Soil erosion and the possibility of its control in the watershed of the water reservoir "Prvonek"

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1. Abstract

The reservoir "Prvonek" was built for water supply of the towns Vranje, Vranjska Banja-Spa, Bujanovac and the surrounding villages in south-east Serbia.The Vranjsko-Banjska River watershed upstream of the reservoir is in the hilly-mountainous area of south-east Serbia, known for its intensive processes of water erosion. As the consequence of erosion, great quantities of sediment from the watershed reach the hydrographic network of the Vranjsko-Banjska River and threaten to reduce significantly the designed volume and the life of the water reservoir. Also, the deposited sediment in the water reservoir causes a series of damage, which can be defined as ecological risks, e.g.:mechanical pollution of water caused by turbidity and chemical pollution of water, because various chemical substances get into water with the suspended sediment.

This paper presents the study results obtained during the period 2001 - 2005 aiming at the assessment of the state of erosion in the watershed, sediment transport as well as the possibility of erosion control and the reservoir protection against silting up and all other damage caused by sediment.

Key words: soil erosion, sediment transport, water reservoir, damages, erosion control

2. Introduction

The problem of water supply in Vranje has been topical for quite a long time. The dam and the reservoir »Prvonek« were constructed for the permanent solution of the water supply problem of Vranje, Bujanovac and the surroundings. The lake filling started on May 1st, 2005. The dam »Prvonek« is erected on the Vranjsko-Banjska River, the right tributary of the river Južna Morava, 9 km upstream of Vranjska Banja-Spa, near the village Prvonek. The dam »Prvonek« is earth-rockfill dam with sloped central clay core within the dam body. The main elements of the dam are:

- height of the dam - 87.5m
- volume of the reservoir to the elevation of normal backwater – 20.0 million m^3

This paper presents the research of erosion and sediment transport in the Vranjsko-Banjska river watershed upstream of the reservoir "Prvonek" and the potential erosion control in the watershed and the protection of the reservoir against silting up. The research was carried out during the period 2001-2005.

3. Subject and method

The Vranjsko-Banjska river watershed is situated in south-east Serbia, in the municipality Vranje with several settlements: Vranjska Banja-Spa, Duga Luka, Prvonek, Brezovica, etc. (Fig.1). The Vranjsko-Banjska river is a major torrent, total area of the watershed A_{sl}=150.0km^2. The watershed is very accidented, with steep slopes and steep streambed slopes of the main stem and torrential tributaries. The major parameters of the watershed area upstream of the reservoir "Prvonek" are:

- Watershed area, A_{sl}=83.644 km^2
- Watershed length, L=14.63 km
- Mean slope of the watershed, I_{sr}=49.59%

The research included the folowwing stages:

a)collection and study of existing documentation on the watershed including erosion control works (ECW) projects, documentation of implemented ECW, data on state of intensity of erosion processes in the period before 1956;

b)collection of all data on the watershed with respect to natural characteristics, state of the vegetation cover and intensity of erosion processes in the period of research ;

c)calculation of the values of mean annual gross erosion and sediment transport for different time periods (1956, present state and future state).

Land use and erosion status in the watershed are defined based on air photographs and direct field reconnaissance of the watershed, which was the base of the watershed erosion map for three time sections: 1956, present period and future state (after implementing the measures of integral watershed management). Erosion map of the watershed is made by Gavrilović's method (Gavrilović, S., 1972). The water erosion processes are

grouped after Gavrilović's classification into five categories, from excessive to very weak. As there are no measured data on sediment transport in the watershed, the values of mean annual gross erosion and sediment transport for different time periods (1956, present state and future state) are calculated by Gavrilović's method of erosion potential (Gavrilović, S., 1972).

Figure 1 Study area

4. Results of research

4.1 Characteristics of Vranjsko-Banjska river watershed

The study complex is composed of Tertiary plutonic rocks, forming the Surdulica granodiorite pluton. The accessories of granodiorites are quartzlatites. The following rocks are represented in the area of the Vranjsko-Banjska river watershed: gneisses, micaschists, amphibolites, dacites, dacite-andesite tuffs, Miopliocene conglomerates (gravel, sand, clay), sand reefs and sandy clays in the alluvial plains.

The bedrock has conditioned the development of a genetic series of soils on acid siliceous rocks, starting from the bare rocks – stony ground and sirozem (lithosol), rankers and brownised soils, to skeletoid acid brown soil (dystric cambisol), because the nature of this bedrock gives these soils a specific mark and is an important diagnostic sign for soil classification.

The most important climate parameters for the development of erosion processes are precipitation and air temperature. The average annual air temperature is 11.1°C, during the growing season 17.4°C. The pluviometric regime of the watershed has all characteristics of the continental central European type, and it is characterised by mean annual precipitation 850 mm.

Land use in the watershed is an important factor affecting runoff and soil erosion intensity. Land use is the result of anthropogenic influences. Thanks to the biological works in the watershed during the period 1952-1990, and especially after 1975, the state in the watershed was improved, but it is still below the satisfactory degree of protection.

4.2 Erosion processes

As the result of natural characteristics and anthropogenic factors, water erosion in the Vranjsko-Banjska River watershed is manifested in almost all visible forms. Depending on the general development of erosion processes and based on the classification of torrential regions by Gavrilović, the drainage basin of Vranjsko-Banjska River can be classified as the area of medium erosion (current state). The consequence of intensive erosion is the washing of the soil layer from the ploughlands, degraded forests and pastures in the upper part of the watershed and the silting up of fertile areas and the reservoir "Prvonek" in the lower part of the watershed. In addition to the direct damage, great damage is caused by floods, destructive force of the torrent in the channel of Vranjsko-Banjska river, and the damage caused by road destruction

Table 1 presents the shares of individual erosion categories, based on the erosion map. (current state) Mean value of Gavrilović's erosion coefficient in the entire watershed is Z = 0.504. Based on the Table 1, in general, the prevailing processes in the watershed are classified as medium erosion, which is a considerably more favourable situation than in 1956. Namely, at that time, the prevailing processes in the watershed in general were the processes of very severe erosion with mean Gavrilović's erosion coefficient in the entire watershed Z = 1.0. The improvement is the result of erosion control works (first of all afforestation and grassing). In the period from 1956 to 1990, significant erosion control works (ECWs) were performed, i.e.:

- check dams in the middle and upper course - 13 pieces
- afforestation of bare lands in the watershed – 387.80 ha
- grassing of bare lands - 393.2 ha.

Table 1 Distribution of erosion processes in the watershed

	Category of erosion	Erosion coefficient Z	Area km^2	%
I	Ekscessive erosion	1.25	2.500	2.99
II	Intensive erosion	0.85	4.400	5.26
III	Medium erosion	0.55	49.294	58.93
IV	Weak erosion	0.30	27.200	32.52
V	Very weak erosion	0.10	0.250	0.30
			83.644	100.00

4.3 Gross erosion and sediment transport

Table 2 Gross erosion and sediment transport in Vranjsko Banjska river watershed

N^0		1956	2007
1	Category of erosion	**II**	**III**
2	Erosion coefficient (Gavrilovic) - **Z**	1.0	0.504
3	Annual gross erosion **W**.....m^3·year^{-1}	245,570	87,866
4	Specific annual gross erosion **W$_{sp}$**.....m^3·year^{-1}·km^2	2,936	1,050
5	Annual sediment transport **G**..... m^3·year^{-1}	177,547	63,527
6	Specific annual sediment transport **G$_{sp}$**..... m^3·year^{-1}·km^2	2,123	759.50

As there were no measured data, mean annual gross erosion and sediment transport were determined by S. Gavrilović's method (Gavrilović, S., 1972). The calculated values of mean annual gross erosion and sediment transport (reaching the reservoir) for the state of erosion in the watershed in 1956 and the current state are presented in Table 2. As it can be seen, mean annual gross erosion and sediment transport are currently almost three times lower than in 1956 (as the results of performed erosion control works and the migration).

The value of mean annual volume of sediment inflowing into the reservoir does not seem to be high. However, the life of the reservoir should be al least 50 years, which means that, if erosion in the watershed keeps the same intensity, the volume of sediment deposited in the reservoir will be fifty times greater, i.e.: $G_{50} = G_{year} \cdot 50 = 63.527{,}26 \cdot 50 = 3{,}176.363$ m^3.

An even greater problem is that, together with the suspended sediment from the watershed slopes, various organic and inorganic substances reach the hydrographic network of the watershed and the reservoir itself: fertilisers, pesticides, biogenic elements and other substances present in the eroded soil. This causes the chemical contamination of water in the watercourses and in the reservoir.

4.4 Strategy for the protection of the reservoir "Prvonek"

Bearing in mind the significance of the reservoir "Prvonek", the most economical and the most suitable solution is the integral management of the entire watershed, which gravitates to the reservoir. This means practically to perform those erosion control works (biological and engineering) which would simultaneously eliminate both current and future erosion damage, and improve the water in the torrents, so that the reservoir is

supplied with pure water. Based on the detailed analysis of the distribution and intensity of erosion processes in the watershed, and taking into account the sustainable development of the region, the following ECWs are proposed:

- afforestation (broadleaves and conifers) - 850 ha
- grassing with grass mixture - 420 ha
- orchard establishment on terraces - 150 ha
- check dam construction in the hydrographic network - 7,500 m^3.

The result of erosion control works and measures will be the reduced sediment inflow into the reservoir. Thanks to erosion control works and measures, land productivity will be increased and considerably higher yield will be obtained, which is a benefit for landowners.

4.5 The expected effects of the predicted erosion control works

If all the predicted erosion control works are realised, further reduction of erosion intensity will follow and the processes of weak erosion (after Gavrilović's classification) will prevail in the watershed. The result will be the reduced mean annual gross erosion and sediment transport, so that by the end of the period, only 38,350 $m^3 \cdot year^{-1}$will inflow into the reservoir "Prvonek" (in fifty years 1,917,510.0 m^3). If we take into account that the percentage of bedload sediment is 35% of the total amount (based on field study and measurements by S. Kostadinov (Kostadinov, S., Marković,S., 1996), i.e. about 13,420 m^3, which will be retained by the predicted transverse structures (check dams) in the upper and middle courses, the annual amount of suspended sediment reaching the water in the reservoir will be 24,930 m^3 (in fifty years 1,246,500 m^3). This inflow of sediment into the reservoir is acceptable from the aspect of sustainable utilisation of water in the reservoir.

Table 3 Mean annual gross erosion and sediment transport after planned erosion control works

N^0		After ECW
1	Category of erosion	**IV**
2	Erosion coefficient (Gavrilovic) – **Z**	0.360
3	Annual gross erosion **W**.....$m^3 \cdot year^{-1}$	53,043
4	Specific annual gross erosion $\mathbf{W_{sp}}$.....$m^3 \cdot year^{-1} \cdot km^2$	634
5	Annual sediment transport **G**..... $m^3 \cdot year^{-1}$	38,350
6	Specific annual sediment transport $\mathbf{G_{sp}}$..... $m^3 \cdot year^{-1} \cdot km^2$	458.5

5. Conclusions

The watershed of the reservoir "Prvonek" is situated in a hilly-mountainous region in south-east Serbia and it is exposed to intensive processes of water erosion. As the result, more than 63,000 m^3 of sediment will inflow annually into the reservoir water, causing a series of damages, such as: reduction of reservoir capacity, mechanical contamination of water, chemical contamination of water, other economic and ecological damage. Based on the detailed field study, the strategy of erosion control measures and works is proposed in the aim to decrease erosion intensity in the watershed and the inflow of sediment into the reservoir water. The strategy is based on the integral management of the watershed and on the sustainable use of natural resources: land and water. After the implementation of these measures and works, the intensity of erosion will be decreased (weak erosion will prevail in the watershed) and annual sediment transport to the reservoir will be reduced to 24,930 m^3. In this way, the life of the reservoir "Prvonek" will be prolonged and its water quality will be protected.

6. References

Gavrilović,S., (1972) Inženjering o bujičnim tokovima i eroziji (Engineering of torrents and erosion) (in Serbian). *Journal "Izgradnja", Special edition*, Belgrade.

Kostadinov,S., Marković,S., (1996) Soil erosion and effects of erosion control works in the torrential drainage basins of southeast Serbia. *Erosion and Sediment Yield: Global and regional Perspectives* (Proceedings of the Exeter Symposium, July 1996). IAHS Publ.no.236.1996, p.p. 321-332.