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Comparison of Some Physical Properties of Soil and River Sediment

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ABSTRACT: In this research, a comparison of some physical properties of two natural media was made, namely, a selected soil sample from the northwestern segment of the Skopje valley and a sample of river sediment from the river Vardar. The primary parameters of the samples are determined, such as: granulometric composition, specific mass and volume mass in different compacted condition. The secondary physical characteristics are followed, which are a consequence of the previously listed, which are the porosity of the samples and the capillary characteristics. These, further define the following characteristics of the media: maximum water permeability, characteristics of the water transport process and heat transfer through the examined sample layer. Simultaneously, the changes of temperature and moisture at a defined point of the experimental layers are monitored (under appropriate experimental conditions, namely, an emphasized / amplified ΔT is set) and the phenomena are explained.

Keywords: soil, river sediment, porosity, heat transfer, water permeability.

INTRODUCTION

A several mechanisms of the heat transport through soils and river sediments are well-known. An advantage in studying thermal processes is the heat itself which, as a significant indicator offers the opportunity to monitor it advantageously (Kalbus et al., 2006). The heat transport in soils is an outcome of the exchange of energy transfer mechanisms, especially near the soil surface, depending on the thermal properties of the soil. The main thermal feature includes the specific and volumetric heat capabilities, thermal conductivity, and diffusivity (Usowicz, 1992, Hiraiwa et al., 2000). Even though the exact features can be included in the river sediments, it has recently been reviewed that the thermal characteristics of sediments vary less than the hydraulic properties (Anibas et al., 2011). Due to the small range in values, the thermal properties are rarely estimated on the spot, yet their values are given based on published data (Anibas et al., 2011, Schmidt et al., 2006, Anibas et al., 2009, Jensen et al., 2011, Meinikmann et al., 2013). Adequate porosity is the portion of absolute porosity that grants fluid flow (Stephens et al., 1998, Sheckelford et al., 2013). The grain dimensions, shapes, and arrangement are the essential parameters that affect the porosity and permeability in unconsolidated sediments and soils. For example, the adequate porosity of an analyzed soil sample can influence not only the heat flows via the respective solid and fluid phases, it can impact the heat interaction between the two phases. Resuming to capillary force and relative permeability, both rely on the fluid-fluid and mineral-fluid interchange energies. If the capillary force disappears, the relative permeability of the phase evolves equivalent to its saturation level. The velocity of water interpenetration in the porous system is a function of the permeability, capillary force, water saturation, boundary conditions, interfacial tension, etc. (Graue et al., 2011, Mason et al., 2013, Zhang et al., 1996). Thus, for this paper, the properties of heat transfer and water permeability of two completely different systems, in terms of porosity, structure, and composition, have been studied simultaneously.

MATERIALS AND METHODS

The soil samples for analysis were collected from the micro-locality in the Skopje Valley, on the southern slope of the mountain Skopska Crna Gora. The river sediment samples for analysis were collected from the river Vardar, right before the confluence with river Treska (Figure 1).

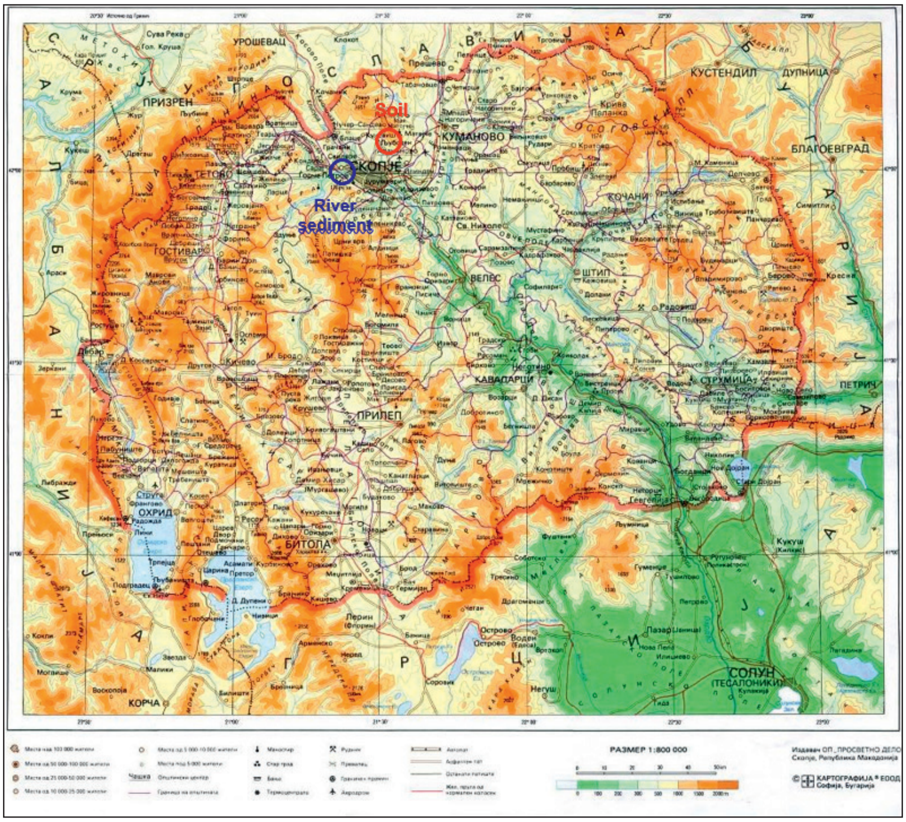
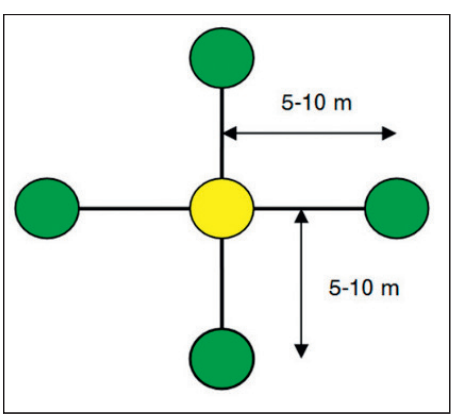


Figure 1. Geographical map of the Republic of North Macedonia with examined micro-localities



In order to reduce the probability of incorrect analysis, the material was collected as a composite sample. The material for analysis is a representative composite of 5 samples collected according to the specified sampling scheme (Figure 2). Therefore, the samples for analysis were collected from the primarily defined point, but also from its immediate surroundings.

Figure 2. Sampling scheme

As a natural media the soil and the river sediment are uninsulated open systems that permanently exchange energy and matter with the environment. These exchanges cause variations in the temperature and moisture. In the laboratory under adequate conditions, the water permeability was determined (Figure 3).

Figure 3. Laboratory experiment for water permeability

The heat transfer from the bottom up (simulation of winter conditions), was defined at higher temperature gradient. The temperature of the heating surface in the experiment was 180°C. The heat transfer mechanism is similar to the natural process, which has a lower temperature gradient. The temperature was measured on a thermometer type TECPEL DTM-3102, and the moisture was measured on a moisture meter type PMS-714 (Figure 4).

Figure 4. Laboratory experiment for heat transfer

The heat transfer and water permeability are affected by the structure. Therefore, the basic parameters were determined. The specific mass was determined on a pycnometer. The volume mass was determined using a graduated laboratory beaker. The porosity was also defined. Granulometric composition was defined applying a wet sieve analysis (Čankulovska et al., 2022, Šiškova et al., 2022). The mineralogical-petrographic examination was performed on the SM-POL Leitz-Wetzlar microscope.

RESULTS AND DISCUSSION

In Table 1 the determined physical parameters are presented.

Table 1. Physical parameters

	Specific mass (g/cm3)	Volume mass (g/cm3)	Porosity (%)
Soil	2.690	1.152	48.9
River sediment	2.725	1.272	50.1

The granulometric composition of the soil is presented in Table 2. The dominant grain fractions are the coarsest (+0.125 mm) with 32.86 % and the finest (-0.032 mm) with 40.89 %. In the soil, the relatively high mass content of the finest grain fraction (-0.032 mm) indicates a significant content of clay. Clay easily forms aggregates and lump, which modifies the properties of the soil (Figure 5).

Table 2. Granulometric composition of the soil, mass (%)

Dimensional fraction	Soil
+0.125 mm	32.86
-0.125 +0.100 mm	7.12
-0.1 +0.071 mm	8.05
-0.071 +0.050 mm	5.12
-0.050 +0.032 mm	5.96
-0.032 mm	40.89
Σ	100.00

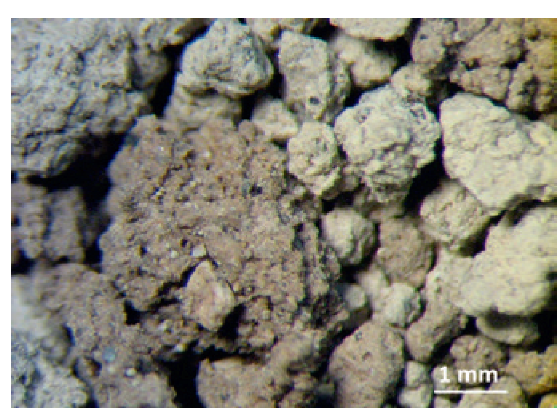


Figure 5. Microscope image of the soil

In Table 3 the granulometric composition of the river sediment is presented. The absolutely dominant, with a mass content over 77 %, is the coarsest fraction (+0.125 mm). The other fractions are evenly distributed and are present in a lower content (Figure 6).

Table 3. Granulometric composition of the river sediment, mass (%)

Dimensional fraction	River sediment
+0.125 mm	77.05
-0.125 +0.100 mm	2.82
-0.1 +0.071 mm	7.21
-0.071 +0.050 mm	4.32
-0.050 +0.032 mm	5.14
-0.032 mm	3.46
Σ	100.00

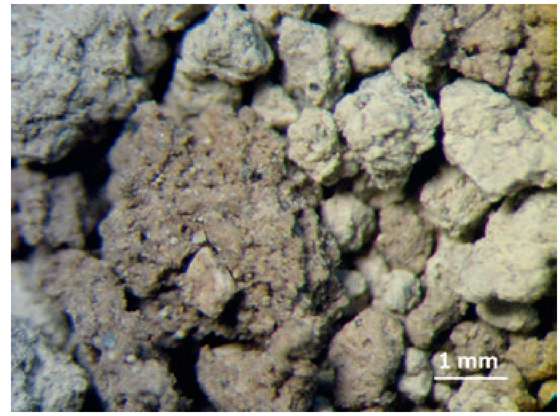


Figure 6. Microscope image of the river sediment

From the comparative histogram presented on Figure 7, variations in the mass content of various dimensional fractions are noticeable. This ratio of the dimensions of the mineral grains has an intense impact on the porosity of the two media, soil and river sediment.

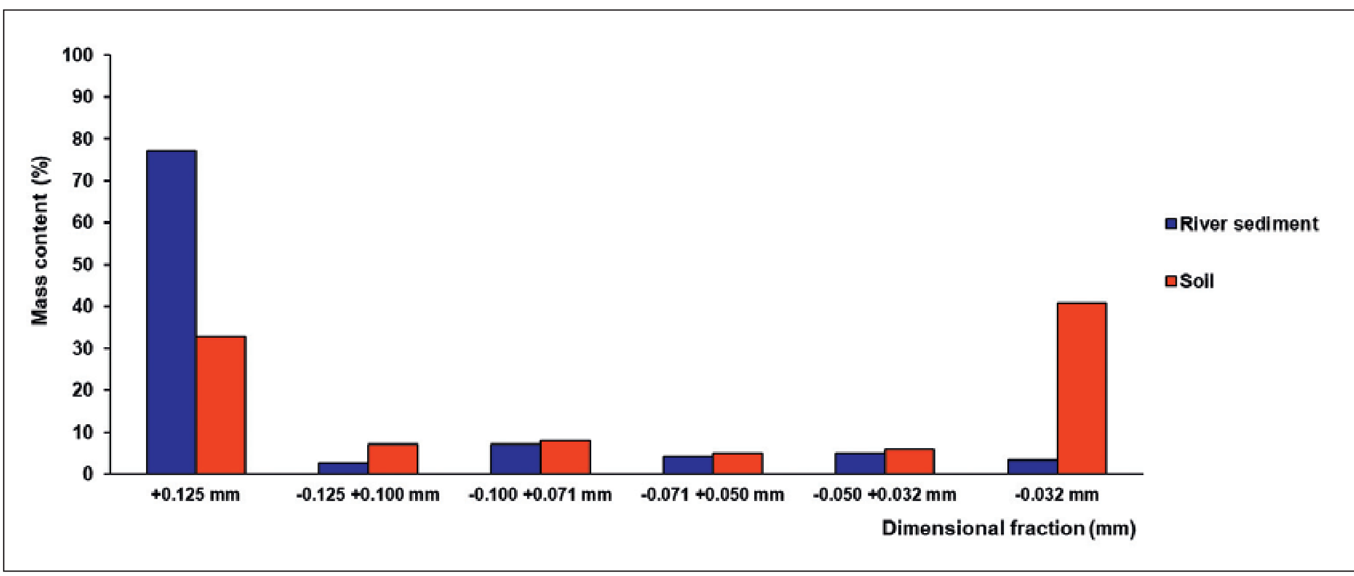


Figure 7. Comparative histogram of mass content of the various dimensional grain fractions

The heat transfer in the soil and river sediment at dry state is mainly through the air in the pores, by direct (with contact) and indirect heating of mineral grains. The pores at dry state are unfilled, so the transfer of warm air is with constant low resistance. Therefore, the curves of the diagram have a smooth shape, without local fluctuations (Figure 8.). It is characteristic that the rate of heat transfer in the river sediment in the segment up to approximately 50 minutes of the heating process is faster than that in the soil, and then the opposite follows.

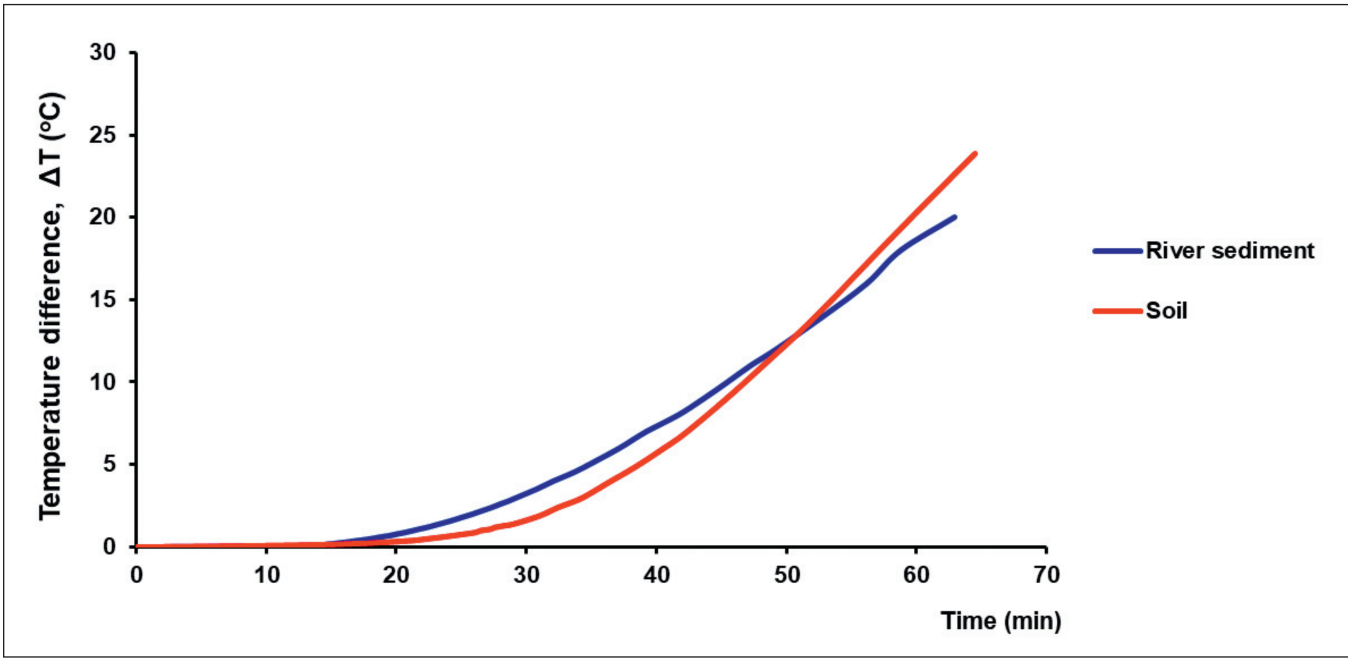


Figure 8. Heat transfer at dry state

From the obtained results, a several different mechanisms of the influence of moisture on heat transfer can be defined. Initially, the heat absorbed by water (vapor) is transferred to the upper layers of the medium. As the upper layers have a lower temperature than the layers in which water evaporates, the vapor condenses on the mineral grains of the medium (soil or river sediment). As a consequence, an increase of the moisture was observed. In that time and space segments, the heat is transferred to the mineral grains, reducing the rate of transfer to the upper layers. The measured temperature values oscillate moderately, under influence of the gas phase transfer rate. A specific segment is the conduction of heat through contacts of the mineral grains. As a consequence of all the above, there is a total heat transfer, which confirms the shape of the curves (Figure 9).

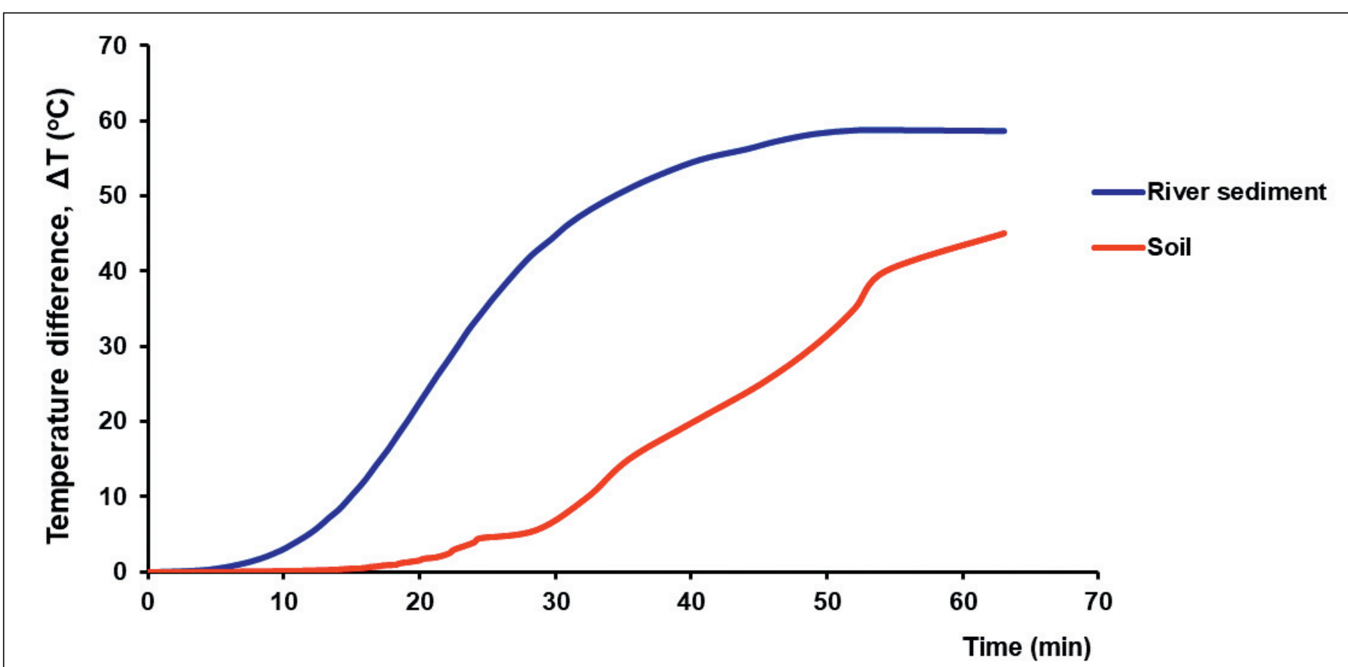


Figure 9. Heat transfer at state of 10 % moisture

The porosity of the medium has an impact on the transfer rate of the gas phase. It is directly influenced by the dimensions of the pores, the ratio of capillary and non-capillary pores, size and shape of the mineral grains, their arrangement and degree of aggregation etc. The soil also contains lumps, which form pores of significantly larger dimensions (cavities).

The aggregates and cavities reduce or increase mass and heat transfer in a various stages of the experiments. These fluctuations are easily perceived from the diagrams. From the diagram in Figure 10, it can be perceived that the fluctuation of the temperature and moisture of the soil are in the same time period. A slight delay of the moisture indicates the initial heat transfer through the air of unfilled pores, immediately followed by an intense wave of heat transfer through the water vapor, with characteristic fluctuations.

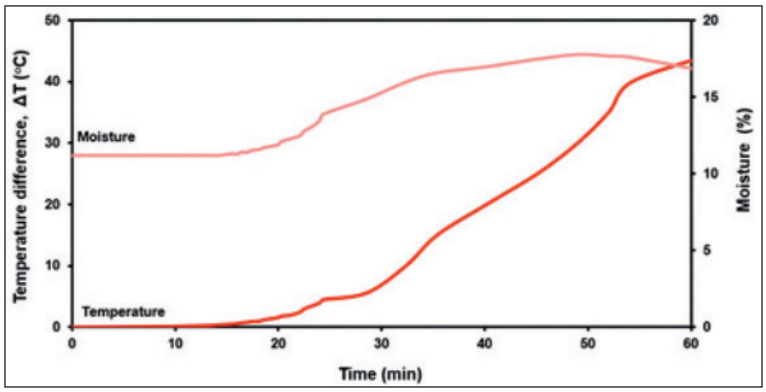


Figure 10. Temperature and moisture changes of the soil

The diagram of the river sediment has some variations (Figure 11). There are no significant fluctuations. An increased delay of the moisture in relation to the temperature can be perceived (at the measuring point). This phenomenon is a consequence of the fact that the river sediment in the lower layer does not have free pores (filled with air) at the beginning of the experiment, so it takes more time for the water temperature in the pores to increase. The increase of moisture at the measuring point, which is a consequence of the transfer of water vapor from the bottom up, has a higher rate in the river sediment in the earlier stages of the experiment, and later it is the opposite.

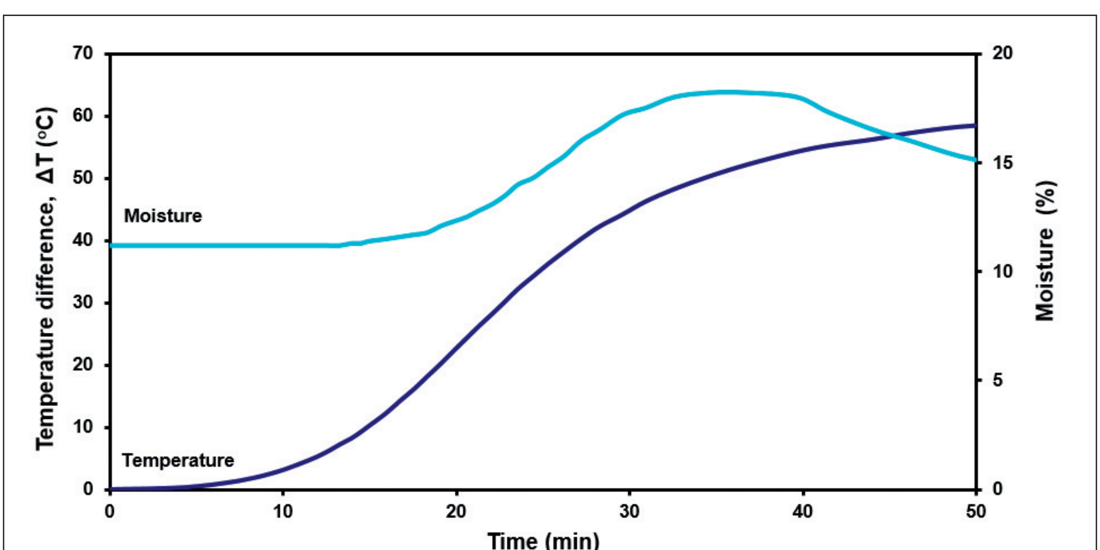


Figure 11. Temperature and moisture changes of the river sediment

The experiment of the water permeability, indicates that porosity has a dominant impact. The results are presented in a diagram (Figure 12). It is noticeable that the water transfer is more complex in the soil than in the river sediment, where the rate is approximately constant. From the obtained results, the water permeability rate for different time segments was calculated. In the initial segment, the maximum water permeability rate of the soil is 0.47 $cm^3/cm^2 \cdot min$, while in the sediment it is 0.23 $cm^3/cm^2 \cdot min$. The following is a segment of the process where the water permeability rate of the two media is approximately equal (0.23-0.25 $cm^3/cm^2 \cdot min$). In the final segment of the experiment, the water permeability rate of the river sediment is maintained at an approximately constant value (minimally decreases to 0.20 $cm^3/cm^2 \cdot min$), while there is a significant decreases in the soil to approximately 0.033 $cm^3/cm^2 \cdot min$.

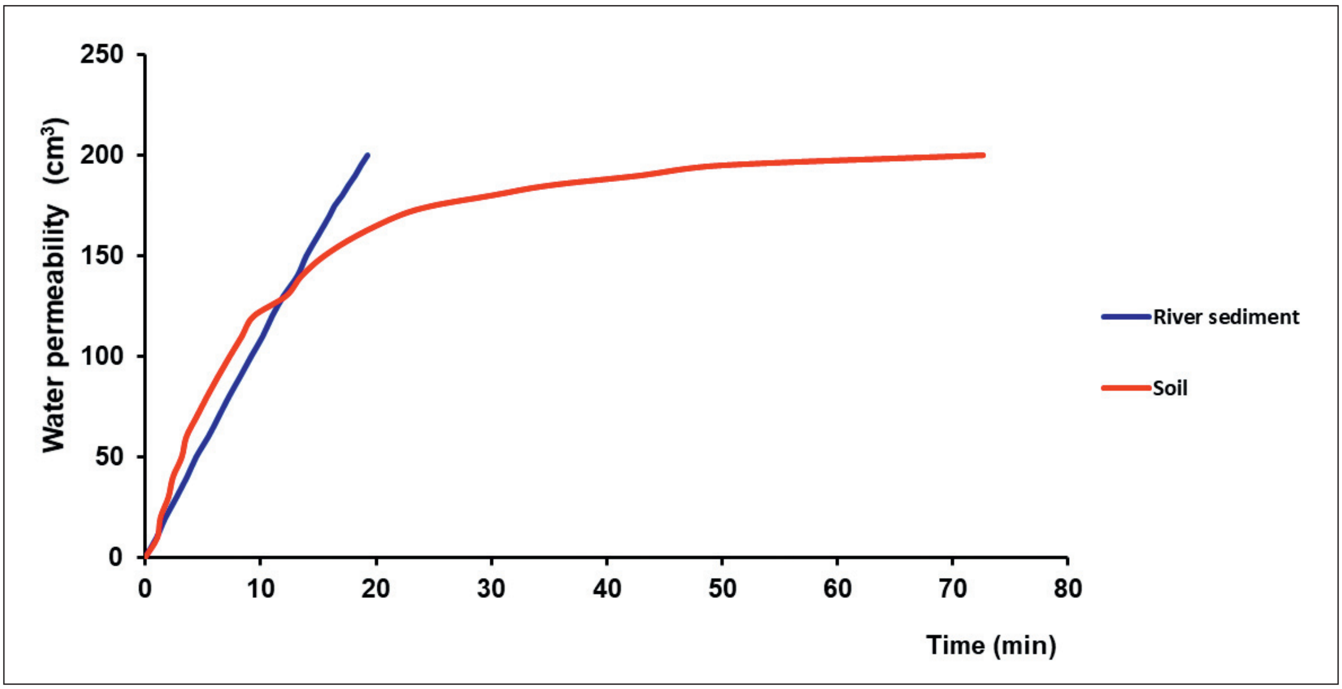


Figure 12. Water permeability

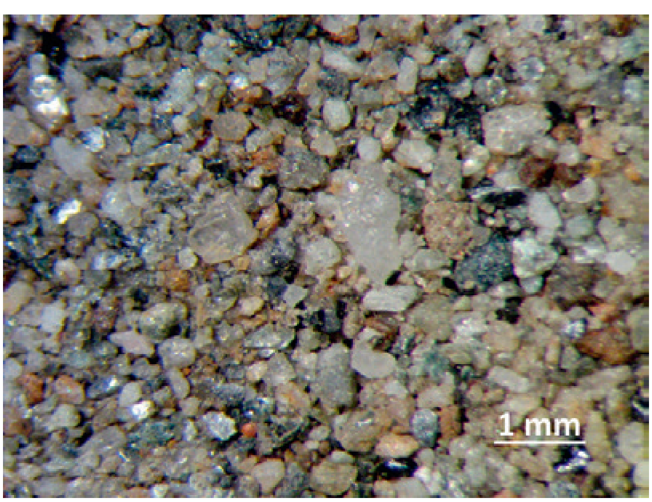


Figure 13. Microscope image of relative uniform porosity of the river sediment

Comparing the results of the experiments for the two media, it can be concluded that the river sediment has a relatively uniform range of the pore size (Figure 13).

In the soil, unlike the river sediment, micropores (in the aggregates) and pores (between the aggregates) in a comparable content are present. A significant part of the volume are the cavities in the space between the lumps (Figure 14). Therefore, the water permeability of the soil has a different characteristics compared to the river sediment.

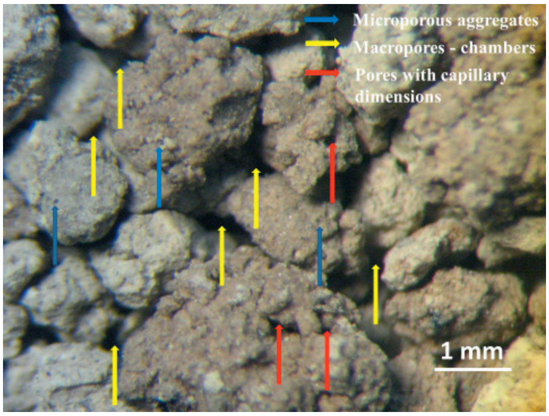


Figure 14. Microscope image of the different types of pores in the soil

The soil has an intensive inertia in various segments, which can be observed in the comparative diagram on Figure 12. The segments with different water permeability rate in the soil are a consequence of inert filling and draining of the cavities (large pores between the aggregates and lumps), combined with the partial equilibrium of the drainage rate in a particular segment of the experiment. An additional impact on the drainage rate is the reduction of the water column above the medium during the experiment (5.0 cm to 0.0 cm).

CONCLUSION

From the obtained results of the performed experiments for the water permeability and the heat transfer of the two media, soil and river sediment, it can be concluded:

The heat transfer, as well as the transfer of the soil solution or water, depends on the porosity of the system, i.e the dimensions of the pores and their ratio, in each medium individually. The porosity of the system is affected by the size and shape of the mineral grains, their arrangement and degree of aggregation. The variations between soil and river sediment is intentionally observed.

The porous system of the soil dominantly contains macropores, which are part of the aggregates. It also contains capillary pores formed between the coarse mineral grains and smaller aggregates, as well as non-capillary pores (cavities) located between the larger aggregates and lumps of soil. The porous system of river sediment is different from that of soil. Dominantly contains capillary pores formed between mineral grains (there is no aggregation process). It also contains pores of slightly larger dimensions (between the coarse mineral grains) which form channels that allow drainage (intensively compared to the soil).

The maximum values for the water permeability rate are significantly various. For the soil it is 0.47 $cm^3/cm^2 \cdot min$, and for the river sediment it is 0.23 $cm^3/cm^2 \cdot min$. The heat transfer is mostly through the air and water (vapor) of the porous system, as well as through the contacts of the mineral grains. For these two natural media, the water permeability and the heat transfer through porous system are specific, and the variations are pointed on the diagrams.

Water permeability and heat transfer of soil and river sediment as macro-physical properties are a direct consequence of porosity, and an indirect consequence of the granulometric composition of the medium. All determined parameters from this research are characteristic for specific types of soil and river sediment and can be applied in the planning of the irrigation regime by agricultural activities, as well as monitoring and protection of groundwater.

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