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ASSESSMENT OF SEDIMENT INPUT INTO THE MODRAC ACCUMULATION WITH DETERMINATION OF EROSION CHARACTERISTICS OF THE MODRAC ACCUMULATION CATCHMENT AREA

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Summary

Determining the erosion characteristics of a catchment area is very important in managing the catchment area itself, as well as in managing water resources, especially if it is a multipurpose reservoir. Factors that determine the erosion process in a watercourse catchment area, or the sediment regime of a watercourse, could be divided into those that practically do not change or those that do not change significantly over a period of several years, and factors that are subject to change during the year, depending on meteorological and climatic changes over the catchment area. For preventive action and prevention of erosion, and thus flash floods, and filling of reservoirs, it is necessary to analyze and determine precisely the erosion coefficient of the catchment area. On the other hand, water resources management includes a number of activities such as planning, design, construction, management, maintenance, monitoring and control of constructed facilities, in order to assess and increase their efficiency. Accordingly, it is necessary to specifically plan all activities in relation to reservoirs as key facilities for managing the water regime of a catchment area and processes within the catchment area.
Keywords: erosion, sediment, meteorological changes, climate change, erosion coefficient, water resources, sediment, catchment area, deposition.

1. INTRODUCTION

The Modrac reservoir is the only available water resource in the Tuzla region and its surroundings. Bearing in mind the fact that the useful volume of the reservoir is limited, and that over time the reservoir is filled with hauled sediment and coal dust as floating sediment, and that consumers - the population, industry and others - must be provided with a water supply with a high degree of safety. Surplus water needs to be used to the maximum for the purpose of electricity production, and there is a need to optimize the system, i.e. more efficient management of the water resource of the reservoir, i.e. to prove the maximum utilization of the reservoir while constantly providing all the necessary amounts of water to which the Modrac reservoir is connected [1].

Hydroaccumulation "Modrac", as a multi-purpose reservoir, was created by the construction of the Modrac dam in 1964 in the Modrac Strait on the Spreca River. The reservoir consists of the rivers Spreca and Turija with their tributaries. The total area of the catchment area in the profile of the dam is approximately 1189 square kilometer, which makes up over 60% of the entire river basin. Of the total area of the basin, the river Spreča occupies 832 square kilometer, the river Turija occupies 240 square kilometer, while the rest of the basin belongs to the accumulation of the immediate basin 117 square kilometer [1].
The increasing and often conflicting demands for the use of water resources have led to the need for more complex management methods, including reservoir volume management.
In some reservoirs, already 10-20 years after their construction, the sediment volume reaches 20-30% of the total reservoir volume. [2].
The purpose of the assessment of the transfer of sediment to the hydroaccumulation is to realize the possibility of a more expedient management of natural water resources, protection from the harmful effects of water, as well as protection of water from pollution.
By analyzing the sediment transport in watercourses, i.e. tributaries, and the total amount of sediment deposited in the Modrac reservoir, real data are obtained about the amount of sediment introduced into the Modrac reservoir, the dynamics of sediment input, and the degree of pollution of this type of water body.

2. WATERSHED AREA MODELING

At the time of today's technology, which is widely available, the most effective tool for modeling the catchment area is the geographic information system (GIS). GIS is a system for managing spatial data and the attributes associated with them. In the strictest sense, it is a computer system capable of integrating, storing, editing, analyzing and displaying geographic information. One of the oldest definitions of GIS is:
"GIS is a special type of information system in which the computer database includes precisely defined relationships between spatially distributed objects, activities and events, which are spatially defined as points, lines and surfaces (polygons) [3].
In GIS, the data are related to these points, lines and polygons and are thus stored for research and analysis [3].
Modeling of the catchment area of the multi-purpose reservoir was done in the ArcGIS software package, in which all the foundations and input data for the calculation were prepared, the modeling of the Modrac reservoir basin and the hydrological hydraulic calculation was done in ArcSWAT. In the aforementioned software, on the geoinformation platform (GIS), the results were obtained: the flow of the main watercourses in the catchment area of the Modrac reservoir, soil saturation and sediment transport in the watercourses and their transport to the Modrac reservoir.
The input data for modeling in the ArcGIS software package, i.e. in the GIS tool - ArcSWAT, are:

- digital terrain model,
- map of the catchment area's surface use,
- map of the pedological composition of the catchment area's soil,

- hydrometeorological data (precipitation, temperature, wind, solar insolation and air humidity).

The following figure (Figure 1) shows how the ArcSWAT software works, the required substrates and substrate analysis, and the results obtained with this approach to the catchment area's research.

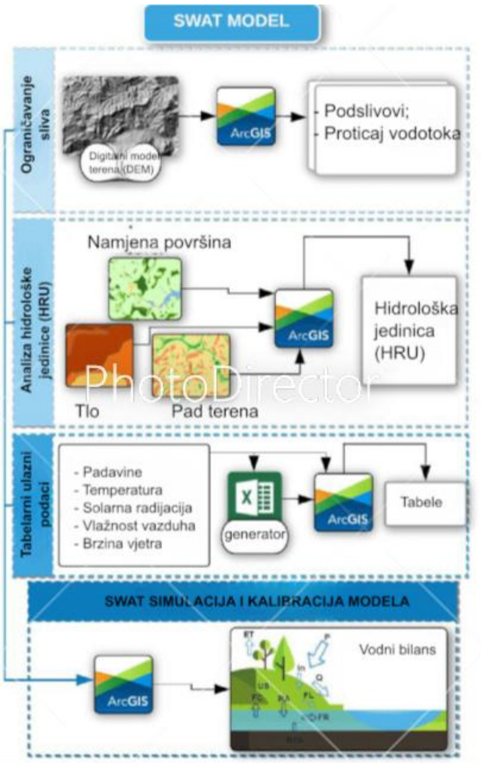

Figure 1. Presentation of the mode of operation of the ArcSWAT model [3]

The digital terrain model, as one of the most important sources, was downloaded from the USGS Earth Explorer, the data of the digital terrain model is SRTM 30 m. SRTM 30 m is a file containing digital elevation data for an international research program, which was used to obtain digital elevation models on a global level.

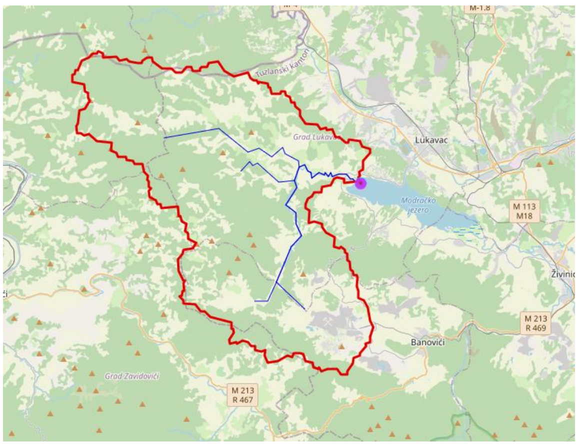

Figure 2. Digital terrain model of the wider area with the drawn boundary of the Modrac reservoir catchment area, https://mghydro.com/watersheds/

The land use and land cover map is also a digital data map and a necessary basis for the analysis of the catchment area and for the calculation in the aforementioned software package. The resolution of this map is quite high, and as of 2020 it is 10 m.

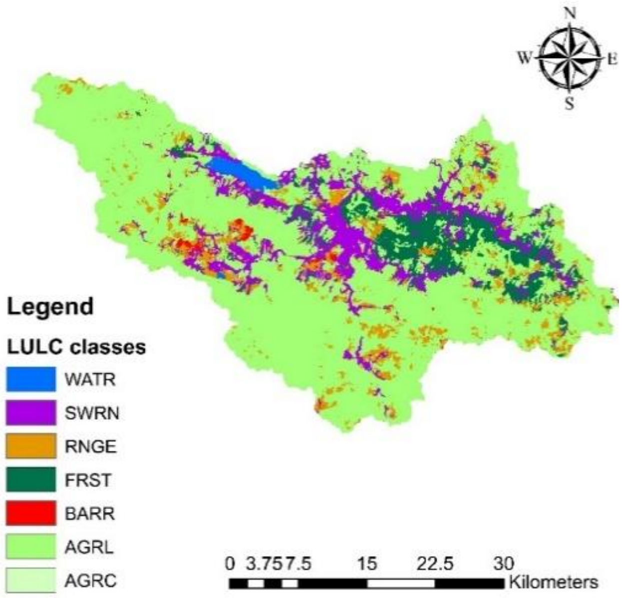

Figure 3. Land use and land cover map [3]

Bearing in mind the available input data that are necessary for modeling the catchment area, in this paper, data on the amount and transport of total sediment were compiled for a series of 8 years in the period 2014-2021.

The soil map is also a map with digital data on the pedological characteristics of the catchment area. For the subject basin of the Modrac reservoir, the mentioned soil map with pedological characteristics was taken from the website www.fao.org, which contains a database of pedological soil characteristics at the global level. [4].

The said map contains databases relating to data and maps compiled using field surveys supported by remote sensing and other environmental data, expert opinion and laboratory analyses [4].

Figure 4 shows the soil map of the Modrac reservoir basin according to the dominant soil classification. The catchment area of the Modrac reservoir is dominated by three dominant soil types, namely:

- Rankers (U3-2c) indicates shallow rocks with solid or fragmented non-calcareous rocks;
- Luvisol (Lg43-2ab) are soils associated with short-term water saturation in the profiles; and
- Cambiosols (Bd66-1/2bc), are widespread soils developed on different lithologies that play a significant role in the pedological development of this relatively young soil [4].

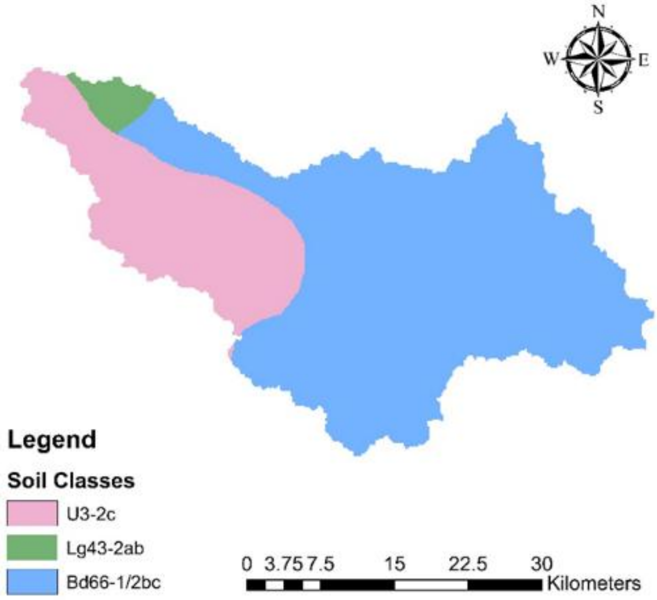

Figure 4. Soil map of the Modrac reservoir basin by dominant soil classification [4].

Hydrometeorological data are also used as a basis for the analysis of the catchment area and obtaining results on the flow in watercourses (inflow into the Modrac reservoir), transport of drift (sediments), soil saturation, input of nutrients into the reservoir (organic load). Hydrometeorological data were taken for a series of 8 years (2014 - 2021) from the Modrac rain gauge station.

3. MODELING RESULTS

In this paper, time steps are used to evaluate the SWAT model. Different evaluation parameters were used to evaluate the models and their performance as recommended by Moriasi et al. (2007), i.e.:
- Nash–Sutcliffe efficiency (NSE),
- graphic technique using hydrographs,
- standard RMSE observation deviation ratio (RSR) i
- percentage bias (Pbias).

In addition, the index of agreement (D) and coefficient of determination (R2) were also calculated and compared for all results obtained by modeling in SWAT software. The terrestrial part of the hydrological cycle is based on the water mass balance. Hydrological processes and the application of the SWAT model are simulated daily for each HRU - hydrological unit, in time steps using the following soil water balance equation [5].

$$SW_t = SW_0 + \sum_{i=1}^{n}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \quad (1)$$

where is:

SW_t – total water content in the soil (mm)

SW_O – initial soil water content (mm)
R_{day} – amount of precipitation per day (mm)
Q_{surf} – amount of surface runoff per day (mm)
E_a – evapotranspiration per day (mm)

w_{seep} – amount of percolation (extraction) – raising the groundwater level (mm)
Q_{gw} – amount of groundwater (mm)

The Penman-Monteith method of real evapotranspiration as well as potential transpiration is used for the calculation. Modified method CN curves with a modified rational method are used for the calculation of surface and peak runoff [6].
The universal equation of soil erosion and amount of sediments was defined by Williams in 1995 [7]:

$$sed = 11{,}80 \text{ x } (Q_{surf} \text{ x } q_{peak} \text{ x } area_{hru})^{0{,}56} \text{ x } K_{usle} \text{ x } C_{usle} \text{ x } LS_{usle} \text{ x } CFRG \qquad (2)$$

where is:

sed – amount of sediment (t/dan)
Q_{surf} – surface runoff volume (mm)
q_{peak} - peak surface runoff rate (m^3/sek)
$area_{hru}$ – hydrological area unit HRU (ha)
K_{usle} - soil erosion factor (taken: 0,013 t/ha)
C_{usle} - land cover and management factor
LS_{usle} - topographic factor
CFRG - coarse fragment factor

Below are graphical results from the SWAT model in diagrams showing the relationship between precipitation as input data and sediment quantities as the result of this analysis.

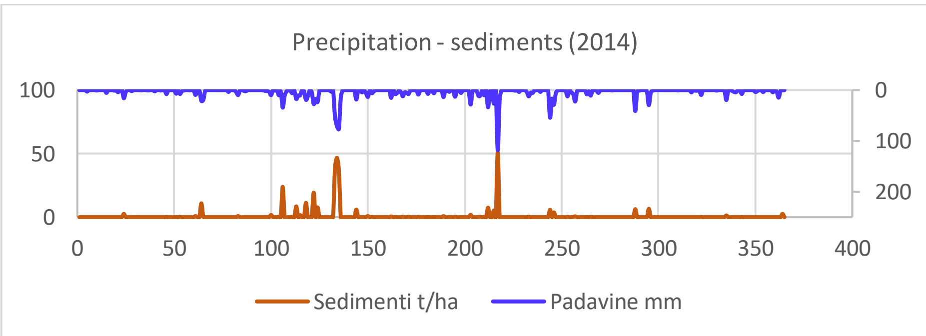

Figure 5. Diagram of precipitation and sediments in 2014

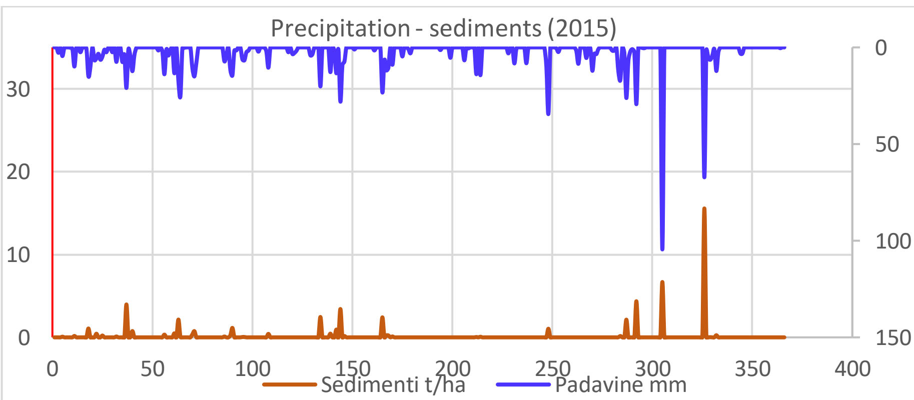

Figure 6. Diagram of precipitation and sediments in 2015

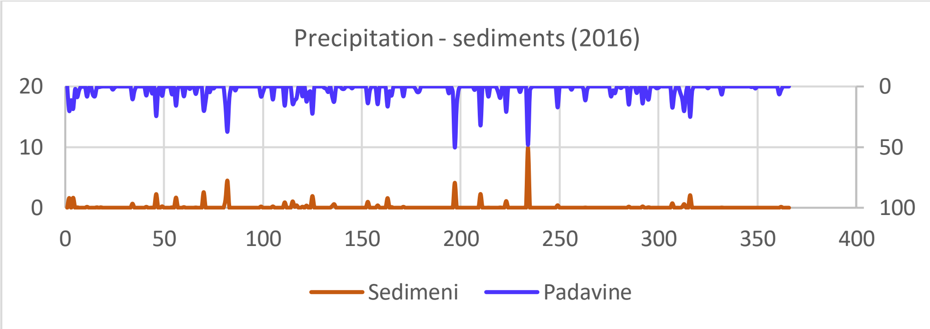

Figure 7. Diagram of precipitation and sediments in 2016

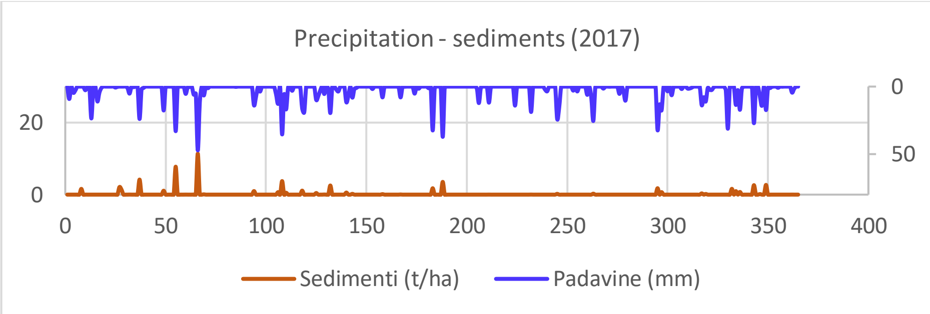

Figure 8. Diagram of precipitation and sediments in 2017

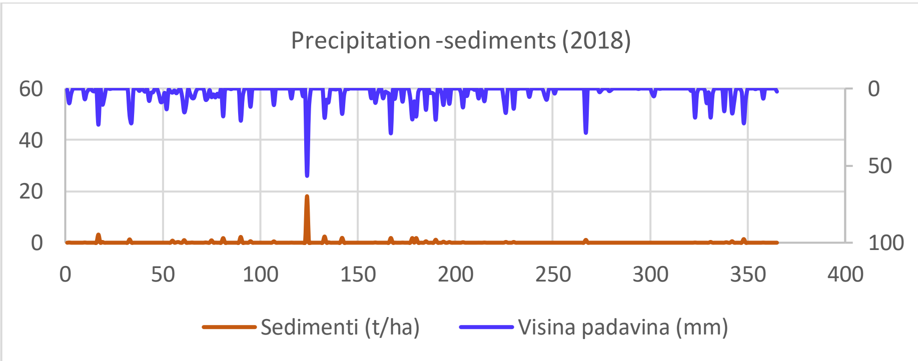

Figure 9. Diagram of precipitation and sediments in 2018

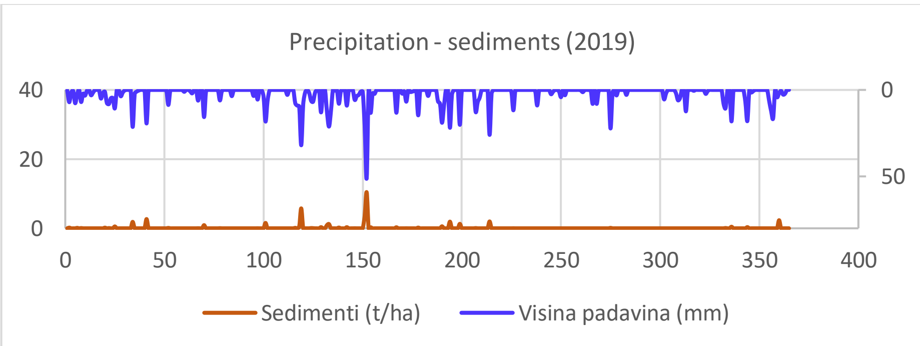

Figure 10. Diagram of precipitation and sediments in 2019

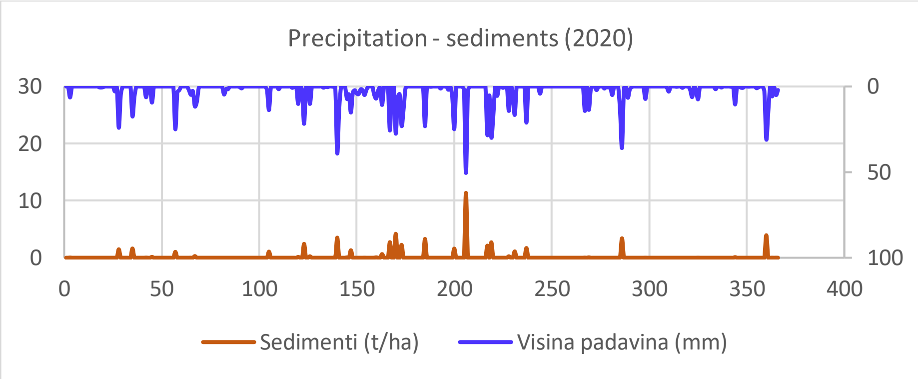

Figure 11. Diagram of precipitation and sediments in 2020

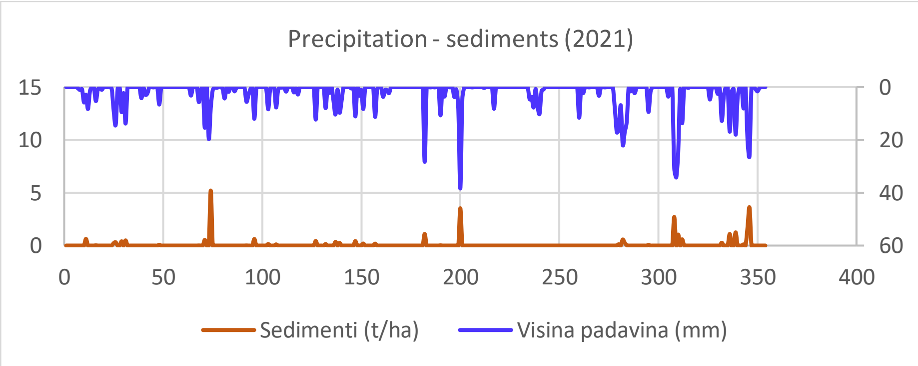

Figure 12. Diagram of precipitation and sediments in 2021

For the results obtained for the period 2014 - 2021, correlation and simple regression were performed, the relationship between precipitation and sediments (sediment), their mutual relationship shown through the Pearson coefficient R2. The stated Pearson coefficient R2 is tabulated for the period 2014-2021. [8].

Table 1. Tabular presentation of Pearson coefficient R2 for the period 2014-2021

Year	Average annual precipitation (mm)	Amount of sediment (deposit) t/ha	Pirson coefficient R^2
2014	1430,20	319,62	0,9527
2015	870,80	47,06	0,9348
2016	989,20	48,78	0,9248
2017	982,90	58,40	0,9593
2018	966,50	48,46	0,9369
2019	896,90	41,76	0,8643
2020	915,60	55,08	0,8935
2021	814,00	28,89	0,7366

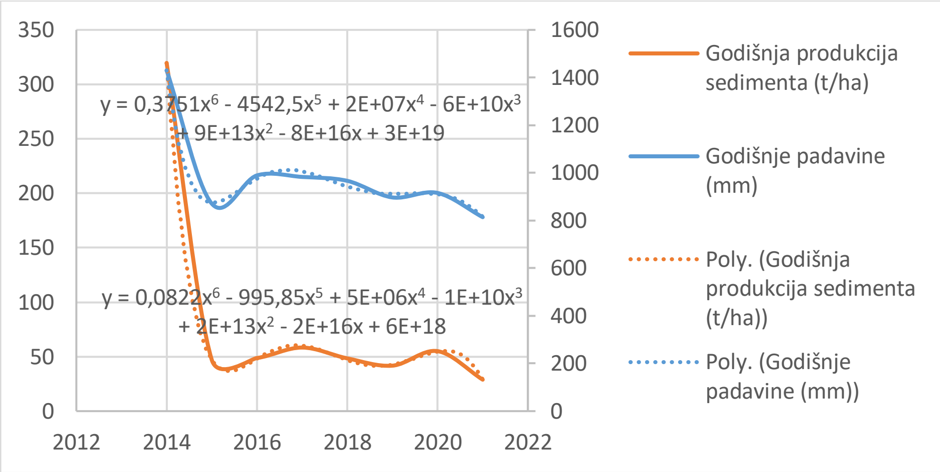

Figure 13. Diagram of precipitation and sediments (annual values) for the period 2014 - 2021.

4. ANALYSIS OF EROSION CHARACTERISTICS OF THE RIVER BASIN AREA

The influence of the erosion characteristics of the catchment area on the filling of a multipurpose reservoir depends on several key factors, including the intensity and annual frequency of erosion, as well as the specifics of the relief and position of the reservoir system. Erosion leads to the transport of sediment from the upper parts of the catchment area to the reservoir, which causes its filling process and a decrease in functional capacity. In order to take preventive action and prevent erosion, it is necessary to analyze and determine with sufficient precision the erosion coefficient of the catchment area in question. If the erosion coefficient is known, other parameters can be managed more easily and the actual situation on the ground can be improved. [9].

In practice, the formula of S. Gavrilović is often used for this method of calculation [10]:

$$W_{god} = T \times H_{god} \times \pi \times \sqrt{Z^3} \times A \qquad (3)$$

where are:

W_{god} – the total amount of production of erosion sediment (m^3/god)
T – area temperature coefficient (°C)
H_{god} – average annual precipitation (mm)
Z – basin erosion coefficient
A – catchment area (square kilometer)

If the most unfavorable case is taken in order to determine the maximum force of erosion processes in the basin of the Modrac reservoir, for the year 2014, with the temperature coefficient T=1.07 (4), the result of the erosion coefficient is obtained, which is Z=0.84 [9].
The temperature coefficient is calculated according to the formula [9]:

$$T = \sqrt{\frac{t_0}{10}} + 0.10 \qquad (4)$$

where is:
t_0 – average annual air temperature (°C)

CONCLUSION

This paper presents the modeling of the catchment area of the "Modrac" reservoir with GIS tools. In relation to the input data, the value of the daily amount of sediments (sediment) introduced into the reservoir "Modrac" was obtained. The correlation and regression value of precipitation as an input data and the amount of sediment as a result of this analysis, the Piroson coefficient R2, which describes their mutual connection, is given. It is important to point out that the R2 coefficient for the year 2014 is 0.9527, which is a very large positive relationship, as well as for the following years in the given period. The largest Pearson coefficient was read in 2017 and is 0.9593, and the smallest in 2021, which is 0.7366 (Table 1).
The diagram shown in Figure 13 shows the annual values of precipitation and sediment production in the Modrac reservoir basin for the period 2014-2021. The curves of the listed annual values are described by the following polynomials that most closely describe the given curve:

- annual precipitation $y = 0.3751x^6 - 4542.5x^5 + 2*10^7x^4 – 6*10^{10}x^3 + 9*10^{13}x^2 – 8*10^{16}x + 3*10^{19}$,
- annual sediment production $y = 0.0822x^6 - 995.85x^5 + 5*10^6x^4 - 10^{10}x^3 + 2*10^{13}x^2 – 2*10^{16}x + 6*10^{18}$.

Also, the goal of this work is to analyze and sufficiently accurately determine the erosion coefficient of the catchment area of the Modrac reservoir, using the available input data, and ultimately, on the basis of it, define the ranking of the catchment's vulnerability to erosion processes. Given that, according to literature data, the erosion coefficient ranges from 0.1 to 1.50, it can be concluded that the Modrac reservoir basin belongs to the basins that are moderately susceptible to erosion, and thus to the production and transfer of sediments into it.
The stated theoretical propositions highlight the complex connection between erosion processes in the watershed and the filling of the multi-purpose reservoir, which requires an integrated approach in the planning and protection of this ecosystem. [11].

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