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Estimating soil erosion and sediment transport in the drainage basin of the proposed Selova Reservoir, Serbia

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Abstract In recent years construction work has been performed on the River Toplica with the aim of building a dam that will form the water supply for reservoir Selova. The basic purpose is water supply, but flood protection, sediment retention, production of hydro-electricity, breeding of fish, irrigation and tourism are important secondary benefits. This paper describes the headwaters of the River Toplica drainage basin and the nature and extent of its erosion and sediment transport processes. There are no measured data regarding sediment transport in the drainage basin, so the evaluation of sediment transport and potential reservoir siltation was based on empirical methods developed using research and direct measurements in experimental drainage basins elsewhere in Serbia.

Key words headwater; reservoir siltation; sediment transport; soil erosion; water reservoir

INTRODUCTION

The River Toplica (south Serbia) is the largest left tributary of the River Južna Morava, both by water discharge and by drainage basin area, which amounts to 2217 km^2 (Fig. 1). The Water Management Plan of the Republic of Serbia, as the basic document identifying the main strategies of water utilization in Serbia, includes the construction of a reservoir on the River Toplica. The drainage basin of the reservoir covers the eastern slopes of the Mountain Kopaonik in the central part of Serbia. The "Selova" reservoir, now in the final stage of construction, will be the source of water supply for the population of the settlements in Niški District and Toplički District. The other purposes include: protection from flooding, sediment retention, production of hydro-electricity, breeding of fish, irrigation and tourism. The total area of its drainage basin upstream of the dam site is 349.0 km^2, and the design volume of the reservoir is 70×10^6 m^3.

The drainage basin of the "Selova" reservoir is characterized by intensive erosion, which produces high quantities of sediment. This material, transported by flood events, will cause the reduction of the available storage capacity.

PHYSICAL CHARACTERISTICS

The main parameters of the Toplica drainage basin upstream of the Selova reservoir are presented in Table 1. Based on the resistance to erosion, the rocks of the Toplica drainage basin can be classified into four groups:

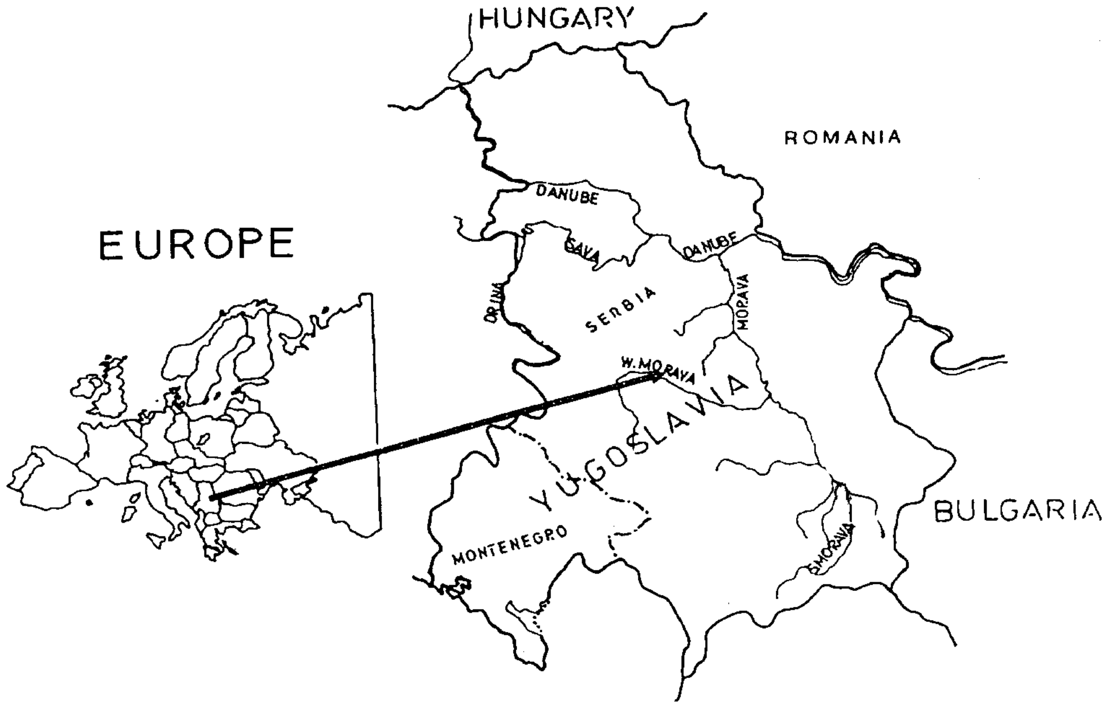

Fig. 1 Study area.

Table 1 The parameters of the drainage basin.

Parameters	Symbol	Units	Values
Drainage basin area	A	km^2	349.0
Drainage basin length	L	km	33.0
Drainage basin parameter	O	km	93.0
Drainage basin mean altitude	N_{sr}	m	984
Drainage basin mean altitudinal difference	D	m	501
Drainage basin mean slope	I_{sr}	%	37.4
Stream bed slope	I_t	%	4.72
Local erosion basis	H	m	1 557
Drainage density	G	km km^{-2}	2.23

(1) The Toplica drainage basin, except its source area, is cut into very erodible flysch-like sedimentary rocks. The rocks have a very heterogeneous composition, coarser-grained in the lower units, and finer-grained in the upper. Slopes developed on this substrate are highly unstable and produce large volumes of predominantly medium- and fine-grained sediment. It should be noted that they are extremely susceptible to water-borne erosion. Volcanogenic-sedimentary rocks, which are even more erodible, also belong to this group.

(2) The second group of rocks, regarding erodibility, includes crystalline limestones, dolomites, limestones and serpentinites. These rocks are characterized by higher strength parameters compared to rock group (1). Serpentinites have differing resistance, depending on the depth, and their hardness increases with the depth. The superficial parts of these rocks produce debris, which is coarse to medium grained.

(3) Medium-resistant rocks—harzburgites, compared to the groups (1) and (2), are characterized by a greater hardness and lower yield of coarse-grained debris on the surface.
(4) Resistant rocks in the drainage basin include all the remaining igneous rocks—quartz latite, granodiorite, basalt, gabbro, diabase.

The main hydrogeological feature of the study basin is the absence of any significant groundwater storage. The consequence is the relatively flashy response to precipitation events and a very low baseflow condition.

The River Toplica is formed by Đerekarska Reka and Blaževska Reka. The valleys of the rivers Toplica, Đerekarska Reka and Blaževska Reka are very narrow, occasionally gorge type. According to the data of the Hydro-Meteorological Service of the Republic of Serbia for the Donja Selova gauging station for the period 1951–2001, the highest water discharge was 260 $m^3 s^{-1}$ (19 November 1979), and the lowest 0.060 $m^3 s^{-1}$ (1 August 1952). The ratio of the recorded maximal and minimal discharges is 4333, meaning that this stretch of the Toplica can be classified as an extreme torrent.

Soil formation in the drainage basin is mostly conditioned by the mountainous relief, often with slope gradients of 30–45º. The soils are mostly very shallow (about 75% of the area) and shallow (about 20%). According to the Soil Classification of Serbia the soils of the study area are classified as the following types: soils on hard rocks (lithosol), colluvial soil (colluvium), black soils on compact limestone (calcomelanosol), humus-siliceous soil (ranker), eutric brown soil (eutric cambisol), dystric brown soil (dystric cambisol) and alluvial deposit (fluvisol). Land-use in the drainage basin includes: forests (40.2%), thin degraded forests (14.1%), farmyards (13.7%), bare lands (6.8%), arable lands (7.4%), pastures and meadows (16.5%) and orchards (1.3%). In the forest associations, the greatest area is covered with oak, submontane beech and fir. Bare lands mainly extend in the source areas of the rivers Đerekarska, Blaževska, Lukovska and Mala Reka and these areas represent significant sources of sediment.

The mean air temperature in the multiannual period, measured at the weather station Kuršumlija, as the nearest one to the drainage basin, is 10.3ºC. January is the coldest and the only month in the year with a negative mean monthly temperature (–0.49ºC). The warmest month is July, with 19.8ºC. The mean multiannual rainfall of 891.9 mm was calculated based on the isohyet map of the drainage basin.

EROSION AND SEDIMENT TRANSPORT

Soil erosion in the drainage basin upstream of the Selova reservoir

The result of natural sensitivities and inappropriate land use in the Toplica drainage basin upstream of the Selova dam are intensive water erosion processes in the forms of sheet, rill and gully erosion. Erosion of different intensities occurs throughout the drainage basin, but the processes of severe and excessive erosion occur primarily down the northern tributaries of the drainage basin, e.g. the Pavaštička Reka, Mala Reka, Kačaruša, sub-basins, along with the Đerekarska Reka and Blaževska Reka systems in the headwaters.

The present study reports the findings of a reconnaissance survey of erosion processes in the Toplica drainage basin upstream of the Selova dam. The drainage basin was divided into 12 sub-catchments (Table 2). Based on the field reconnaissance, an erosion map of the drainage basin was produced using the scheme of Gavrilović (1972) .The state of erosion in a drainage basin is expressed by an erosion coefficient which shows the intensity of erosion. Table 2 presents erosion coefficients (Z and α) and the degree of torrentiality of the region (m) (Gavrilović, 1972). The coefficients are calculated using the morphometric parameters in Table 1 combined with climate and soils data and used to estimate sediment transport in the drainage basin in the absence of gauged data. The calculated erosion coefficient (Z), for the whole drainage basin upstream of the Selova reservoir was 0.49, and indicates that erosion of medium intensity was prevalent throughout the drainage basin.

Table 2 Survey of erosion coefficients in sub-catchments.

No	Sub-catchment	Erosion coefficient:		Degree of torrentiality	Area (km^2)
		Z	∝	m	
I	Međusliv "A"	0.60	3.35	0.84	4.2
II	Pavaštička reka	0.49	2.60	0.76	5.4
III	Pavaštčki potok	0.37	2.00	0.60	8.2
IV	Magovski potok	0.44	2.27	0.73	6.4
V	Mala reka	0.52	2.80	0.78	25.2
VI	Kačaruša	0.56	3.07	0.81	22.5
VII	Đerekarska reka	0.55	3.00	0.80	42.0
VIII	Blaževska reka	0.53	2.87	0.79	59.3
IX	Lukovska reka	0.48	2.55	0.75	114.3
X	Međusliv "B"	0.43	2.20	0.72	23.2
XI	Adžovski potok	0.40	2.05	0.70	6.2
XII	Rankovica	0.42	2.14	0.715	32.1
	Toplica River	0.49	2.60	0.76	349.0

Analysis of the available database of sediment measurements

As plans for the construction of Selova dam have been known for some time, the experimental drainage basin "Gornja Toplica" was established in 1960. Hydrological and sediment measurements were carried out in the Toplica drainage basin during the period 1960–1985. Three gauging stations in this drainage basin are especially significant these being the Magovo on the River Toplica (F_{sl} = 180 km^2), upstream of the Lukovska Reka confluence; the Merćez on the Lukovska Reka (F_{sl} = 114.3 km^2), and the Donja Selova on the Toplica, in the zone of Selova reservoir (F_{sl} = 350 km^2).

With the establishment of the Gornja Toplica experimental catchment these three gauging stations started measuring suspended sediment, yielding a significant 25-year record of sediment flux. Based on the monthly and annual balances of suspended sediment transport during the study period, the average annual sediment transport amounts to 22 000 t. In the absence of gauged bed load data, it was assumed that bed load amounts to 20% of the suspended sediment flux so that the resulting total of annual sediment transport is estimated at 26 400 t. The assessment of the dynamic sedimentation problems in the future Selova reservoir is based on these data.

From reconnaissance of the Selova reservoir drainage basin and the resulting erosion map, it is concluded that the suspended sediment flux estimates of the River Toplica and Lukovska Reka were significantly underestimated. The reason for this discrepancy results from the method of sediment measurement in the River Toplica and Lukovska Reka, which is not adapted to the highly episodic character of sediment transport in the torrents. Kostadinov (1993) estimated that more than 80% of the total annual sediment is transported in torrential waves. Torrential waves have specific dynamics, meaning that great variations of water discharge and sediment transport occur over very short time intervals (shorter than 24 h). Thus, if the samples are taken only once a day, e.g. at 07:00 h, which is the usual practice of the Republican Hydro-meteorological Service of Serbia, the passage of a torrential wave may be missed or grossly underestimated.

As the measurement of sediment transport in torrential waves is of crucial significance for the real analysis of total annual transport of suspended sediment, it is necessary to analyse the maximal concentrations of suspended sediment, as well as the values of sediment transport by one torrential wave. This means that if the sedigraphs of torrential waves are not well recorded, the results will significantly underestimate the true flux.

Calculation of mean annual sediment transport

Because of the imperfect methodology of measurement (only one sample per day), it is argued that the result of the average annual 26 400 t is a very low value. For this reason, we calculated the mean annual sediment transport by the application of an empirical method. In the management of torrential drainage basins in Serbia, and also in the neighbouring countries, mean annual sediment transport in hydrologically non-gauged drainage basins is calculated by empirical methods (Poljakov, 1948; Gavrilović, 1972). During the last 10 years, the modified method of Poljakov–Kostadinov (Kostadinov, 1993, 1996, 2004) has been developed. Table 3 presents the calculation results according to these three methods.

The modification of Poljakov's method was based on the measurement of sediment transport (suspended sediment and bed load) in seven experimental drainage basins in Serbia. (Kostadinov, 1993, 2004).

Taking into account that, based on the erosion map, the calculated erosion coefficient (Gavrilović, 1972) for the whole drainage basin upstream of the Selova reservoir was $Z = 0.49$ (medium erosion) it can be assumed that according to the present conditions

Table 3 Calculated average annual sediment transport for the Toplica River.

Method		Sediment transport	
		Total (m^3 $year^{-1}$)	Specific sediment transport (m^3 $year^{-1}$ km^{-2})
1	Polyakov (1948)	322 200	923
2	Gavrilovic (1972)	213 353	611
3	Polyakov-Kostadinov (1993)	109 742	314

in the drainage basin, the annual sediment transport amounts to 110 000 to 150 000 m^3 $year^{-1}$. The available capacity of the reservoir is going to be reduced by this volume.

Actual problems on Selova reservoir

The drainage basin upstream from the Selova dam is situated on the eastern slopes of mountain Kopaonik, and features intensive water erosion processes. In addition to the generally known damage caused by erosion and torrents (soil loss, loss of soil fertility, water loss, torrential floods and landscape degradation), significant damage will be caused to the future Selova reservoir including a loss of the storage capacity due to siltation by eroded sediments, and increased contamination of water by sediment and chemical pollutants (contaminants and nutrients).

CONCLUSION

Natural characteristics and inappropriate land use in the Toplica drainage basin, upstream of the future Selova reservoir, conditioned the occurrence of intensive water erosion processes and frequent torrential floods. During the period 1960–1985 sediment transport was measured on the River Toplica and its tributaries, upstream of the profile of the future Selova reservoir. Because of the imperfect methodology of measurement (only one sample per day), it is argued that the resulting annual average 26 400 t is a very low value. For this reason, we calculated the mean annual sediment transport by the application of the empiric methods. The calculation performed by the application of three empiric methods produced different results. Taking into account that the modified method of Poljakov-Kostadinov was based on the measurements of sediment transport in seven experimental drainage basins in Serbia, we adopted the result obtained by the calculation according to this method. So, it can be concluded that in future the average annual sediment transport into the Selova reservoir is going to amount to between 110 000 and 150 000 m^3. It is going to cause multiple damage and first of all it will affect the water quality. For this reason, it is necessary to undertake the required erosion control works in order to reduce the intensity of erosion in the drainage basin, and in this way also the sedimentation of the water Selova reservoir.

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