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ARE FLOATING RIVER SEDIMENTS DECREASING ON BULGARIAN TERRITORY?

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ABSTRACT: An analysis is made of the formation factors and regime of floating river sediments on the territory of Bulgaria, considering the influence of the relief (land surface), climatic conditions such as rainfall intensity, snowmelt, wind effects, water erosion, afforestation (forest vegetation), the amount of river runoff, and anthropogenic activity. A period of 35 years (1951-1995) is covered, characterized by intensive hydrotechnical construction and industrialization in Bulgaria. The twofold impact on the quantity and quality of suspended sediments from anthropogenic activity has been revealed. It is difficult to find reliable data for an accurate quantitative assessment, but the general conclusion the research conducted is that there has been a noticeable tendency to decrease the amount of suspended sediment in most rivers in the country in recent decades.

KEY WORDS: sediment runoff, water runoff, river catchment, erosion, industrialization

1. INTRODUCTION

River sediment runoff affects the safety and normal functioning of constructed engineering and other facilities within rivers so the study of river sediments has important technical aspects and applied relevance. In this sense, the Bulgarian Terms of Reference for the Development of the River Basin Management Plan of the Ministry of Environment and Water of 2004, Terms of Reference (2004) requires that the assessment of water resources and surface river runoff should also assess (i) factors and patterns of solid runoff formation; (ii) morphometric patterns and characteristics of solid runoff; (iii) analysis and estimation of solid river runoff at characteristic points.

The formation of fluvial deposits is a multifactorial process influenced by natural conditions and anthropogenic activities in the catchment area. Suspended and bed load sediments enter the river channel mainly from the surface of the catchment area together with slope runoff and less from the surface of the river bed, according to Simons & Senturk (1977). The type and shape of the relief affect the velocity of water flowing over the land surface, and therefore contribute to amplifying or attenuating surface erosion and deposition. Climatic conditions and the resistance of the land surface to erosion also determine the amount and type of river sediment.

Historically, intensive industrialization took place in Bulgaria in the second half of the last century (from 1945 to 1985) then gradually declined. The first Unified Water Management Plan of 1950 (as an update and extension of the 1920 Statewide Water Program) aimed primarily at building reservoirs and water-use systems to meet public water needs, primarily through engineered facilities. During this period (4 decades), intensive hydraulic engineering construction, development of the ore mining industry, mainly in mountainous areas were carried out with increased anthropogenic activity and land use change, which undoubtedly influenced the rivers and the formation of suspended river sediments and their quantity and material composition. With the democratic changes that have taken place since 1990, this activity and this construction have decreased.

This paper attempts to answer the question of what are the changes in the solid runoff of the rivers that have occurred in the last decades on the territory of Bulgaria. An analysis is made of the factors of the formation and the regime of the river sediments on the territory of Bulgaria, reflecting the influence of topography (land surface), climatic conditions such as rainfall intensity, snowmelt, wind effects, water erosion, forest cover (forest vegetation), the amount of river runoff and anthropogenic activity. The period covered is several decades of the last century and beyond. Data from field measurements of solid runoff in Bulgaria is used.

2. TERRITORY OF BULGARIA AND FORMATION AND REGIME OF RIVER SEDIMENTS

Floating (suspended) sediments account for 80-90% of all solid runoff from rivers, the rest is bottom sediment, Hristova (2012). In the present analysis, preference is given to floating river sediments, for which empirical information has been collected in Bulgaria from measurements started in 1951-1952, initially at several hydrometric stations, Gergov (1995) subsequently extended and continued to the present day. The stations are unevenly distributed over the territory of Bulgaria, Figure 1. Measurements of suspended sediments are made at 130 hydrometric stations, Hristova (2012).

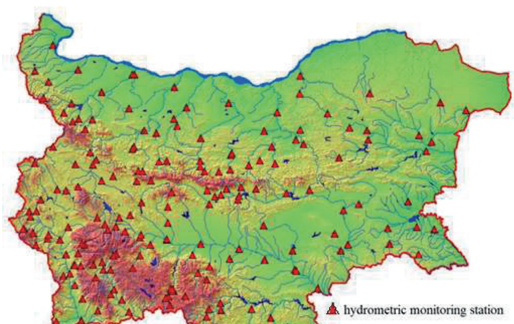

Figure 1 Map of Bulgarian territory with main river monitoring stations.

The altitude on about 20% of the Bulgarian territory is more than 800 meters a.s.l. (average elevation is 480 m). This higher zone plays an important role in the formation of river sediments and for providing water resources in Bulgaria.

The quantity and formation of river deposits are determined by climatic conditions, the intensity of erosion processes (the susceptibility of the bed surface to erosion), and hydrological factors. They are also influenced by anthropogenic impacts from economic activity. Climatic conditions determine the input of solids into water courses during rainfall and snow melting, and the cessation of sediment inflow during dry periods of the year. The impact of intense precipitation is most significant because it dilutes and transports large amounts of solids, Pechinov (1970), Papazov (1970). The relationship between heavy rainfall and the amount of eroded soil for black fallow under leached black soil conditions in Bulgaria has been demonstrated by Mandev (1974).

The floating sediments in the Bulgarian rivers have large intra-annual fluctuations, significant volumes during periods of high water, with several monthly maxima and minima. The turbidity of the river waters varies from 12 g/m^3 and reaches up to 9500 g/m^3 under certain conditions, Hristova (2012). There is a well-defined altitudinal zonation - turbidity decreases with increasing altitude.

3. IMPACT OF FOREST VEGETATION AND WOODLAND COVER

The slope of hills and forest cover determine the velocity of flowing water and the rate of erosion. The trend is positive for terrain slope and negative for afforestation. Forests cover 38% of Bulgaria's territory, according to the Strategic Plan for the Development of the Forestry Sector 2014 - 2023. Over the last decades, forest areas have been steadily increasing, leading to a decrease in river sediments. At 100% afforestation of the catchment, regardless of the slopes, the amount of sediment floating in the rivers and the turbidity of the river water are insignificant, while at 22% forest cover. the turbidity is high, regardless of the small slopes, Pechinov (1963). The close relationship between slope gradient and erosion intensity is confirmed by the studies of Gencheva and Lukanov (2002). Erosion covers about 15% of forest land. The average fulling of forests in Bulgaria is about 0.7 and is very close to the threshold value below which forests cannot have a protective purpose (Hristova, 2012). The erosion processes and the amount of solid runoff generated by them also depend on the type of forest plantation.

The relationship between forest cover and river water turbidity is close to hyperbolic and can be represented by multiple clouds of points, Papazov (1970) or bands (Figure 2) specific to particular watersheds and riverbeds due to the dependence of turbidity on other factors such as forest cover type, availability of grassy areas (meadows, pastures), watershed slope, etc. The least sediments come from forest areas with plantations of black pine, red juniper, holm hornbeam, hairy oak, Vezev and Nikolov (1968). In the Pirin Mountain region, solid runoff is formed only in cultivated sloping mountain lands and from plantations with removed forest litter, Angelov et al. (1975). Forest dead litter protects the soil from erosion and reduces the amount of solid particles entering water courses.

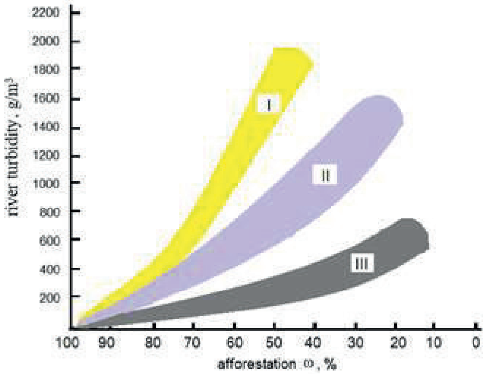

Figure 2 Dependence between turbidity of river waters and afforestation of the catchments ω, (I, II, III - catchments with different characteristics as slope of the terrains, type of forest plantations, grass cover, etc.), adapted from Papazov (1970).

4. INFLUENCE OF RIVER RUNOFF

River runoff Q with its volume and intra-annual distribution, directly influences the amount and regime of floating sediment R and actually increases sediment load. A previous study of the Mesta catchment area, Ivanov and Bournaski (2019) based on continuous measurements of Q and R shows that the formation of floating sediments is mainly influenced by climatic characteristics with specific rainfall, snow melting, and physico-geographic features of the territory, Figure 3.

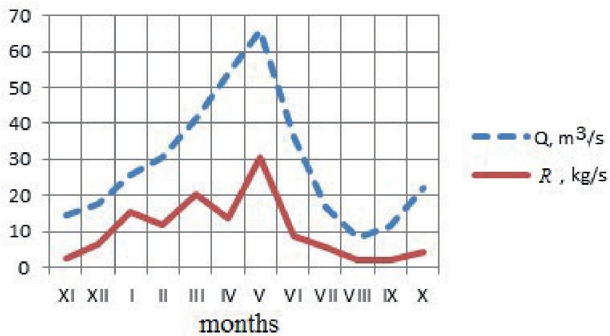

Figure 3 Average monthly water and suspended sediment quantities in Hadzhidimovo monitoring station (Mesta catchment) with drainage basin area 2260 km^2. Average multiannual R_{av} = 10.2 kg/s and Q_{av} = 30.0 m^3/s.

The maximum of the sediment flow R coincides with the maximum of the water Q, Figure 3. This nature of water discharge and sediments is typical for small rivers with small area of the drainage basin, which prevail on Bulgarian territory. For the same Mesta River, a decrease in sediments is observed after 1975, Table 1. The decrease in the module of suspended sediments for the period 1981–1990 is obviously due to the great drought in the country during this period.

Table 1

Mean annual modulus of the suspended sediments *MR* of the Mesta River at the point "Momina Kula" (drainage basin area 1510 km^2) for three different time periods, Geography of Bulgaria (2002)

Period	1955 – 1975	1961 – 1980	1981 – 1990	1961 – 1990
MR, t/an.km^2	265*	196.6	54.8	149.4

* taken from Hydrological Reference book (1984)

The influence of the river flow rate *Q* on the magnitude of *R* during the arrival of high water is interesting. The magnitude of *R* depends on whether it is during a rising or falling wave, Figure 4. There is a hysteresis, and sediments are significantly smaller during decreasing wave. The main amount of sediment passes during high water.

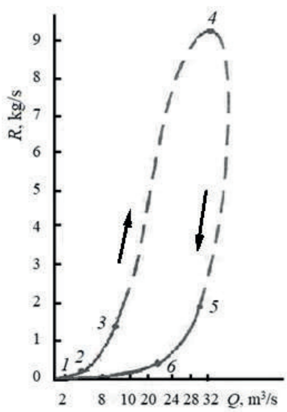

Figure 4 Dependence between the quantity of suspended sediments *R* and flow rate *Q* when passing high waters, point "Yakoruda" of the Mesta River, 1954-1955, adapted from Petkov and Pechinov (1958).

5. ANTHROPOGENIC ACTIVITY AND RIVER SEDIMENTS

The main pressure of human activity on the river systems in Bulgaria can be summarized as follows: the major water users are hydropower, agriculture, domestic, and industrial sectors, while the major pollution sources are wastewater from urban settlements, industries (pollution from mines and quarries for aggregates), animal breeding farms, and agricultural lands (disposal of agricultural materials). During the old totalitarian regime (from 1945 to 1990), the country had developed hydropower systems (the hydropower cascades „Dospat-Vacha“, the „Batak water-power road“, the „Belmeken-Sestrimo“ complex in the high-mountainous parts of the Rilo-Rhodope massif, and a number of complex purpose dams were built), developed water supply facilities (service population: over 98%), and large irrigation systems (irrigation area: over 1,200,000 ha in total), including large inter-basin transfer of water for power generation with little consideration of the environmental aspects like river water quality, environmental flows, etc. (JICA, 2008). Also, inadequate river management has been causing many problems, like excessive extraction of sand and gravel from riverbeds and flood plains, illegal dumping of solid waste into rivers, and erosion of riverbanks and flood dikes.

The changes that occurred in the river systems, in particular river water abstraction, forced many Bulgarian authors to define a period of natural regime of river runoff (and solid runoff) until 1975 and a period of disturbed regime of river runoff after 1975.

Anthropogenic impacts on the quantity and regime of suspended sediments and turbidity are multidirectional. Solid runoff is greater in rivers with man-cultivated lands and intensive mining activity, typical of the second half of the last century in Bulgaria. On the other hand, hydrotechnical construction, in particular the constructed dams, retains part of the river sediments (fully dragged sediments). The amount of sediment in the water courses decreases when aggregates are extracted from the riverbeds. The erosion of the river beds is limited by the numerous engineering fortifications built in the period 1945 - 1990, such as barrages, stone thresholds, and shore reinforcement. Figure 5 shows the reduction of floating sediments in the watershed of the Maritsa River after the construction of the dams of the "Belmeken" hydropower complex in Rila.

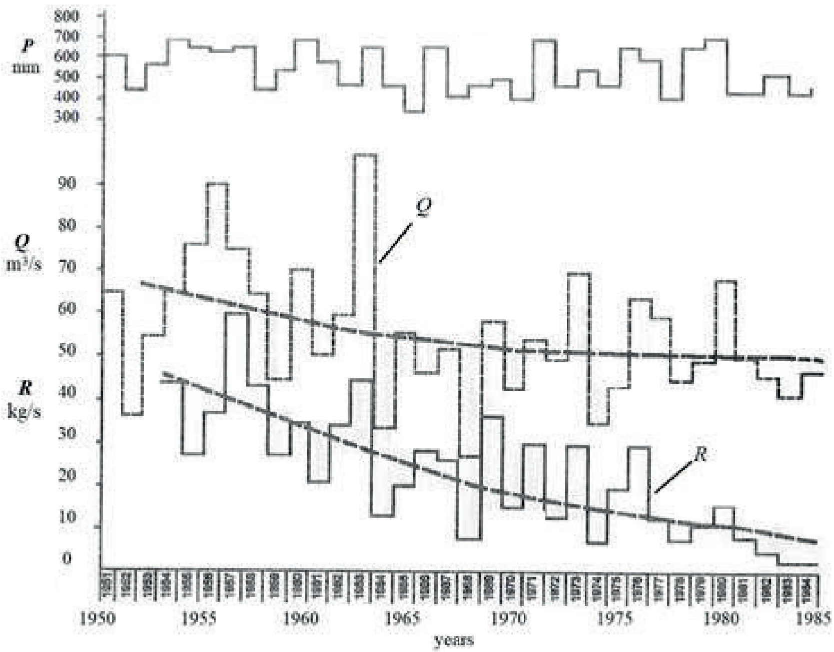

Figure 5 Variation of precipitation *P*, suspended sediments *R* and water discharges *Q* in the Maritsa River at Plovdiv, taken from Pechinov (1990).

For example, for the transboundary Mesta-Nestos River, according to the authors Andredaki et al. (2011) the mean annual value of sediment yield at the outlet of the Nestos River basin on Greek territory on the Aegean Sea, before the construction of the dams, is about 1.9×10^6 tn, while, after the construction of the dams, the mean annual value amounts to 0.33×10^6 tn. It means that the construction of the dams implies a dramatic decrease (about 84%) of the sediments supplied directly to the basin outlet and indirectly to the neighbouring coast.

Field measurements of the amount of suspended sediments in river systems over several decades clearly show a recent decrease in their amount, Figure 6. The figure shows averaged sediment data at mean mounthly river discharge for two time periods, 1961-1980 and 1981-1995 at typical hydrometric stations of the main rivers (all have anthropogenic impacts such as small or large dams, sand and gravels abstractions, mining activities into river catchment, etc.).

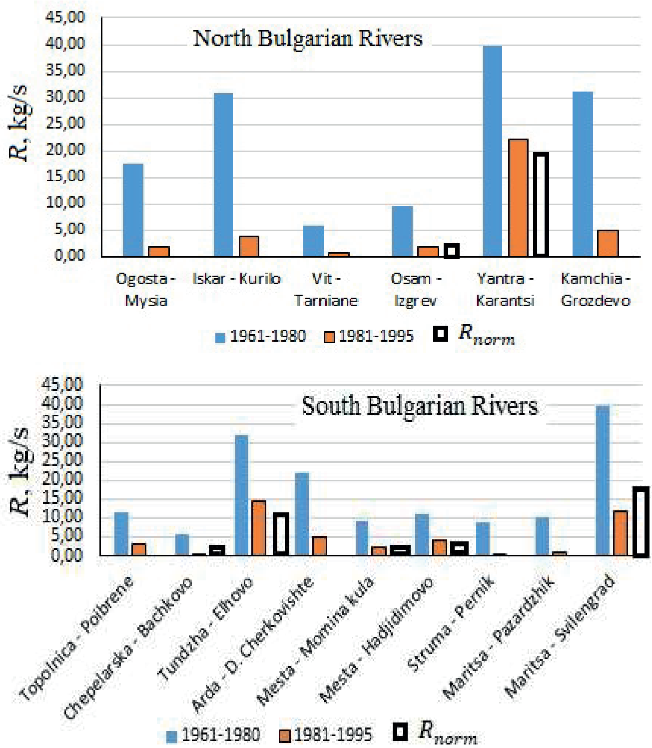

Figure 6 Suspended sediments in rivers of Northern and Southern Bulgaria for two characteristic periods. The norm R_{norm} was determined based on data from the NIMH (2022), Geography of Bulgaria (2002).

Even if the measured sediments after 1980 are at a lower river discharge (disturbed), the decrease in the amount of sediment is noticeable.

Similarly, the modulus of suspended sediments in semi-mountainous river basins also decreases over time, Figure 7.

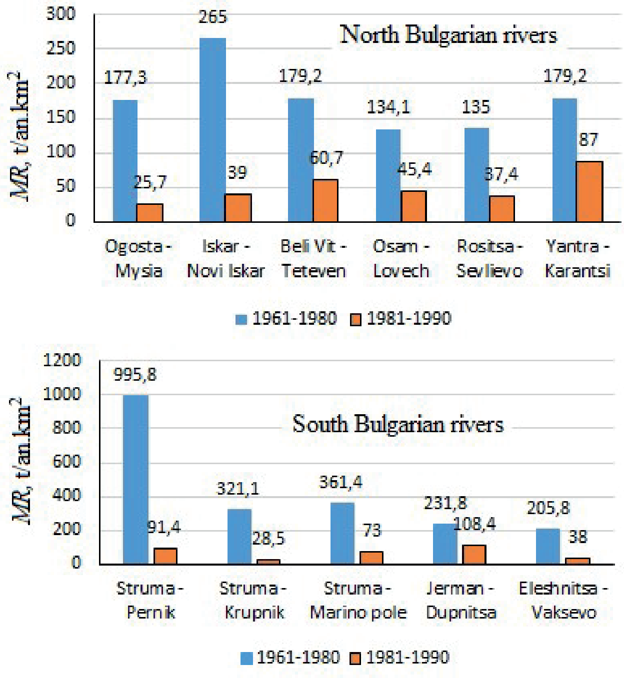

Figure 7 Modulus of suspended sediments in river basins from Northern and Southern Bulgaria for two characteristic periods, Geography of Bulgaria, (2002).

The intra-annual distribution of monthly mean values of suspended sediments of two rivers in northwestern Bulgaria averaged over two time periods 1963-1980 and 1980-1989, Gergov (1995) is shown in Figure 8. There is a shift of monthly extremes from February to March at station 11800, and an increase of monthly values for some months during the second period at station 15850.

The average turbidity of river waters at 15 river points measured in May 2023 compared to the norm for a long period (1961 – 1990) is shown in Table 2. In 9 of these 15 points, the turbidity at the present moment is less than the norm for Bulgarian rivers.

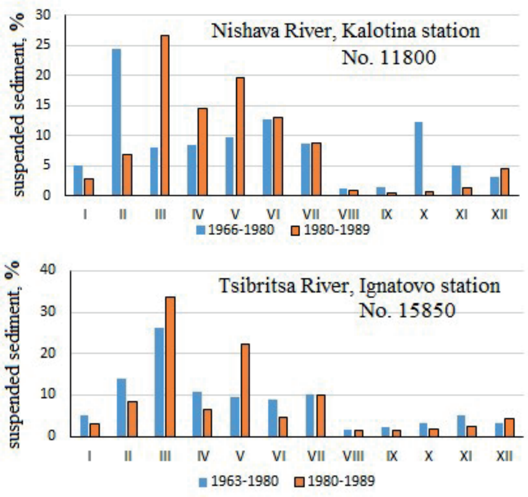

Figure 8 Intra-annual distribution by month of the floating sediments of the Nishava River and the Tsybritsa River for two typical periods according to data from Gergov (1995).

Table 2

Average monthly turbidity of river waters for the month of May 2023, (http://hydro.bg viewed on August 18, 2023)

River	Station	Turbidity (g/m^3)	Turbidity (norm) (g/m^3)
Northern Bulgaria			
Iskar	Novi Iskar	139.70	185.10
Ogosta	Kobilyak	97.55	60.25
Yantra	Karantsi	225.90	452.24
Osam	Izgrev	907.80	192.48
Vit	Disevitsa	88.83	52.27
Southern Bulgaria			
Topolnica	Koprivshtica	32.53	117.17
Maritsa	Pazardzhik	72.68	147.40
Maritsa	Svilengrad	60.47	154.72
Chepelarska	Bachkovo	165.73	131.76
Tundzha	Elhovo	65.56	750.91
Jerman	Dupnitsa	201.47	237.18
Struma	Razhdavitsa	71.90	48.89
Struma	Марино поле	140.80	218.65
Mesta	Momina kula	214.30	126.40
Mesta	Hadzhidimovo	136.70	185.63

6. SPECIFIC GRAVITY OF DEPOSIT MATERIALS/ WEIGHT OF ALLUVIAL MATERIALS

The most common mineral of the earth's crust and the main component of river sediments is quartz with a specific gravity of 2.65 g/cm^3, and this value is generally accepted as a representative characteristic of the specific gravity ρ_s of river sediments (Simons, Senturk, 1977). Empirical data from measurements of ρ_s from all 130 hydrometric stations in Bulgaria, for which water samples for river sediments are available, are summarized for a five-year period (1986-1991) by the formula, Gergov (1995)

$$\rho_s = \frac{\sum \rho_{si} \cdot Q_i}{\sum Q_i},$$

where Q_i is the average amount of water in the i-th consecutive season/period of suspended sediment formation, ρ_{si} - specific weight of sediments in the i-th season/period. The thus formed set of empirical data ρ_s is characterized by a minimum value of 2.07 g/cm^3, a maximum of 2.73 g/cm^3 and an average value of $\rho_{s.aver}$ = 2.54 g/cm^3 with a variance of 0.12, Gergov (1995) for the entire country. As can be seen, the average value of the specific weight of the sediments in Bulgaria, 2.54 g/cm^3, differs from that recommended in the special literature and is smaller by 4%. Changes in the specific gravity of suspended sediments are related to the content of transit sediments, organic particles and pollution of river water, and of sand fractions.

7. CONCLUSION

The intensive hydrotechnical construction, diversions of river water, and industrialization in the last century led to changes in the river systems on Bulgarian territory, which formed a period of natural river runoff (and solid runoff) until 1975 and a period of anthropogenic impact on the rivers (disturbed runoff regime) after 1975. The present analysis shows a twofold direct impact on the amount of suspended river sediments from changed land use and anthropogenic activity in recent decades in Bulgaria. A tendency to decrease suspended sediments was observed in most rivers of the country during the period 1981 - 1995 compared to the period 1961 - 1980. The average module of floating sediments also decreases over time, decreasing significantly during the drought period 1980 - 1994. Factors reducing river sediments are the construction of dams, extraction of aggregates from the riverbeds, increased forest areas, etc. A decrease in the specific weight of the transported solid particles in the Bulgarian rivers is also observed. At the same time, it is difficult to find reliable data for an accurate quantitative assessment after the year 2000, which requires further research and field measurements. The acquired knowledge and collected information may have practical application in engineering calculations and planning measures for the protection of river ecosystems.

ACKNOWLEDGEMENTS

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REFERENCES

1. Andredaki, M., Hrissanthou, V., Kotsovinos, N. 2011. Calculation of Sediment Reduction at the Outlet of the Mesta/Nestos River Basin caused by the Dams. In J. Ganoulis, A. Aureli, & J. Fried (Eds.), Transboundary Water Resources Management: A Multidisciplinary Approach: Transboundary Lakes and Rivers (pp. 205-214). Wiley-VCH Verlag GmbH & Co. GaA. https://doi.org/10.1002/9783527636655.ch5
2. Angelov, S., A. Mandev, St. Kerensky, 1975. On water and solid runoff in the mid-montane belt of the Sandanski part of Pirin., Forestry Science, 1, 72-80 (in Bulgarian)
3. Gencheva, I., Lukanov A. 2002. Intensity of erosion processes in part of the catchment area of the Varbitsa River., Problems and Perspectives for Development of the Eastern Rhodopes, Sofia University "St. Clare Ohridski", 33-38 (in Bulgarian)
4. Gergov, G. 1995. Runoff of rivers in Bulgaria., Doctor of Science thesis, Sofia, (in Bulgarian)
5. Hristova N., 2012. River Water of Bulgaria, TiptopPress, ISBN 978-954-723-0804 (in Bulgarian)
6. Hydrological reference book, 1984. Hydrological reference book of Rivers in the Republic of Bulgaria, IV, 1984, Directorate General "Hydrology and Meteorology" at the Bulgarian Academy of Sciences, Sofia (in Bulgarian)
7. Ivanov I., Bournaski E. 2019. Suspended sediments and water flow of the Mesta river on the territory of Bulgaria., Proc. 19th Int. Conf. Transport and Sedimentation of Solid Particles, Cape Town, (Eds. J.Sobota and R. Haldenwang), ISSN 0867-7964, pp.319-326.
8. JICA, 2008. The study on integrated water management in the Republic of Bulgaria, Japan International Cooperation Agency, March 2008.
9. Mandev, A., 1974. On the relation of heavy rainfall to soil erosion with a view to its prediction, Forestry Science, 1, 52-61 (in Bulgarian)
10. NIMH, 2022. National Institute of Meteorology and Hydrology, 2021 Annual Hydrometeorological Bulletin
11. Papazov, R., 1970. Turbidity and sediments of rivers in Bulgaria. Proceedings of the Institute of Water Problems, Volume XII, BAS Publishing House, 111-142 (in Bulgarian)
12. Petkov, Al. D. Pechinov, 1958. Floating sediments of the rivers in Bulgaria. Works of the IHM, I, 3-64 (in Bulgarian)
13. Pechinov, D., 1963. Sediments from small catchment areas and silting of small dams., Works of IHM, XIV, 141-163 (in Bulgarian)
14. Pechinov, D., 1970. On some questions about the formation and regime of suspended sediments on rivers in Bulgaria. Proceedings of IHM, XVII, 5-57 (in Bulgarian)
15. Simons, D., Senturk F.1977. Sediment Transport Technology: Water and Sediment Dynamics, ISBN-13: 978-0918334664 ISBN-10: 0918334667
16. Terms of Reference, 2004. Terms of Reference for the Development of the River Basin Management Plan of the Ministry of Environment and Water (in Bulgarian)
17. Vezev, L., Nikolov V. 1968. On the anti-erosion effect of some tree and shrub species in the lower forest zone of the Sandanski region., Forestry Science, 1, 31-39 (in Bulgarian)