogr., 41, 3; 329-337, 1970.
10. **Józefaciuk Cz., Józefaciuk A.:** Principles of recultivation and restoration of gullies (in Polish). IUNG Puławy, 1980.
11. **Józefaciuk Cz., Józefaciuk A.:** Management programme for Grodarz river catchment to protect Kazimierz against erosion risks. Antierosion measures as the base of rational management of upland regions (in Polish). Puławy 12-14.09.1984; 5-15, 1984.
12. **Józefaciuk Cz., Józefaciuk A.:** Evaluation of different methods of loess gully management. I. Fo-rest management (in Polish). Pam. Puł., 91; 153-169, 1988a.
13. **Józefaciuk Cz., Józefaciuk A.:** Evaluation of different methods of loess gully management. II. Colmatation reservois (in Polish). Pam. Puł., 91, 171-184, 1988b.
14. **Józefaciuk Cz., Józefaciuk A.:** Evaluation of different methods of loess gully management. III. Technical-biological management (in Polish). Pam. Puł., 95; 21-34, 1989a.
15. **Józefaciuk Cz., Józefaciuk A.:** Evaluation of different methods of loess gully management. IV. Filling-up (in Polish). Pam. Puł., 95; 35-49, 1989b.
16. **Józefaciuk Cz., Józefaciuk A.:** Evaluation of different methods of loess gully management. V. Complex management with various technics (in Po-lish). Pam. Puł., 102; 172-190, 1993.
17. **Józefaciuk Cz., Józefaciuk A., Nowocień E.:** The concept and realization of erosion measures in the farm Kogutki. Soil protection against degradation caused by water erosion (in Polish). IUNG Puławy, S (79), 5-45, 1994.
18. **Józefaciuk Cz., Józefaciuk A., Nowocień E., Rubaj J.:** Evaluation of orchard management in rolling loess terrain on the example of the Olszanka Farm. Protection of Agroecosystems Threaten with Erosion (in Polish). Puławy, September 11-13, 1996, 1, 229-243, 1996.
19. Karte des Westlichen Russlands 1:100 000, K36. Nowo-Alekssandrija. 1915.
20. **Maruszczak H.:** The state of forestation and changes in Lublin region in the years 1830-1930 (in Polish). Ann. UMCS, B, 5, 109-179, 1952.
21. **Maruszczak H.:** Characteristic refiel forms in loess areas of the Lublin Upland (in Polish). Czas. Geogr., 29, 3, 335-354, 1958.

22. **Maruszczak H.:** Gully erosion in eastern part of the south Poland upland belt (in Polish). Zesz. Probl. Post. Nauk Roln., 151; 15-30, 1973.
23. **Maruszczak H.:** Secular tendencies and extreme phenomena in relief development of the Lowland Polish loess uplands in historical time (in Polish). Czas. Geogr., 57, 2; 271-282, 1986.
24. **Maruszczak H., Michalczyk Z., Rodzik J.:** Geomorphological and hydrogeological conditions of denu-dation processes in the Grodarz watershedin Lublin Upland (in Polish). Ann. UMCS, B, 39; 117-145, 1988.
25. **Maruszczak H., Trembaczowski J.:** Geomorphological effects of rainstorm in Piaski Szlacheckie near Krasnystaw (in Polish). Ann. UMCS, B, 11; 129-160, 1958.
26. **Mazur Z., Mazurek T., Pałys S., Węgorek T.:** Efficiency of biotechnical structures in gullies near Opoka Duża (in Polish). Zesz. Probl. Post. Nauk Rol., 292; 137-150, 1985.
27. **Mazur Z., Pałys S.:** Water erosion in loessial basin in the Lublin Upland in the years 1956-1991 (in Polish). Ann. UMCS, E, 47, 219–229, 1992.
28. **Michalczyk Z.:** Characteristics of water status in the Grodarz catchment area (in Polish). Przew. Ogólnopol. Zjazdu PTG, Lublin 13-15.IX.1984, II, 125–130, 1984.
29. **Mozoła R.:** Characteristics and evaluation of water erosion conservation measures performed in the Lublin Upland gullies (in Polish). Zesz. Probl. Post. Nauk Roln., 130, 91-115, 1972.
30. **Nakonieczny S.:** Selected methods for protection against development of water erosion forms (on the example of Kazimierz Dolny area) (in Polish). Zesz. Probl. Post. Nauk Roln., 170, 151-158, 1975.
31. **Nowocień E.:** Dynamics of road gully development in loessial region (in Polish). Pam. Puł., 107, 101-111, 1996.
32. **Nowosad M.:** Extreme snow winter 1995/97 in Lublin. Extreme Meteorological, Hydrological and Oceanographic Phenomena (in Polish). Warszawa, November 12-14, 1997, 116-119, 1997.
33. **Parczewski W.:** Conditions of occurrence of high water in small rivers (in Polish). Wiad. Służby Hydrolog. i Meteorol., 8, 3, 1960.
34. **Pożaryska K., Pożaryski W.:** Geological guide-book for Kazimierz and its vicinity (in Polish). Wyd. Muzeum Ziemi, Warszawa, 1951.
35. **Pożaryski W.:** Pleistocene in the Vistula gorge through south uplands (in Polish). Prace Inst. Geol., 9, 1953.
36. **Pożaryski W., Maruszczak H., Lindner L.:** Chronostratigraphy of Pleistocene deposits and development of the Middle Vistula valley, with special attention to the gorge through south Poland uplands (in Polish). Prace PIG, 147, 1994.
37. **Repelewska-Pękalowa J., Pękala K.:** Geomorphological characteristics of loess gully catchment area for the design of erosion conservation measures (in Polish). Zesz. Probl. Post. Nauk Roln., 357, 17-35, 1988.
38. **Rodzik J.:** Intensity of contemporary denudation processes in configurated rolling loess area near Kazimierz Dolny (in Polish). Przew. Ogólnopol. Zjazdu PTG, Lublin 13-15.IX .1984, II, 125-130, 1984.
39. **Rodzik J., Janicki G., Zagórski P., Zgłobicki W.:** Heavy rainstorms in the Lublin Upland and their effect on the relief of loess terrain (in Polish). Dokum. Geogr. IGiPZ PAN, 11, 45-68, 1998.
40. **Rodzik J., Janicki G., Zgłobicki W.:** Response of agroecosystem in the loess basin to episodic runoff during heavy rainstorm. Protection of Agroecosystems Threaten with Erosion (in Polish). Puławy, September 11-13, 1996, 1, 201-214, 1996.
41. **Starkel L.:** Role of exterem phenomena and secular processes in relief evolution (on the exapmlc of flysh Carpaths) (in Polish). Czas. Geogr., 57, 2, 203–213, 1986.
42. Tactics Map of Poland 1:100 000. Sec. Puławy. WIG Warszawa 1937.
43. **Teodorowicz-Czerepińska J.:** Kazimierz Dolny. Historic and Urban Monography (in Polish). Towarzystwo Przyjaciół Kazimierza, Kazimierz, 1981.
44. Topographic Map of the Kingdom of Poland 1:126 000. Kol. V, Sek. VI. 1839.
45. **Ziemnicki S., Fijałkowski D., Węgorek T.:** Efficiency of technical and biological reinforcement of gullies in Opoka Duża (in Polish). Zesz. Probl. Post. Nauk Roln., 193, 211-235, 1977.
46. **Ziemnicki S., Kudasiewicz Z.:** Development of aforestated gully in the Góry Pieńczowskie (in Polish). Zesz. Probl. Post. Nauk Roln., 170, 77-97, 1975.
47. **Ziemnicki S., Mazur Z., Pałys S.:** Development loess gully on the Kwaskowa Góra (in Polish). Zesz. Probl. Post. Nauk Roln., 170, 7-24, 1975.
48. **Ziemnicki S., Naklicki J.:** State and development of three gullies in the Lublin Upland (in Polish). Zesz. Probl. Post. Nauk Roln., 119, 23-45, 1971.
49. **Ziemnicki S., Pałys S.:** Loess gully in Magierów and project for its protection (in Polish). Zesz. Probl. Post. Nauk Roln., 222, 91-107, 1979.