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CONSIDERATIONS ON RESERVOIR SEDIMENTATION AND HEAVY METALS CONTENT WITHIN THE DRENOVA RESERVOIR (B&H)

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Abstract: Reservoir sedimentation is a serious problem in many areas with high sediment yield. The main objective of this research is to analyse the storage capacity of Drenova reservoir and to determine the quality of water and sediment, particularly the content of heavy metals. Integrated GPS system and echo-sounder were used during the bathymetric survey in order to estimate sediment deposition in Drenova reservoir. The 2012 current state Digital Elevation Model (DEM) was compared to the preconstruction state DEM, which was compiled from geodetic bases and project documentation, thus enabling determination of all changes in the storage of Drenova reservoir. The results of this comparison showed that in the past 30 years, the storage capacity of Drenova reservoir decreased by 262,963 m^3 and 274,342 m^3 based on the normal and maximum water level. Drenova accumulation area is covered with 348,216 m^3 of sediment, which decreased the ineffective space by 69.64% and the total operational space by 5.81%. Water analysis of Drenova reservoir showed usual physical chemical parameters for these types of reservoirs and that it corresponds to maximum allowable concentration for the II class water level. The enrichment factor for metal concentrations showed that the anthropogenic influence is moderate for Ni and As, while it is minor for Cr, Cd, Mn, Zn and Cu, and it indicates no enrichment for Pb. The obtained results not only enabled defining potential locations for sediment desilting and its proper disposal in the basin, but led to consideration of other possibilities regarding duration span of Drenova reservoir.

Key words: Bathymetric surveys, Drenova accumulation, enrichment factor, heavy metals, sediment deposition.

1. INTRODUCTION

Reservoir sedimentation is a serious off-site consequence of soil erosion (Lal, 1990; Tošić et al., 2011; Tošić et al., 2012a). In particular, it leads to large water management and environmental consequences (Hansen et al., 1996; Morris & Fan, 1999; Tošić et al., 2012b; Tošić et al., 2012c). Reservoirs around the world are losing on average about 1% of their storage capacity annually (WCD, 2000). This increases sediment storage behind dams causing serious problems for water supply and flood control, changes in water and sediment quality, ecosystem development up-and downstream of dams. Furthermore, it can also have large implications for coastal geomorphic processes (Morris & Fan, 1999; WCD, 2000).

Deposited sediments are comprised of different components of mineral and organic origin transported through river basin and present a reservoir of trace elements from different parts of a basin (Ghrefat & Yusuf, 2006), but also an important indicator of aquatic environment pollution (Gong et al., 2008). Dynamic distribution of trace elements between the phase of sedimentation and water (Hansen et al., 1996) is regulated by complex physical, biochemical and microbiological processes.

The mineral material removed from water reservoirs is often utilized for agricultural purposes or for earth work in the catchment area. Such utilization of chemically uncontrolled bottom sediments is connected with the risk of increasing the content of harmful substances-including heavy metals in the soil environment. Determination of the quantity of sediment pollution, including concentration of heavy metals, is not only essential for the estimation of utilization possibilities of the removed sediment, but may also be helpful in the evaluation of state of the environment (Dragićević et al., 2010; Wojtkowska, 2011; Boyacioglu, 2012).

Water reservoirs in rapidly eroding regions are the most vulnerable to sedimentation problems. With regard to quick reduction of reservoirs capacity, reservoirs are periodically desilted, namely after ten or more years, even decades. For these reasons, systematic capacity surveys of water reservoirs are usually carried out using the conventional equipment. The two most common conventional techniques for sedimentation quantification are: a) direct measurement of sediment deposition by bathymetric surveys, and b) indirect measurement by inflow-outflow survey method (Morris, & Fan, 1999; Furnans & Austin, 2008).

Water reservoirs in the area of Republic of Srpska-B&H, do not have sediment monitoring and are, therefore, usually subjected to bathymetric measurements. Recently, in the world we have many studies about reservoir sedimentation (Kress et al., 2005; Ceylan et al., 2011; Furnans & Austin, 2008) but, in the Republic of Srpska-B&H, it is the first case study on water reservoir in which earlier topographic data is compared with recent bathymetric data and is used to analyse the changes in the reservoir storage capacity.

According to project documentation, duration expectancy of Drenova reservoir is 30 years. Given the fact that it has been more than thirty years since this water management facility started accumulating, and also numerous problems that emerged in the last two years (the flood in June 2010 caused approximate material damage of 7.2 million, including downstream areas of the reservoir), it was necessary to analyse and define the possibilities of sustainable management of the reservoir. Therefore, the main objective of this research was to analyse the storage capacity of Drenova reservoir and to determine the quality of water and sediment (especially heavy metal contents). The obtained results not only enabled defining potential locations for sediment desilting and its proper disposal in the basin, but led to consideration of other possibilities regarding duration span of Drenova reservoir.

2. MATERIAL AND METHOD

2.1. Study area

The Drenova reservoir is located at 44°52'13'' N, and 17°31'13'', with elevation of 161 m above sea level (Fig. 1). The main purpose of the object built in 1978 was mitigation of flooding waves. However, due to the increase in water needs of the municipality of Prnjavor, the accumulation has been used for water supply as well. The Vijaka river is the main stream, by whose damming the Drenova accumulation was formed, with catchment area of 68.34 km^2. The average annual flow rate below dam is 1.72 m^3/s, and the average flow rate of the Vijaka river is 3.29 m^3/s.

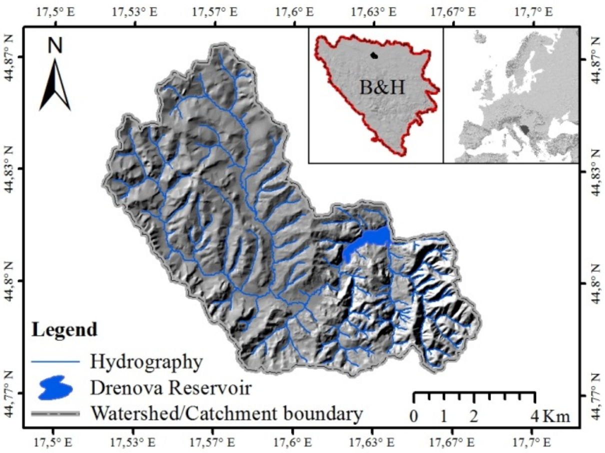

Figure 1. Location of study area - Drenova reservoir

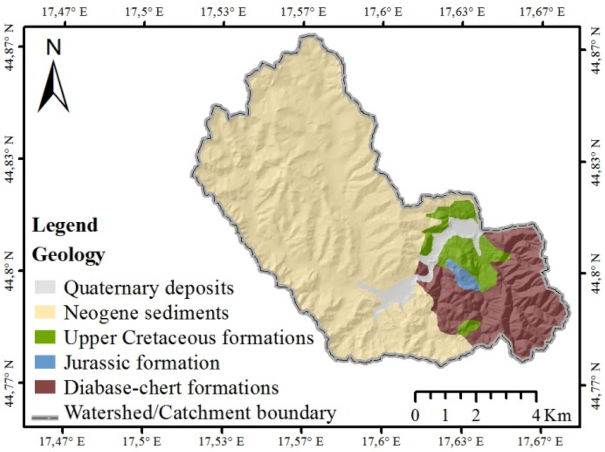

Figure 2. Geological map – Drenova catchment

Other tributaries of the accumulation are smaller, but only the Drenovica river has a significant role in terms of siltation of the accumulation. The composition and age of the geological structure of the catchment of the accumulation of Drenova are of the following nature: Jurassic formation, diabase-chert formations, Upper Cretaceous formations and Neogene sediments (Fig. 2). Based on the analysis of surface representation of certain lithologic members, it was found that 73% of the basin accumulation are neogene sediments, which is significant in terms of erosion processes and material import in the accumulation, and thus the siltation of the accumulation is of special importance (Tošić et al., 2012c).

Basic characteristics of the reservoir and dam: dam-reservoir Drenova; type of dam: stone layer with lofty concrete surface; type of spillway: overflow spillway; building height: 15 m; ground height: 13 m; crest length: 320 m; dam crest elevation: 174.00 m; normal water level elevation: 167.50 m; bottom elevation of the reservoir: 161.00 m; spillway elevation: 172.00 m; torque tube: 163.80 m; shaft spillway elevation: 167.50 m; reservoir capacity at spillway level: 5,984,699 m^3; reservoir capacity at normal backwater: 2,460,301 m^3; dead storage (ineffective space): 500,000 m^3; surface at normal backwater: 731,643 m^2; surface at maximum backwater: 796,402 m^2; normal water level 689,640 m^2 (Hrkalović & Barbalić, 1978).

2.2. Survey Methodology

Reservoir sedimentation surveys require a combination of bathymetric and topographic methods. Bathymetric method is performed to determine the underwater topography, while topographic method is employed to map the area above the water level (Furnans & Austin, 2008).

Bathymetric survey of a reservoir, conducted by using integrated GPS system and echo-sounder, is a possibility of performing measurements of sediments depositions. The recording is performed by a three frequency RTK (Real Time Kinematic) GPS receiver and by one or dual frequency echo sounder. With respect to technological advances in the field of GPS measurements and ultrasonic depth measuring devices, the process of integration by surveying and real-time data processing became more distinct, which found its usage in this case study as well (Kress et al., 2005; Furnans & Austin, 2008). The case study includes GSR2700ISX SOKKIA GNSS; ECHO SOUNDAR: SonarMite BT, "Ohmex" (240kHz) and a rubber raft Maestral (type 11.2).

Verification of measured permanent geodetic points and determination of altitude points of the immediate surroundings of Drenova reservoir preceded bathymetric survey. Upon completion of the geodetic points control and base station setup, the control of water depth was performed in several different places by a telescopic rod, Secchi disk and echo sounder. By using previously mentioned methods, the control showed the measured depths variation from ± 0.05 to ± 0.1 m, thus achieving a satisfactory level of precision.

Bathymetric measurements on the reservoir Drenova were conducted in May, 2012, over cross-sections with pre-designed range of 10 m. The base of GPS-RTK device was set on a defined geodetic point while a recorder (Allegro) was set and attached to the right side of the rubber raft. The recorder (Allegro) simultaneously receives data from the GPS device and echo sounder, displaying a three-dimensional figure on the basis of previous adjustments of the device. Upon completion, the data from Allegro are exported as .csv text file format containing information about the number of measurement points, y-coordinates, x-coordinates and z coordinates for depth.

Special attention is devoted to controlling completed bathymetric surveys through both independent bathymetric surveys and Drenova reservoir length surveys, thus providing intersection points of cross-section directions of surveying and points of length surveying-the survey direction. According to the analysis, the results of bathymetric survey correspond to the acceptable accuracy system of bathymetric survey, and are fully acceptable for further processing and digital modelling of the reservoir.

Collected data were processed using AutoCad Civil 3D and ArcInfo 10. The points gathered during bathymetric survey demanded previous quality control because of errors shown on certain points during the measurement. Upon completion of data filtering, we approached to the conversion of TIN model data to digital elevation model (DEM) – GRID data, raster data of Drenova reservoir and immediate surrounding preconstruction and current state.

Several methods of interpolation were tested while developing a digital elevation model (DEM) of Drenova reservoir and immediate surrounding using a software package ArcInfo 10, whereas, the universal kriging method was used while developing the final elevation model (DEM) for both current and preconstruction state (Medved et al., 2010).

Applying the universal kriging method of interpolation, we developed a digital elevation model (DEM) of 5x5 meter resolution of the current and preconstruction state. Upon completion of DEM preconstruction survey and DEM current survey, the shown difference between the two surveys was used for sediment volume calculations. The preconstruction survey was used to produce a preconstruction Digital Elevation Model (DEM) of the area near Drenova reservoir from 1978. The preconstruction data for this DEM were taken from geodetic bases and project documentation. Current bathymetric and topographic survey together with GIS was used to produce a Digital Elevation Model (DEM) of Drenova reservoir in the current state. In addition to the bathymetric survey of Drenova reservoir, geodetic survey was performed within the normal backwater of 167.50 m, maximum backwater of 172.00 m, current position of the shoreline and position of the crest and spillway.

There are several methods for computing volumes of sediment, especially the one based on range. This case study was based on both current and preconstruction state digital elevation models (DEM) used for creating cross-sections, namely 256 cross-sections with a range of 10 m. The sediment volume was computed by the average end-area method (Morris & Fan, 1999; Furnans & Austin, 2008):

$$V = \frac{L(E_1 + E_2)}{2} \tag{1}$$

Where: L - length between ranges E_1 and E_2 is the cross-sectional end-area of the ranges bounding the downstream and upstream limits of the reach. In order to determine total sediment volume of the reservoir Drenova, it was necessary to calculate the volume of each segment (V) according to the pattern (Morris & Fun, 1999; Furnans & Austin, 2008):

$$\Sigma V = V_1 + V_2 + V_3 + ... + V_n \tag{2}$$

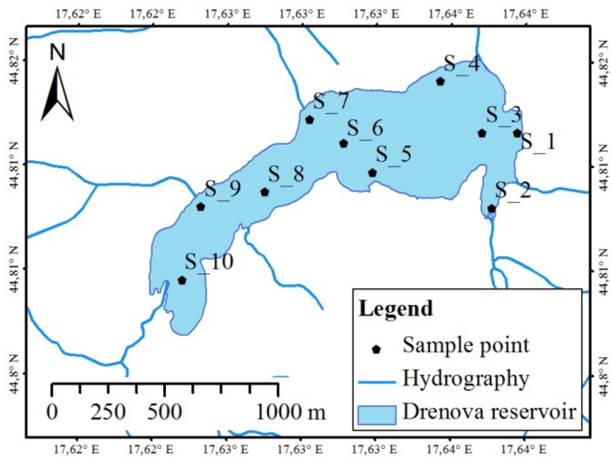

Figure 3. Locations of water and sediment sampling-Drenova reservoir

2.2.1. Water and sediment sample collection and pre-treatment

Surface water samples were collected in PVC bottles from ten different locations in the water reservoir (Fig. 3); samplers were stored in a cold-box and then transferred to a laboratory. Additionally, at the same locations upon completion of sampling on June 3, 2012, sediment samples were taken from the sediment surface layer. The Bridge-Ekman grab sediment sampler was used for collecting surface sediment down to 15 cm.

Importantly, the grab sampler should protect the sample from disturbance, minimize washout and allow easy access to the surface layer by lifting movable cover flaps (Simpson et al., 2005). Sediment samples were put in a plastic bag to prevent any oxidation reaction of sediments and were placed in an icebox until analysis. All samples were analysed three times, and results are given as mean values.

The water and sediment samples contain trace elements (e.g. Fe, Mn, Cr, Pb, Cd, As, Cu, Zn, and Ni), which have been determined after oxidation in the solution. The content was determined by atomic absorption spectrophotometry (AAS), flame and graphite furnace technique on Varian AA1275 GTA95. Reference methods used for the determination of trace elements: Fe (EPA M 236.1) Mn (EPA M 243.1) Cr-total (EPA M 218.1) Pb (EPA M 239.2) Cd (EPA M 213.2) As (EPA M 206.2), Cu (EPA 220.1 M), Zn (EPA 289.1 M), Ni (EPA 249.2 M). In addition to trace elements, the analysed water samples showed the fundamental physical-chemical parameters: pH (SRPS H.Z1.111), BOD5 (SRPS EN 1899-1), ammonium ion (SRPS H.Z1.184), nitrates (Stand. Met. 4110B), nitrites (Stand. Met. 4110B), sulfates (Stand. Met. 4110B), chlorides (standard Met. 4110B), orthophosphates (Stand. Met. 4110B), total phosphorus (SRPS EN 6878). All analyses were conducted according to the certified reference material.

2.2.2. Methods for estimating pollution impact

The geo-accumulation index (Igeo) of Muller (1969) was used to determine the intensity of metal pollution. The index is defined as:

$$I_{geo} = \log_2\left(\frac{Cn}{1.5 \cdot Bn}\right) \tag{3}$$

Where: Cn - the measured concentration of the examined metal ‘n’ in the sediment; Bn - the background concentration of the metal ‘n’; Factor 1.5 is the background matrix correction factor due to lithogenic effect.

Baseline values in average crustal material according to Taylor (1964): 1.8 $mgkg^{-1}$ for As, 0.2 $mgkg^{-1}$ for Cd, 12.5 $mgkg^{-1}$ for Pb, 70 $mgkg^{-1}$ for Zn, and crustal material according to Taylor & McLennan (1981): 3.6 % for Fe, 71 $mgkg^{-1}$ for Cr, 32 $mgkg^{-1}$ for Cu, 720 $mgkg^{-1}$ for Mn and, 49 $mgkg^{-1}$ for Ni. The geo-accumulation index scale consists of seven grades or classes: <0 - unpolluted; 0-1 unpolluted to moderately polluted; 1-2 moderately polluted; 2-3 moderately to strongly polluted; 3-4 strongly polluted; 4-5 strongly to very strongly polluted, and >5 - very strongly polluted.

2.2.3. Enrichment factor

Assessment of anthropogenic influence on deposited sediments is calculated by a normalized enrichment factor (EF) for uncontaminated metal concentrations above background levels (Salomons & Förstner, 1984; Abrahim & Parker, 2008). The EF is calculated according to the following equation:

$$EF = \frac{(M_x / Fe)_{sample}}{(M_b / Fe)_{crust}} \quad (4)$$

Where: M_x - the sediment sample concentrations of the heavy metal and Fe (normalizing element), while M_b - the sediment sample concentrations in a suitable baseline reference material (Salomons & Förstner, 1984). According to the assessment criteria proposed by Birch (2003), if the EF < 1 indicates no enrichment, < 3 is minor; 3-5 is moderate; 5-10 is moderately severe; 10-25 is severe; 25-50 is very severe, and > 50 is extremely severe (Amin et al., 2009). Statistical analyses were performed using the SPSS software (version 16). The significance of their correlations was analysed via the Pearson correlation matrix (SPSS, 2007).

3. RESULTS AND DISCUSIONS

After the construction of Drenova reservoir, the monitoring of sediment was not established and the repeated reservoir capacity surveys to determine the total volume occupied by the sediment were not performed. For that reason, this case study was based on the state analysis, namely the analysis of the year 1978 - preconstruction state and of the year 2012 - the current state.

Digital elevation model of the preconstruction state 1978 was carried out with reference to the project documentation, geodetic bases with the range of 1:2500 and topographic data (Fig. 4). This model included the maximum water level area-elevation of spillway (172 m) that was flooded after the obstruction of Vijaka river and the construction of Drenova dam in the previous period which led to sediment accumulation inside of it. Therefore, the obstruction of the river flow led to the artificial creation of area suitable for sediment accumulation delivered by the Vijaka river or at the confluence with its tributaries around Drenova reservoir, and also due to shoreline erosion.

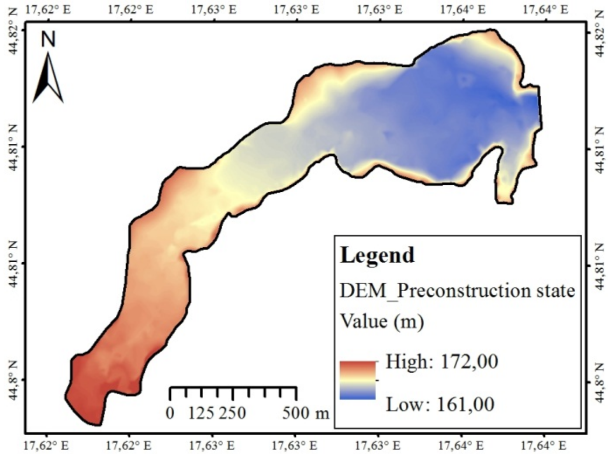

Figure 4. Digital elevation model (DEM) of Drenova reservoir from 1978 - preconstruction state

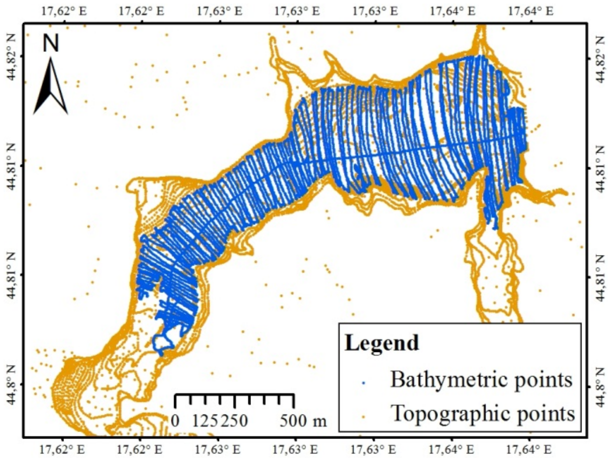

Figure 5. Location of bathymetric and topographic survey points in Drenova reservoir and the accumulation area.

Geodetic survey of the reservoir within the maximum water level and the survey of shoreline current state, dam crest state and shaft spillway state all preceded the bathymetric survey of Drenova reservoir. The above mentioned geodetic surveys had in view field data collecting, which alongside with the preconstruction state bases enable creation of the current state digital model of Drenova reservoir at the maximum water level suitable for geodetic surveys considering its current water level. During the bathymetric survey of Drenova reservoir, 11,053 points containing information about the position and depth were gathered. The bathymetric survey was performed on the underwater part of the reservoir appropriate for rubber raft and the usage of echo sounder (Fig. 5). The other part of the reservoir, namely the one within the maximum water level, was surveyed with a more conventional method-a classical geodetic survey. Digital elevation model (DEM) of the current state from the year 2012 was created using the described methodology for digital elevation model along with the data of bathymetric survey and the ones from geodetic survey of the part of the reservoir which was not currently under water (Fig. 6).

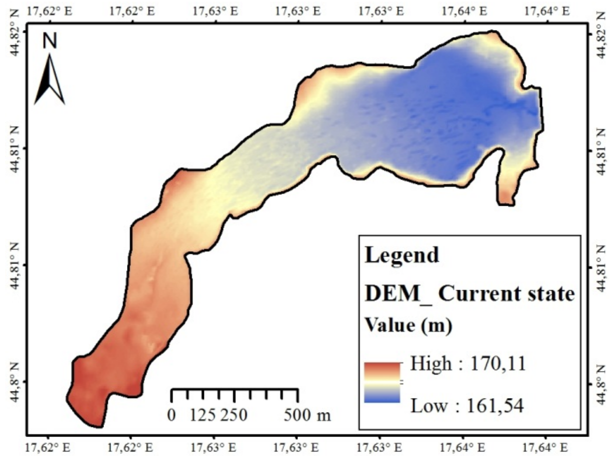

Figure 6. Digital elevation model (DEM) of Drenova reservoir from 2012 - current state

The analysis of the digital elevation models (DEM) of the preconstruction state from the year 1978 indicated that the underwater space with the normal water level was 731,646 m^2 and that the capacity of Drenova reservoir at normal water level elevation of the reservoir was 2,460,301 m^3. The underwater area at the maximum water level, according to preconstruction state of the year 1978, was 796,402 m^2, and the capacity of Drenova reservoir at maximum water elevation of the reservoir was 5,984,699 m^3.

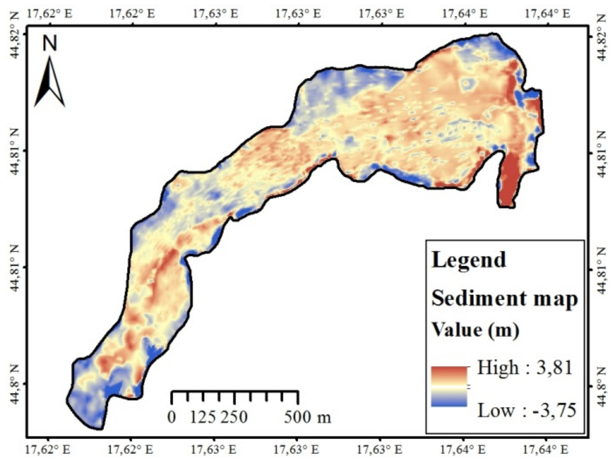

Figure 7. Sediment distribution in the Drenova reservoir

From the comparison of these two digital models of the accumulation area, preconstruction and the current state model, we obtained the sediment maps (Fig. 7). They indicate the spatial distribution of the sediment in the accumulation area, the sediment thickness (the layer of sediment allocated in the accumulation area), the spatial arrangement of the accumulation surfaces resulted from intensive shoreline erosion, and the surfaces with abundant sediment accumulation associated to the Vijaka river and its tributaries.

By analysing the sediment distribution maps, it is obvious that the accumulation area of Drenova reservoir has uniform longitudinal deposit geometry. The average sediment thickness was 43 cm, the highest sediment thickness computed immediately of the dam up to 3.81 m, while large amounts of sediment were removed during the process of shoreline erosion, and the negative values up to -3.75 m were expressed on the sediment maps at these places. These values can also be monitored at the places where the old riverbed is not covered with sediment. For computing volumes of sediments in Drenova reservoir, we used the average end-area method. In order to determine changes in the accumulation area, we created 256 ranges, namely cross-sections, on digital elevation models of the accumulation area - preconstruction and current state of the years 1978 and 2012 (Fig. 8).

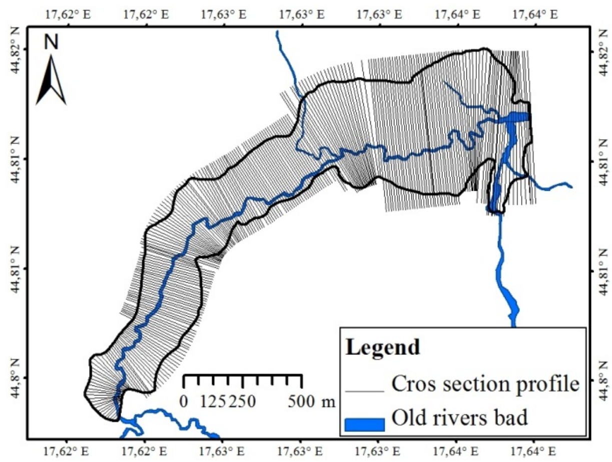

Figure 8. Cross-sectional profile of Drenova reservoir

The total deposited sediment of 348,216 m^3 was determined by analysing the cross-sectional profile from digital elevation model - the preconstruction and current state of the accumulation area, and by using the average end-area method (equation 1), and equation (2).

The survey results indicate that in the past 30 years, storage capacity of Drenova reservoir decreased by 262,963 m^3 and 274,342 m^3 based on the normal and maximum water level, respectively. Drenova accumulation area is covered with 348,216 m^3 of sediment, which decreased the dead storage by 69.64% and the total operational space by 5.81%. Today, the capacity of Drenova reservoir at normal and maximum water elevation is 2,197,338 m^3 and 5,710,357 m^3 respectively (Table 1).

Table 2 shows the average values of the basic physical, chemical parameters of water, while table 3 shows the average contents of trace elements in the water and sediment. Samples 1, 2, 3, 4 were taken at the very high sediment level site (Fig. 7). Samples 5, 6, 7 were taken within the middle part of the reservoir, with lower level of sediment than the previous four samples. Samples 8, 9, 10 were taken in the area with very low sediment level but where spots with higher level of sediment also appear, depending on the water course. Table 2 shows the water quality is determined by physical chemical parameters and they satisfy maximum allowable concentration for the second water class (Official Gazette RS 50/2012).

Table 1. Relevant indicators of the Drenova reservoir over the period 1978-2012

Indicator	1978	2012	Storage and area losses
Storage capacity at normal reservoir water level 167.5 m	2,460,301 m^3	2,197,338 m^3	10.68 %
Storage capacity at maximum reservoir water level 172.0 m	5,984,699 m^3	5,710,357 m^3	4.58 %
Dead storage	500,000 m^3	348,216 m^3	69.64 %
Reservoir area at normal water level	731,646 m^2	689,640 m^2	5.74 %

Table 2. The average content of trace elements in the Drenova reservoir

Parameters	pH - value	BOD mg O_2	Ammonium ion mgN/l	Nitrites mgN/l	Nitrates mgN/l	Chlorides mg/l	Sulphates mg/l	Orthophosphates mg P/l	Total P mgP/l
Min	7.230	3.000	0.020	0.005	2.840	11.690	80.760	0.020	0.005
Max	7.590	3.200	0.420	0.005	7.860	17.580	110.200	0.020	0.005
Range	0.360	0.200	0.400	0.000	5.020	5.890	29.440	0.000	0.000
Average	7.360	3.160	0.107	0.005	6.089	13.041	91.155	0.020	0.005
Standard deviation	0.104	0.070	0.134	0.000	1.567	1.713	9.272	0.000	0.000
Skewness	1.100	-1.658	1.651	1.186	-1.034	2.455	1.033	1.186	1.186
Critical level for class II	65-8.5	5.000	0.300	0.000	3.000	100.000	100.000	0.100	0.200

BOD - Biological Oxigen Demand

Table 3. Concentration of the heavy metals in water and sediments in the Drenova reservoir

Parameters	Fe	Mn	Cr	Pb	Cd	As	Cu	Zn	Ni
	Water (mg/l or PPM)								
Min	0.0300	<0.0200	<0.0500	<0.0020	<0.0002	<0.0050	<0.0500	0.0050	0.0030
Max	0.1800	<0.0700	<0.0500	<0.0020	<0.0002	<0.0050	<0.0500	0.0200	0.0120
Range	0.1500	0.0500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0150	0.0090
Average	0.0890	0.0270	0.0500	0.0020	0.0002	0.0050	0.0500	0.0090	0.0046
Standard deviation	0.0448	0.0149	0.0000	0.0000	0.0000	0.0000	0.0000	0.0058	0.0029
Skewness	1.0658	2.7851	1.1859	-1.1859	-1.1859	1.1859	1.1859	1.3638	2.1033
Critical limits*	0.3000	0.1000	0.0500	0.0500		0.0100	0.0100	0.003-0.2	
EU standards 1988$	0.2000	0.0500	0.0500	0.0100	0.0050	0.0100	2.0000	3**	0.0200
	Sediment (mg/kg or PPM)								
Min	21487	682.25	64.95	2.20	0.11	3.66	29.24	33.43	185.29
Max	34268	1384.90	339.03	6.22	0.44	11.84	41.51	367.08	807.82
Range	12780	702.66	274.08	4.02	0.33	8.18	12.27	333.65	622.53
Average	28620	978.74	142.24	3.67	0.28	7.81	35.24	84.80	338.27
Standard deviation	3620	208.41	74.45	1.44	0.09	2.75	4.03	94.70	171.50
Skewness	-0.70	0.40	1.97	1.05	-0.06	-0.26	0.26	3.09	2.25
OSPAR (2004)			10-100	5-50	0.1-1.0	1-10	5-50	50-500	5-50
Critical limits*			100-380	85-530	0.8-2	29-55	36-90++	140-480	35

* Regulation on limit values for pollutants in surface and ground waters and sediments, and the deadlines for their achievement (Official Gazette of RS 50/2012). $ Council Directive 98/83/EC on the quality of water intended for human consumption. ** WHO standards, 1993. *** Regulation on limit values for pollutants in surface and ground waters and sediments, and the deadlines for their achievement (Official Gazette of RS 50/2012): concentration expressed within the range of concentration of pollutants in the sediment that are at the background level. Sediment is slightly polluted. Sediment disposal without special measures of protection is allowed during the dislocation. ++ Regulation on limit values for pollutants in surface and ground waters and sediments, and the deadlines for their achievement (Official Gazette of RS 50/2012): concentration expressed within the range from the level of natural background radiation to the content that indicates pollution. Sediment disposal without special measures of protection is not allowed.

The cycle of nitrogen (ammonium, nitrite, and nitrate) indicates relatively low values, as well as the content of orthophosphate, total phosphorus. The content of trace elements in the water of Drenova reservoir (Table 3) is lower than the standards of the EU (1988) and WHO (1993).

Contents of trace elements in deposited sediments of Drenova reservoir are within the concentration that expresses the background level up to the minor pollution level, except for the contents of Cu, Ni and Cr (Official Gazette of RS 50/2012).

Cu content in the samples from locations 1 and 5 is slightly above the pollution level criteria, while the contents of Ni and Cr significantly above the criteria. Calculated geo-accumulation indexes for Fe (-2.46 to -0.65), Pb (-3.09 to -1.59), Cu (-0.72 to -0.22) and Mn (-0.66 to 0.36) are in the category of unpolluted. Geo-accumulation index for Cd (-1.45 to 0.55-location 6) is in the category of unpolluted to moderately polluted. Geo-accumulation index values for Zn (-1.60 to 1.81 - location 4) and Cr (-0.71 to 1.67) are in the class of unpolluted to moderately polluted, As (0.44 to 2.13) is in the category of unpolluted to moderately-strong polluted and Ni (1.33 to 3.46) is in the category of moderately-strong polluted. The highest values of the geo-accumulation index for Cr, Ni, and Zn are measured at sites of high sedimentation level, while the highest Cd and As values are measured in the middle part of the reservoir with lower sedimentation rate. Enrichment factor values and the Pearson's correlation coefficients of trace elements in sediments are shown in tables 4 and 5.

Calculated sediment trace metals enrichment factor decreases in the line Ni > As > Cr > Cd > Mn > Zn > Cu > Pb (Table 5). The enrichment factor shows that the anthropogenic influence is moderate for Ni and As, while it is minor for Cr, Cd, Mn, Zn and Cu, and for Pb indicates no enrichment.

Total contents of As in the deposited sediments are at the level of background level, but due to anthropogenic activities in the basin, deposited sediment is enriched with this element. However, the contents of Ni and Cr are above the average background level, caused primarily by the way of soil use, namely the soil formed of serpentinites and peridotites at 8.5% of the river basin surface. Many authors state the geological correlation between Ni and Cr (Adriano, 2001; Kabata-Pendias & Pendias, 2000) and also the one between copper and zinc. Therefore, it is not uncommon that these forms are correlated (Table 6).

The common origin of Ni and Cr is also confirmed by the correlation coefficient (0.997**). There is also a strong correlation between Cu and Zn (0.475**). Arsenic (As) is in a significant correlation with Fe (0.635**), then with Cd (0.534**) and Cu (0.790**). Arsenic can reach the river ecosystems through natural geological processes and anthropogenic activities and is also associated with the presence of iron (hydro) oxides (Violante et al., 2010; Pfeifer, et al., 2002). Arsenic is often associated with other elements, such as Cu.

Table 4. Enrichment ratio (ER) values of the trace elements in Drenova reservoir sediments

Sample	Mn	Cr	Pb	Cd	As	Cu	Zn	Ni
1.	1.58	3.14	0.29	1.23	5.64	1.40	1.03	10.14
2.	1.64	**5.00**	0.30	0.58	2.68	0.96	0.52	**17.27**
3.	1.32	2.41	0.20	1.60	6.07	1.34	1.03	8.32
4.	1.21	2.84	0.27	1.60	6.50	1.65	6.72	9.07
5.	1.88	1.85	0.24	1.57	6.58	1.51	1.04	6.76
6.	1.87	1.97	0.28	2.67	7.99	1.32	1.08	6.97
7.	**7.05**	**3.35**	**1.40**	**6.42**	**9.49**	**3.83**	**2.40**	**13.87**
8.	1.50	2.06	0.67	1.94	2.72	1.36	1.14	7.25
9.	2.25	1.81	0.83	3.17	5.14	1.59	1.15	6.49
10.	1.57	2.32	0.31	1.83	8.72	1.59	1.23	7.55

Table 5. Correlation coefficients of the trace elements from sediments

	Fe	Mn	Cr	Pb	Cd	As	Cu	Zn	Ni
Fe	1								
Mn	0.222	1							
Cr	**0.806****	**0.417***	1						
Pb	0.149	**0.517****	0.254	1					
Cd	0.145	**0.542****	-0.045	**0.595****	1				
As	**0.635****	0.294	0.344	-0.042	0.**534****	1			
Cu	**0.577****	0.309	0.329	0.064	0.412*	**0.790****	1		
Zn	0.127	-0.325	0.074	-0.155	-0.011	0.225	**0.475****	1	
Ni	**0.790****	**0.460***	**0.997****	0.272	-0.033	0.321	0.307	0.033	1

Pearson's correlation coefficients for pairs of variables are given.
** Correlation is significant at the 0.01 level. * Correlation is significant at the 0.05 level.

The basic anthropogenic origin of arsenic (As) in the soil is from the combustion of municipal solid waste, usage of pesticides (herbicides, fungicides and insecticides) (Matera & Le Hecho, 2001). Through the accumulation process, trace elements are included in the biochemical processes of the elements circulation and thus reach the surface and ground waters.

Being included in the biochemical processes of the elements circulation, they are subjected to different changes that affect their mobility, binding and flushing or surface transporting during an erosion process. Therefore, in order to determine the impact of a possible delay in the deposited sediments of a basin, it is necessary to analyse the chemical separations, particularly for elements that enrich the deposited sediment. Adverse effects of trace elements are mainly attributed to ion forms soluble in water or adsorbed on suspended particles, i.e., complexed with mineral and organic components. As a result of these processes, trace elements adsorbed on suspended particles are transferred from the water component into the deposited sediment component. Resuspension of deposited sediment particles is the result of turbulence at the "water-sediment" level (De Vries & Bakker, 1996). Although the deposited sediment is enriched with Ni, Cr, As, Cu, Zn and Cd, the contents of these elements in Drenova reservoir are significantly below the critical value.

4. CONCLUSION

The survey results indicate that in the past 30 years, Drenova accumulation area is covered with 348216 m^3 of sediment, which decreased the dead storage by 69.64% and the total operational space by 5.81%. The water quality showed a satisfies maximum allowable concentration for the second water class (Official Gazette RS 50/2012). The enrichment factor for metal concentrations showed that the anthropogenic influence is moderate for Ni and As, while it is minor for Cr, Cd, Mn, Zn and Cu, and it indicates no enrichment for Pb.

Given the geological characteristics of the basin, it can be concluded that the contents of trace elements in the deposited sediment have geological origin. However, it is necessary to analyse the chemical separation of Ni, Cr and As, thus defining their origin. Their concentration in the sediment, from any source including the parent material, creates a kind of material that must be removed and disposed in a safe way. A considerable amount of deposited sediment can be deposited in areas of the basin with a dominant quantity of serpentinites which can be dangerous, because they belong to easily erodible rocks, and the erosion process can quickly return them to the reservoir.

In order to overcome the existing problems, besides the allocation of basin areas where the deposited sediment from the reservoir would be accumulated, it is necessary to access and implement the erosion control measures on the entire surface of the basin, in order to reduce the amount of the deposited sediment that reaches Drenova reservoir. Alongside with the erosion control measures in the basin, it is necessary to build landfill and retardation compartments. The water intake structure is currently positioned at the very bottom of the, at the foot of the dam. In order to enter the reservoir area with a higher water quality, it is necessary to lift the water intake structure for 2.0 m This level of water intake and a greater quantity of water would significantly affect the water quality.

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