THE DEGREE OF SILTING AND THE IMPACT ON ALLUVIAL DEPOSITS IN THE RIVER BEDS OF BISTRIŢA RIVER BASIN

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ABSTRACT. The degree of silting and the impact on alluvial deposits in the river beds of Bistriţa River basin. Since 1960 the Bistriţa River basin came under the profound influence of anthropic incidence. This river basin represents a pattern of use for hydropower potential: reservoirs (9); channels (61 km); water dams; transfers of flows; protection structures works for banks and slopes; relocation of human settlements (13 villages); gravel pits; galleries; viaducts; communication paths, etc. Bistriţa River development has led to significant changes in the structure of the hydrological regime, through the regularization of water flows and by creating significant discontinuities in the transit of silt. Lately there has been an increase in water turbidity in the highlands. Solid flows on the lower course register a continuous decrease because of the existence of reservoir. During the execution of the hydraulic structures turbidity and sediment yield increased. When brought into service intense processes of silting occurred. Analysis covers the sediment yield in Bistriţa River basin and the evolution in time of the degree of silting of reservoir. Average production of silt varies between 1.5-2 t/ha/year. Annual rate of silting in reservoirs is between 0.6% (Izvorul Muntelui) and > 2% (Pângăraţi, Racova). Racova Reservoir was decommissioned in 2011.

Keywords: silting, hydraulic structures, storage reservoir, sediment yield

1. INTRODUCTION

The construction and operation of reservoirs is closely related to the sediment yield run-off. The transit of sediment influences the silting of the reservoirs, leading to reduction of storage volume. For an efficient and long term operation of the storage volume a number of actions are necessary in order to reduce to a minimum the sediment production. Storage reservoirs have emerged as a result of socio-economic development aiming to mitigate the floods, to meet the needs of electricity; ensure water supply, irrigation, and industrial development of fisheries etc. (Romanescu et al., 2010, 2011).

Anthropogenic activities consist in afforestation, soil erosion control, construction of channels and reservoirs, bed regularization, irrigation, drainage, ballast operation, bed silting off, torrents development etc. All activities have significant effects on the natural drainage system, both solid and liquid. The article analyzes the production and transport of sediment, as well as the evolution of reservoir silting of the river basin (Romanescu and Bounegru, 2012).

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2. GEOGRAPHICAL SETTING AND CHARACTERIZATION OF BISTRIŢA RIVER BASIN

Bistriţa River springs from Rodna Mountains, from the union of two streams: Putreda and Bistricioara. It crosses the Eastern Carpathians, passing through the towns Vatra Dornei, Bicaz, Piatra Neamţ, Roznov, Buhuşi and Bacău. Bistriţa River is the largest tributary of Siret River and they confluence downstream Bacău. Due to the river hydropower, Bistriţa represents a model of national hydrographic pattern recovery (Ujvari, 1970). It has a length of 278 km and a total of 193 water courses coded. Bistriţa River basin has an area of 7039 km². The main tributaries of Bistriţa River are: Dorna, Neagra Şarului, Neagra Broşteni, Borca, Sabasa, Bistricioara, Bicaz, Tarcău, Cracău, Romani and Trebeş (Fig. 1). From a mathematical point of view the elongated river basin falls between: 24°47’55”, 27°00’49” long. E and 46°29’33”, 47°44’42” lat. N. (Basin Water Administration, Siret, 2013).

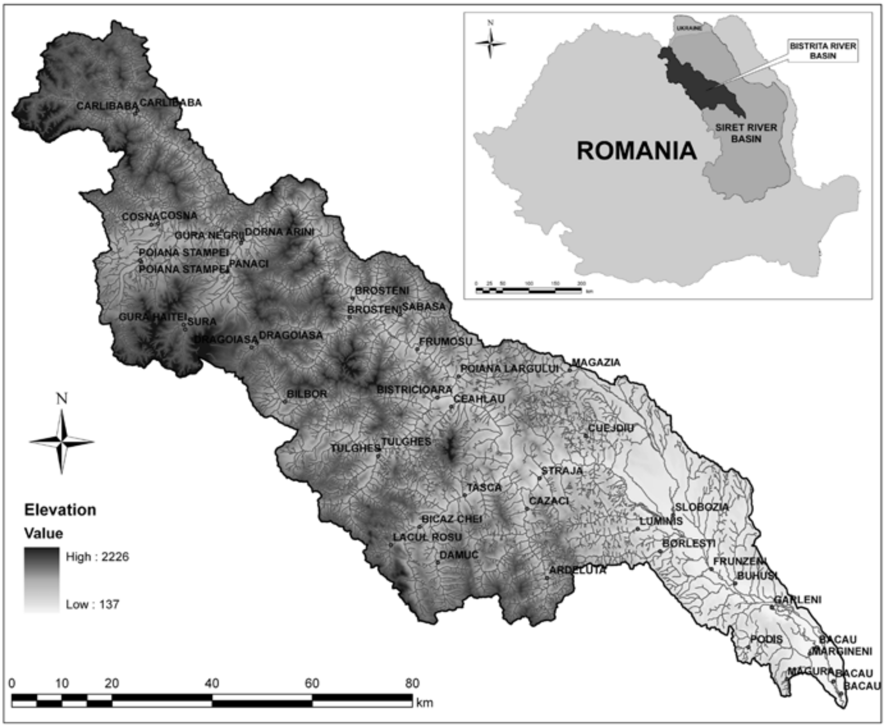

Fig. 1. Localization of Bistriţa River Basin and the hydrometrical stations

The physical-geographical characteristics of Bistriţa River basin show differentiations from West to East, the river basin overlaps in sequence on the mountain units (Eastern Carpathians) and on the foothills (Moldavian Subcarpathians). Bistriţa River has NNW-SSE orientation, draining downstream all the three major geological units of the Eastern Carpathians. After 1960 the Bistriţa River hydropower has been developed by building a number of 9 reservoirs, 13 hydropower, channels, dams, transportation flows, asset protection of banks and slopes, relocation of human settlements (villages); gravel pits; galleries; viaducts; communication paths, etc. The largest reservoir is Izvorul Muntelui with a volume of 1.12 billion m³ (Romanescu, 2005; Romanescu and Bounegru, 2012).

The basic factor of the liquid and alluvial runoff is the precipitation. Bistriţa River basin rainfall exhibits great variability reflected in the flow regime. Another natural factor influencing the runoff is represented by the geological composition. Rocks by their properties (porosity, permeability, absorption capacity, degree of compaction, etc.) influence the liquid and alluvial runoff. Type and flow regime are subject to factors that influence geomorphological modeling. Sediment yield varies according to the flow and nature of the rocks (Donisă, 1968).

3. METHODOLOGY

The research was conducted based on data from: old existing sources; water cadastre between 1970 and 2011; or from observations at the monitored gauging stations. The database comprises liquid and solid flow measurements, morphometric data, etc. of the Bistriţa River basin. The basin includes 30 gauging stations where levels, solid and liquid flow rates, temperatures, chemical characteristics etc. are measured.

The hydrometric network monitors only the silt flow. The bed-load transport has been determined as percent of the silt, as recommended in the literature (Diaconu and Şerban, 1994; Zăvoianu et al., 2010). Other data used in the analysis of silting are represented by studies on the topobatimetry of the reservoirs (volumetric curves).

The geological, geomorphological and soil data etc., comes from scholastic literature. The cartographic material is based on the 1:25,000 scale maps developed by the Military Topographic Directorate from Romania. The database has been processed both graphically and statistically, to achieve the objectives of the article. The software used for graphic processing of the database is Microsoft Excel. The maps were made using ArcGIS 9.3 software. The article analyzes the degree of silting of the reservoirs and their impact on the sediment yield in Bistriţa River basin.

4. RESULTS AND DISCUSSIONS

Being located in the high area, with various morphohydrographic features and intensive anthropization Bistriţa River basin is experiencing problems controlling the sediment production and the rate of silting in the reservoirs. The formation and evolution of the runoff involves numerous physical-geographical, hydraulic and energetic factors which interact in continuous interdependence which is why the human factor has a significant impact.

The physical-geographical characteristics of the Bistriţa River basin have different properties from West to East. From geological point of view it belongs, almost entirely (until Racova) to Eastern Carpathians geosynclines, consisting of extremely varied hard rocks. The production of sediment and the degree of silting of the reservoirs are influenced by structure and geological development, fragmentation and energy relief, vegetation cover (afforestation), soil types, formats, etc.

The high values of the slopes in the high mountain area on a hard rock background with a high coefficient of afforestation are not relevant to the amount of sediment production. The maximum transit is located in the low altitude territories, in the subcarpathian area with soft, easy erodible rocks and predominance of agricultural areas. This feature is highlighted by the increasing values upstream to downstream. This phenomenon is characteristic to all eastern water courses of the Eastern Carpathians.

The transit silt refers not only to the runoff, but all three stages: erosion, transport and alluviation. Soil erosion control works, building reservoirs, afforestation actions, adjustments, discharge regulation, works to strengthen the banks, etc. result in reducing the volume of sediment yield (Diaconu and Şerban, 1994; Enea and Romanescu, 2012). During the execution of bed-works (use of ballast, excavation, consolidation of banks etc.) suspended silt resume thus increasing the sediment yield. Finally the silt is deposited in reservoirs, thus decreasing downstream sediment yield. Therefore all these processes lead to important changes in the transit of silt (Table 1).

Table 1. Basic elements of liquid and solid runoff

No	River	Hydrometrical station	Area km²	Medium hight m	Medium flow m³/s	Medium Alluvial Flows kg/s		
						R(suspension)	G(bed-load)	Total
1	Bistriţa	Dorna Giumalau	758	1255	12.1	3.23	3.23	6.46
2		Dorna Arini	1690	1206	25.0	5.78	5.78	11.6
3		Frumosu	2858	1172	38.1	10.7	8.56	19.3
4	Carlibaba	Carlibaba	111	1253	1.66	0.212	0.212	0.424
5	Dorna	P. Stampei	132	1305	2.33	0.615	0.615	1.23
6		D Candreni	565	1138	7.51	1.36	1.36	2.72
7	Dornisoara	P Stampei	47	1066	0.660	0.100	0.1	0.200
8	Neagra	Sura	48	1522	1.27	0.379	0.379	0.758
9	Neagra	Gura Negrii	312	1256	4.21	2.46	2.46	4.92
10	Haita	Gura Haitei	40	1450	0.966	0.274	0.274	0.548
11	Sarisor	Panaci	44	1223	0.680	0.024	0.024	0.048
12	Barnar	Barnar	93	1228	1.10	0.025	0.025	0.050
13	Neagra	Brosteni	292	1220	4.02	0.637	0.637	1.27
14	Bolatau	Poiana Largului	59	847	0.482	0.424	0.340	0.764
15	Bistricioara	Tulghes	408	1073	3.12	0.835	0.835	1.67
16		Bistricioara	760	1041	6.29	2.94	2.94	5.88
17	Schit	Ceahlau	40	977	0.537	0.901	0.720	1.62
18	Bicaz	Tasca	496	1053	4.90	1.96	1.57	3.53
19	Oantu	Oantu	40	769	0.556	0.007	0.004	0.011
20	Cuejdiu	Cuejdiu	65	705	0.489	0.743	0.600	1.34
21	Cracau	Slobozia	445	577	1.80	1.43	0.430	1.86

For the suspended solid flow a continuous increase in the average multi-annual values from West to East is shown. If made a correlation between sediment yield and average altitude of Bistriţa River basin one may conclude that the average altitude is not the factor that determines the production of sediment (quantitative), but a set of elements: geological composition, toughness of rocks, the energy and the fragmentation of the relief, drainage slopes, etc. On the same average altitudes the silt production differs (Fig. 2).

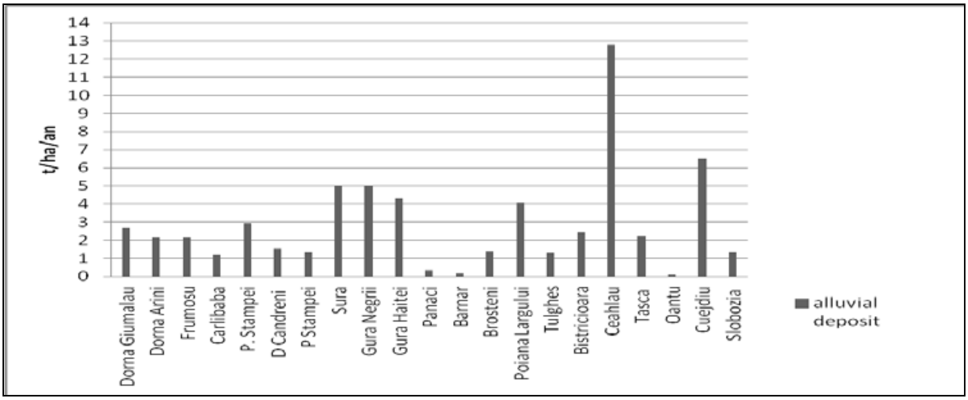

Fig. 2. Alluvial deposits in Bistriţa River basin

During 1955-1966 Bistriţa River has been developed hydropower, leading to important changes in hydrological regime. The construction of reservoirs and adjacent structures (tailraces, headraces, flow transfers, asset protection of banks and slopes, exploitation in gravel pits, etc.) involved steep water flow regulation and significant discontinuities in the silt transit. In this situation the problem of quantitative determination of silt in the solid flow is interconnected with the anthropogenic influences.

To determine the silt transit on undeveloped areas classical hydrometric methods were used. The developed Bistriţa River sector presents different conditions for the effluence and origin of silt. The lack of direct measurements caused inability to process statistical ranges of values. The transit of silt has been determined indirectly by exploiting existing information on reservoir silting, for which have been drawn updated capacity curves (Fig. 3).

The results are in accordance with the physico-geographical characteristics of the area and the values resulting from direct observations. Izvorul Muntelui reservoir, for which both methods were applied, has the following result values for specific sediment yield: 0.96 t/ha/year-by means of gauging and 1.37 t/ha/year-by indirect methods. It is considered to be an acceptable agreement because part of the accumulated volumes originated from landslides on the slopes (from higher elevations).

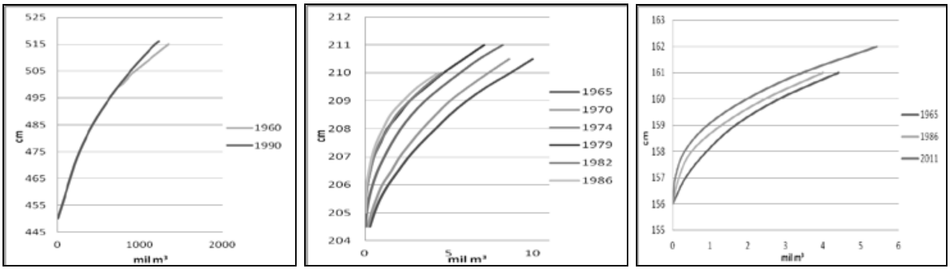

Fig. 3. Degree of silting at Izvorul Muntelui Reservoir, Racova Reservoir and Bacau Reservoir

Besides the role of regularization of the flow regime, the reservoirs have a very important role in mitigating flood waves. Among the reservoirs in Bistriţa River basin, Izvorul Muntelui is the only one to retrieve floods with 1% insurance, 360 million cubic metres, respectively. The other reservoirs began to develop a high degree of silting (Table 2).

Table 2. Characteristics of reservoirs in Bistriţa River basin

No	**Reservoir**	**Year of commissioning**	**Dam height (m)**	**The initial volume NNR (mln m³)**	**The current volume NNR (mil m³)**	**The upstream basin area (km²)**	**Degree of silting (%)**
1	Poiana Teiului-Topoliceni	2004	15.5	0.7	0.7	2886	0
2	Izvorul Muntelui	1960	127	1230	1122	4022	8.80
3	Pângaraţi	1964	28	6.00	2.01	5142	**66.5**
4	Vaduri	1966	27	5.60	2.39	5213	**57.3**
5	Bâtca Doamnei	1963	22.3	10.0	6.50	5290	**35.0**
6	Reconstrucţia	1963	8.15	0.25	0.23	5403	8.00
7	Racova	1965	20	4.37	emptied	6580	-
8	Gârleni	1965	19	5.10	2.30	6758	**54.9**
9	Lilieci	1966	19	7.40	5.40	6775	**27.0**
10	Bacău	1966	18	5.40	4.23	6814	22.0
11	Taşca (r. Bicaz)	1980	20	0.10	0.09	512	0.01

After analyzing the degree of silting of the reservoirs within the basin it was concluded that most of the reservoirs are choked even more than 50% (Table 2), which means that additional flow rates can no longer be stored entirely and devastating floods can occur. Exceptions are Topoliceni, Taşca, Izvorul Muntelui and Reconstrucţia reservoirs (intake of silt deposited in the reservoir was removed from the cuvette by successive clogging).

Izvorul Muntelui reservoir is the largest in the system, with a basin area of 4025 km², located entirely in mountains (volcanic mountains, crystalline-Mesozoic and flysch), which means that the sediment yield is generally low so that the degree of silting is only 8.80%. The energy and the high fragmentation of the relief are balanced by the presence of hard rocks and extensive wooded areas.

The other reservoirs, although placed in cascade, show silting phenomena because solid flows are transited and transported downstream. Pângăraţi reservoir has a larger catchment area (1117 km ^{2}), while the others have associated smaller basins (under 110 km^2). Most of them are located in the piedmont, an area with a large production of sediment: 2,0-15,0 t/ha/year (Olariu, 1990). To obtain rates of silting for each reservoir, in the absence of direct measurements, we performed comparisons between the capacity curves (Fig. 3).

The obtained values largely justify the source of silt for each reservoir. During periods of high water, when the capacity of turbines is exceeded, the excess water is discharged on channel sections passing a reservoir to another. Also during overflows and emptying reservoirs processes, flushing upstream-downstream occur so that sediment yield is increasing in reservoirs. The silting process of the reservoirs is also quite active during dry periods due to the suspensions which are retained completely by the reservoirs.

To combat the reservoir silting the following works can be done: drainage and hydraulic flushing; dredging-very expensive because of the high energy consumption and the need for additional land for storage of silting (useful for smaller basins such as: Pângăraţi, Vaduri); mineral aggregates operation from the lacustrine cuvette for construction works; hydraulic lavage-applies to all reservoirs on the Bistriţa River basin; mechanical interventions-for silt accumulations tail. The success of these measurements depends on the thorough knowledge of the liquid and solid regime and its effect on the reservoir silting.

5. CONCLUSIONS

The acknowledgment and the control of the production of sediment is of great importance for the future design of the geographical landscape. In the context of accelerated economic development, the role of the human factor becomes especially important through permanent changes in the water flow and silt regime. Transit of sediment yield and silting of reservoirs are in direct dependence with the geographical location of the basins which make the origin of silt.

The reservoir silting has the following negative effects: by reducing the volume affects the ability and the capacity to exploit the reservoirs; raising the bottom of the reservoirs changes hydraulic parameters of riverbeds thereby reducing the capacity of transit flow (both operating and high waters); decreased transit capacity reduces water flow safety by raising the share of remuu and flood events. In the future it will be done a prognosis of the evolution of reservoir silting. Depending on the speed of this phenomenon a number of scenarios will be carried out (using modelling programs) for future developments of the reservoirs, which currently are in an advanced stage of silting. A strategy for the design of new construction that can cope with any possible risk of hydrological phenomena must be designed.

REFERENCES

1. Diaconu, C., Şerban, P. (1994), *Sinteze şi regionalizari hidrologice*. Editura Tehnica, Bucuresti.
2. Donisa, I. (1968), *Geomorfologia Vaii Bistritei*. Editura Academiei, Bucuresti.
3. Enea, A., Romanescu G. (2012), *Natural and accelerated silting in the Red Lake basin (Bicaz).* Lucrarile Seminarului Geografic "Dimitrie Cantemir", 33:19-28.
4. Olariu, P. (1990), *Controlul productiei de aluviuni in bazinul hidrografic Bistriţa*. Lucrările celui de al III-lea simpozion „Provenienta si efluenta aluviunilor", Piatra Neamt.
5. Romanescu, G. (2005), *Riscul inundatiilor in amonte de lacul Izvorul Muntelui si efectul imediat asupra trasaturilor geomorfologice ale albiei*. Riscuri si catastrofe 4: 117-124.
6. Romanescu, G., Stoleriu, C., Romanescu, A.M. (2010), *Lacul Stanca-Costesti si rolul sau in atenuarea inundatiilor pe raul Prut.* Riscuri si Catastrofe, An IX, 8(1):153-165.
7. Romanescu, G., Stoleriu, C., Romanescu, A.M. (2011), *Water reservoirs and the risk of accidental flood occurrence.* Case study: Stanca–Costesti reservoir and the historical floods of the Prut river in the period July–August 2008, Romania. Hydrological Processes, 25(13):2056-2070.
8. Romanescu, G., Bounegru, O. (2012), *Ice dams and backwaters as hydrological risk phenomena – case study: the Bistriţa River upstream of the Izvorul Muntelui Lake (Romania).* WIT Transactions on Ecology and The Environment, 159:167-178.
9. Zavoianu, I., Herisanu, G., Vartolomei, F., Cruceru, N. (2010), *Relatii intre scurgerea de aluviuni ca fenomen de risc pentru colmatarea lacurilor de acumulare si factorii de mediu.* „Resursele de apa din Romania. Vulnerabilitate la activitatile antropice". Editura Transversal, Targoviste, 44-49.
10. Ujvari, I. (1970), *Geografia apelor Romaniei.* Editura Stiintifica, Bucuresti.
11. * * * Administraţia Bazinală de Apă Siret, Bacău, (2013). *Arhiva*. Bacău.