Acta Tecnología - International Scientific Journal about Technologies
Volume: 3 2017 Issue: 4 Pages: 7-24 ISSN 2453-675X

Received: 12 Nov. 2017
Accepted: 02 Dec. 2017

EVALUATION OF QUANTITATIVE AND QUALITATIVE INDICATORS OF GROUNDWATER IN TERMS OF THEIR USABILITY AS A PRIMARY ENERGY SOURCE FOR HEAT PUMPS

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Keywords: heat pump, groundwater quality, quantity of groundwater, hydrogeological conditions
Abstract: The central aim of this article was based on knowledge of the quality and quantity of groundwater on the territory of the Slovak Republic to determine appropriate placement selected heat pumps water / water type. It was necessary to determine the technical parameters of selected devices and their requirements for quality and quantity of primary heat source, ie groundwater and hydrogeological conditions of Slovakia. As a bonus this article provides an overview of current developments in the Slovakian market for heat pumps.

1 Introduction

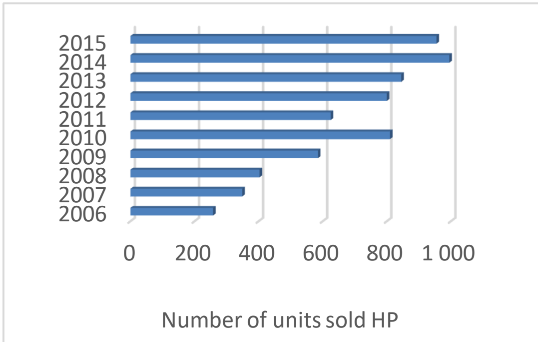
The Slovak Republic is among the countries with the richest supplies of water in its territory, whether on the surface or under the surface. Not only the geological structure of Slovakia, but also its geographical location in Central Europe, with a relatively even distribution of precipitation during the year, is of great importance. These waters have different uses, of course the main is supply drinking water for the population, further in the industry, agriculture, healthcare, and so on. As part of the European Union's effort to achieve sustainable development, the industry sector has grown strongly in recent years with a focus on renewable energy, for normal household applications. We can rank here heat pumps (hereafter HP). Regarding the efficient use of water, heat pump of water / water type is a very good example, due to its high efficiency at the optimal qualitative and quantitative conditions of the used groundwater.

The main objective of this contribution is to find out, on the basis of the analysis of indicators of quantity and quality of groundwater on the territory of the Slovak Republic, the appropriate placement of selected heat pumps from different producers. To achieve this, we chose two partial goals. Firstly to detec and compare the requirements of individual heat pumps to the primary source of thermal energy, ie groundwater, in terms of quantity and quality required for optimal operation. The second sub-objective is to identify and map groundwater status in the Slovak Republic based on qualitative and quantitative aspects.

2 Heat pumps on Slovakia

The HP market is very difficult developing, as is shown by Chart no. 1. While only about 260 units were sold in 2006, 800 were sold in 2010 and almost 1,000 units were sold in 2014, of which 585 were air / water and 312 were water / water. In 2015, the number of sold air / water units increased to 721, but only 234 pieces were sold in the land / water / water type [1][2].

Chart no. 1 Development of sales of HP in Slovakia in 2006 – 2015 (processed according to [1] [2])



In addition, from 1 December 2015 until the end of 2018 in Slovakia, the project "Green for Households", which is managed by the Ministry of Environment of the Slovak Republic through the Operational Program Quality of the Environment, is under way. Families in Slovakia can, after fulfilling the conditions set, obtain subsidies for selected facilities generating electricity or heat, which also includes HP. The aim of this project is to promote an energy efficient, low-carbon economy in all sectors and to revive the market environment with RES facilities in households [2].

3 Hydrogeological circumstances Slovakia

Slovak water management has a significant focus on groundwater, which is justified due to the fact that the total area of the Slovak State of 49 035 km2 occupies the hydrogeological area of about 43 420.4 km2 (88.5%). [3] [4] However, the amount of groundwater is unevenly distributed on the territory of Slovakia, while abundant reserves are recorded in the Bratislava and Trnava regions (46%), and in the Prešov and Nitra regions it is significantly lower. [5] Individual territories that have the same or similar groundwater regimes (hydrogeological conditions) and are defined by the geological boundary are called hydrogeological units. In Slovakia we divide them into seven [6]:

- Hydrogeological whole of the nuclear mountains, crystalline Veporské vrchy and Slovenské Rudohorie,
- Hydrogeological whole of mesozoic rocks,
- Hydrogeological whole of the cliff band,
- Hydrogeological whole of paleogeneous sediments of flysch band,
- Hydrogeological whole of sedimentary neogen,
- Hydrogeological whole of non-vulcanites,
- Hydrogeological whole of quaternary sediments.

Besides the hydrogeological units, the territory of Slovakia is also divided intothe 141 hydrogeological zonee, which serve as the basic assessment units for the water balance ofgroundwaterr. The deployment of the zones is shown in figure 1 [4]. The State Geological Institute Dionýza Štúra (ŠGÚDŠ) no longer uses this partition methodology to zones and prefers to divide into regions and units, but the Slovak Hydrometeorological Institute (SHMÚ) still applying it in its reports and water management balances.

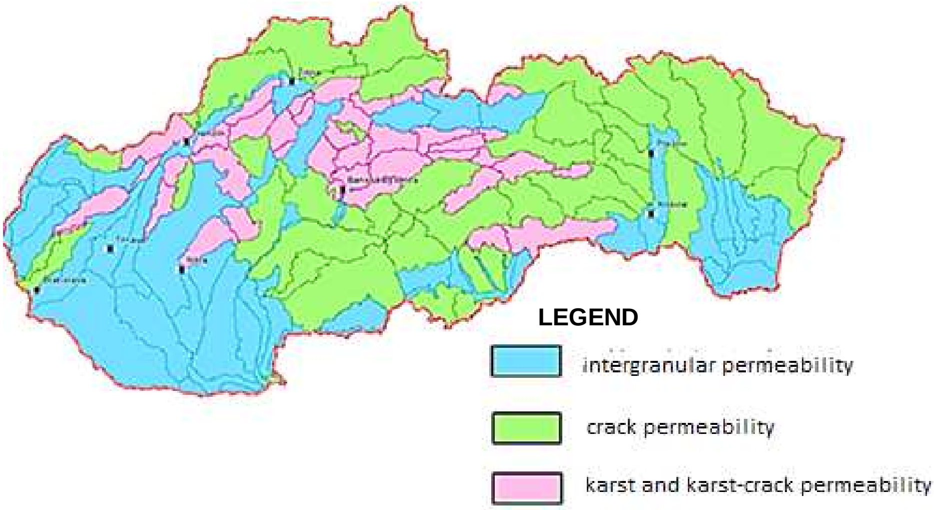


Figure 1 Hydrogeological zones in the Slovak Republic and their permeability (processed according to [4], [7])

4 The technological parameters of selected water / water heat pumps, focusing on their requirements for the quality and quantity of groundwater

Water / water heat pumps whose primary source of thermal energy is groundwater are typically provided by an open system of two wells. The water drawn from the pumped well is subject to qualitative and quantitative requirements [8]. In terms of groundwater quality, ie its purity and chemical composition, the basic monitoring parameters with most of the heat pumps are the same because the water quality affects only those parts of the primary circuit of the pump that are in direct contact,so pipe duct and evaporator (plate heat exchanger) [9].

The cleanliness of the water used and the elimination of most of the solids can be ensured by installing the filter and its regular cleaning to prevent the clog, heat transfer degradation, and hence reducing the efficiency of the heat pump [10].

Qualitative indicators of chemical composition of water include [9], [10], [11]:

- pH - if it is low, the water is aggressive and able to dissolve some metals,
- hardness - evaluation of the amount of Ca and Mg,
- aggressive CO2 - a free CO2 form capable of etching surfaces, increasing the aggressiveness of water,
- electrical conductivity - expression of salt content in water, eg. chlorides and sulphates,
- Fe and Mn values - their increased presence in water can make to corrode the parts of the device.

The specific requirements of individual selected HPs from different manufacturers, or distributors, for groundwater quality, are usually to the installation manuals of the device..

In terms of quantitative conditions, each HP has its own recommended flow as in the primary so and secondary circuits, and these data are part of the technical parameters (see Table 1). The flow along with the water temperature in the primary part of the heating system must be monitored regularly, because in case of limiting or interrupting the flow, the efficiency of the heating system is reduced or the heating system switches off completely, and the water in the evaporator can freeze at a low temperature of the heat source. Negative consequences can be the damage of the evaporator to the accident at which the working medium escapes. That is why in this section, it is customary to install flow detectors, respectively, flow meters that shut off the compressor in case of inadequate flow of water and stop the operation. In order to avoid similar complications, a pumping test is performed prior to the installation of HP the water / water type, which determines the richness of the groundwater source (wells). However, the success of this test does not guarantee a steady flow over a longer period of time [10].

Table 1 Selected HP arranged according to the recommended flow rate

Type HP	COP	Flow [$m^3.h^{-1}$]
NIBE 5 kW	4,09	0,65
NIBE 6 kW	4,17	0,72
NIBE 8 kW	4,46	1,08
G-TERM 5006.3	5,08	1,1
G-TERM 5007.3	5	1,5
NIBE 12 kW	4,3	1,55
G-TERM 5008.3 Ai	5,07	1,6
G-TERM 5009.3	5,3	1,9
BUDERUS WPW90 I / G-TERM 5011.3	5,1 / 4,83	2
G-TERM 5010.3 Ai	5,29	2,1
G-TERM 5014.3 Ai	5,25	2,9
BUDERUS WPW140 I	5,2	3,3
G-TERM 5017.3 Ai	5,59	3,6
G-TERM 5021.3 Ai	5,61	4,4
BUDERUS WPW210 I	5,5	5
G-TERM 5024.3 Ai	5,71	5,1
G-TERM 5027.3 Ai	5,7	5,8
BUDERUS WPW270 I	5,1	7
G-TERM 5062.3	5,13	7,2
G-TERM 5072.3	5,17	8,3
BUDERUS WPW440 IP	5,9/5,7	9,5
G-TERM 5089.3	5,17	10,3
G-TERM 5109.3	5,15	12,6
BUDERUS WPW920 IP	5,9/5,4	20

5 Methodics

In the previous section, we had defined requirements, respectively. limits of the most important quantitative and qualitative indicators which is necessary to pay attention when considering over HP with an open water / water system whose primary source of thermal energy is groundwater. Adhering to the recommended values of these indicators should ensure not only efficient operation but also a longer service life device. Subsequently, we analyzed these indicators in groundwater on the territory of the Slovak Republic using the groundwater Atlas map created by ŠGÚDŠ in 2011. The output of this analysis is the follow-up information, which was also processed by ArcGis software, and thus were obtained the below mentioned of maps outputs. It is clear that the geological component of the rock environment in which groundwater is found has a significant influence on the values of our monitored indicators.

The steps we have chosen can be summarized as follows:

1.We found out which indicators are primarily observed for underground water used by the heat pump - temperature, flow, chemical composition.

2.We have selected 25 heat pumps from 3 manufacturers - Buderus, Nibe and G-Term Slovakia. The individual pumps belong to different power categories, they have different COP and, in particular, the recommended flow rates are different. Based on the available information, it is assumed that the water quality requirements are the same.

3. Subsequently, we have individually surveyed values at selected points in each hydrogeological zone for each indicator in the map application, which is freely available on the ŠGÚDŠ website. To get real results, we chose 3 to 6 points, averaged the values which we obtained and assigned geographic coordinates to each point. They allowed us to create maps in the ArcGis softwer and showing the territory of Slovakia which is and which is not in accordance with our qualitative and quantitative conditions.

4. After completing the above steps, we were able to review our findings. In addition to the course of the individual indicators in the SR, we could use the filter of the MS Excel and find on the obtained data:

- the highest value of the indicator,
- the lowest value of the indicator,
- the total average value of the indicator in the whole territory of our state,
- the most frequently occurring indicator value in Slovakia,
- which indicators in individual zones are higher/ lower than our conditions and thus constitute an obstacle to using groundwater in water / water heat pump.

By doing so, we should fulfill our main objective and determine where hydrogeological zones are suitable to place our heat pumps which groundwater utilizing and where it is not appropriate due to unfulfilled conditions.

6 Evaluation

6.1 Quantitative indicator of groundwater

The quantitative indicator that was considered in the article and which we consider to be important for the HP activity is the inflow. We found out that (Figure 2, Figure 3):

Highest detected value: 118,35 m3.h-1
Lowest detected value: 0,12 m3.h-1
Total average value: 6,72 m3.h-1.
The most common value (modus): 5,4 m3.h-1.

Almost every one of the 25 HPs has a different recommended minimum flow rate. For ease of assessment

Volume: 3 2017 Issue: 4 Pages: 7-24 ISSN 2453-675X

of our findings, we have aligned heat pumps from the smallest to the largest required groundwater flow (see Table 2). We have assumed that if the HP has a recommended minimum flow rate of 0.65 $m^3.h^{-1}$, they are also possible use in zones with the flow rate 2 and 8 $m^3.h^{-1}$ respectively because it can be controlled relatively simply by for example with a throttle valve.

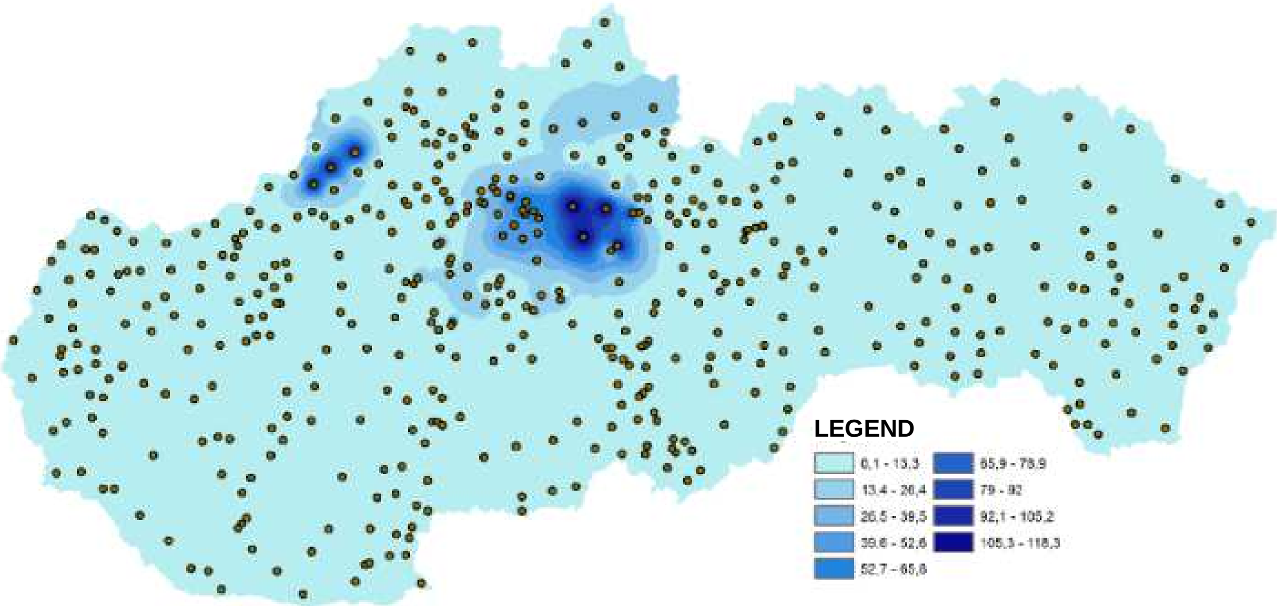


Figure 2 Flow of groundwater in Slovakia (processed according to[12]

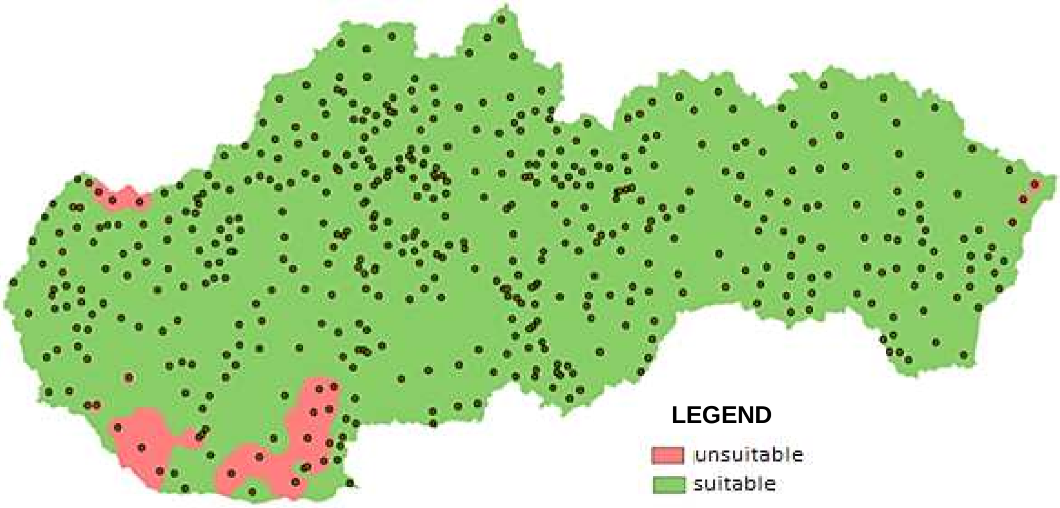


Figure 3 Territory suitable/unsuitable with flow requirements (processed according to [12])

6.2 Qualitative indicators of groundwater

The suitability of the hydrogeological zones for HP from the point of view of quality was evaluated according to the manufacturer's technical manuals, focusing on groundwater temperature and chemical composition. In their assessment, we have focused on the boundary values of individual elements or compounds towards which not only the steel parts of the evaporator but also the copper ones are resistant to corrosion, incrustation and total evaporator degradation.

6.2.1 Temperature

The lowest appropriate temperature for the HP we took into consideration was 7 °C. We have found that the groundwater of Slovakia in most of the zones meets this condition, and even in some places are achieving significantly higher temperatures (Figure 4, Figure 5).
Highest detected value: 15,2 °C
Lowest detected value: 4,8 °C
Total average value: 10,6 °C
The most common value (modus): 9 °C

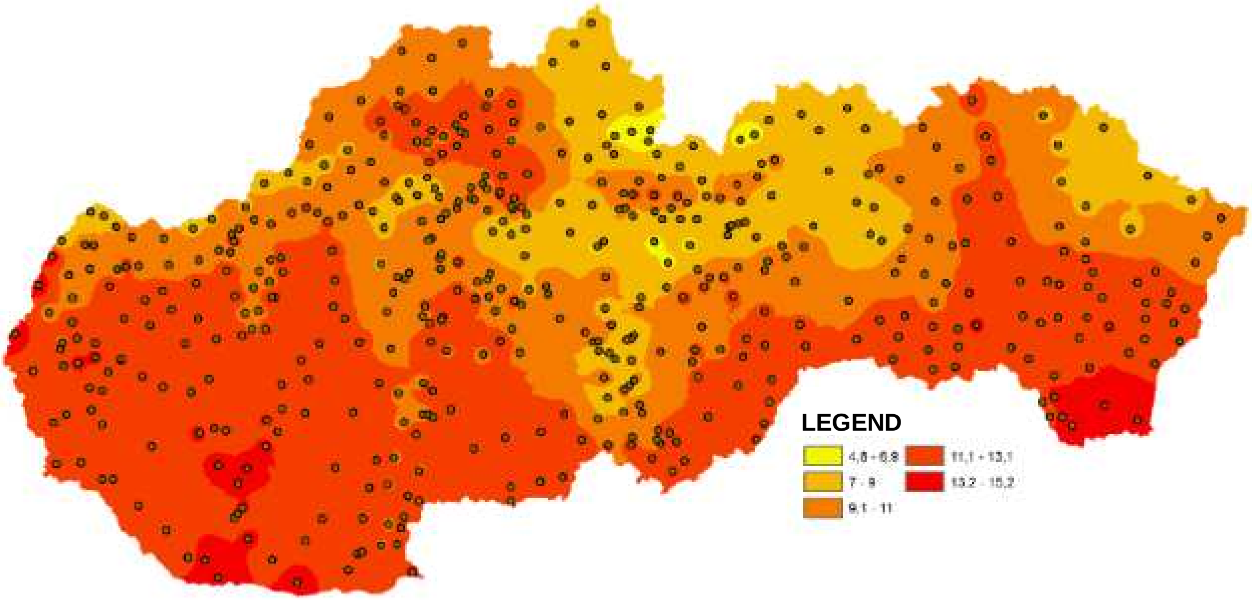


Figure 4 Groundwater temperature at SR (processed according to [12]))

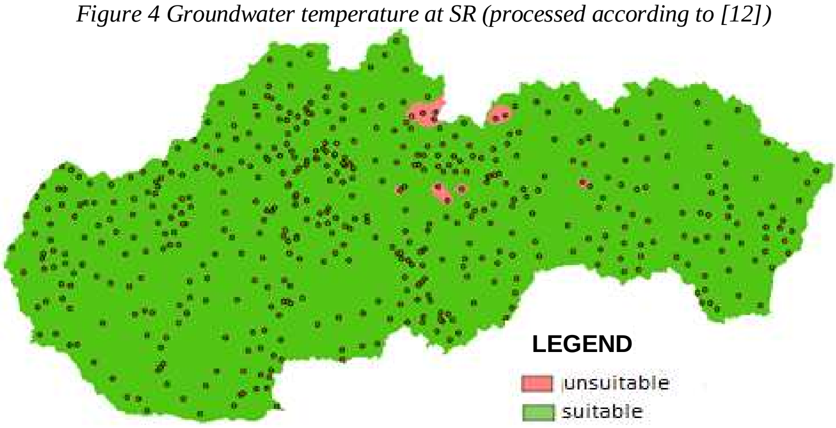


Figure 5 Territory suitable/unsuitable with temperature requirements (processed according to [12]

6.2.2 Iron

The limit value for this element is 0.2 mg.l^{-1}. If the iron concentration in groundwater is higher, the risk of corrosion also increases. It is one of the main indicators that are monitored in the water for your HP (Figure 6, Figure 7).

Highest detected value: 0,85 mg.l^{-1}
Lowest detected value: 0,01 mg.l^{-1}
Total average value: 0,44 mg.l^{-1}
The most common value (modus): 0,74 mg.l^{-1}

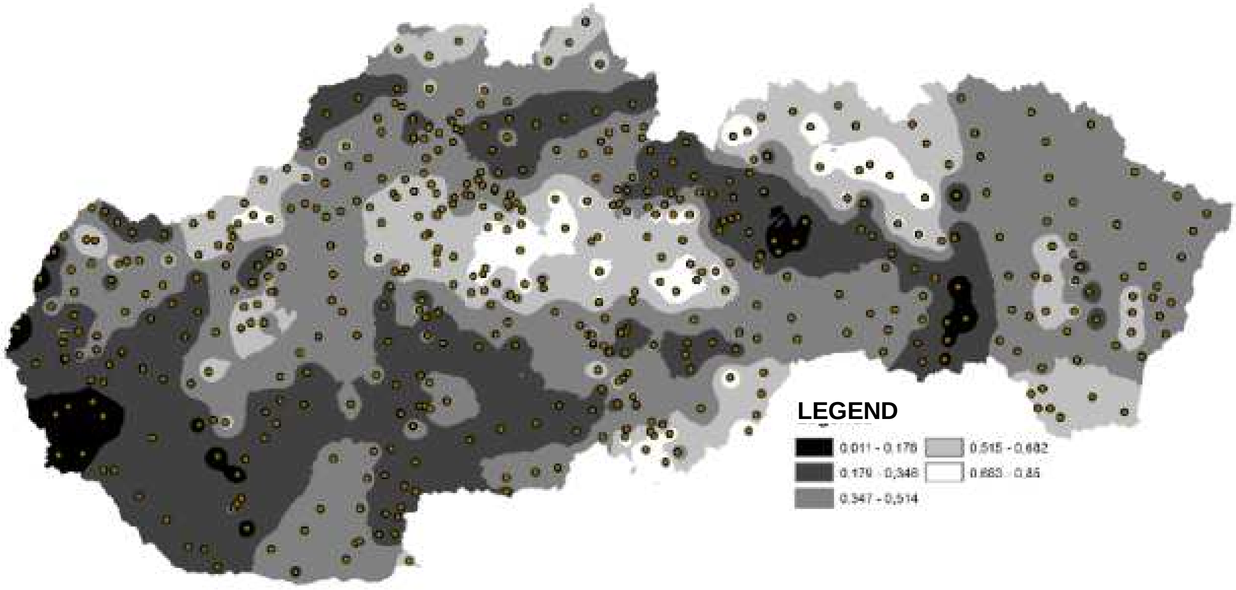


Figure 6 Quantity of iron in groundwater of Slovakia (processed according to [12])

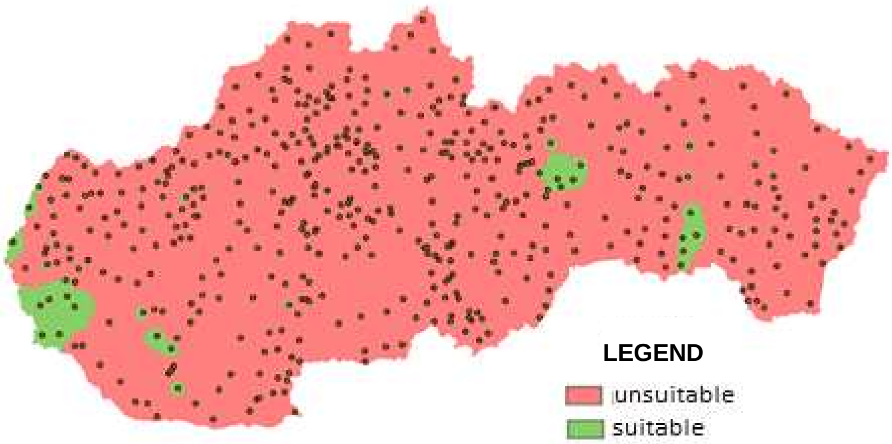


Figure 7 Territory suitable/unsuitable with iron requirements (processed according to [12])

6.2.3 Manganese

Since it is commonly found with iron, it is the second important indicator of the chemical composition of water. Its limit value, which should not be exceeded, is 0,1 mg.l^{-1} (Figure 8, Figure 9).

Highest detected value: 1,67 mg.l^{-1}

Lowest detected value: 0,01 mg.l^{-1}

Total average value: 0,30 mg.l^{-1}.

The most common value (modus): 0,02 mg.l^{-1}

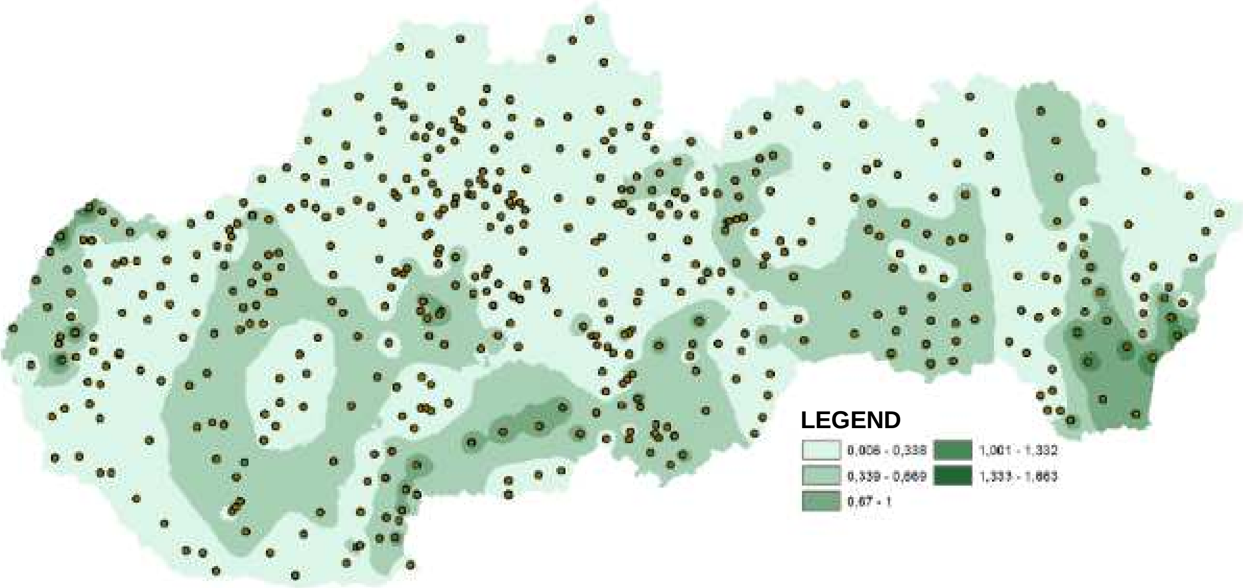


Figure 8 Quantity of manganese in underground waters of Slovakia (processed according to [12])

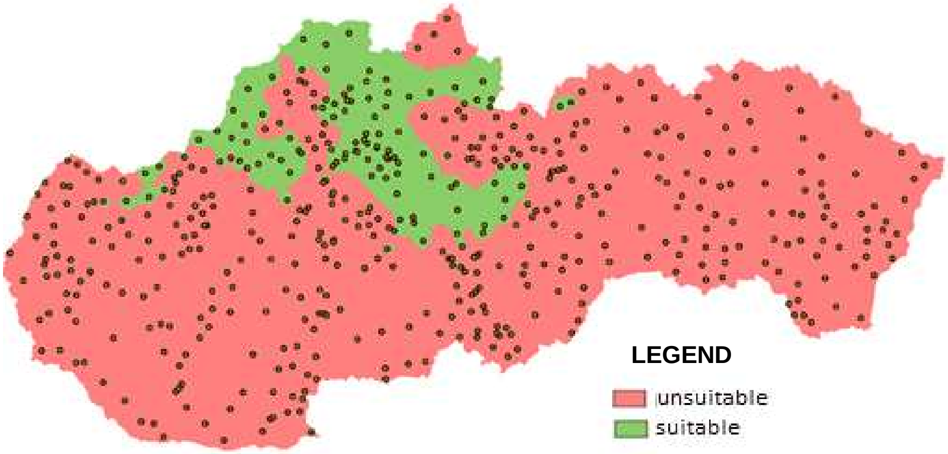


Figure 9 Territory suitable/unsuitable with manganese requirements (processed according to [12]

6.2.4 pH value

Like for many other devices, are does not suit to heat pumps too acidic or too alkaline water. The recommended values of BUDERUS are 7.5 - 9 [10] (Figure 10, Figure 11).

Highest detected value: 10,6
Lowest detected value: 7
Total average value: 8,2.
The most common value (modus): 8,8.

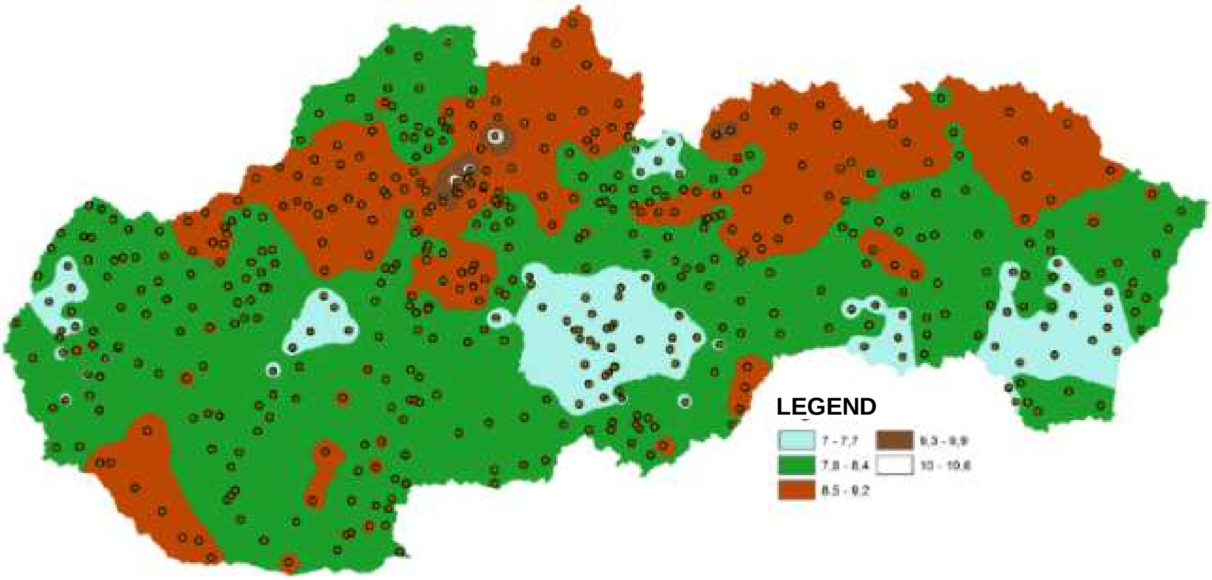


Figure 10 pH values of underground waters of Slovakia (processed according to [12])

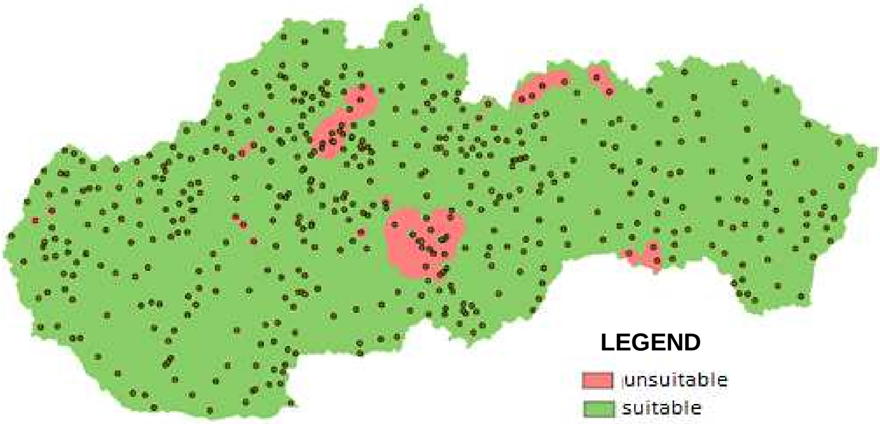


Figure 11 Territory suitable/unsuitable with pH requirements (processed according to [12])

6.2.5 Hardness of water

Too hard water is not suitable for the evaporator, as limestone deposits can occur, respectively scale in. It is recommended that water reaches a maximum of 4,5 mmol.l^{-1} (Figure 12, Figure 13).

Highest detected value: 13,23 mmol.l^{-1}
Lowest detected value: 0,30 mmol.l^{-1}
Total average value: 4,32 mmol.l^{-1}.
The most common value (modus): 10,71 mmol.l^{-1}.

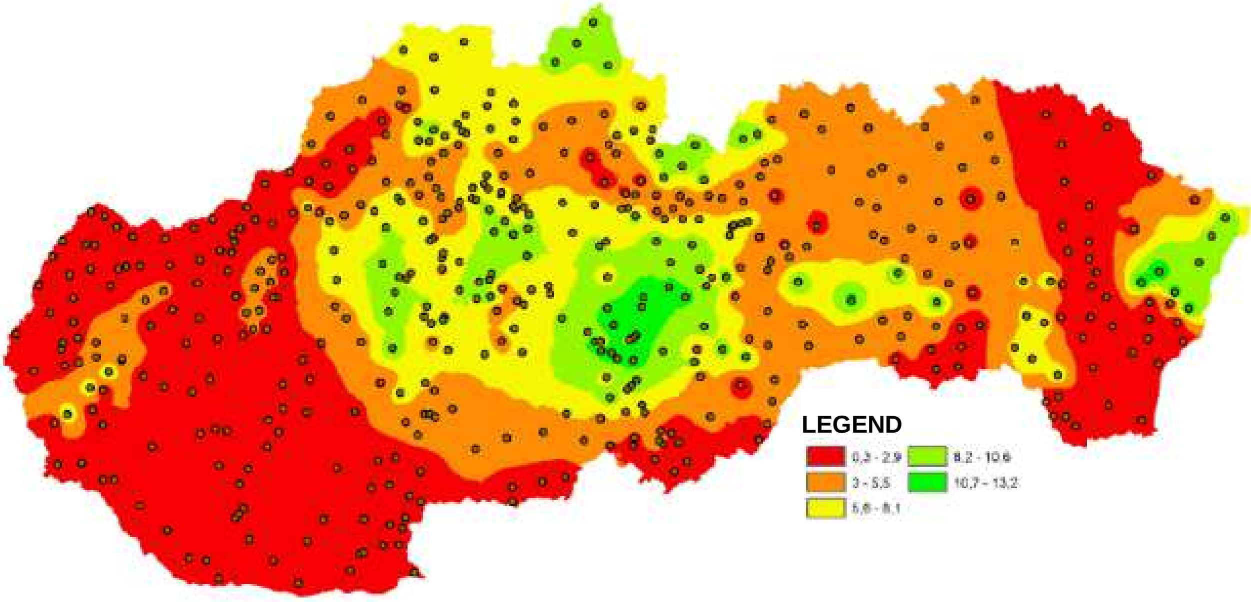


Figure 12 Hardness of groundwater in the SR (processed according to [12])

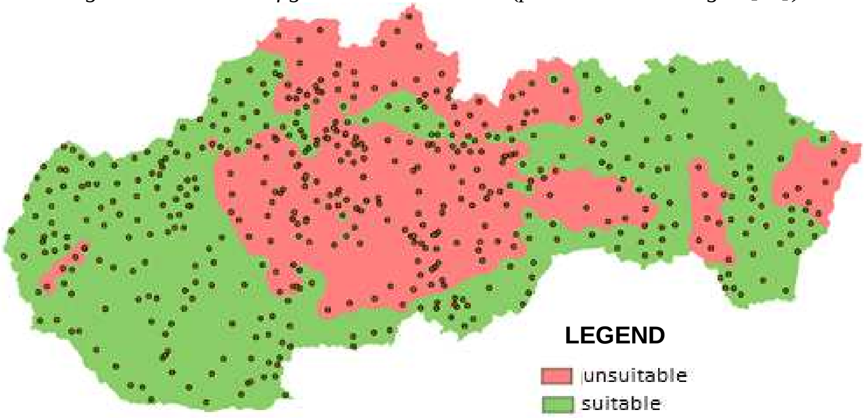


Figure 13 Territory suitable/unsuitable for hardness requirements (processed according to [12])

6.2.6 Bicarbonates

In order to avoid the occurrence of incrustations in the evaporator and the source water was not too hard, the concentration of bicarbonates should be in the range of 70-300 mg.l^{-1}. Only about 1/3 of the zones meet this requirement, typically value is less than 70 mg.l^{-1} (Figure 14, Figure 15).

Highest detected value: 452,55 mg.l^{-1}
Lowest detected value: 11,77 mg.l^{-1}
Total average value: 84 mg.l^{-1}.
The most common value (modus): 19,32 mg.l^{-1}.

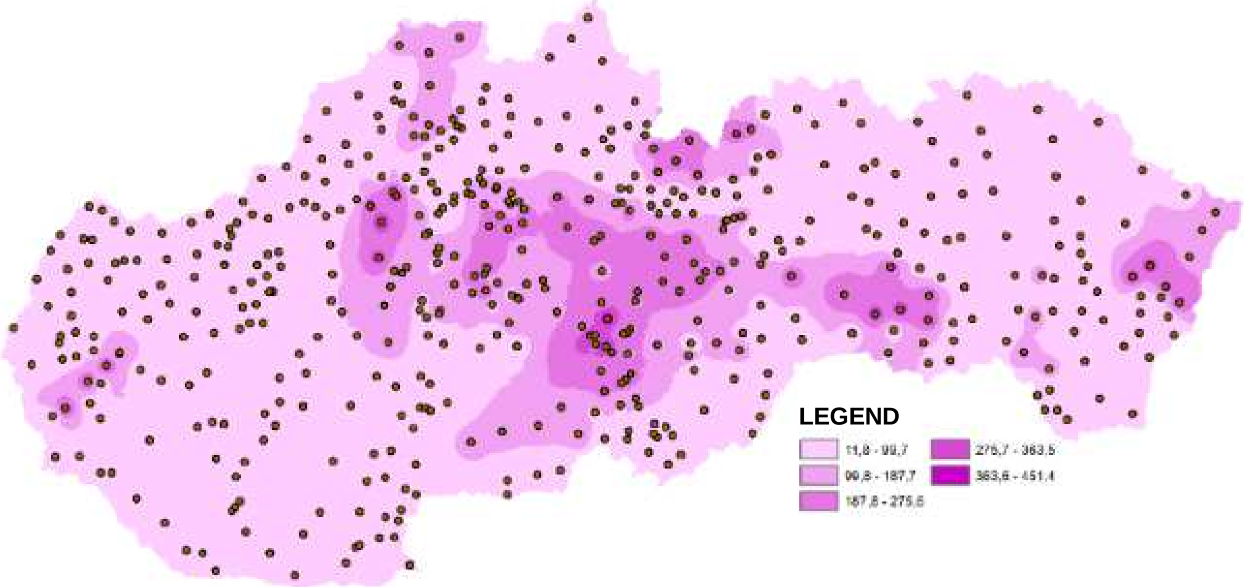


Figure 14 Concentration of HCO_3 in groundwater (processed according to [12])

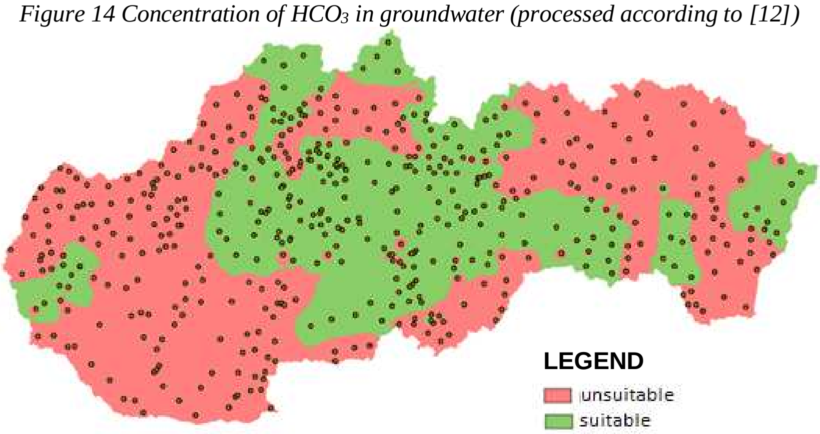


Figure 15 Territory suitable/unsuitable with HCO_3 requirements (processed according to [12])

6.2.7 Sulfates

It is not recommended at sulphates that their concentration in groundwater exceeds 70 mg.l^{-1} Higher quantities may indicate that groundwater is contaminated (Figure 16, Figure 17).

Highest detected value: 174,39 mg.l^{-1}
Lowest detected value: 2,83 mg.l^{-1}
Total average value: 38,91 mg.l^{-1}.
The most common value (modus): 62,17 mg.l^{-1}.

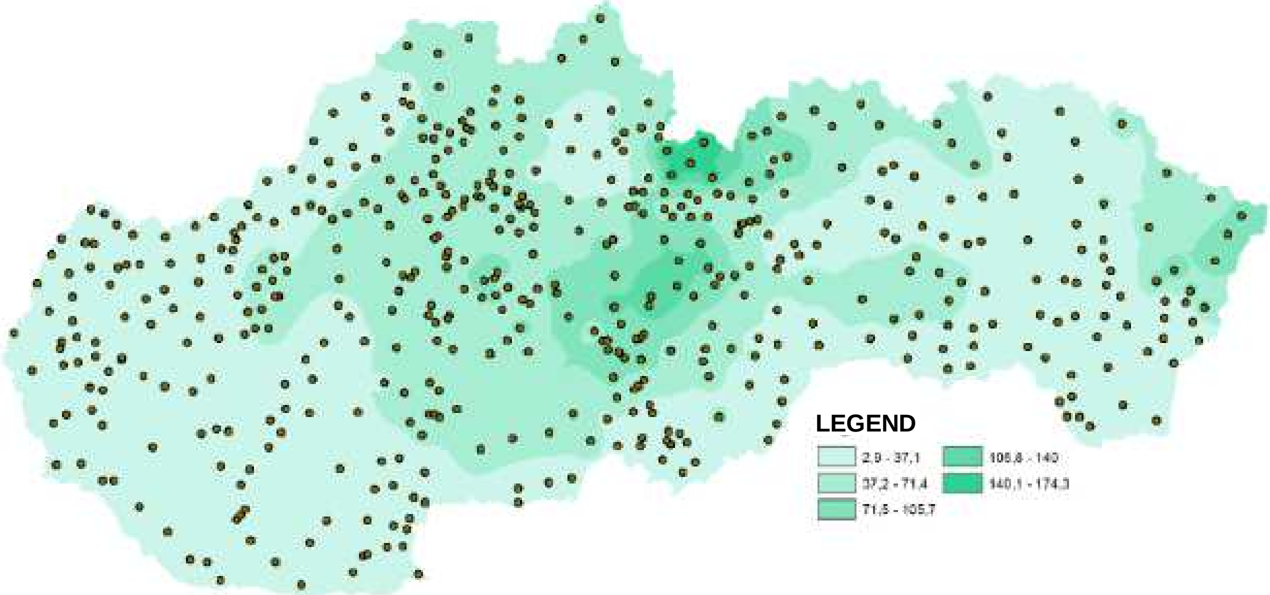


Figure 16 SO_4 quantity in groundwaters SR (processed according to [12])

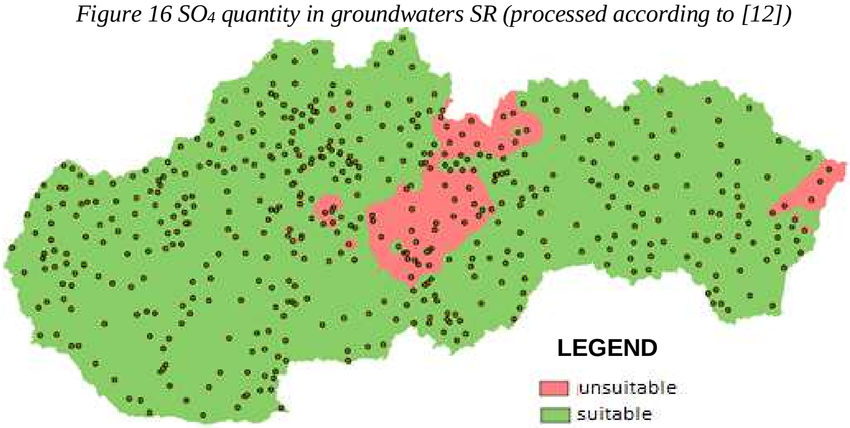


Figure 17 Territory suitable/unsuitable with SO_4 requirements (processed according to [12])

6.2.8 Aggressive CO_2

So as groundwater flowing to the evaporator not should to be too aggressive, the concentration of aggressive CO_2 should be less than 25 mg.l^{-1}. Higher concentration notice water is already considered aggressive by [13] (Figure 18, Figure 19).

Highest detected value: 53,66 mg.l^{-1}
Lowest detected value: 0,32 mg.l^{-1}
Total average value: 14,29 mg.l^{-1}.
The most common value (modus): 27,32 mg.l^{-1}.

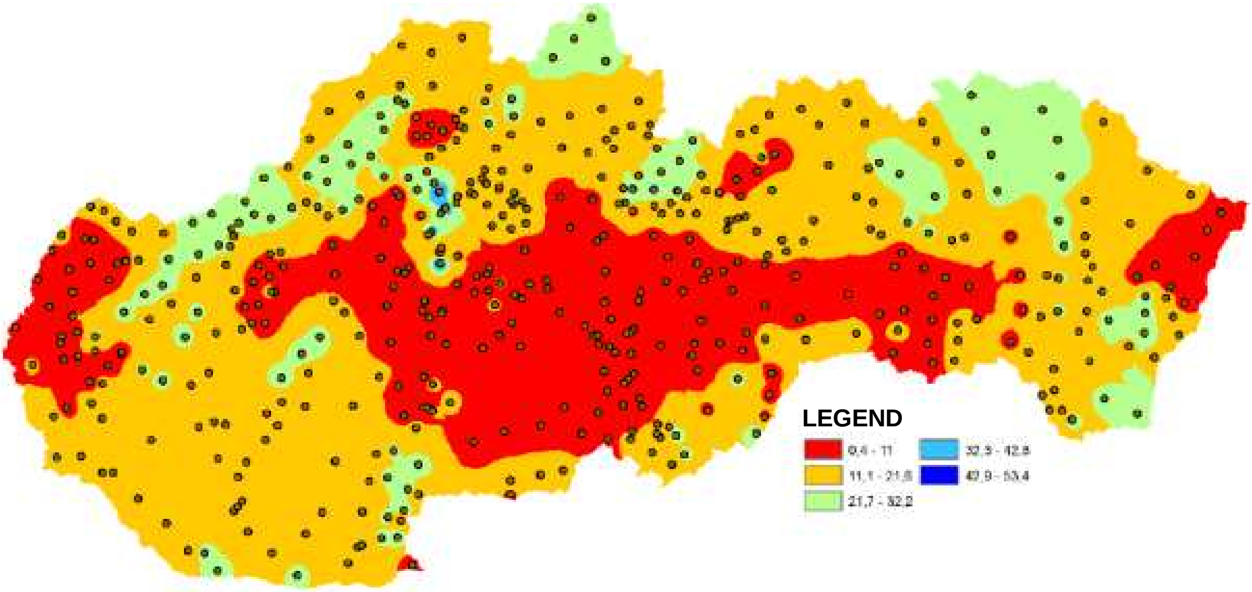


Figure 18 The amount of aggressive CO_2 in groundwater of the SR (processed according to [12])

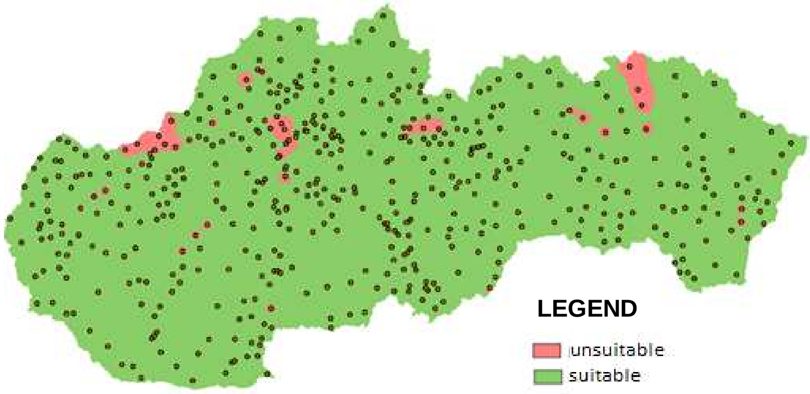


Figure 19 Territory suitable/unsuitable with aggressive CO_2 requirements (processed according to [12])

6.2.9 Electrical conductivity

The electrical conductivity (also referred to as EC), is a good indicator of water pollution similar like sulphates. Its recommended values are 10-500 $\mu S.cm^{-1}$ (Figure 20, Figure 21).

Highest detected value: 1888,3 $\mu S.cm^{-1}$
Lowest detected value: 86,2 $\mu S.cm^{-1}$
Total average value: 630,13 $\mu S.cm^{-1}$.
The most common value (modus): 657,89 $\mu S.cm^{-1}$.

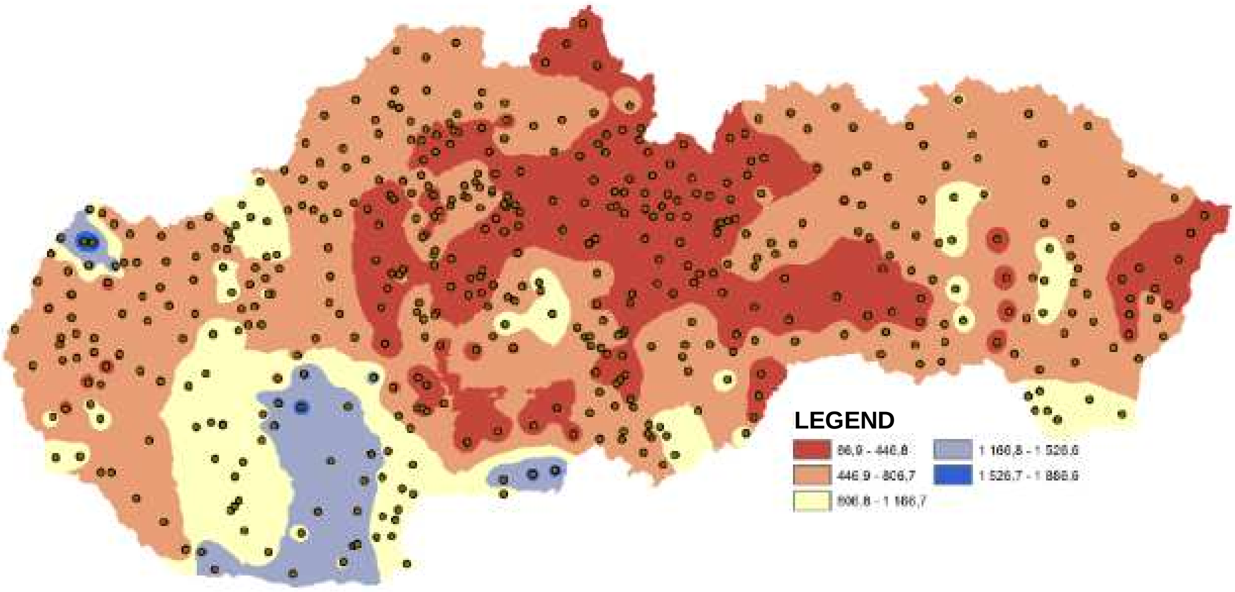


Figure 20 Electrical conductivity in underground waters of Slovakia (processed according to [12])

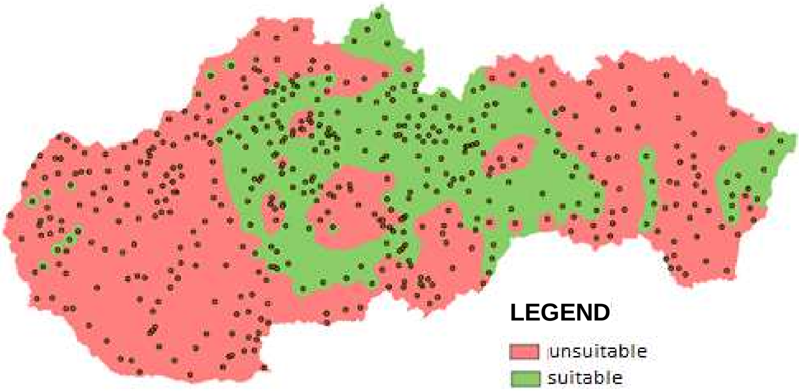


Figure 21 Territory suitable/unsuitable for electrical conductivity requirements (processed according to [12])

6.2.10 Chlorides

The chlorine concentration in groundwater used by HP should be less than 300 mg.l^{-1} (Figure 22, Figure 23)
Highest detected value: 90,51 mg.l^{-1}
Lowest detected value: 2,00 mg.l^{-1}
Total average value: 25,89 mg.l^{-1}.
The most common value (modus): 3,42 mg.l^{-1}.

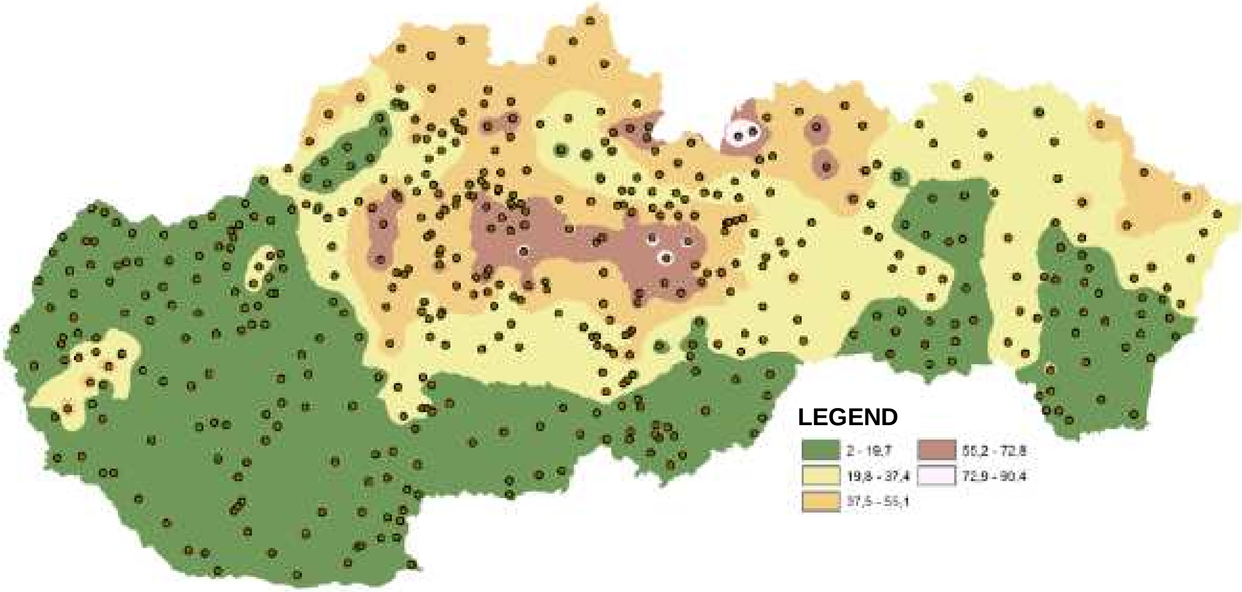


Figure 22 The amount of chlorides in groundwater of Slovakia (processed according to [12])

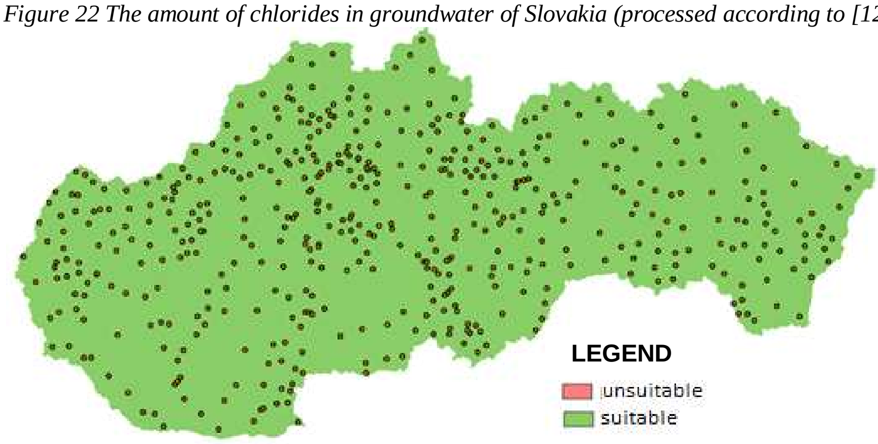


Figure 23 Territory suitable/unsuitable for chlorides requirements (processed according to [12])

6.2.11 Nitrates

The amount of nitrate in the water, that is the heat source for HP should be less than 100 mg.l^{-1} (Figure 24, Figure 25).
Highest detected value: 27,96 mg.l^{-1}
Lowest detected value: 0,68 mg.l^{-1}
Total average value: 10,00 mg.l^{-1}.
The most common value (modus): 19,32 mg.l^{-1}.

Acta Tecnología - International Scientific Journal about Technologies
Volume: 3 2017 Issue: 4 Pages: 7-24 ISSN 2453-675X

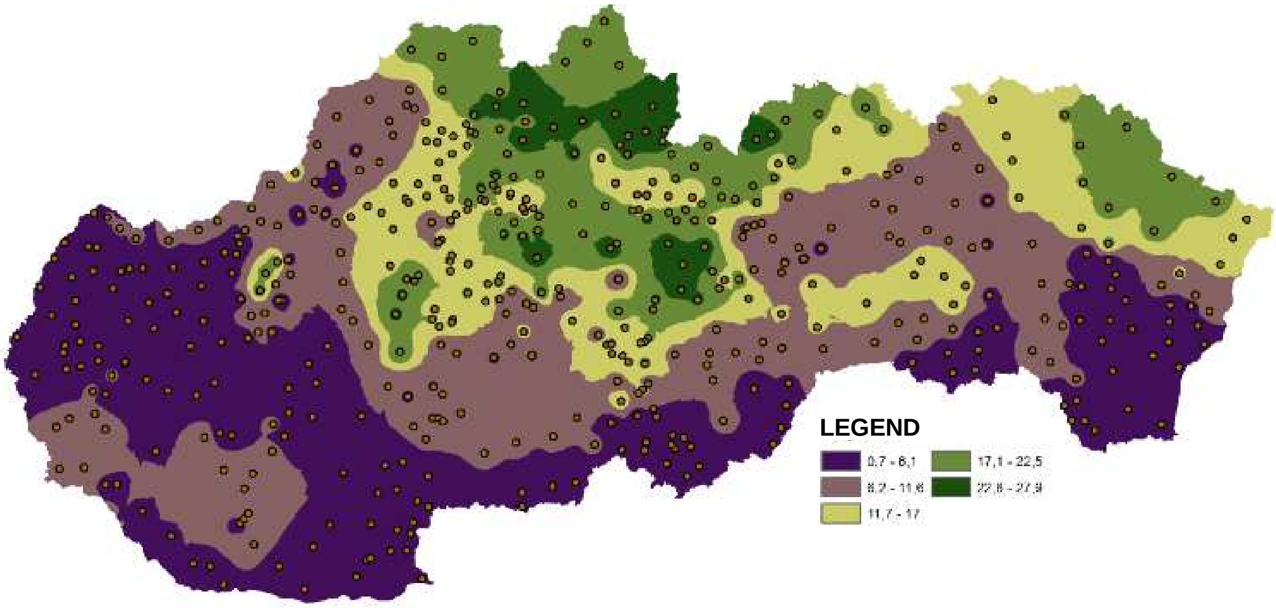


Figure 24 Concentration of nitrates in groundwater of SR (processed according to [12])

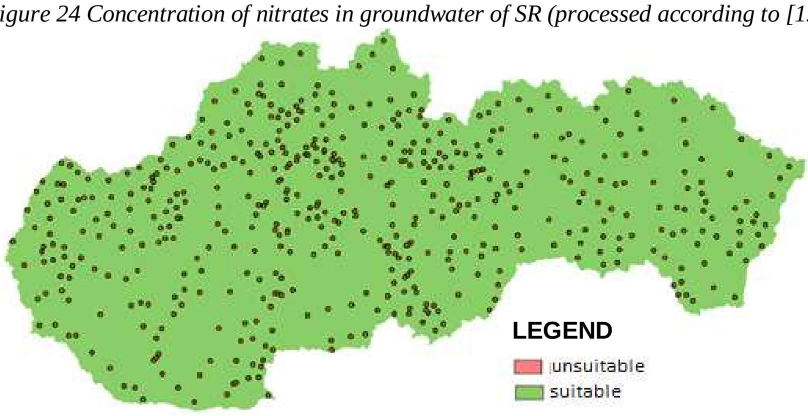


Figure 25 Territory suitable/unsuitable for NO3 requirements (processed according to [12])

6.2.12 Aluminum

The concentration of aluminum in groundwater, as well as iron, should not exceed 0.2 mg.l^{-1} (Figure 26, Figure 27).

Highest detected value: 0,428 mg.l^{-1}
Lowest detected value: 0,008 mg.l^{-1}
Total average value: 0,07 mg.l^{-1}.
The most common value (modus): 0,008 mg.l^{-1}.

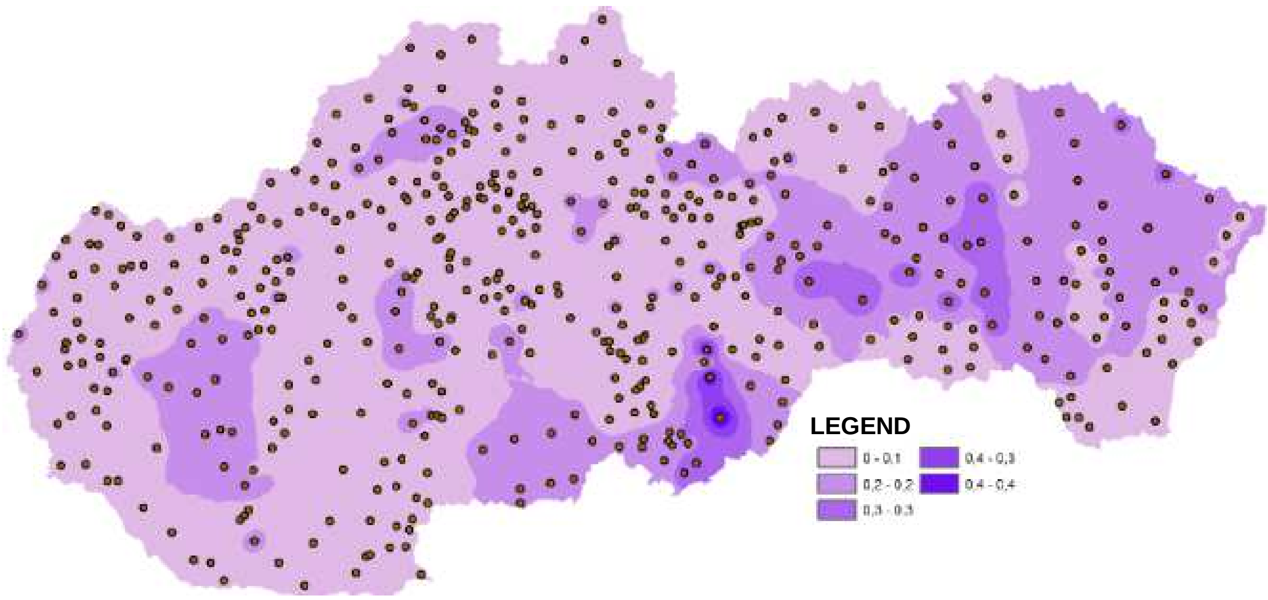


Figure 26 Amount of aluminium in groundwater SR (processed according to [12])

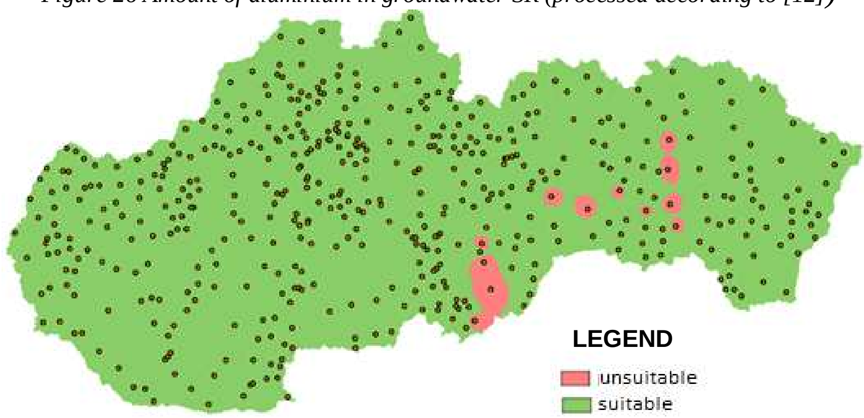


Figure 27 Territory suitable/unsuitable for Al requirements (processed according to [12])

Graph no. 2. (Figure 28) shows how many zones have higher or lower values of individual indicators than are recommended by manufacturers, distributors, resellers, or heat pump installers, and therefore do not meet HP's requirements for the quality and / or quantity of groundwater used.

The graph shows that 120 hydrogeological zones in Slovakia have higher iron values than 0.2 $mg.l^{-1}$, 99 zones have manganese concentrations higher than 0.1 $mg.l^{-1}$, 96 zones have lower or higher bicarbonate content, such as the recommended range of 70-300 $mg.l^{-1}$ and 95 zones, has an electrical conductivity higher than 500 $\mu S.cm^{-1}$. Increased hardness was found in 54 zones. Exceeding these indicators significantly increases the risk of corrosion of the evaporator.

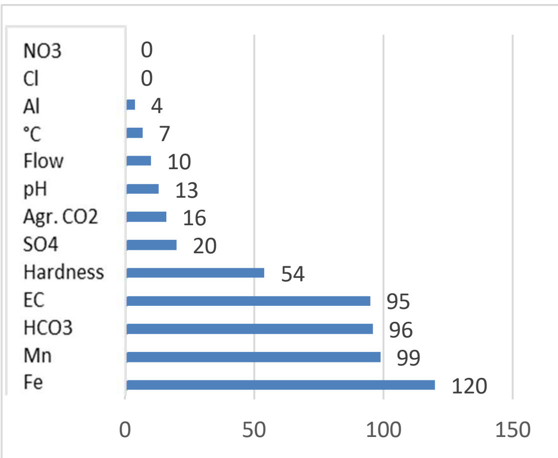


Figure 28 Number of hydrogeological regions not meeting the individual surveyed indicators

Regarding the flow, we found in ten zones that the well capacity of the wells, respectively boreholes in the given areas is less than 0.65 $m^3.h^{-1}$. This would significantly negatively affect the operation and effectiveness of HP (Figure 29, Figure 30).

A lower temperature than 7 °C was detected in only 7 zones, which means that this indicator should not be a major problem for HP installation in our territory.

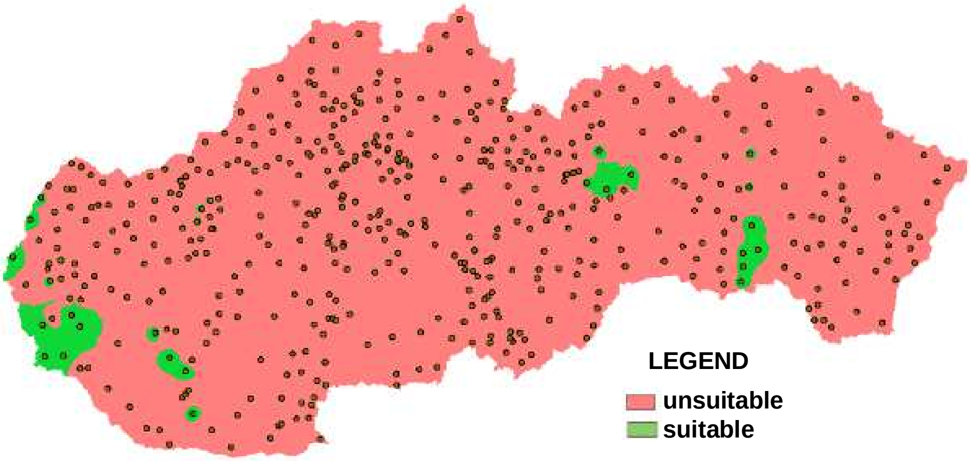


Figure 29 Areas suitable/unsuitable the requirements for t, p, Fe, pH, hardness (processed according to [12])

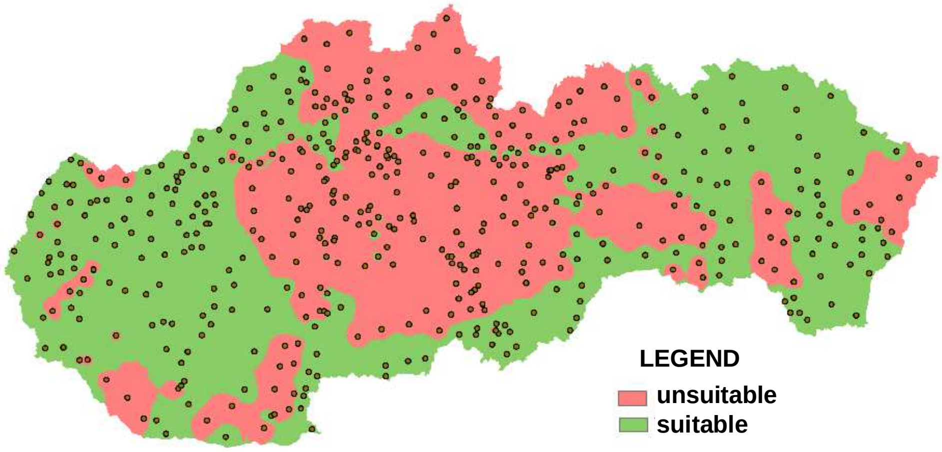


Figure 30 Areas suitable/unsuitable the requirements for t, p, pH, hardness (processed according to [12])

Conclusion

Finally, we can state that the ground waters of Slovakia in terms of temperature are very suitable for use by heat pumps, as its values often range from 7 to 15 °C. In terms of quantity, respectively, flow, depends substantially on the particular location where the heat pump will be installed, although the flow should be sufficient in most of the area, at least four devices with lower output. From the point of view of quality, most groundwater in our territory is not suitable for direct use by heat pumps, due to the high probability of corrosion in the primary part of the system circuit, but after the treatment (softening) of the water used afterwards using heat pumps is very appropriate, efficient and environmentally acceptable.

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Review process
Single-blind peer reviewed process by two reviewers.