Activity report about field measurements in the pilot area Ljubljana

Deliverable D.T3.2.2 Updated database of existing and additionally measured data at the pilot areas	**Final Report** **01 2019**

Šram D., Koren K., Janža M., Rajver D., Novak M.

[1] Affiliation

Contact details of author: dejan.sram@geo-zs.si

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1. Executive summary in English language

This report summarise activities related to new measurements obtained within project GeoPLASMA-CE which have been partly presented already by Janža et al (2017). New measurements have been focused on geothermal parameters and parameters which effects on normal working of geothermal systems. To obtain the optimal possible results we have harmonised geological map, collected and analysed the boreholes applicable for installation of loggers and collected and analysed existing groundwater chemical compositions reports. Based on the geological map we have determined locations for rock and soil sampling used for estimation of thermal parameters. Sensors with loggers were installed in selected boreholes for measuring the groundwater parameters (temperature, water level and electric conductivity). Based on the results from chemical composition reports sampling campaign for collecting and analysing the groundwater chemical composition was organised.

The spatial distribution of thermal conductivity was estimated with measurements of thermal conductivity on 47 representative samples of 18 lithostratigraphic units. The measured values range between 0.63 and 5.18 $Wm^{-1}K^{-1}$. Continuous groundwater temperature measurements were established in 19 observation wells. The measured values in central part of Ljubljansko polje aquifer range between 10.6 °C and 14.6 °C, while in the Ljubljansko barje aquifer the temperature increases up to 15.7 °C. Close to the Sava River, on observation well Pincome-8 where the groundwater recharge occurs temperature range from 6.7 to 15.7 °C. Multi-level groundwater temperature measurements in 9 observation wells indicate three different conditions: both negative and positive temperature gradients and a constant temperature in different depths of the aquifer, which reflects the deeper geothermal or hydrogeological conditions and the anthropogenic impact.

Due to high oxygen and low ferrous iron (Fe^{2+}) content in Ljubljansko polje aquifer, problems with heat-pump systems are not present. In contrary in confined aquifer of Ljubljansko barje, the low oxygen and high ferrous iron (Fe^{2+}) content pose a risk for shallow geothermal installations.

2. Executive summary in national language

V poročilu so povzete aktivnosti povezane z novimi meritvami, ki so bile že delno predstavljene v članku (Janža et al. 2017). Z novimi meritvami smo se osredotočili predvsem na geotermalne parametre od katerih je odvisno delovanje geotermalnih sistemov. Za zagotovitev najbolj optimalnih rezultatov smo v ta namen posodobili in uskladili površinsko geološko karto, izbrali smo opazovalne vrtine primerne za vgradnjo merilcev ter zbrali in pregledali obstoječa poročila, ki obravnavajo kemijsko sestavo podzemne vode. S pomočjo usklajene geološke karte smo izbrali lokacije za odvzem vzorcev, katerim smo izmerili toplotne parametre. Merilci temperature, električne prevodnosti in gladine podzemne vode so bili nameščeni v izbrane opazovalne vrtine. Glede na rezultate iz poročil so bila določena vzorčna mesta, kjer smo odvzeli vzorce podzemne vode za dodatne kemijske analize.

Toplotna prevodnost kamnin na pilotnem območju je bila določena na podlagi 47 vzorcev kamnin iz 18 litostratigrafskih enot. Vrednosti toplotne prevodnosti se gibljejo med 0.63 in 5.18 $Wm^{-1}K^{-1}$. Zvezne meritve temperature podzemne vode so bile vzpostavljene v 19 opazovalnih vrtinah. Temperatura podzemne vode se giblje med 10,6 °C in 14,6 °C na Ljubljanskem polju medtem, ko je najvišje izmerjena 15,7 °C na Ljubljanskem barju. Na opazovalni vrtini Pincome-8, ki je v neposredni bližini reke Save in napaja vodonosnik se izmerjene temperature gibajo v razponu od 6,7 do 15,7 °C. Zvezne meritve temperature podzemne vode po globini na 9 merskih mestih kažejo tri različne trende. Zaznana sta tako pozitiven kot negativen temperaturni gradient ter konstanta temperatura po globini. To kaže na antropogeni vpliv iz površja ter globje geotermalne in hidrogeološke pogoje.

Zaradi visoke vsebnosti kisika in majhne vsebnosti železa (Fe^{2+}) težav z delovanjem geotermalnih sistemov na Ljubljanskem polju ni. Ravno nasprotna situacija je na Ljubljanskem barju kjer ima podzemna voda nizke vsebnosti kisika in visoke vsebnosti železa (Fe^{2+}), kar lahko vpliva na delovanje geotermalnih sistemov (obarjanje železa).

3. Introduction

3.1. Aim and scope of this report

This report describes the field measurements performed in the pilot area Ljubljana, which have been performed within the frame of Activity A.T2.3.2. It aims at a full documentation of the assessed field data, which will be published at the GeoPLASMA-CE web portal (www.geoplasma-ce.eu).

This report contains:

- An overview of parameters measured in the pilot areas for creating the aimed project outputs
- A brief description of the methods applied for measurement and data processing
- A documentation of the field measurements performed in the PA area
- A short description of the results achieved and how these results contribute to the generation of thematic outputs.

3.2. Overview of the chosen strategy for field measurements

Pilot area Ljubljana comprise in general tree major lithological units (unconfined aquifer, confined aquifer and surrounding hilly areas with essentially no groundwater resources). Till now the observations have been focused mainly on the groundwater quality and quantity such as water level and chemistry but less the temperature and thermal parameters. Within the GeoPLASMA-CE project we have focused on characterisation of geothermal conditions. We have established monitoring network for continuous measurement of groundwater temperature, with measurement points distributed over all pilot area and different depths. Along the continuous temperature measurements, we have organised two campaigns in which groundwater temperature was measured on additional measuring points which extended the monitoring network and enable better insight into the groundwater temperature distribution in the pilot area. To estimate risk of scaling and corrosion for shallow geothermal systems groundwater samples were taken and chemical composition was analysed. Based on the geological map of pilot area in scale 1: 25 000, 47 rock samples were taken to measure thermal parameters.

4. Documentation of field measurements

4.1. Measurements of thermal parameters

4.1.1. Measurements of the thermal parameters of rocks and hard soil

Campaign for filed measurements and collecting rock samples started in July 2017 and ended with measurements in laboratory in November 2017.

Sampling of rocks and hard soils was performed on 18. 7. 2017 and 20. 7. 2017, laboratory TC (thermal conductivity) and TD (thermal diffusivity) measurements followed on dates 4.9.2017, 22.9.2017, 25.9.-29.9.2017 and 17.11.2017. Thermal parameters of soft soil were measured on 21.7. 2017, 27.7.2017, 28.7.2017 and 1.8.2017.

For the evaluation of the thermal parameters of the rocks, it was necessary to sample many different types of rock in the field. In the field, the main lithostratigraphic units which cover larger areas and their most common lithological varieties were sampled in several localities. Altogether, 47 samples from 18 solid rock units were collected. The measurements of thermal conductivity (TC) and thermal diffusivity (TD) on compact rocks and also on hard soil (e.g. clays and similar soils that are not too soft) were performed in the laboratory using Thermal Conductivity Scanner (TCS), produced by TCS Lippmann and Rauen GbR (Popov et al., 2017). The TC and TD measurements were carried out on 47 rock samples with 86 rock pieces. All these rock pieces were measured to obtain better representative mean values of the thermal properties of rocks for each lithological unit.

The optical scanning technology is based on the scanning of the plane or cylindrical surface (along the cylinder axis) of a studied sample with a focused, mobile and continuously operated heat source in combination with infrared temperature sensors (Popov et al. 1999; 2012). The determination of thermal conductivity values is based on the comparison of excessive temperatures of standard samples (having a known thermal conductivity λR) with excessive temperatures of one or more unknown samples being under heating by the movable concentrated heat source. The thermal conductivity of samples is calculated as a result of a comparison of the excessive temperatures using the standard thermal conductivity values. For the TCS method, a low tolerance is prescribed for the flatness of the sample surface (+/- 0.5 mm), and hence, almost all the samples were first cut with a circular saw to cope with this requirement. The simultaneous measurements of TC and TD use a 2-channel type of temperature sensor measuring two temperatures after heating at spots located some mm apart.

4.1.2. Measurements of the thermal parameters of unconsolidated sediments

Field measurements of the thermal parameters, the TC and thermal resistivity, of the softer or unconsolidated and porous sediments were carried out at 7 localities (3 lithological units). They were performed with the use of the KD2 Pro thermal properties analyser (Decagon Devices, 2016), which is especially dedicated for soft and loose sediments (Fig. 1). Typically, the probe for measuring TC and thermal resistivity consists of a 6 cm (optionally 10 cm) long needle with a heater and temperature sensor inside. More recently, the heater and temperature sensors have been placed in separate needles, both 3 cm long and 6 mm apart. Within such a dual probe, the analysis of the temperature versus time relationship for the separated probes yields information on TD and volumetric specific heat capacity along with TC and thermal resistivity.

Figure 1: Field measurement of the thermal parameters with the KD2 Pro meter (Janža et al., 2017).

4.1.3. Groundwater temperature measurements

Initial campaign for groundwater temperature monitoring has been set up for continuous measurements on 17 locations (Fig. 2). Single-level (8 locations) and multi-level measurements (9 locations) (Fig. 3) have been performed with GSR 120 NTG loggers (15 pcs) (Internet 3) and HOBO temperature loggers (44 pcs) (Internet 4). Along with the temperature measurements, GSR 120 NTG loggers also enable measurements of the water level and the electrical conductivity of the groundwater.

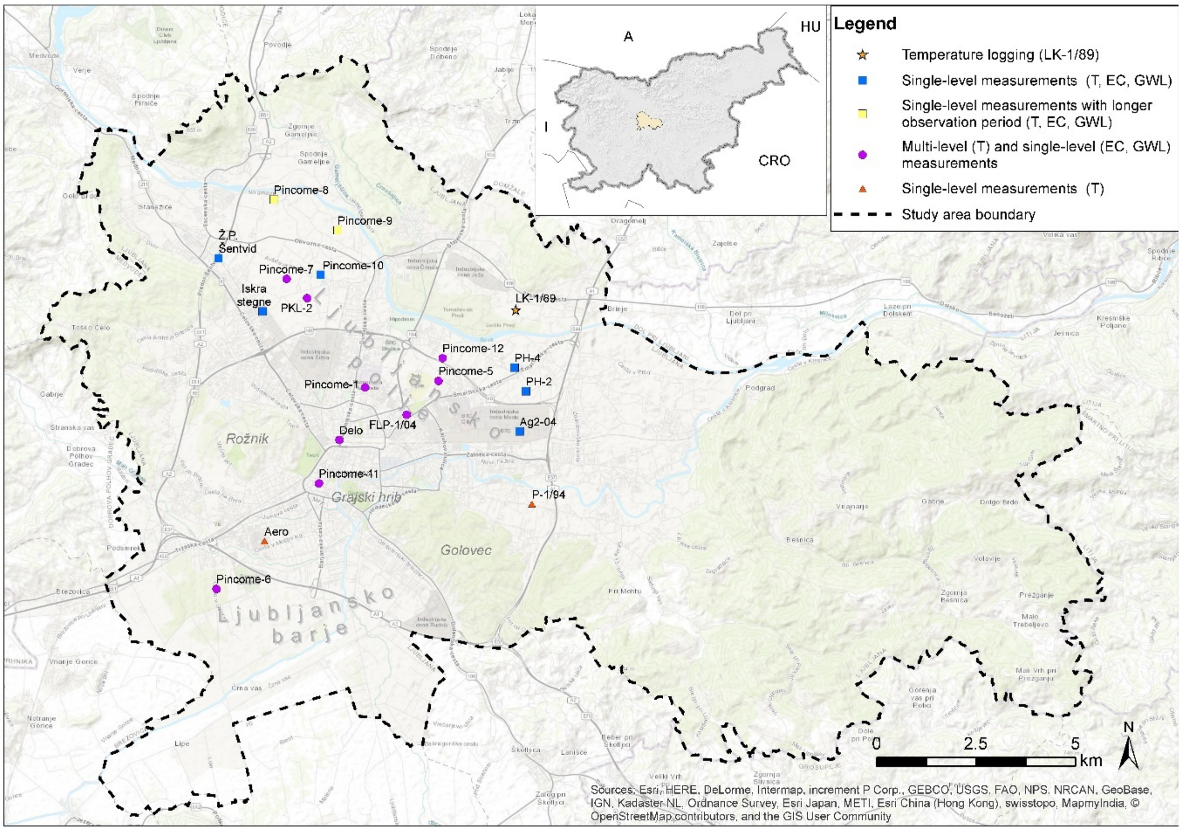

Figure 2: Location of boreholes for groundwater measurments (Janža et al., 2017).

Loggers were installed in May 2017 and set up to record measurements at one-hour intervals. The spatial distribution of measurement locations was designed in a way to capture the influence of the factors which presumably affect the groundwater temperature in the study area (e.g. recharge from the Sava River and the urban area heat island). Data were collected periodically in 6-week average. Until November 2017 it was clear that on most locations groundwater temperature measured does not vary a lot. Therefore it was decided to reorganise the measuring network. In November 2017 loggers from existing observation wells with constant data were relocated to observation wells Pincome-8 and Pincome-9. Those two observation wells are close to river Sava where groundwater recharge occurs. Loggers were installed on 1m depth interval.

Last data collected for GeoPLASMA-CE project purposes of new measurements have been collected on December 2018.

Along with continuous temperature measurements two campaigns for additional measuring of groundwater temperature were organised. The observation wells where loggers could not be installed but one-time measurements were possible were included in the campaigns. With the campaigns we have expand existing observation network and gathered new data on temperature distribution in the subsurface. In total 16 observation well were included which are all under maintenance of public company VO-KA (Vodovod-Kanalizacija).

Campaigns took place on 9.5. 2017 and 15.3.2018.

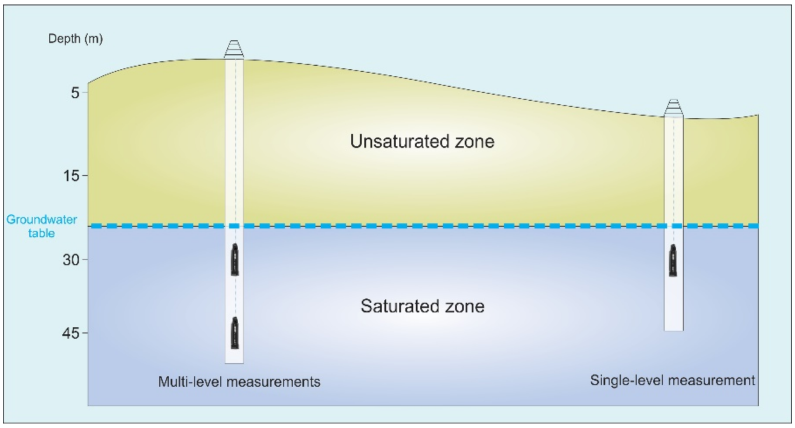

Figure 3: Scheme of multi-level and single-level measurements in observation wells (Janža et al., 2017).

4.1.4. Chemical composition

Field measurements and sampling of groundwater for defining its chemical composition were focused on area of Ljubljansko barje aquifer, where problematic groundwater conditions for implementation of shallow geothermal systems were indicated (Fig. 4).

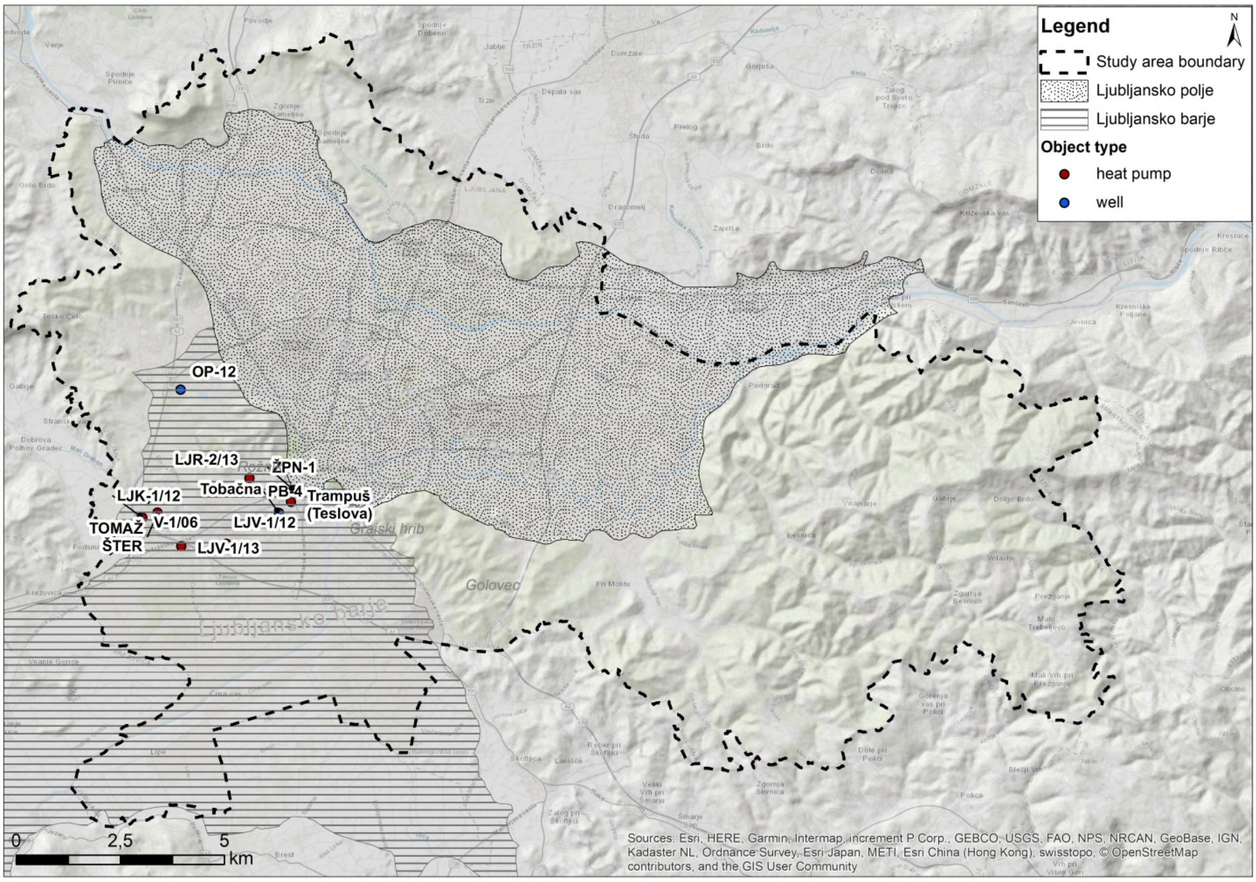

Figure 4: Groundwater sampling points (sampling performed on 27th and 28th of March and 14th of May 2018) (Janža et al., 2018).

Groundwater sampling from wells was performed with Grundfos M1 submersible pump. At locations of installed heat pumps samples were taken from taps. Physico-Chemical

Parameters: pH value, temperature, Eh, electrical conductivity, dissolved oxygen, oxygen content, content of dissolved iron (Fe^{2+} and Fe total) and groundwater level were measured with portable WTW device. Then samples for chemical analysis of following parameters were taken: HCO_3^-, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^-, NO_3^- and Fe (if the value on field was above 3 mg/L). They were stored in 1 L plastic bottle. Groundwater sampling from wells was performed with Grundfos M1 submersible pump. At locations of installed heat pumps, samples were taken from taps. First field parameters with portable WTW device: pH value, temperature, Eh, electrical conductivity, dissolved oxygen, oxygen content, content of dissolved iron (Fe^{2+} and Fe total) and groundwater level were measured. Then samples for chemical analysis of following parameters: HCO_3^-, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^-, NO_3^- and Fe (if the value of Fe tot. on field was above 3 mg/L) were taken. They were stored into 1 L plastic bottle. Additional samples for analysis of manganese and sulfide content were also taken. For chemical analysis of manganese sample in 1 dL plastic bottle was taken. First it was filtered through 45 µm filter and then acidified with HNO_3 so pH value was less than 2. For sulfide, sample was also filtered through the 45 µm filter into 250 mL glass flask and then it was stabilized with NaOH.

Sampling campaign was performed on 27th and 28th of March and 14th of May 2018.

5. Data processing

Groundwater samples for chemical composition have been further processed using Statistica 13, Langelier saturation index online calculator, ordinary kriging Interpolation method in ArcMAP and PHREEQC.

5.1. Transfer of field data to the joint databases

In a last step, the processed field data have been summarized, documented and transferred to the following databases:

- Metadata database of relevant input data (D.T3.1.2) for a full documentation of the achieved datasets.
- Key value database for publishing the achieved results (D.T3.2.1).

The metadata description of the produced datasets follows the joint concept on geodata management, which is described in Deliverable D.T2.3.1.

The summarized of datasets, shown in the key value database are characterized by:

- Number of individual measurements (≥1)
- Presentation of either alpha-numeric (e.g. <0,01 mg/l) or numeric values
- The dataset is characterized by a single or mean-, minimum- and maximum value as well as by the standard deviation (in case of at least 3 single datum points).
- All presented values are allocated to a measurements period, a surface location and a depth interval of the measurements.

6. Results

6.1. Thermal parameters

The results of TC and TD measurements show a great variety in the thermal properties of different lithological units. The heterogeneous nature of the rock samples is noticeable, especially TC, which is a consequence of the mineral composition, rock density, their structure and texture and the pores' filling (water saturation) (Kappelmeyer & Haenel, 1974; Beck, 1988). It must be stressed that despite the efforts to simulate the natural conditions as much as possible, no rock sample could be completely water saturated, due to the lack of appropriate pressure devices. On the other hand, particularly compact solid rock samples are less susceptible to water saturation, therefore their rock status has been assigned as slightly or partly saturated or just wet during the TC and TD scanning. Some examples are presented herein in regard to the rock samples with typical low (Fig. 5a), average (Fig. 5b) or high (Fig. 5c) values of TC.

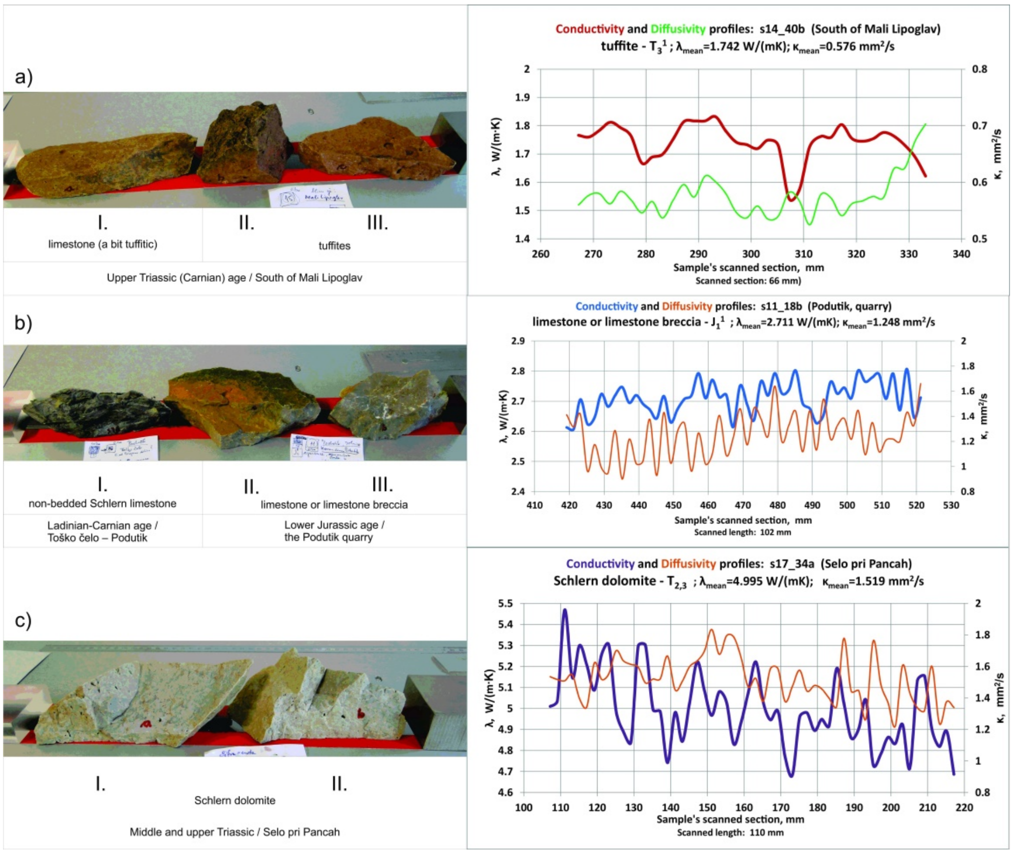

Figure 5: Set of rock samples along the scanning line of TCS meter (left); the TC and TD profiles from the scanning of rock samples (right) (Janža et al., 2017).

The results of thermal conductivity measurements (Fig. 5) show that the rocks with high TC are especially dolomites and quartz conglomerates (3.6 to 5.4 Wm-1K-1). Those with average to high TC are marly dolomites, Dachstein limestones grading into dolomite, quartz sandstones, quartz-dolomitic sandstones, conglomerates, limestones with cherts, red limestones, tuffites and some sandstones (2.8 to 4.2 Wm-1K-1). Those rocks with average TC parameter are limestones, marly limestones, (carbonate) sandstones, tuffs, most siltstones and mudstones (2.3 to 3.6 Wm-1K-1), while those showing low TC values are notably shales and some tuffites, and less remarkably some marlstones and siltstones or claystones (1.4 to 2.5 Wm-1K-1).

The results of the field measurements with the KD2 Pro needle probes show that water saturation plays a very important role. Also, the manner of measurements is of great importance, as the method requires a very precise and delicate setting of the needle probes into the measured material. They are mostly within the expected range of these parameters. TC is obviously higher (1.2 to 1.81 Wm-1K-1) at those localities where the needle probe was inserted in a softer sediment very close to gravel pieces, and also where it was inserted in water saturated sandy clay, sand and silt. Measurements with the needle inserted in dry loose sediments gave quite low TC (0.6 to 0.8 Wm-1K-1). The spatial distribution of TC based on the harmonized geological map and measurements of TC is presented on the thermal conductivity map (Fig. 6).

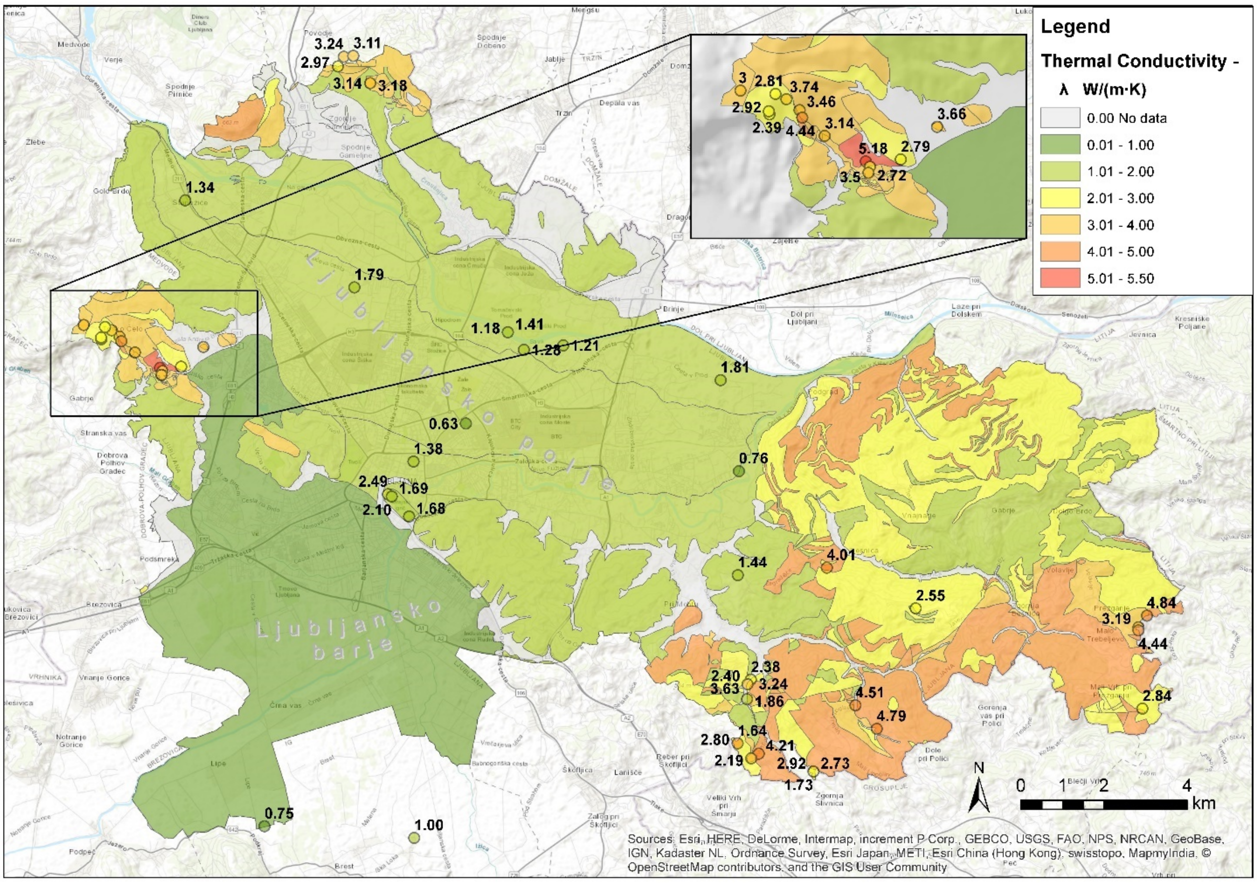

Figure 6: Thermal conductivity map (Janža et al., 2017).

6.2. Groundwater temperature

The measured groundwater temperatures (GWTs) range between 10.6 °C and 14.6 °C at the Ljubljansko polje and increase up to 15.7 °C in the deepest part of the well Pincome-6 at the Ljubljansko barje. Close to the Sava River, on observation well Pincome-8 where the groundwater recharge occurs temperature range from 6.7 to 15.7 °C.

Measurements show relatively stable conditions and no significant changes of temperature over time. Exceptions are the measurements in the wells Delo and FLP-1/04, where fluctuations of temperature at some deeper levels are observed. These fluctuations show no trend, thus it can be assumed that they have been caused by anthropogenic influence (e.g. leaking sewage or heating systems, nearby installed heat pumps) or damaged loggers.

Stable temperature conditions indicate an absence of intensive groundwater recharge or inflow of fresh water. On the contrary, GWT measurements in the well Pincome-9 long term(Fig. 7) and short term multi-level (Fig. 8) located closer to the Sava River, where an intensive groundwater recharge from the river has been interpreted (Janža, 2015), show annual fluctuations which follow the air or surface water temperature changes with a lag time of about 6 months. Measurements on the observation well Pincome-8 next to Sava River shows temperature range from 6.7 °C to 15.7 °C.

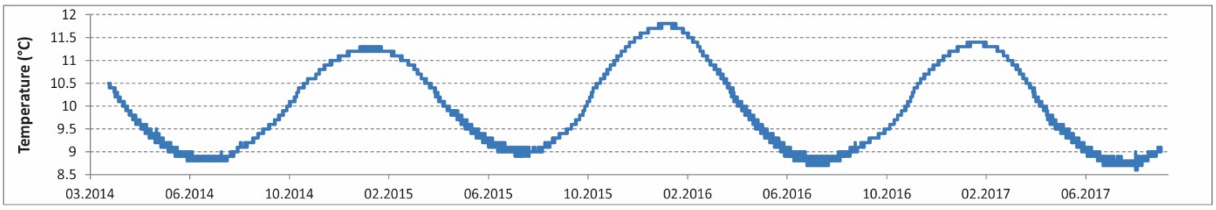

Figure 7: Single-level groundwater temperature time series measured in observation well Pincome-9 (Janža et al., 2017).

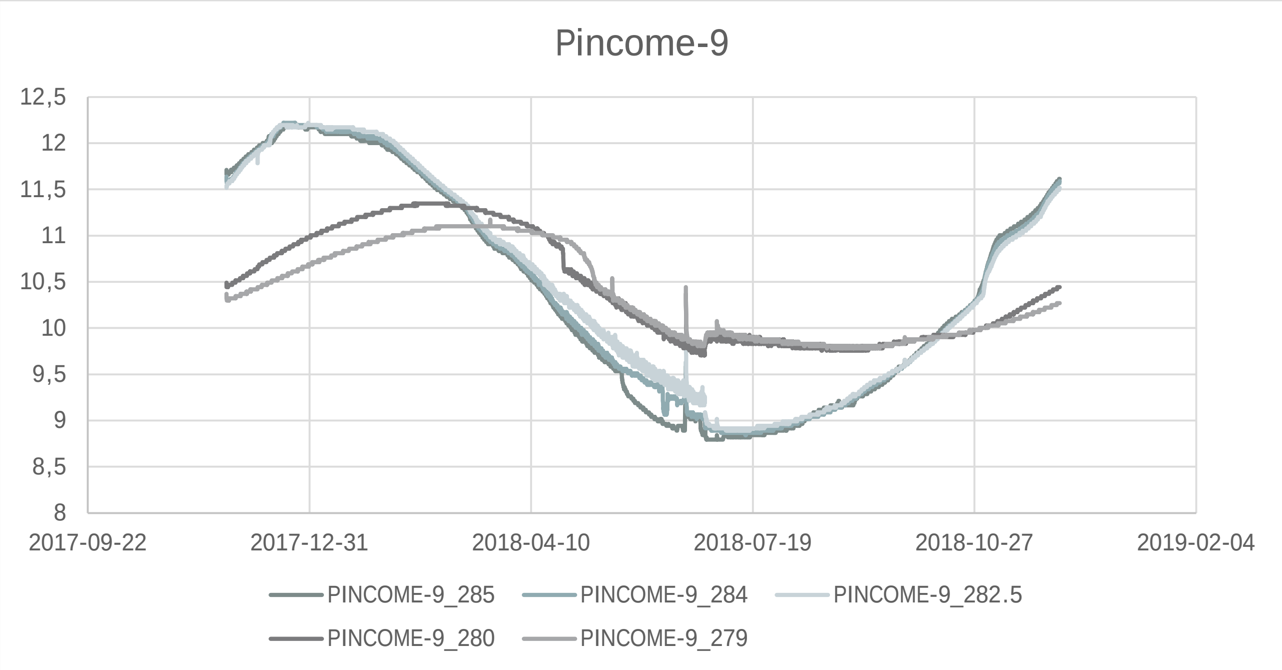

Figure 8: Multi-level groundwater temperature time series measured in observation well Pincome-9.

Based on multi-level GWT measurements, the observation wells can be classified into three groups. In the wells PKL-2, Pincome-1, Pincome-5, Pincome-7, and Pincome-12, there are very small changes or practically no noticeable vertical temperature gradient. In wells Pincome-11, FLP-1/04, and Delo, noticeable are temperature decreases with depth and negative gradients which slightly differ among the wells. In contrast to this, in well Pincome-6 in the Ljubljansko barje aquifer, a clear positive temperature gradient is visible and an increase of temperature with depth up to 15.7 °C, measured at 118 m depth (Fig. 9).

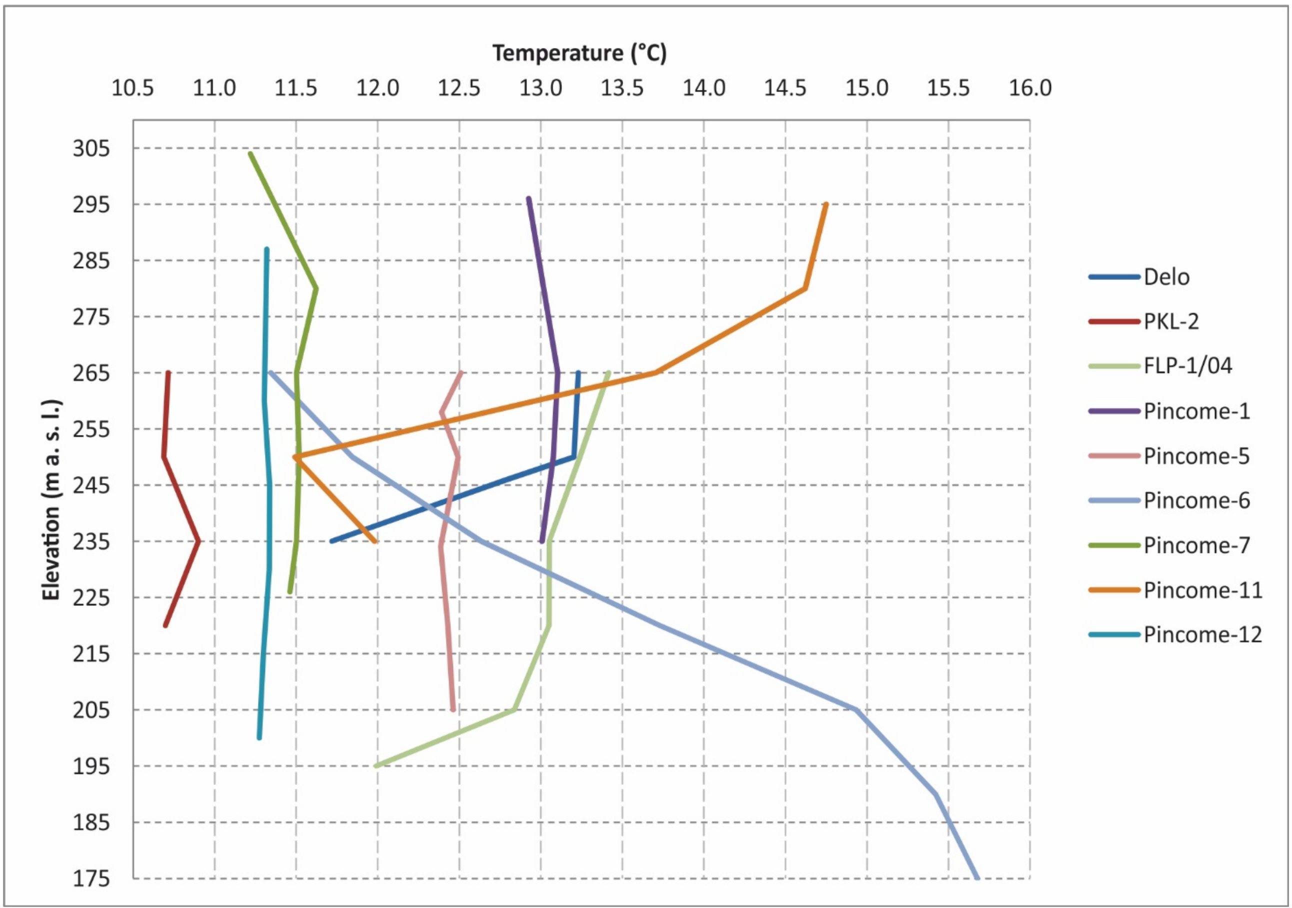

Figure 9: ***Multi-level groundwater temperatures in observation wells (Janža et al., 2017).***

The observed characteristics could be related to different factors. The first group of wells, except the well Pincome-1, is located outside or at the edge of the urban area, where the anthropogenic impact on GWT is minimal and the measured GWTs reflect undisturbed natural background conditions.

The second group of wells is located within the urban area, where increased temperatures in the upper part of the aquifer could arise from anthropogenic heat sources. Positive temperature anomalies or subsurface urban heat islands are often observed phenomena beneath cities.

The positive temperature gradient in well Pincome-6 probably originates from an increased heat-flow density and geothermal anomaly related to the thermal convection zone in the Triassic carbonate rocks below the Quaternary sediments (Živanović & Rajver, 2004).

6.3. Chemical composition

Altogether data from 126 observation points was used, 91 in the area of Ljubljansko polje aquifer and 35 in the area of Ljubljansko barje aquifer. Data contain measurements of basic chemical parameters (anions and cations) which were used for determination of the water type and the ion-balance for each observation object.

7. Summary and conlusions

7.1. Thermal parameters and groundwater temperature

The distribution of ground thermal conductivity was derived with the help of a detailed geological map, representative rock sampling and measurements of the samples' thermal parameters. The results show that dolomites and quartz conglomerates have the highest thermal conductivity and, on the contrary, shales and tuffites, and some marlstones and siltstones (or claystones), have the lowest value of thermal conductivity among the geological units in the study area. This is important for the use of the shallow geothermal potential, as the higher thermal conductivity of the subsurface allows for a better heat extraction rate and higher efficiency of geothermal installations. The groundwater temperature measurements indicate relatively stable temporal conditions and a GWT range between 10.6 °C and 14.6 °C at the Ljubljansko polje and up to 15.7 °C in the deepest part of the Ljubljansko barje. Multi-level GWT measurements in observation wells show three different trends: negative, positive and no geothermal gradient in the aquifer, which in general depend on the location of the well and the related anthropogenic impact or the deeper geothermal and hydrogeological conditions.

7.2. Chemical composition

According to the analysis performed evaluation on archive data there are no critical areas of high risk of manganese or iron precipitation, and carbonate scaling were identified. There have been identified some individual observation wells with risk of metal corrosion. Values of Calculated Langelier index of on data from additional measurements shows that in groundwater water sampled in wells and heat pump taps risk tends too corrosion is indicated (LSI < 0) – no lime scale formation. But since expected temperature changes of groundwater are smaller than Δ 5 °C, this kind of risk is not relevant.

Due to high oxygen and low iron content in Ljubljansko polje aquifer, risk of iron precipitation is not present. In contrary in confined aquifer of Ljubljansko barje, the risk of iron precipitation is present, especially in upper 70 m (top clayed layer and Upper gravel aquifer).

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