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Original scientific paper

CHARACTERIZATION OF THE COASTAL SEDIMENT FROM THE RIVER OF VARDAR, RIGHT BEFORE THE CONFLUENCE WITH THE TRESKA RIVER

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A b s t r a c t: This study was based on the characterization of the coastal sediment from the river of Vardar, right before the confluence with the Treska river. The mineralogical composition of the river sediment was determined by X-ray analysis. The granulometric distribution of the grains from the river sediment was determined as a basic parameter that has an impact on its physical properties. A microscopic observation on various dimensional fractions of the grains were performed. The porosity and capillary system of the river sediment in correlation with the structure was defined. The transfer of moisture horizontally and vertically from the water line was examined. Therefore, the heat transfer was monitored by measuring the temperature at various depths (0, 5, 10 and 15 cm) and various distances (1, 1.5 and 2 m) from the river water line. The properties of the river sediment are affected by the deposited minerals and organic material from the river basin, as well as horizontal and vertical transfer of moisture and heat.

Key words: Vardar; river sediment; characterization; temperature; moisture

КАРАКТЕРИЗАЦИЈА НА КРАЈБРЕЖНИОТ СЕДИМЕНТ ОД РЕКАТА ВАРДАР, ПРЕД ВЛИВОТ НА РЕКАТА ТРЕСКА

А п с т р а к т: Оваа студија се базира на карактеризација на крајбрежниот седимент од реката Вардар, пред вливот на реката Треска. Минералошкиот состав на речниот седимент беше определен со рендгено-структурна анализа. Гранулометриската дистрибуција на зрната од речниот седимент беше дефинирана како основен параметар кој има влијание на неговите физички особини. Беше направен микроскопски преглед на различните димензиони фракции на зрна. Беа објаснети порозноста и капиларниот систем на речниот седимент во корелација со структурата. Беше испитан трансферот на влагата, хоризонтално и вертикално од речната линија. Преку мерење на температурата на различна длабочина (0, 5, 10 и 15 cm) и различно растојание (1, 1.5 и 2 m) од речната линија беше мониториран и трансферот на топлина. Особините на речниот седимент зависат од депонираните минерали и органска материја од речниот басен, како и од хоризонталниот и вертикалниот трансфер на влага и топлина.

Клучни зборови: Вардар; речен седимент; карактеризација; температура, влага

1. INTRODUCTION

The coastal river sediments are mainly contained of mineral grains. The mineral grains were formed by the physical and chemical weathering of the rocks. The grains have different mineral composition, and thus a various specific mass which is crucial for the formation of the river sediment. Also, grains vary in size and shape, from large boulder stones to colloidal-sized segments, rounded to angular-shaped. The dominant grains in the river sediments are quartz and clay, depending on the mineralogical composition of the terrain [1–3]. Examination of the sediment provides a data on the sediment origin, composition, structure and properties [4, 5].

The coastal river sediments are important in the water resources management [6, 7]. The Republic of North Macedonia is zoned in four river basins: Vardar, Strumica, Crn Drim and Južna Morava. The watershed regions of the river basins are presented and examined by Jovanovski [8], through his hydrogeological survey of the groundwater in Macedonia. Additionally, geology and diverse geological formations in the Republic of North Macedonia, defined in previous studies, have resulted in a complex geological database [9–15].

Taking all into consideration, it led to the idea of delivering a comprehensive review of the mineral coastal sediment from the river Vardar through the analysis of sediment near the basin of the river Treska. Near the course of the river Vardar, a few kilometers above the defined sample points, there is a travertine mine – Svilare [16], as well as few kilometers above it, a chromium and iron mine – Raduša [17] is located. Some of the identified minerals in the river sediment are expected to originate from there

2. MATERIALS AND METHODS

The Vardar River basin is the largest watershed in the Republic of North Macedonia. It is linked with a several smaller sub-watersheds of the rivers: Treska, Crna, Pcčsnja, and Bregalnica. The surface waters from the northwest massif arrive from the elevated zones of Shar Mountain. They overflow and deposit a large quantity of the river sediment [18]. The examination area of this study is located near (before) the confluence with the river Treska into Vardar (Figure 1).

Therefore, two sample points are defined, named as sample point I and sample point II (Figures 2 and 3). Sediment samples for analysis were collected at various distances of 1, 1.5 and 2 m (properly named as 1, 2 and 3) from the river water line.

(a) Geographical map

(b) Satellite map

Fig. 1. Location of the examination area

Fig. 2. Sample point I

Fig. 3. Sample point II

Mineralogical composition of the river sediment was defined on DRON X-ray diffractometer ($2\theta = 2 – 60^o$; *UA* = 38 kV; *IA* = 18 mA; 1°/min; CuKα/Ni). The wet sieve analysis was used to determine the granulometric composition of the river sediment and was performed on a set of standard sieves with a perforation size of 0.125 mm, 0.100 mm, 0.071 mm, 0.050 mm, and 0.032 mm. Various dimensional fractions of grains were observed on an optical microscope type SN-POL, Leitz-Wetzlar [19, 20].

Also, the temperature and moisture of the river sediment were measured at various distance from the river water line (1, 1.5 and 2 m), and at various depths (0, 5, 10 and 15 cm). The temperature of the sediment was measured on a thermometer type TECPEL DTM-3102, and the moisture was measured on a moisture meter type PMS-714.

3. RESULTS AND DISCUSSION

The X-ray analysis identifies the minerals present in the river sediment. XRD on Figure 4 indicates the dominant content of quartz, calcite and albite. Muscovite and clinochlore exist in a smaller quantity.

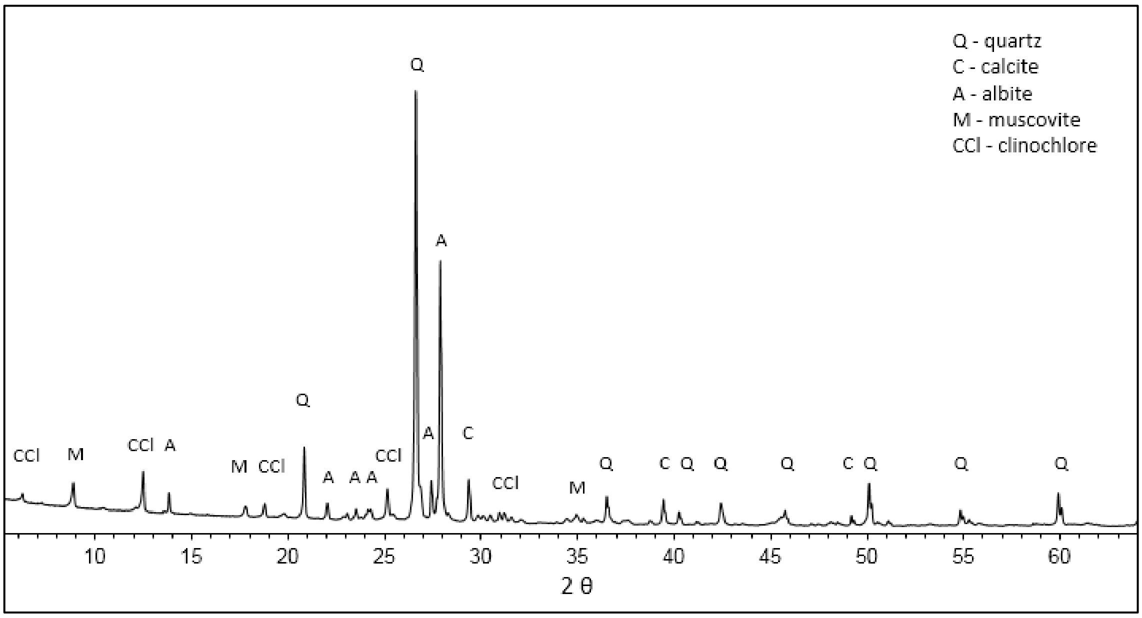

Fig. 4. XRD of the coarse fraction of grains (+0.125 mm)

The chemical composition of the coarse fraction of grains (+0.125 mm) was determined by silicate chemical analysis. The results are presented in Table 1.

Table 1

Chemical composition of the coarse fraction of grains (+0.125 mm), (mass %)

SiO_2	76.32
Al_2O_3	8.04
Fe_2O_3	2.18
CaO	3.16
MgO	0.43
Na_2O	1.95
K_2O	1.24
SO_4	tr.
l.w	6.03
Σ	99.35

The sum of the chemical analysis is 99.35%, while the remaining 0.65% are admixtures.

The granulometric composition of the river sediment was determined by wet sieve analysis (Table 2). In all samples collected for analysis, the dominant dimensional fraction of grains with over 60% of mass content is the coarse fraction (+0.125 mm).

Table 2

Granulometric composition of the river sediment, (mass %)

Dimensional fraction of grains (mm)	I.1	I.2	I.3	II.1	II.2	II.3
+0.125 mm	78.46	78.78	60.66	84.98	81.97	83.45
–0.125 +0.100 mm	3.38	3.12	2.87	2.60	2.66	2.30
–0.100 +0.071 mm	8.59	6.90	19.56	4.17	6.16	3.89
–0.071 +0.050 mm	4.90	4.12	4.94	3.50	4.45	4.05
–0.050 +0.032 mm	1.67	3.96	6.77	1.72	1.75	2.77
–0.032 mm	3.01	3.12	5.21	3.05	3.02	3.55
Σ	100.00	100.00	100.00	100.00	100.00	100.00

The finer fractions have a minimal content and are almost equally represented in all examined samples (Figure 5), with a slight deviation in the sample I.3 (collected from sample point I at distance 2 m from the river water line), where an increased content of 19.56% of the fraction (–0.1 + 0.071 mm) can be noticed.

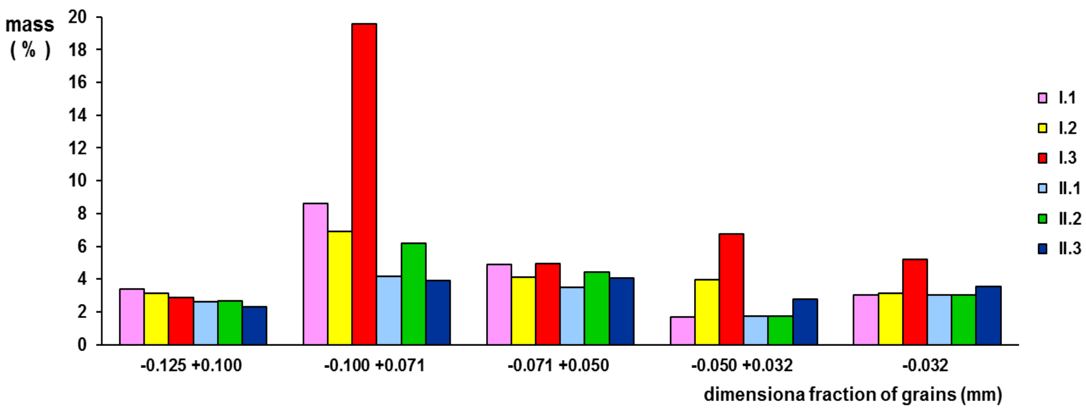

Fig. 5. Histogram of mass content of the finer fractions of grains

This granulometric distribution indicates the dominance of the capillary network among the coarse grains. There are finer grains in the interstices that create smaller capillaries. The existence of capillaries of various sizes reflects on the heat transfer and moisture retention of the river sediment.

Quartz, calcite and feldspars are dominant in the coarse fraction of grains (+0.125 mm) from wet sieve classification. Clay and other minerals as admixtures are present. Due to the clay, the grains form light-brown coloured aggregates with irregular shapes (Figure 6).

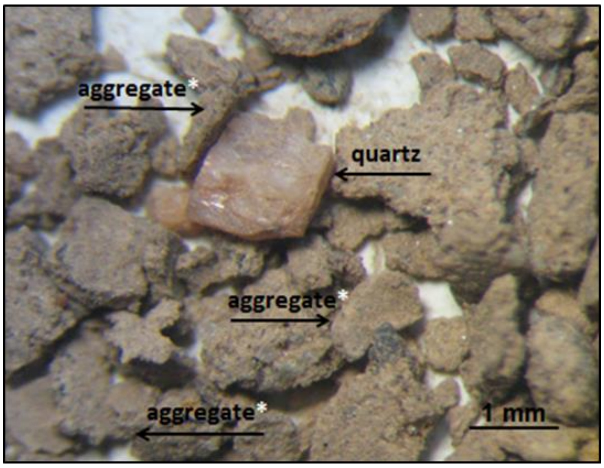

Fig. 6. Microscope image of fraction of grains (+0.125 mm)

They were treated with HCl acid (10%) and had an intensive reaction. It can be observed that the creamy-white quartz grains are dominant. The grains are angular shaped as if they had not been transported. Feldspar grains and metallic-black mineral grains (probably Fe-Mn oxides) are also present in minimal quantities. These grains are irregular, with elongated angular shapes. Muscovite is a minor admixture. The slightly-greenish grains of chlorites (clinochlore) with irregular shapes are as well rare (Figure 7).

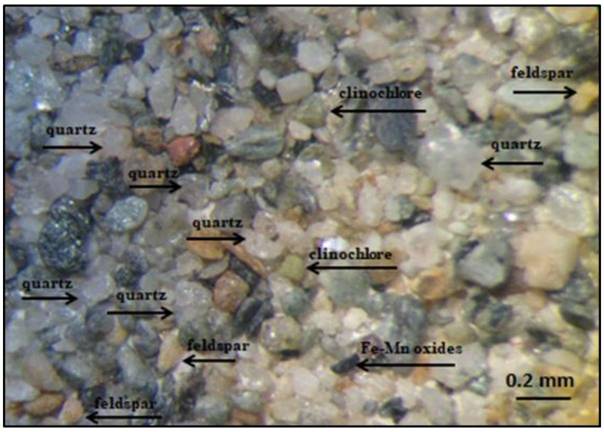

Fig. 7. Microscope image of fraction of grains (+0.125 mm) after treatment with HCl acid (10%)

Observing the fine fraction it can be confirmed that it has a similar mineralogical composition. Dimensional fraction of grains (-0.050 +0.032 mm) is presented on Figure 8. However, here, the individual mineral grains are not marked, due to their small size.

The content of carbonates in the river sediment was examined, as a segment of chemical analysis. It was determined in all fractions separately, as well as in the integral sample collected from both sample points. From the histogram on Figure 9, a gradual increase of the carbonates (calcite) content in the fine fractions was noticed. The phenomenon is natural and it is a consequence of the lower hardness of the calcite compared to the quartz. During the river transport there is a mutual friction, therefore, the softer mineral is transformed into the fine fractions of smaller dimensions. The insignificant reduction of the calcite content in the finest fractions is relative, due to the presence of clay which has fine dimensions by origin.

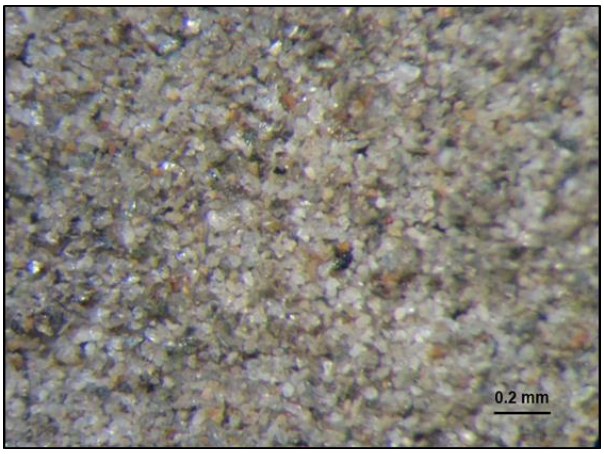

Fig. 8. Microscope image of fraction of grains (–0.050 +0.032 mm)

The content of organic matter in the river sediments was also determined, by heating the sediment samples at temperature of 600ºC (Table 3). The data vary in a small range from 1.21% to 1.82%. The variations are mainly due to two reasons: disproportionate distribution of the grains in various zones of the river sediment (clay grains are the dominant carriers of organic matter, which dominantly exist in certain zones), as well as the moisture content (which is carrier of dissolved organic matter that remains in the river sediment after drying).

Table 3

Content organic matter in the river sediment, (mass %)

Sample point	Organic mater
I.1	1.39
I.2	1.21
I.3	1.82
II.1	1.6
II.2	1.21
II.3	1.41

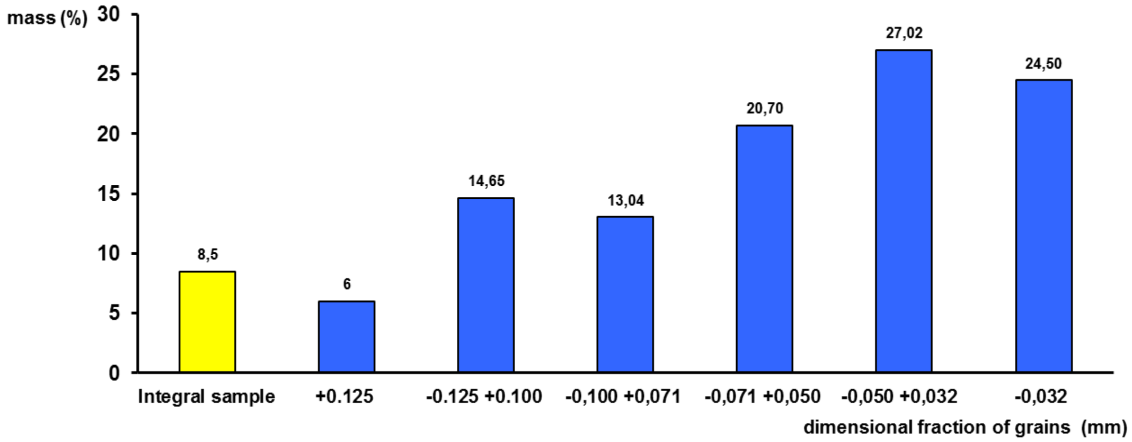

Fig. 9. Histogram of the carbonates content, mass (%)

The surface temperature of the river sediment mainly depends on sunlight exposure (Figures 10 and 11). Deeper in the river sediment the temperature is approximately constant due to the kinetics of penetration of the atmospheric temperature. There is some deviation at II.2 where the lowest temperature was measured since it was covered in shade.

The moisture increases deeper into the river sediment (Figures 12 and 13), as a consequence of the terrain and the influence of the root system of the nearby plants. An additional factor that has an impact is the exposure of sunlight, or if the measure point is in the shade.

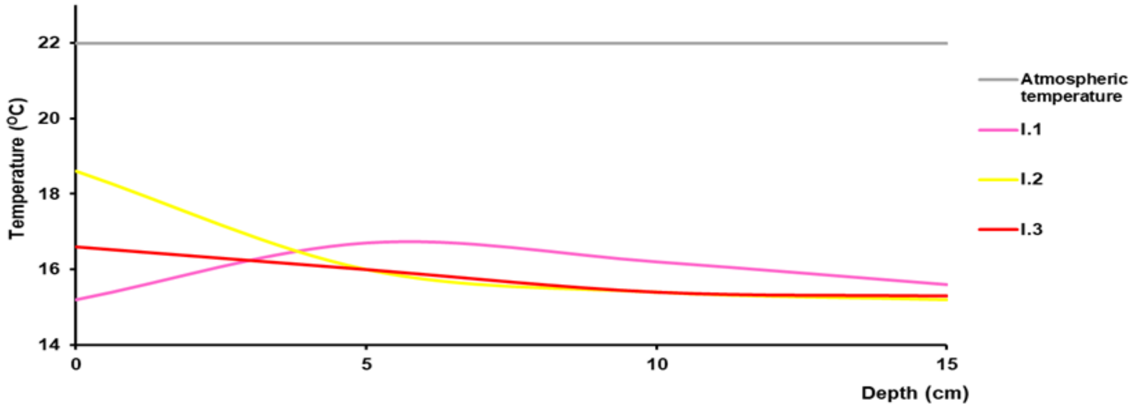

Fig. 10. Temperature of the river sediment at sample point I

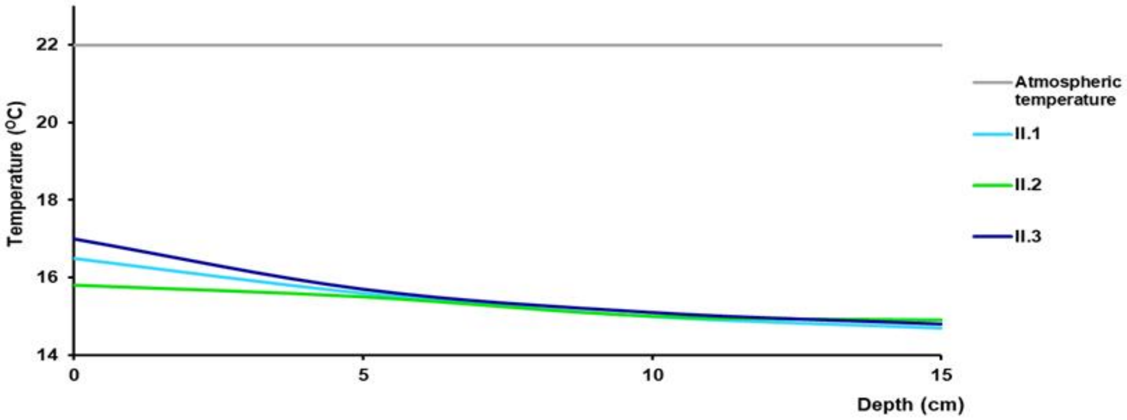

Fig. 11. Temperature of the river sediment at sample point II

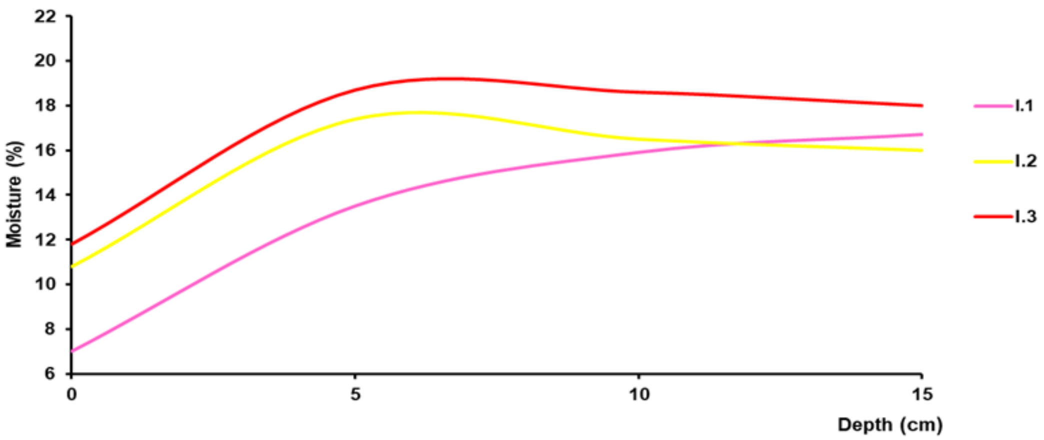

Fig. 12. Moisture of the river sediment at sample point I

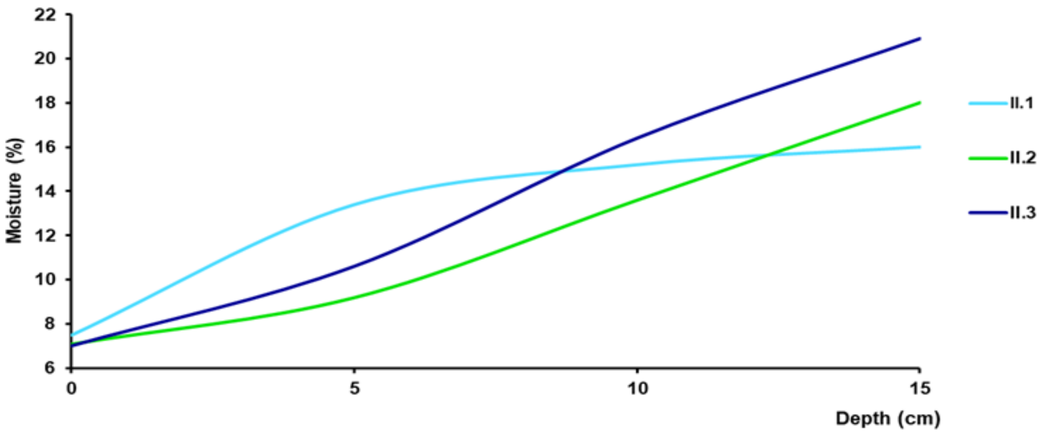

Fig. 13. Moisture of the river sediment at sample point II

The deviation of the moisture values at depth of 15 cm is probably affected by the zonal inhomogeneity of the sediment. The two dominant differently colored layers are visible, which has various water affinity (Figure 14). There is a minimal deviation of the moisture values at sample point I, as a consequence of different physical and chemical properties of the sediment layers.

Fig. 14. Zonal inhomogeneity of the river sediment – layers in different colors

The measured temperature and moisture of the river sediment are influenced by several factors: mineralogical composition, granulometric distribution of the grains, level of the river water line, distance from the water line, depths of the sediment layer, day-night temperature oscillations etc. The noticed phenomena occur on intermediate boundary of water-air-soil (river sediment). The presented data on Figure 15 are based on the water line. At minimal distance from the water line, certain temperature deviations were noticed in the river sediment (lower values were measured), under the influence of the lower values of the atmospheric temperature at night. Therefore, under the influence of the higher values of the atmospheric temperature during the day, an increased temperatures of the river sediment were measured as a consequence of the heat transfer.

The heat transfer is more intense vertically in the sediment (through the boundary with atmospheric air) than horizontally (river water penetrates through the pores and capillaries of the sediment). At longer distances from the river water line, horizontally the temperature of the sediment equals the temperature of the water, which is constant all day-night cycle. At depth of 20 cm from the surface (and at the level of the water line) the atmospheric temperature is no longer affected, i.e. there is a constant temperature in the river sediment. Indeed, at more intense temperature changes in the atmosphere (extremely high temperatures in summer or extremely low temperatures in winter), the distance from the surface with a constant day-night temperature in the sediment would deviate. The heat transfer through the sediment is carried by two media: the mineral grains and the water circulating through the capillary system. The values for the measured moisture of the river sediment indicates inhomogeneous distribution, i.e., deviations at various distances from the river water line and at various depths in the sediment.

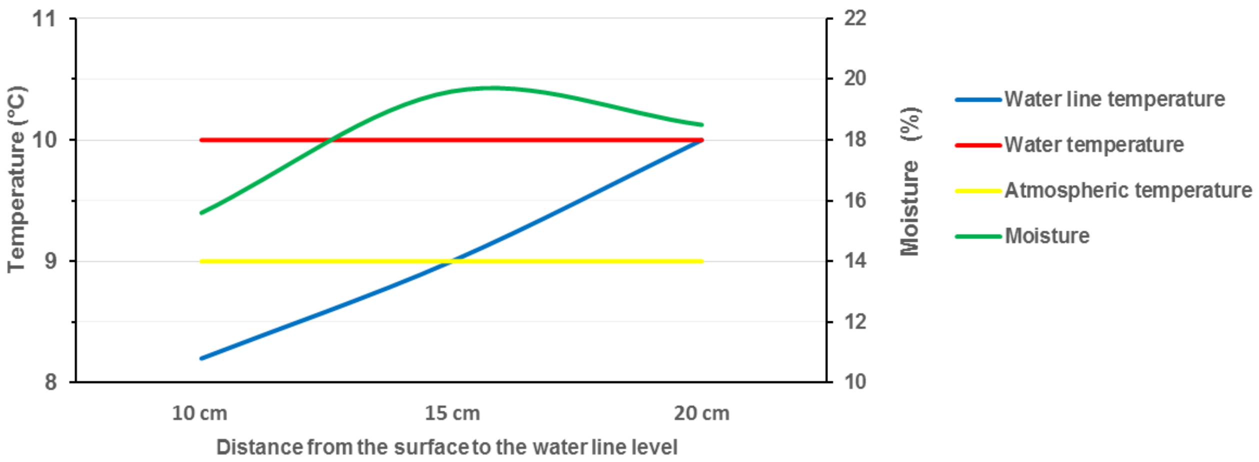

Fig. 15. Temperature and moisture of the sediment in correlation with atmospheric temperature, distance from river water line and depths of sediment layer

This phenomenon can be explicitly explained by the data from the granulometric analysis, where the dimensions and the ratio of mineral grains in the sediment are defined. The dimensions of the grains define the capillary characteristics; therefore, it is logically that homogeneous sedimented medium (sedimentation under laminar conditions) has a defined regularity of moisture distribution. In this case, the sedimentation was performed under turbulent conditions, caused by the various regimes of the river flow. Therefore, the mineral grains were not always evenly sedimented, creating zones with different granulometric characteristics.

This phenomenon was observed on the vertical profile of the sediment (Figure 14), where two unevenly distributed horizontally zones of different color exist.

4. CONCLUSION

This study defines characteristics of the coastal river sediment from the Vardar river, near the confluence with the river of Treska. The sediment samples for analysis were collected from two sample points at various distances of 1, 1.5 and 2 m from the river water line.

X-ray analysis detected quartz, calcite, and albite. Muscovite and clinochlore are admixtures. The coarse fraction (+0.125 mm) and the fine fraction (–0.125 mm) have a similar composition with minimal deviation of the ratio of the minerals. Microscopic observation confirms the identified minerals on the XRD. Relatively sharp edges and irregular shape on the mineral grains, suggests of transport at minimal distance in the riverbed. In the river sediment the coarse fraction (+0.125 mm) with over 60 % has a dominant mass content. In the coarse fraction the grains are aggregated due to the presence of clay. The content of calcite increases in the finer fractions, as a consequence of the friction during the transport. The content of organic matter has certain variations depending on the annual seasons and the hydrological condition.

The measured temperature of the river sediment indicates the influence of different factors: distance from the water line, depths of the layer, atmospheric temperature, water temperature, period of the day, period of the year etc. The measured values pointed-out that the moisture increases deeper into the river sediment. The structure of river sediment has an impact on the distribution of moisture. Moisture is affected by the capillary network, which depends on the granulometric composition of the river sediment. Also, the moisture is correlated with the hydrological conditions.

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