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SUSPENDED SEDIMENTS AND WATER FLOW OF THE MESTA RIVER IN BULGARIA

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This study aims to quantify the sediment formation of the semi-mountainous Mesta river, characterized by moderate continental and alpine climate, with a Mediterranean influence in the lower reaches. The relation between the water discharge (*Q*) and suspended sediment concentration (*SSC*) at three characteristic points along the river has been analysed based on continuous measurements of the gauge stations in the territory. The floating sediments uniformly distributed along the water section are determined by criterion for solid particles size. The dependence of the sediment quantities from the high water caused by rainfall and snow melting in the river basin, related to the cold Atlantic cyclones or warm Mediterranean influence, is also distinguished.

KEY WORDS: suspended sediments, water flow, river basin, climate

1. INTRODUCTION

For the rational and sustainable use of the waters in a river basin, data are necessary not only for the amount of river runoff, but also for the floating sediments. The data for the sediments and their distribution according to the particles size is also necessary when designing water reservoirs, in particular within the process of determining the dead-storage capacity of the reservoir, water intakes, pumping stations, channels and irrigation systems, for the purposes of water supply, etc. The beginning of regular suspended sediment measurements in Bulgaria dates back to 1951 as a response to the needs of hydrotechnical construction, Bournaski et al. (2008), Gergov et al. (1991).

Sediment is the product of weathering of rocks. The picture of the sediment movement in a global aspect was described by Holman (1968). According to him, there are about 20.10^9 tones of alluvium, annually entering into the world's oceans, which is equal to the speed of denudation of 75 mm for 1000 years.

The formation of sediment and its transport in the Mesta River is reviewed in this paper, as well as the factors influencing this process – natural and anthropogenic, and their relation to water flow. Mesta river is a trans-boundary river in Bulgarian territory flowing into Greece. Data is presented on quantities of floating sediment at characteristic points along the length of the river.

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2. RIVER BASIN DATA

For the beginning of the river a spring was accepted at 2240 m altitude in the Rila Mountain, which is the highest mountain in Bulgaria, as well as the Balkan Peninsula. From the beginning to the Greek border (at 388 m elevation), the length of the river is L = 125.9 km. To the north, the river's drainage basin flows through parts of the Rila Mountains, then on the west of the Pirin mountains and then on the east of the Western Rhodopes. There are two valleys located at the foot of these mountains: Razlozhka – with average attitude of 850 m, and Gotsedelchevska – with average attitude of 510 m. The structure of the river basin varies widely due to physical and geographic conditions. The average attitude is 1318 m. Overall, 32% of the drainage basin is higher than 1400 m. The total river basin area in Bulgaria is 2767.1 km^2, Ivanov (2004), 49% of which are forests. There are 93 settlements situated in the drainage basin, six of which are towns, with a total population of about 133,851 Ivanov (2004). The catchment area is a unique natural system with abundance of water resources. There are two artificial reservoirs along the river for electric power production and irrigation purposes in the Greek territory.

3. FORMATON OF THE SEDIMENTS

The suspended sediment in the river and its tributaries is material from the surface of the river basin, which enter the rivers under the influence of different forces. The main amount of sediment is due to surface erosion in the catchment and river erosion in high areas of Mts Rila, Pirin and Rhodopes. The result of these erosion processes is variable both during the different seasons of the year, and during the high-water waves. The distribution of the solid particles along the stream section and their velocity of movement depend on the size and the density of the particles, on the one hand, and on the other – the velocity and the temperature of the carrier liquid. Depending on how they are being transported, the sediments are divided between bottom sediments (dragging along the bottom) and floating sediments.

The bottom sediments consist of large materials – rock pieces, stones, gravel and large sands. They move by rolling, jumping or dragging along the stream bottom. Their movement is possible only when the velocity of the carrier turbulent flow is bigger than a certain terminal velocity (critical or drag velocity).

Floating sediments are small particles – clay, small sands, etc. Depending on the size of the particles and their density, they can be evenly or irregularly distributed along the stream section. The particles that are uniformly distributed along the stream section move with a velocity equal to the velocity of the carrier liquid. In this uniform state can be particles with diameter $d \leq \sqrt{1{,}8 \frac{\nu_0^2}{g} \frac{\rho_0}{\rho_s - \rho_0}}$, Ivanov (2001), where ν_0 is the coefficient kinematic viscosity of the carrier liquid; ρ_s – density of the transported solid particles; ρ_0 –water density; g – acceleration due to gravity. The solid particles of larger diameter than the so determined d are unevenly distributed along the section and the character of their distribution is determined by the diffusion theory.

Dividing the sediments into bottom and floating is conditional; depending on the state of the stream over time and according to the location along the river length. Particles from the bottom alluvium can be transported by floating and vice versa.

The formation of the sediments and their type of transportation depends on many natural factors, the main ones being: precipitation - its type, quantity and intensity; geological structure; steepness and slopes area; the density of the river network; and the soil type. The influence of these factors in the drainage basin of the Mesta River has not been well studied, Bournaski et al. (2008), Gergov et al. (1991). There is no in-depth study about the way that varied human activity in the river basin reflects on the processes of sediment formation. In general, it is known that human activity has an influence on the erosion processes in the river basin and watercourse, as well as on the transport of the eroded materials. This influence in the river catchment and watercourse is multi-faceted. The surface washing-out and erosion in the mountain slopes of the drainage basin can be vastly decreased with increase in the density of plant cover. Wischmeier and Smith (1956) showed that by only increasing the grass cover over unusable land it is possible to decrease the soil loss up to 250%. On the hand, decreasing forests, contributes to the development of intensive soil erosion, and their complete destruction leads to a dramatic increase in the volume of solid sediments. The construction of access roads in forests and other parts of the catchment areas, forest and grass fires also contributes to increased surface erosion and increased sediment deposition. The way in which agricultural land is ploughed in the drainage basin also has an influence. According to Piest et al. (1968) planimetric ploughing in fields with slight slopes and low-wide soil layers allows decreasing the erosion with 50% in comparison to ploughing in length. Terracing of slopes is also a measure for decreasing the erosional volumes, entering into the river tributaries and in the river itself. Human activity in settlements, such as construction and roads repair, laying sewerage, sanding roads during winter period, etc., all contribute to the entering of solid particles in the river. Many of these factors are present in the catchment of the Mesta River, but unfortunately for now it is impossible to quantify their impact.

The activities in the riverbeds and its tributaries also have an influence on the sediments. The extraction of sand and gravel from pits in riverbeds and from flooded banks is especially harmful. As a rule, the regulation of the river's watercourse with the aim to improve the hydraulic characteristics of the stream, contributes in developing and increasing the sediment transportation. Our researches, Ivanov (2004), show that there are such corrected sections in the watercourse of Mesta, which are mainly connected to the road line Razlog – Gotse Delchev and in some of its tributaries, such as Kanina River in the lower stream and Glazne River in the territory of the town of Bansko.

4. SEDIMENTS OF THE MESTA RIVER

For the sediment load of the Mesta River we can judge according to the visual observations we have made and the experimental data about the floating sediments at three hydrometric monitoring stations along the river – Yakoruda in the upper stream of the river, Momina Kula in the middle stream and at Hadzhidimovo in the lower stream, Gergov et al. (1991), Hydrologic guide (1984). Sample collection and processing is carried out in accordance with the Bulgarian State Standard and the relevant instructions of the Bulgarian

Academy of Sciences, Gergov et al. (1991). The experimental data of the sediments are jointly reviewed with the experimental data of the water quantities. There is close connection between the water quantity and sediment quantity of the Mesta River. The river flow is genetically a product of the climate, i.e. a result of the active influence of precipitation, temperature and evaporation. The precipitations in the basin are the main component. The climatic conditions in the catchment are quite different. When examining the territory along the main river, Mediterranean climatic influences, then moderate continental and finally alpine influences can be seen. This has an effect on the flow regime and the sediments and their intra-annual distribution. It is shown on the multiannual average statistical data about the flow in the three monitoring stations of the river Ivanov (2005), that two main phases are distinguished in the regime of the intra-annual distribution of the river flow: spring-summer abundance of water with maximum flow in May and summer-autumn low water with a minimum in August-September. After the summer-autumn low water, there is a third phase – late autumn-winter, which is characterized by a slight and gradual increase of the river flow (September, October, November), typical for the river tributaries and the river itself with a drainage basin at altitude above 1500 m.

The origin of sediment in the Mesta River catchment is considerably more complicated than those of the water quantity. It depends on both climatic conditions, and physico-geographic features of the catchment area. However, for the conditions of the Mesta River the rainfalls and snowfalls are determining. This determines the relation between the river water runoff and the sediment runoff in both intra-annual and in multi-annual aspect. The influence of the high water floods in the catchment area is specific. They are accompanied by intensive sediment formation. The total floating sediment in some of the high water floods can reach up to 60% and more of the annual sediment flow.

High waters in the Mesta River catchment are not uncommon. They can occur in almost all annual seasons, Ivanov et al. (2005). During the cold part of the first half of the year, the precipitation processes of the Mediterranean influence have a particular role for the high-water floods, and during the warmer half of the year – rainfalls, caused by the cold Atlantic cyclones. The strongest influence is from the high waters with maximum water quantities simultaneously resulting from rain and melting snow. Such high waters in the catchment occur during January, February, March and even during April.

The high waters at the Yakoruda point in the upper stream of the river and those at Momina Kula and Hadzhidimovo are genetically different, Hydrologic guide (1984). At Yakoruda point, characterized by tributaries from the Rila Mountains, storm and rain waters are dominant, occurring during May, June, July and August. The curve of the average multi-annual monthly distribution of the water discharge Q at this point is geometrically similar to the curve of the average multi-annual monthly quantity of the sediments *SSC*, and this is shown in Figure 1.

At the points of Momina Kula and Hadzhidimovo, where the influence of the river's tributaries from Mts Pirin and West Rhodopes is typical, the dominant high waters are snow-rainy waters and rain-snowy waters. A significant part of this occurs during January - March. Stormy-rainy high waters in May and June are frequent for these points. Typical for these two points is that most of the high waters occur at the same time, which has a significant influence on the sediments and their intra-annual distribution. The simultaneous high water flood along the entire catchment of the Mesta River has been registered in 15-

16 March 1962, respectively with 190.84 l/s/km^2 in Yakoruda point; 347.0 l/s/km^2 in Momina Kula point and 318.6 l/s/km^2 in Hadzhidimovo point, Hydrologic guide (1984).

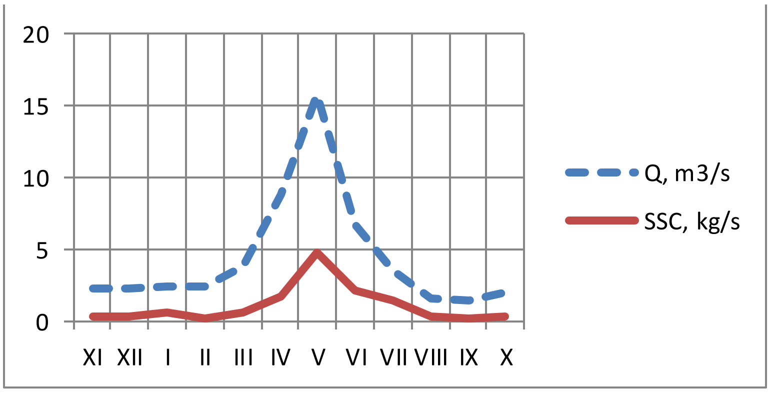

Figure 1. Average monthly water (Q, m^3/s) and suspended sediment (SSC, kg/s) quantities at Yakoruda monitoring station with drainage basin area 261.8 km^2. Average multiannual: SSC_{av} = 1.1075 kg/s; Q_{av} = 4.343 m^3/s; alluvial module 134 t/km^2; turbidity SSC_{av}/Q_{av} = 255 g/m^3.

High waters have a significant effect over the shape of the distribution curve of the average monthly quantity of floating sediments. This curve for Momina Kula and Hadzhidimovo is not geometrically similar to the curve of the average monthly water quantity.

Shown graphically on Figures 1, 2, and 3 are the average multi-annual monthly water (Q, m^3/s) and sediment (SSC, kg/s) quantities at the three points of Yakoruda, Momina Kula and Hadzhidimovo for the period starting from 1955, Bournaski et al. (2008), Hydrologic guide (1984). From the Yakoruda data in Figure 1 it can be seen that both curves are similar in the nature of their change. The maximum sediment quantity occurs during the most intensive entry of waters in the river, i.e. during the most intensive taking out of erosional materials from the river basin in this section. This explains the coincidence of the maximum of quantity of the floating sediments with the maximum of the water quantity. This nature of change of the curves of water discharge and sediments is typical for small rivers with small drainage basin areas, such as Mesta River is in its upper stream. The drainage basin in this section of the river is mountainous, with a large slope and covered with forests. The surface of the soil is frozen or covered with snow during the beginning of the spring high waters, and therefore alluvial material removal is insignificant, as is the sediment flow of the river. During the winter months (November, December, January and February) the area of the river catchment in this section is snow-covered or with frozen surfaces. The erosional material from the surface of the drainage basin does not practically go into the river. The alluvial material is from the river erosion and is practically insignificant and constant in time. In the beginning of spring (February, March) and during the spring high water there is alluvial material entering in the river flow from the area of the drainage basin and the floating sediment starts increasing, reaching its peak in May.

During the summer period (May – September), i.e. the period of decreasing the water quantity, the sediment flow is also decreasing, following the course of the change in water discharge. In the period of summer low water, the alluvial flow is formed by the floating sediments. It could be assumed that the floating sediments are dominant during the period of the spring high water. For this upper section of the river, upon high waters from rain and snowmelting or from intensive rain pouring into the drainage basin, the alluvial flow is an aggregate of bottom floating sediments. The bottom sediments, depending on their size, when entering the river into the plain, are gradually deposited at a considerable distance along the river.

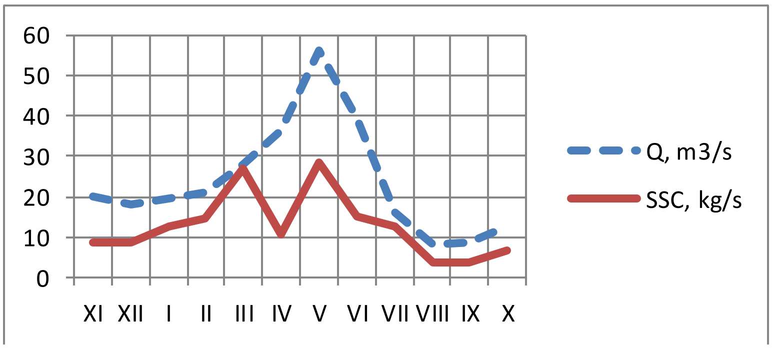

Figure 2. Average monthly water (Q, m^3/s) and suspended sediment (SSC, kg/s) quantities at Momina Kula monitoring station with drainage basin area 1510 km^2. Average multiannual: SSC_{av} = 12.578 kg/s; Q_{av} = 23.673 m^3/s; alluvial module 297 t/km^2; turbidity SSC_{av}/Q_{av} = 532.41 g/m^3.

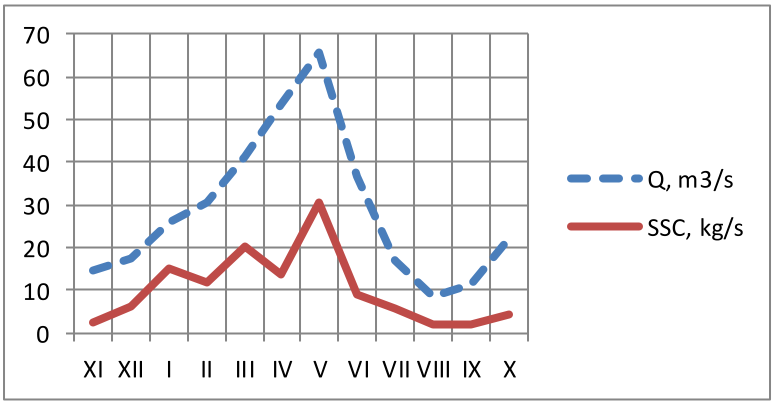

Figure 3. Average monthly water (Q, m^3/s) and suspended sediment (SSC, kg/s) quantities at Hadzhidimovo monitoring station with drainage basin area 2260 km^2. Average multiannual: SSC_{av} = 10.2 kg/s; Q_{av} = 30.0 m^3/s; alluvial module 142 t/km^2; turbidity SSC_{av}/Q_{av} = 340 g/m^3.

If we compare the data from Figure 2 and 3 with the data from Figure 1, it can be seen that the curves of the water discharge Q at the three river points are similar. The similarity is especially between Q at measuring stations Yakoruda and Momina Kula.

The picture concerning the floating sediments *SSC* is a little bit different. At Momina Kula and Hadzhidimovo, there is no similarity between the change of the water flow Q and the sediment *SSC*, but the maximum of the sediment flow coincides with time with the maximum of the water in May. The minimums also coincide. This characteristic curves change for the floating sediment flow *SSC* Momina Kula and Hadzhidimovo is caused by the influence of the high flows from partial high waters in the drainage basin of these two hydrometric points as a result of the Mediterranean climate influence in the area.

5. CONCLUSIONS

The suspended sediment load of the Mesta river demonstrates large variability in time and space. Reasons for the high sediment loads are the steep slopes of the river valleys, deforestation on some mountain sides, lack of plants above a certain altitude and some anthropogenic impact resulting in extreme surface erosion processes. This study was based on the visual observations we have made and the limited experimental data of the floating sediments at three hydrometric monitoring stations along the river. The interdependence of sediment quantities from the water runoff was analysed. There is no data available for the bottom sediments of the Mesta River in the national monitoring network of the country.

The study shows that the formation of floating sediments is mainly influenced by climatic characteristics with specific rainfall and physico-geographic features of the Mesta catchment area. The influence of the entering water flows from high waters caused by alpine climate and Mediterranean influence in the lower reaches of the river is particularly strong. A more in-depth study on the impact of anthropogenic factors on the process of alluvium formation in the catchment is needed.

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