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FOREST REVIEW

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SOIL EROSION RATES IN TWO SUCCESSIVE RESERVOIR CATCHMENTS: SPILJE AND GLOBOCICA RESERVOIR, MACEDONIA

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ABSTRACT: The catchments of the reservoirs Spilje and Globocica are positioned in the western part of Macedonia. This part is known for the more than average rainfall (800-900 mm/annually) for the country and large portion of the catchment is consisted of forests and natural grasslands. In the past, this region had been a huge economic centre. As a part of the process of migration, many of the mountainous regions of Macedonia have been practically deserted. This had a huge effect on the environment and it largely diminished the human impact. The catchment of the reservoir Globocica is beginning from the outflow of the river Drim from the Ohrid Lake. The main water source for this reservoir is the river Drim and some minor tributaries. The catchment of the Spilje reservoir is beginning from the Globocica dam, continuing the flow of the Drim River and also form north the second main tributary is Radika River. The two catchments were mapped for erosion according to the Erosion Potential Method (EPM) by Gavrilovic. The two erosion maps created for the two reservoir catchments show very different results. The catchment of the reservoir Globocica is one of the most preserved catchments from soil erosion point of view with average erosion coefficient (Z) of 0.29, specific annual production of erosive sediment is 394 $m^3km^{-2}yr^{-1}$., and the specific annual transport of erosive sediment is $247m^3km^{-2}yr^{-1}$. On the other hand the catchment of the reservoir Spilje is one of the most erosive areas in the country, with average erosion coefficient (z) of 0.44, specific annual production of erosive sediment is *776* m^3/km^2/ann., and the specific annual transport of erosive sediment is *541* m^3/km^2/ann.
Keywords: Soil erosion, erosion rate, EPM, reservoir sedimentation

1 INTRODUCTION

Erosion phenomena and processes in the catchment areas and torrential activity in riverbeds cause endangerment and destruction of hydropower and irrigation facilities and systems, settlements, roads, water supply facilities, industrial facilities and large areas of productive lands (Trendafilov et al, 2014).

Reservoirs are designed to operate for a limited amount of time, but often their lifespans are reduced by sedimentation. Despite the designed life, reservoirs realistically have a project life defined as the period during which the reservoir can reliably serve the purposes it was originally constructed for. Reaching of the project life, the failure to meet designed needs occurs typically before half of the storage volume of the reservoir is reduced from sedimentation. The storage capacity, or reservoir yield, is expressed"as a function of available storage volume in the conservation pool" (Nikitina, 2011).

Reservoir sedimentation is a serious consequence of soil erosion with large environmental and economic implications. On the other hand, reservoir sedimentation also provides valuable information on erosion problems and sediment transport within a drainage basin. A reservoir can be considered as a large scale experiment, as the outlet of a giant erosion plot (Verstraeten and Poesen, 2000).

The main purpose of sedimentation surveys in reservoirs is to "determine the volume and weight of sediment accumulated between surveys, or during the recorded period of storage" (Hall, 2010). The information provided by a survey of this type can be used to approximate sediment yields, assess sediment damages, and predict reservoir storage life expectancies. Siltation of the reservoir and other factors continue to create water quantity and quality problems that affect the many uses of the reservoirs in general like providing potable water, flood control, recreation, irrigation, production of electricity, etc. Solving this problem is an enormous challenge that requires gathering crucial information about the state of the reservoir. Bathymetric mapping and reservoir assessment are becoming particularly important. These data are vital in creating and analysing protective sedimentation measures in watersheds.

During the last fifty years in the country there were built 23 dams and large reservoirs and around 120 small reservoirs in order to ensure sustainable use of existing hydrological potential, managing the water and sediment regime and providing water for various purposes. Existing reservoirs have great contribution in improving and regulating the water regime and sediment, but still the country is very far from a state of full regulation and control of the hydrological potential.

As a consequence of the erosion phenomena and processes in watersheds and torrential activity in the riverbeds, the annual mean sedimentation in the existing reservoirs in the country, without the reservoirs "Lisice", "Kozjak" and "Zletovica" is approximately $3,5x10^6m^3$ erosive sediment (Trendafilov A., 2004). Filling up the reservoirs with erosive sediment is natural process but also is an anthropogenic process, and depending on the erosion potential in the watershed it limits the lifespan of the reservoir to a greater or lesser extent.

1.1 Monitoring of the filling up of the reservoir with erosive sediment

Given the great importance of reservoirs for the overall development of RM, after their construction, they were constantly monitored for sedimentation.

The main purpose of measuring the volume of deposited sediment in the reservoir is establishing the relationship between the erosion in the watershed and filling the reservoirs with sediment. Based on data for specific transport of sediment (m^3/km^2/year, m^3/ha/year, t/ha/year) and the structure of the erosion processes in the watershed, erosion measures and works are planned in order to reduce the erosion rate in the catchment and to prolong the lifespan of the reservoir (Trendafilov A., 2001).

Based on previous findings, knowledge and experiences derived from the implementation of the EPM (Erosion Potential Method) of S. Gavrilovic it is deemed the most adequate for the country. The model was used for calculation of the average annual production and measured data for deposed sediment in all the reservoirs in the country, and abroad (Mincev, 2015a, b; Spalevic V. et al., 2015

Hydropower facilities and systems, primarily reservoirs are of great importance not only for the power system, but also for the viability, sustainability and improvement of the environment. The longevity, sustainability, profitability of each hydropower system, including hydropower systems Globocica, Spilje Mavrovo, Tikves, Matka, Kozjak, Sv. Petka and others managed by the electrical company ELEM, depends not only on technical and technological level of the plant and sustainability and improving and upgrading of the equipment and facilities of the power plant, but primarily from the water regime and erosion potential / intensity in the watershed and the regime of sedimentation in the reservoir. This means that the disposition of the safest and most modern hydropower plant also does not mean lifelong, affordable and profitable hydropower system, especially if the accumulation is filled up with sediment at a rapid pace.

1.2 Reservoir sediment regime

In the world scientific literature, there are several methods for determining the erosive sediment regime which are primarily based on measured and analytically based values (Trendafilov A. et al., 2002; Blinkov&Kostadinov, 2010). The use of appropriate methodology is conditioned by the existing data about erosive sediment regime.

Various methods for erosion risk assessment are used by various countries in Europe. Generally, three types of approaches exist to identify areas at risk (Eckelmann et al., 2006): qualitative approach, quantitative approach, and model approach. All these methods vary in their characteristics and applicability. All already developed methods and approaches are improved in the recent period through use of GIS enabled technologies. The most spread erosion type in the East and Southeast Europe as well as in whole continent is water erosion (Blinkov & Kostadinov, 2010).

The difficulty in applying the physically-based erosion models to natural landscapes lies in the fact that sediment yield predictions are still widely based on very simple empirical models developed by multiple regression methods between morpho-climate parameters and limited measurements of sediment yield and/or sediment fluxes (Jansen and Painter, 1974; Ciccacci et al., 1980; Mulder and Syvitski, 1996; Poesen et al., 2003, Lazzari et al, 2015).

Reservoir sedimentation is a consequence of soil erosion with large environmental and economic implications. On the other hand, reservoir sedimentation also provides valuable information on erosion process and sediment transport within a drainage basin.

The aim of this paper was to determine the erosion potential of the catchment of the reservoir Spilje and Globochica and to determine the rate of the sediment transport and deposition in the reservoir in order to assess the lifespan of the reservoirs and its sustainability.

2 MATERIALS AND METHODS

2.1 Study area

The catchment areas of the reservoirs "Spilje" and "Globocica" are located in the western part of the Republic Macedonia, with an area of 3,941 km^2 and 301 km^2, respectively excluding the Ohrid Lake catchment.

The catchment area of the Spilje reservoir is constituted of two mayor catchment areas. The northern catchment is represented by the one of the most beautiful rivers in R. Macedonia: Radika River and the southern extends the catchment area of the river Crn Drim. Reservoir "Spilje-Dragozel" stretches east and south of the town of Debar, in its immediate and wider environment, an area of 13.20 km^2.The dam "Spilje" is located on the Crn Drim River, 3.5 km south of the town Debar, about 300m upstream of the Macedonian-Albanian border. The total storage of the reservoir is projected on $540x10^6 m^3$.

The main water source of the Globocica reservoir is the Drim River. The total storage of the reservoir is projected on $58x10^6 m^3$

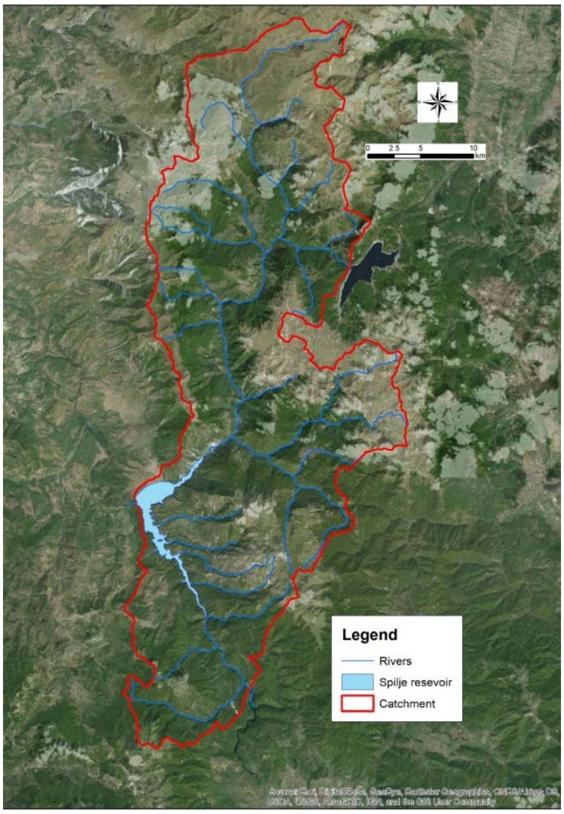

Figure 1: Catchment of the reservoir Spilje

2.2 Environmental conditions

The climate parameters, primarily air temperature, precipitation, wind, insolation, relative humidity and other parameters have a direct or indirect impact on the erosion potential.

Climatic characteristics of the catchment area of the reservoirs are strongly influenced by geographical location, orographic, biogeographic and hydrological conditions of the region. The lowest parts of the basins are affected by the sub-Mediterranean climate, hilly and upland areas are affected by moderate continental and mountainous climate and highland areas are affected by typical mountain climate. The average annual air temperature for the station Struga is 10.7°C and for Ohrid 11.1°C.

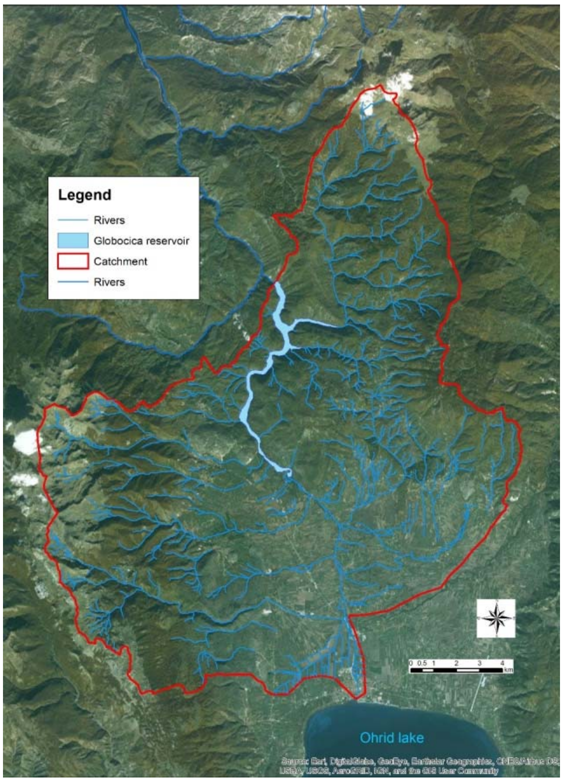

Figure 2: Catchment of the reservoir Globocica

The average annual temperature ranges between 6.9°C for Lazaropole to 7.0°C in Mavrovi Anovi for the period 1971-2000, respectively 4.9°C Popova Shapka to 7.3°C Lazaropole for the period 1981-2010. The pluviometric regime for the catchment of Crn Drim is based on the data for the stations Struga and Ohrid. The average annual rainfall sum is 788,5 mm for Struga, and 698,3mm for Ohrid. The most rainy months are: November, December and January and the driest months are: July and August. *(Source: Spatial plan for the Ohrid-Prespa region 2005-2020, Agency for spatial planning, Skopje, 2007).*

Within the analyzed period (1971-2000), the meteorological stations Mavrovi Anovi and Lazaropole the average annual rainfall amounts are ranging from 931.8 mm in Mavrovi Anovi to 1025.7 mm in Lazaropole.

For the period 1981-2010, the average annual precipitation sum for the analyzed stations Lazaropole and Popova Shapka, are ranging from 898.3 mm for Popova Shapka to 1057.1 mm for Lazaropole. On the higher mountain areas, the annual precipitation sum ranges from 700 to 900 mm and on the highest mountain tops, the annual precipitation sum reaches up to 1250 mm. (Source: Study for a revalorization of the protected area Mavrovo, 2011).

The catchment area of the reservoir "Spilje" has heterogeneous geological structure (Source: Engineering geological and basic geological map of the Republic of Macedonia, Geological Institute, Skopje, 1977). In the catchment area of the reservoir is dominated by the following geological formations: complex phyllites, metasand stones and conglomerates 24%, complex sandstones, clay, argiloshists and limestone 14% and 13% of limestone with chert, clay and massive limestones. The soils are formed and are evolving under the influence of the climate, geological substrate, living organisms and solar energy. As a result the soil forming factors in the catchment can be found the following soil types: brown forest soils (eutric and distric cambisols) 30%, rankers 28%; calcocambisols 12% and lithosols 10%.

The catchment area of the reservoir Globocica has similar geological and soil structure with some differences. Plate dolomite with chert, shale limestone and conglomerate 32%, alluvium 14%, sandstone, shale limestone and conglomerate 12%, marl clay, sands and gravel 11%, phyllite schists 8%, etc. The dominant soils are calcomelanosol 22%, brown forest soils (eutric and distric cambisols) 21%, complex of calcomelanosols, calcocambisols and dolomite 14% and molic fluvisols 11%.

From vegetation aspect can be concluded that the majority of the mountain ranges are covered with forest and grasslands. In the hilly and mountainous region, with the exception of the vicinity of the villages, it is dominated by forest vegetation, primarily of oak forests and beech or beech-fir forests and in the catchment of Adžina Reka, spruce forests. The upper limit of the forest is dominated by alpine and subalpine meadows, rocky and massive rock formations. In terms of erosion, the existing vegetation basically provides relatively good protection of the land from erosion. The worst situation is in the vicinity of the inhabited areas, where the land use is significantly affected by human.

From hidrographic-hydrological aspect, the catchment area of the river Crn Drim has developed hydrographic network and well balanced water regime, primarily due to the large hydro potential of the springs in "St.Naum". The mountain Jablanica is characterized by moderately to highly develop hydrographic network, which strongly influences the run-off and transport of the erosive sediment in the reservoirs "Globochica" and "Spilje". The catchment area of the river Radika has developed hydrographic network with streams characterized with pronounced mountain, subalpine and alpine features, with variable water regime and abundance of springs and surface water.

2.3 Erosion processes and phenomena

As a result of the great ecological diversity, characteristics and specifics of the erosion factors, especially climate, geology and soil, orography and vegetation in the catchment area of the reservoir "Spilje" it is dominated by phenomena and processes of water erosion from pluvial, fluvial and karstic type. The special characteristics of the Radika catchment is that in the subalpine and alpine zone of the mountain range Korab, are also present phenomena and processes of glacial and glacio-fluvial type.

Within the catchment area there are present almost all forms and types of water erosion. In the catchment of Radika there is the biggest landslide in RM in the vicinity of villages Rostushe, Bitushe and Vele Brdo. In mountain massifs built carbonates significant places have phenomena and processes of karst erosion: sipars, depressions, hollows, potholes, caves and other forms and types of karst erosion.

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Fluvial erosion is present in the catchment of Radika River, primarily along the river and along the tributaries: Crn Kamen, Adžina Reka, Nistovska-Ribnichka Reka, Zhirovnichka Reka, as well as direct tributaries of the reservoir: Papradnichka Reka, Breshtanska Reka, Kodzhadzhishka Reka, Dolgashka Reka, Trebishka Reka, Piskupshtinska Reka and other alpine and mountain streams. This type of erosion takes place in riverbeds, and is caused by kinetic-erosive power of the discharge and is the source of large quantities of erosive sediment.

Figure 3: Phenomena and processes of erosion in the catchment of the reservoir Spilje

Figure 4: Phenomena and processes of sedimentation of in the catchment of the reservoir Spilje

Phenomena and processes of deposition-sedimentation is a natural phenomenon which occurs as a result of the relationship between erosive potential of the catchment and the kinetic-transport capacity of the streams. Basically, their extent, characteristics, intensity primarily depend on the state of the erosion in the catchment and hydrographic, hydrological and hydraulic characteristics of the catchment and the watercourses. The process of sedimentation starts in the highest parts of the basin and stream bed, where the largest fractions are deposited, while the smallest factions are deposited in the final recipient or in the case of this study, in the reservoir. In mountainous, and even more in the alpine, subalpine - alpine sections of the streams, the conditions and for retaining sediment are minimal, practically non-existent.

Almost the entire sediment of some streams is transported through the hydrographic network to the final recipient: Radika, Crn Drim and direct tributaries of the reservoir and are deposited in the lowest section of the rivers (Boškov Most and village Dolno Kosovrasti) and Debar Lake and Globocica Lake. On the other hand, the rivers Breshtanska, Trebishka and the most dominant of all others is Dolgashka River bring large quantities of erosive sediment material, mostly minor fractions: dust, clay, sand, gravel and are directly transported and deposited in the reservoir.

2.4 Erosion Potential Method (EPM)

At the moment, there are several methods used for estimating erosion on site and on catchment level. Blinkov and Kostadinov (2010) in their paper stress the good and bad sides of several models for estimation of erosion: EUROSEM, USLE, PESERA, KINEROS, WEP, WEPP and EPM. Several of these methods are able to model erosion from different point of view. Only few deal with transport and deposition of the sediment: EUROSEM, WEPP and EPM.

EPM was chosen to be used in the study because it has the unique trait that was developed in the Balkan region, south Serbia which is very similar in climatic conditions with Macedonia, secondly the ability to predict sediment transport and deposition was developed with calibration of deposited sediment in the existing reservoirs and also the data produced about the erosion potential in Macedonia was developed with the EPM, so the results would be comparable and the methodology would be transferable (Mincev, 2015b; Blinkov&Kostadinov, 2010).

There are several papers explaining the EPM model (see Mincev and Blinkov, 2007) and only shortly will be explained what kind of data was used in the process.

3 RESULTS AND DISCUSSION

3.1 Spilje

In the catchment of the reservoir "Spilje" the dominant type of erosion is IV erosion category on area of 45,674.76 ha, respectively (43.4 %) of the total area of the catchment. The second is III erosion category with an area of 23,027.05 ha, respectively (21.9%) of the total area. The third category by area is the V erosion category, represented with area of 17,547.07 ha, respectively (16.7%) of the total catchment area.

It is concerning that extremely strong phenomena and processes of erosion are present in large areas compared to the total area of the catchment Spilje. The strongest or the most extreme phenomena and processes of erosion (I category) represented an area of 8894.94 ha, respectively (8.4%) of the total area of the catchment, and the phenomena and processes of II category of erosion is prevalent on the area of 8653.58 ha, respectively (8.2%) of the total catchment area. The two strongest categories of erosion (I and II category) cover 16.6% of the total catchment area, which is a high percentage. If these two categories are combined with the III category of erosion, then the total percentage will be 38.5%. So it can be concluded that more than 1/3 of the catchment should be subject to erosion mitigation and remediation measures. These categories are most common in the catchment areas of rivers Breshtanska Reka, Kodzhadzhishka Reka, Dolgashka Reka and Trebishka Reka.

The immediate catchment of the reservoir has the strongest erosion processes together with the highest specific production of erosive material (m^3/km^2/year) and specific transport of erosive sediment (m^3/km^2/year).

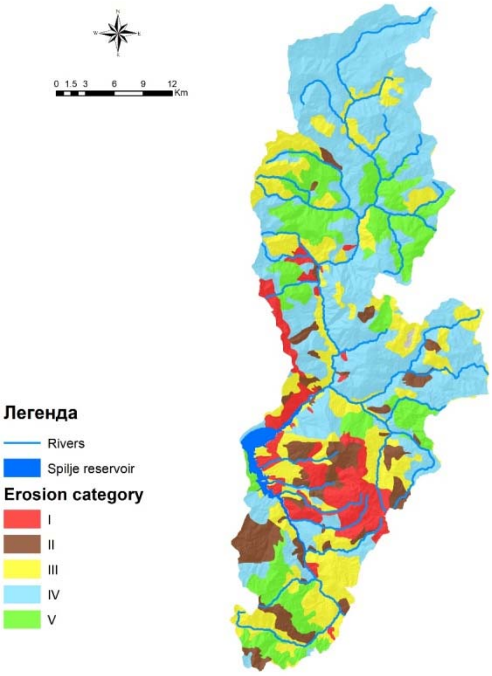

Figure 5: Structure of the erosion by categories in the catchment of Spilje

The largest total mean annual production of erosive material (W) has the catchment Radika 394.041 m^3/year and total mean annual transport of sediment (G) is 275.318 m^3/year. The second is the immediate catchment with total mean annual production 347.352 m^3/year and total mean annual transport of sediment 312.473 m^3/year in particular: Dolgashka, Kodzhadzhichka, Breshtanska, Papradnichka and other major and smaller streams and torrential series which are formed and run in depressive relief forms of Stogovo Mountain. With the lowest mean annual production (100.405 m^3/year) and mean annual transfer of sediment (78.094 m^3/year) is the catchment area of the river Crn Drim.

When the separate streams are observed then the largest total annual production of erosive material of 67.087 m^3/year and the highest total mean transport of sediment of 66.415 m^3/year is Breshtanska Reka (catchment area of 24,76 km^2). Second in line is Dolgashka Reka with a total annual production of erosive material of 53.784 m^3/year) and total mean transport of sediment of 52.248 m^3/year with a catchment area of 20,07 km^2.

The intensity - potential erosion in the catchment areas of the rivers is easily determined by the specific mean annual production of erosive material and specific mean annual transport of sediment.

The largest value for the specific mean annual production of erosive material is Kodzhadzhichka Reka with 3.996 m^3/km^2/year and mean specific transport of erosive sediment of 3.547 m^3/km^2/year. Followed by: Breshtanska Reka with a specific mean annual production of erosive material of 2.709 m^3/km^2/year and mean specific transport of erosive sediment of 2.682 m^3/km^2/year, then Dolgashka Reka with specific mean annual production of erosive material of 2.679 m^3/km^2/year and mean specific transport of erosive sediment of 2.603 m^3/km^2/year, Papradnichka Reka with a specific mean annual production of erosive material of 2.183 m^3/km^2/year and mean specific transport of erosive sediment of 2.039 m^3/km^2/year.

3.2 Globocica

In the catchment of the reservoir "Globocica" the dominant type of erosion is IV erosion category on area of 12,586.1 ha, respectively (41.7 %) of the total area of the catchment. The second is V erosion category with an area of 10,285.7 ha, respectively (34.1%) of the total area. The third category by area is the III erosion category, represented with area of 6,687 ha, respectively (22.2%) of the total catchment area. The first two categories are only 1.2% of the total area.

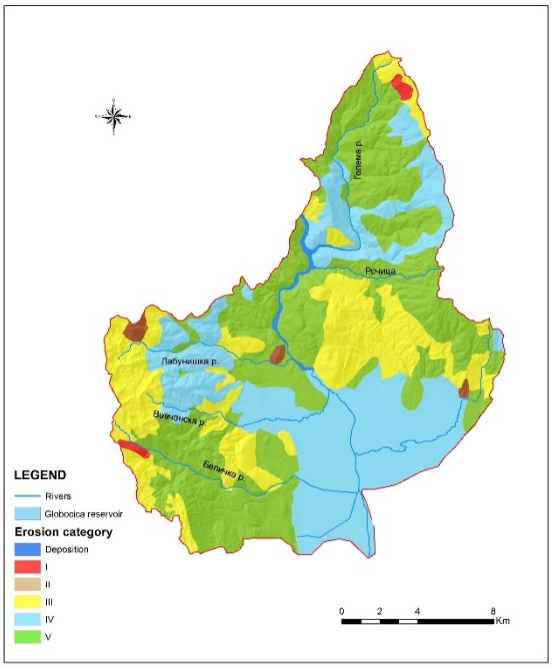

Figure 6: Structure of the erosion by categories in the catchment of Globocica

When comparing the total amount of produced and transported sediment the immediate catchment of the reservoir and the catchment of the Drim River have similar values. The produced sediment is higher of the catchment of the Drim River, 54% vs. 46% of the area. On the other hand the total transported sediment to the reservoir is slightly higher in the immediate catchment, 53% vs. 47%.

Separately, the highest transporters of sediment per unit area is coming from the catchment of Labunishka Reka 479 m^3/km^2/year. Also, other rivers with high transport values are Rechica and Golema Reka, 300 and 278 m^3/km^2/year, respectively.

4 CONCLUSIONS

According to the current situation in certain parts of the basin, primarily due to unfavourable environmental conditions, it cannot be expected that without the support of the human, nature will be able to establish the expected balance, primarily in the immediate catchment area of the reservoir Spilje, where the intensity of erosion is extremely large.

In catchment area affected by mildly strong, strong

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and extremely strong phenomena and processes of erosion, inevitably it is required planning and undertaking appropriate erosion mitigation activities. All these activities should be aimed at reducing the severity of erosion, reduction of the erosive material production and transport. The results of the mitigation activities are aimed at reducing the dynamics of sedimentation in the reservoir, extending the life of the reservoir and a sustainable, cost-effective planning and utilization of the hydropower potential of the available water from the catchment of the reservoir Spilje.

On the other hand, the catchment of the reservoir Globocica has much milder erosion processes. It can be concluded that the situation is much better. This is mainly due to lower or in some cases non-existent human impact.

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