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Soil erosion and effects of erosion control works in the torrential drainage basins of southeast Serbia

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Abstract The region of southeast Serbia (especially the Grdelička Klisura gorge and the Vranjska Kotlina valley) is well-known for very intensive erosion processes and, as a consequence, very frequent destructive torrential floods. In order to protect lines of communication and the settlements in this region, very extensive erosion control works (ECW) were carried out after the Second World War, i.e. in the period 1947-1977. In the periods 1957-1958 and 1979-1988, hydrological data (discharge and sediment transport) were collected for three torrential drainage basins. The state of vegetation cover and erosion processes in these drainage basins were also investigated. It has been concluded from this research that although all of the planned works were not carried out, the intensity of erosion processes, and sediment yield and transport in the torrential drainage basins of southeast Serbia has still been significantly decreased and the category of erosion reduced.

INTRODUCTION

Southeast Serbia (especially the Grdelička Klisura gorge and the Vranjska Kotlina valley) is a well-known erosion and torrent region in Yugoslavia. The main river in the region is the Južna Morava, which typically has torrential tributaries. The greatest number of torrent tributaries flow into Južna Morava in the sector of the Grdelička Klisura gorge (143) and Vranjska Kotlina (more than 80). Two very important communication lines cross the Južna Morava valley in this area and connect Europe with Greece and the Mediterranean, namely the Belgrade-Skopje (former Yugoslav Republic of Macedonia)-Athens (Greece) road and railway line.

The torrents in this region in addition to other hazards have caused great damage to these lines of communication in the past. That is why at the beginning of the twentieth century, erosion control works (ECW) were started in this part of southeast Serbia. After the Second World War, i.e. in the period 1947-1977, much more extensive ECW were put in hand. This paper presents the results of research into erosion processes and the effects of ECW in three drainage basins in southeast Serbia, namely Kalimanska Reka (Grdelička Klisura gorge), Repinska Reka and Lještarska Dolina (Vranjska Kotlina valley).

STUDY AREA AND RESEARCH METHODS

Study area

The Kalimanska Reka, Repinska Reka and Lještarska Dolina torrents are the left tributaries of the River Južna Morava (Fig. 1). They belong to the group of hilly-mountainous drainage basins, as illustrated by the topographic parameters presented in Table 1.

The Kalimanska Reka torrent empties into the Južna Morava River flowing through the town of Vladičin Han (southeast Serbia). The parent rock comprises the old Rhodope mass, mainly consisting of the progressively metamorphosed schists of the Vlasina complex (leptynolites, micaschists, amphibolites, leucogneiss and fine grained gneiss) and Neogene sediments (red and grey tuffaceous sandstones, conglomerates and sandy marls). The soils in the drainage basin comprise several varieties of acid brown soils.

The Repinska Reka torrent empties into the Južna Morava River flowing through the village of Priboj Vranski, *c.* 3 km upstream from Vladičin Han. The parent rock and soils in the Repinska Reka drainage basin are the same as in the Kalimanska Reka drainage basin.

The Lještarska Dolina torrent empties into the Južna Morava River, in the district of the village Priboj Vranjski, *c.* 15 km upstream from Vladičin Han. During summer and early autumn, in drought periods, it is dry. The drainage basin is underlain by rocks of different composition which comprise Miocene pyroclastites (tuffs, tufaceous sandstones, volcanic breccias), andesites, arenites, siltstones, marls and dacites. The soil types present are podzol, eroded podzolic skeletal soil and eroded skeletal acid soil.

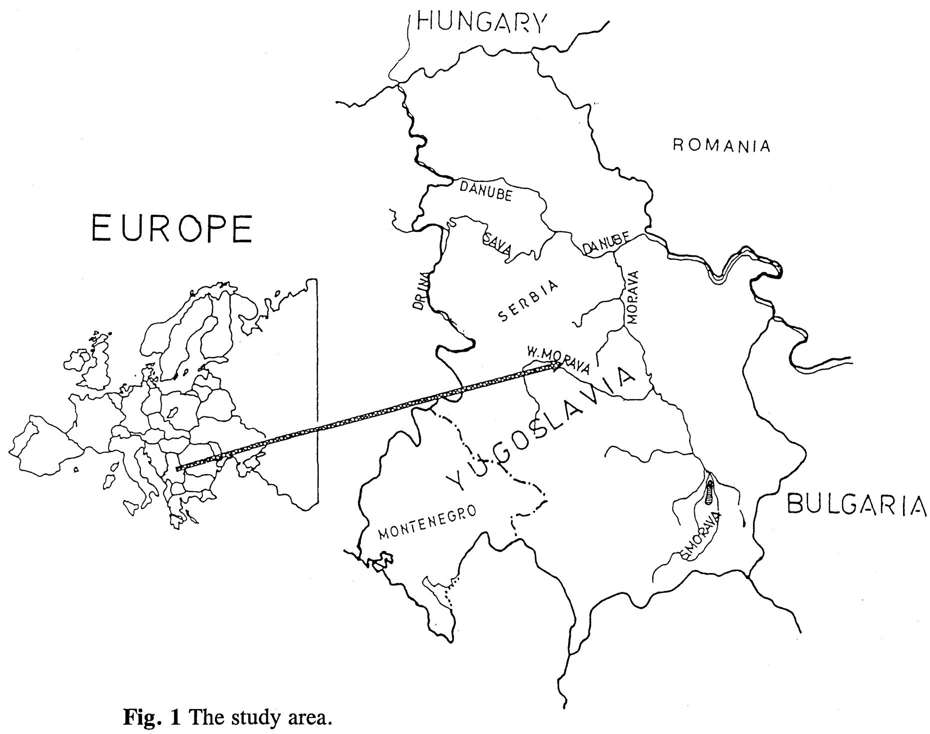

Fig. 1 The study area.

Table 1 Parameters of the drainage basins.

Parameters	Symbol	Kalimanska Reka	Repinska Reka	Lještarska Dolina
Drainage basin area	F (km^2)	16.04	7.82	2.64
Drainage basin perimeter	O (km)	21.90	17.50	9.70
Drainage basin length	L_{g1} (km)	9.50	8.50	4.10
Drainage density	G (km km^2)	2.10	2.15	3.34
Local erosion basis	B_e (m)	955.0	697.00	551.50
Mean elevation of the drainage basin area	N_{sr} (m)	809.96	641.04	722.70
Mean altitudinal difference of the drainage basin	D (m)	474.96	301.04	324.20
Mean slope of the drainage basin area	J_{sr} (%)	40.86	30.60	32.07
Stream bed slope	J_t (%)	10.05	8.20	13.45

Stages of research

The research included the following stages:

(a) collection and study of the existing documentation on the drainage basins including ECW projects, documentation of implemented ECW, data on the state of the vegetation cover and intensity of erosion processes before the ECW were carried out;

(b) survey of the type and scope of ECW;

(c) collection of all the data on the drainage basins and channel with respect to natural characteristics, state of the vegetation cover and intensity of erosion processes after the ECW had been completed;

(e) measurement of water discharge and sediment transport after the ECW had been completed; and

(f) drawing of conclusions regarding the effect of ECW in the drainage basins and channel.

Method of field research

The state of the vegetation cover (land use) in the drainage basins has been assessed through detailed reconnaissance and production of detailed vegetation (land use) maps for both periods (before and after ECW).

The state of erosion in the drainage basin, both its distribution and the intensity, were determined by a detailed erosion map, produced according to the method of Gavrilović (1972). Water discharge was measured by means of hydrometric profiles. Suspended sediment transport was measured by taking water samples and by determining the concentration of solids. Bed load transport was measured by the volume method (Kostadinov, 1985). Measurements of sediment yield and transport were not made in the period before ECW, and values for these were estimated by Gavrilović's method (Gavrilović, 1972).

The classification of erosion processes in the drainage basin according to intensity was done by Gavrilović's method, which classifies the erosive regions into five intensity categories (I = excessive; II = intensive; III = medium; IV = weak; and V = very weak erosion). The quantitative expression of erosion intensity is represented by the coefficient of erosion (Z), ranging between 0.01 and 1.50.

RESULTS

Erosion processes and sediment transport in the period before ECW

The main characteristics of the drainage basins before ECW can be defined with reference to the vegetation cover (Table 2) and the distribution and intensity of erosion processes (Table 5). Owing to the natural conditions of relief, parent rocks, soil types, land use and particularly due to inadequate soil management, excessive (Kalimanska Reka and Lještarska Dolina) and intensive (Repinska Reka) erosion dominated in the study basins (Table 5).

In the Kalimanska Reka drainage basin, sheet and gully erosion were remarkable, and landslide and deep erosion processes in the drainage pattern also occurred. In addition to soil loss due to water erosion, the runoff regime was also disturbed, which was reflected in frequent torrential floods that caused great damage to the town Vladičin Han and the Belgrade-Skopje-Athens railway line and road. For example, in August 1929 a catastrophic flood caused enormous damage to the town and to the communication lines. Reconstruction of peak heights in the flood indicated a the maximum discharge of 149.2 $m^3 s^{-1}$, which is equal to a specific discharge of 9.16 $m^3 s^{-1} km^{-2}$. Catastrophic floods also occurred in 1946, 1947, 1948 and 1951. In this period, however, sediment yield and transport were not measured. Similar flooding affected the Repinska Reka and Lještarska Dolina torrents in the period between the end of the Second World War and 1962.

Table 2 Land use in the drainage basins before ECW.

Culture	Kalimanska Reka		Repinska Reka		Lještarska Dolina	
	(ha)	(%)	(ha)	(%)	(ha)	(%)
Forests	543.60	33.89	355.80	45.50	136.70	51.84
Ploughed land	420.50	26.22	377.00	48.21	58.21	22.07
Meadows and pastures	185.90	11.59	29.70	3.80	7.20	2.73
Orchards	42.50	2.65	1.30	0.16	1.70	0.64
Bare land	411.50	25.65	18.20	2.33	59.92	22.72
Total	1604.00	100	782.00	100	263.73	100

In addition, the Repinska Reka torrent caused great damage to the village of Repince and the Lještarska Dolina torrent to the village of Priboj Vranjski. In the period between 1 May 1957 and 30 April 1958, hydrological data were collected for the Repinska Reka torrent. The following hydrological parameters were recorded (Jovanović *et al.*, 1960):

- annual specific discharge (M_Q) = 0.014 $m^3 s^{-1} km^{-2}$;
- mean annual turbidity of suspended sediment (ρ) = 5.70 kg m^{-3};
- specific annual suspended sediment transport (M_R) = 2273.0 $m^3 km^{-2}$.

Unfortunately, specific annual bed load transport (M_V) was not measured and it was estimated to be about 20% of the annual suspended sediment transport which amounts to 455.0 $m^3 km^{-2}$. Consequently, specific annual transport of total sediment (M_G) was 2728 $m^3 km^{-2}$. Although hydrometric measurements were made only for one year, the results show that erosion in the drainage basin was excessive, which is best illustrated by the annual sediment transport values.

Erosion control works (ECW)

As the largest watercourse which passes through the town of Vladičin Han, the Kalimanska Reka has caused great damage to the town and to the international communication routes by its frequent torrential floods. For several decades following the beginning of twentieth century it was considered an exceptionally destructive torrent. For this reason, ECW started in the Kalimanska Reka in 1927. At first, the lower course was regulated from the confluence in Južna Morava River through the town Vladičin Han, and also before the Second World War, several check dams were constructed in the middle and upper course. The largest part of the ECW was carried out in the period 1953-1968, when all of the conservation works in the drainage basin were completed.

Erosion control works in the Repinska Reka drainage basin started in 1938, when three check dams were constructed in the middle course. The majority of works were completed in the period 1963-1973.

Erosion control works in the Lještarska Dolina drainage basin were carried out in the period 1963-1973. Details of the type and scope of ECW in all three drainage basins are given in Table 3, and examples of the structures built are presented in Figs 2, 3 and 4.

Effects of erosion control works

Land use in the drainage basins was changed as a result of ECW (Table 4). Maps of land use in the drainage basins were produced in 1994. The results of detailed reconnaissance of the drainage basins in 1944 were also used to produce maps of erosion. The state of erosion in the drainage basins before and after ECW (Table 5) reveals that the intensity of erosion processes has been substantially reduced by the works.

Sediment yield is a consequence of erosion processes in the drainage basin. Unfortunately, sediment yield was not measured either before or after ECW. For the sake of comparison, probable sediment yield was calculated according to the intensity of erosion before and after ECW. The calculation (Gavrilović, 1972) is based on mean annual rainfall and the value of the coefficient of erosion for the drainage basin (together

Table 3 Erosion and torrent control works.

Number	Type of ECW	Kalimanska Reka	Repinska Reka	Lještarska Dolina
1	Period of the ECW	1927-1968	1938-1973	1963-1973
2	Regulation of the lower course (m)	700.00	750.00	350.00
3	Stonemasonry check dams (units)	39	7	18
4	Check dams of dry laid masonry (units)	185	20	20
5	Afforestation of bare land with black locust (*Robinia pseudoacacia L.*) (ha)	104.40	57.00	40.35
6	Afforestation of bare land with Austrian pine (*Pinus nigra Arn.*) (ha)	61.00	17.50	14.45
7	Afforestation of thinned and degraded forests with black locust (ha)	101.10	-	-
8	Grassing (mixture of grasses) (ha)	132.30	11.60	3.00
9	Establishment of orchards on steep slopes (ha)	60.80	1.00	2.00
10	Pasture reclamation (ha)	-	20.00	-

with other necessary parameters). The results of the calculation are expressed as a specific mean annual yield of sediment ($m^3 km^{-2} year^{-1}$) and show a substantial decrease of sediment yield in the drainage basins after ECW (Table 6).

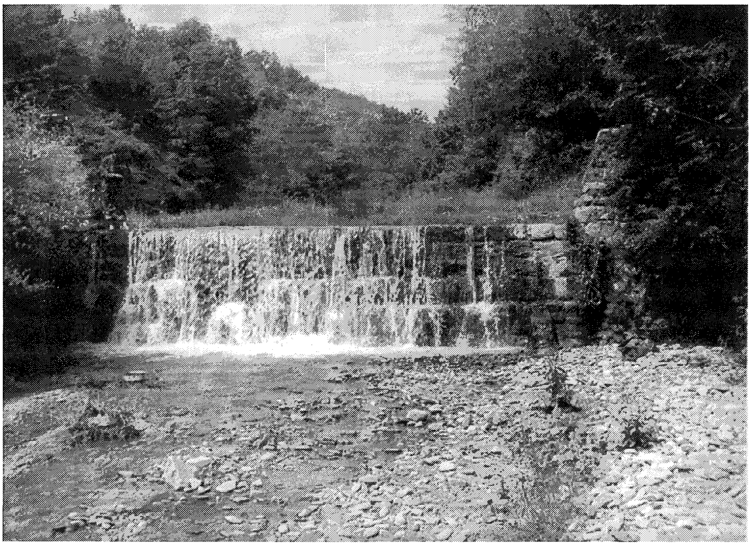

Fig. 2 Check dam in the Kalimanska Reka torrent.

Fig. 3 Check dam in the Repinska Reka torrent.

Fig. 4 Check dam of dry laid masonry and afforestation with Austrian pine (Lještarska Dolina drainage basin.

The quantitative expression of the intensity of erosion processes in the drainage basin is the yield and transport of sediment. In the period 1979-1988, water discharge and sediment yield were measured in the three study basins and the results are presented in Table 7.

Table 4 Land use in the drainage basins after ECW.

Culture	Kalimanska Reka		Repinska Reka		Lještarska Dolina	
	(ha)	(%)	(ha)	(%)	(ha)	(%)
Forests	810.10	50.50	430.30	55.03	191.50	72.64
Ploughed land	355.40	22.16	307.30	39.30	30.96	11.74
Meadows and pastures	318.20	19.84	41.30	5.28	10.20	3.87
Orchards	103.30	6.44	2.30	0.29	3.70	1.40
Bare land	17.00	1.06	0.80	0.10	27.37	10.38
Total	1604.00	100	782.00	100	263.73	100

Table 5 Erosion process intensity in the drainage basins before and after ECW.

Drainage basin	Before ECW			After ECW		
	Category of erosion	Intensity	Coefficient of erosion (*Z*)	Category of erosion	Intensity	Coefficient of erosion (*Z*)
Kalimanska Reka	I	Excessive	1.25	IV	Weak	0.36
Repinska Reka	II	Intensive	0.90	IV	Weak	0.37
Lještarska Dolina	I	Excessive	1.10	III	Medium	0.52

Table 6 Average annual sediment yield in the drainage basins before and after ECW (calculated according to Gavrilović's method).

Drainage basin	Before ECW		After ECW	
	Coefficient of erosion (*Z*)	Annual sediment yield (*W*) (m^3 km^{-2} $year^{-1}$)	Coefficient of erosion (*Z*)	Annual sediment yield (*W*) (m^3 km^{-2} $year^{-1}$)
Kalimanska Reka	1.25	3775.00	0.36	531.00
Repinska Reka	0.90	1868.00	0.37	498.00
Lještarska Dolina	1.10	2350.00	0.52	290.00

DISCUSSION

The research has shown that the intensity of erosion processes was substantially reduced in all the three drainage basins following ECW. The greatest decrease was in the

Table 7 Annual characteristics of sediment transport after ECW.

Drainage basins	Year	H (year) (mm)	M_R ($mm^3\ km^{-2}$)	M_V ($m^3\ km^{-2}$)	M_G ($m^3\ km^{-2}$)	ρ ($kg\ m^{-3}$)
Kalimanska Reka	1979	773.30	13.27	-	-	0.054
	1980	784.60	32.00	-	-	0.054
	1981	775.70	26.70	3.41	30.11	0.047
	1982	561.40	34.88	1.52	36.40	0.093
Repinska Reka	1979	678.90	7.44	-	-	0.058
	1980	743.20	43.86	8.32	52.18	0.148
	1981	625.70	25.96	0.07	26.03	0.121
	1982	526.30	106.03	7.98	114.01	0.449
Lještarska Dolina	1980	579.80	41.73	13.22	54.95	0.285
	1981	544.40	76.07	27.38	103.45	0.142
	1982	681.40	545.60	333.91	979.51	2.104
	1983	559.40	75.65	22.18	97.83	0.173
	1984	576.00	55.00	8.08	63.08	0.150
	1985	598.00	87.34	16.07	103.41	0.273
	1986	600.70	28.58	14.33	42.91	0.292
	1987	667.70	590.24	133.36	723.60	1.678
	1988	713.20	6.35	5.40	11.75	0.015

H (year) = annual precipitation; M_R = specific suspended sediment transport; M_V = specific bed load transport; M_G = specific total sediment transport; ρ = average annual turbidity.

Kalimanska Reka drainage basin. This reflects the fact that ECW were most extensive in the Kalimanska Reka drainage basin (almost 29% of the total area of the Kalimanska Reka drainage basin was affected by ECW, compared to 22.7% in Lještarska Dolina, and 13.6% in the Repinska Reka drainage basin). The highest number of structures (regulations and check dams) were also built in Kalimanska Reka.

Although measured data are not available, calculations by Gavrilović's method show that sediment yield was significantly decreased after ECW. In the Kalimanska Reka, it was decreased by about seven times, and in the Repinska Reka by 3.75 times. The greatest decrease, about eight times, was calculated for the Lještarska Dolina.

The measurements at hydrometric cross sections showed that the specific average annual transport of total sediment (suspended sediment plus bed load) was greatest in the Lještarska Dolina at about 231.0 $m^3\ km^{-2}\ year^{-1}$, followed by the Repinska Reka at about 64.0 $m^3\ km^{-2}\ year^{-1}$ and then the Kalimanska Reka at 33.0 $m^3\ km^{-2}\ year^{-1}$. Although the period of research is relatively short, especially in the Kalimanska Reka and the Repinska Reka, the very low specific transport of sediment recorded in these catchments confirms the positive effects of ECW.

It should be emphasized that during a 1-year period of measurements in the Repinska Reka before ECW, an exceptionally high transport of sediment (*c.* 2700 $m^3\ km^{-2}\ year^{-1}$) was recorded and was about 40 times greater than that recorded after ECW. However, this difference also reflects the influence of higher than average rainfall (with intensive storms) in the earlier period, although it can still be concluded that a significant decrease of sediment transport occurred after ECW.

Another significant positive effect of ECW has been the protection of the two important international lines of communication (the Belgrade-Skopje-Athens road and railway), as well as the settlements in the study area. After ECW there was no damage recorded by any of the three study torrents. To date, ECW have been undertaken at the localities where the processes of erosion were intensive or excessive (in the drainage basin) and where acute problems of damage to road and railway links and to settlements had to be solved (works in the stream channel).

As for areas affected by medium and weak erosion, which almost always occur in ploughed land (because it is on slopes greater than 3%) and in pastures (on slopes above 10-15%), with occasional exceptions, there have not been any significant protection works. Therefore, the systems of erosion control in the study drainage basins have not use in the drainage basins were produced in 1994. The results of detailed reconnaissance of the drainage basins in 1944 were also used to produce maps of erosion. The state of erosion in the drainage basins before and after ECW (Table 5) reveals that the intensity of erosion processes has been substantially reduced by the works.

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The quantitative expression of the intensity of erosion processes in the drainage basin is the yield and transport of sediment. In the period 1979-1988, water discharge and sediment yield were measured in the three study basins and the results are presented in Table 7.

DISCUSSION

The research has shown that the intensity of erosion processes was substantially reduced in all the three drainage basins following ECW. The greatest decrease was in the Kalimanska Reka drainage basin. This reflects the fact that ECW were most extensive in the Kalimanska Reka drainage basin (almost 29% of the total area of the Kalimanska Reka drainage basin was affected by ECW, compared to 22.7% in Lještarska Dolina, and 13.6% in the Repinska Reka drainage basin). The highest number of structures (regulations and check dams) were also built in Kalimanska Reka.

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It should be emphasized that during a 1-year period of measurements in the Repinska Reka before ECW, an exceptionally high transport of sediment (*c.* 2700 m^3 km^{-2} $year^{-1}$) was recorded and was about 40 times greater than that recorded after ECW. However, this difference also reflects the influence of higher than average rainfall (with intensive storms) in the earlier period, although it can still be concluded that a significant decrease of sediment transport occurred after ECW.

Another significant positive effect of ECW has been the protection of the two important international lines of communication (the Belgrade-Skopje-Athens road and railway), as well as the settlements in the study area. After ECW there was no damage recorded by any of the three study torrents. To date, ECW have been undertaken at the localities where the processes of erosion were intensive or excessive (in the drainage basin) and where acute problems of damage to road and railway links and to settlements had to be solved (works in the stream channel).

As for areas affected by medium and weak erosion, which almost always occur in ploughed land (because it is on slopes greater than 3%) and in pastures (on slopes above 10-15%), with occasional exceptions, there have not been any significant protection works. Therefore, the systems of erosion control in the study drainage basins have not been completed. This situation is especially true of the Lještarska Dolina drainage basin which still has some localities with intensive and excessive erosion (as there is still a significant proportion of bare land in this catchment). Consequently, future efforts are required to solve this problem.

Together with soil particles from ploughed land, organic matter and fertilizers and pesticides (applied in agriculture) are also transported, which results in an ecological problem. Namely, organic substances (humus), fertilizers and pesticides cause chemical pollution of water in the streams. In addition, soil erosion of arable land causes great damage because the most fertile soil layer is lost, which decreases its productivity. This can be offset for a while by the application of fertilizers, but frequently the former ploughed land becomes an infertile bare area if adequate measures are not taken in time.

CONCLUSION

Research in the three torrential drainage basins in southeast Serbia has revealed that, as a consequence of ECW, the situation has been significantly improved (from the aspect of the stage of erosion processes) compared with the conditions before the works were put in hand. The situation in the torrential drainage basins is as follows:

(a) Erosion processes have decreased significantly, and the basins now fall into a lower category of erosion. The category of erosion in the Kalimanska Reka drainage basin has changed from excessive to weak, from intensive to weak in the Repinska Reka drainage basin and from excessive to the category medium in the Lještarska Dolina drainage basin.

(b) Sediment yield and transport have also decreased significantly.

(c) The safety of traffic and settlements, as well as the other significant features, has been protected.

(d) Since the erosion control system has not yet been completed, the planned ECW should be carried out throughout the region, if the trend of reduction of erosion process intensity is to continue.

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