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The potential of using groundwater as a heating/cooling energy source in the Vaasa city region of Finland

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Abstract: Groundwater accounts for 1.69% (0.76% as fresh and 0.93% as saline) of the total percentage of water in the world and comprises 99% of the earth's available water. The effects of climate change on the temperature increase in groundwater make it much more useful as a heat source, if it is not deeply located or near the ground surface. Hence there is a growing interest in extracting and storing thermal energy from groundwater and aquifers to contribute to the global clean renewable energy transition. In the Vaasa region of western Finland, the current knowledge of groundwater and unconfined aquifers is limited. To fill in this gap to examine and deepen the knowledge of groundwater and aquifer investigation techniques, defining groundwater effects on the energy borehole, and understanding the aquifers and groundwater, the literature review is conducted based on Tritonia library resources and internet documents using a systematic literature review method. A case study was initiated to explore the appearance of groundwater and aquifers during the drilling operations. It is expected that there is a connection between the aquifers under the sea and the groundwater on land. The possibilities of using groundwater as a heat energy source with groundwater energy utilization systems (GEU) are investigated. The key contribution of this paper is the critical assessment of the factors influencing the drilling process of boreholes that can be generalized to other regional sites. Our review shows that groundwater quality protection is of essential value because of its ecological, hydrological and economic significance.

Key words: Groundwater; groundwater utilization (GEU), Vaasa region, aquifers, renewable energy.

1. INTRODUCTION

Groundwater is defined as water that is found beneath the earth's surface in pores and fractures of soil and rocks. As an important part of the hydrological cycle, one-third of the world's freshwater reservoir is groundwater. Its advantage over surface water is that it is free from pathological organisms, turbidity, radiochemicals and biological contaminations (Patra 2000). An aquifer is defined as a body of porous rock or sediment saturated with groundwater (National Geographic 2022). It is a geologic formation through which groundwater can flow. As an essential part of the hydrological cycle, aquifers collect and store surface runoff that might be lost to the sea (Hilding-Rydevik and Johansson 1998). Groundwater pollution means polluting freshwater sources because groundwater is one of the largest freshwater reservoirs in the world. Water borehole drilling means drilling and casing a hole to access groundwater and extract heat energy. Heat energy borehole storage drilling is the drilling of the ground to use it as heat energy storage. Excessive depletion of groundwater can cause water to have undesirable quality, interfere with water rights, increase pumping charges, decrease or dry upstream flow, and intensify land subsidence (Canter *et al.* 1987). Hence, care should be taken not to contaminate or deplete the flow of current found in aquifers and groundwater.

Borehole drilling has been conducted worldwide. A study made in the UK for the borehole drilling process onshore was facilitated by the application of instrumented borehole drilling techniques in offshore explorations (Gui *et al.* 2002), where the 'noise' in the raw data was used to distinguish setup for ground characterization. A UNICEF project was aimed to assess the groundwater investigation, drilling and supervision capacity in Uganda (Sloots 2010). In Uganda, there is a need for groundwater abstraction permits for those who want to use a borehole equipped with motorized submersible pumps. The drilling process in Uganda initially was very expensive, about US$ 10,000, and then started to drop. Rathinasamy *et al.* (2022) assessed the water borehole drilling challenges in Sothern Johor Bahru in Malaysia and concluded that the volcanic-sedimentary rock has a higher potential for groundwater extraction compared to the Older alluvium.

Groundwater level increases can be advantageous in most areas of the world but also cause damage in some areas. In Aswan, Egypt, the increase in the groundwater level caused severe damage to buildings, leading to poor quality of agricultural land, environmental pollution due to the formation of surface ponds and the destruction of infrastructure due to the lack of good management (Hossen *et al.* 2022). This article shows the importance of good water management to avoid damage to us and also to protect groundwater pollution. Water scarcity caused an increase in the exploration of groundwater sources worldwide (Rathinasamy *et al.* 2022). This statement is in contrast to the case of Aswan of Egypt case situation, because in Egypt the groundwater is flooding rather than being low. To manage groundwater resources, the investigation of the spatial and temporal dynamic behaviour of the groundwater level fluctuation can help (Chen *et al.* 2022).

It has been recommended that water management authorities should develop a groundwater system monitoring network to control the groundwater quality and quantity in real-time (Ullah *et al.* 2022). Hence, measures can be created to prevent the contamination or conditions of groundwater from getting worse. Similar studies on groundwater have also been performed by Kolapo (2021), Goswami and Sekhar (2022), Gebre-Egziabher *et al.* (2022), Azffri *et al.*, (2022) and Fang *et al.* (2022). In Finland, the first studies of the chemical quality of groundwater were made at the beginning of the last century (Artimo 2003). In this study, the potable water available from the few existing groundwater intakes was analyzed. In western Finland, Karro (1999a) studied the quality of bedrock groundwater focusing on nitrogen composition. The current knowledge of the groundwater and unconfined aquifers in the Vaasa region of western Finland is limited (Martinkauppi 2013).

The current paper conducts a literature review for the Vaasa region to fill in this gap. Methods of groundwater investigation are suggested for the case. Groundwater types and the potential of a heat energy source are explained, and suggestions are made to build such groundwater energy utilization (GEU) systems in the Vaasa region. The continuity in the drilling process, types of water movements, the connections between groundwater and aquifers, and the descriptions of the Vaasa region are shortly presented in this context. The main objectives of the study are: 1. To investigate the groundwater appearance during the borehole drilling process. 2. To decide on the continuity of the borehole drilling process. 3. To suggest the implementation of a GEU system in the Vaasa region, mainly in city sites. The novelty of the paper is the suggested recommendations to avoid contamination in the drilling process to help make decisions about the continuity of the drilling process and the use of the GEU system in the city of Vaasa region. Questions raised in this paper can be classified into three parts:

1. *The case study-related questions*: What kinds of water movements are present in groundwater to cool or warm the drilled holes? Is there a direct connection between the two aquifers near the sea and the groundwater? What kind of groundwater and aquifers are present in bedrock? What kind of water is there in the aquifer? What kind of effects does groundwater cause on boreholes?
2. *Helping the decision-making*: Is it possible to continue the drilling of the borehole, if there is an aquifer? How do we manage the continuity of the energy supply drilling process?
3. *Further groundwater energy utilization suggestion*: Why and how can we use groundwater as a heat energy source?

2. MATERIAL AND METHODS

This study adopted a keyword-based method to perform a literature search. The keywords used for publication search were “Groundwater” OR “aquifer” OR “borehole drilling” OR “energy utilization” OR “Vaasa” in the main title, abstract and keywords from digital publication databases, namely, Google and local library resources (Tritonia library of the University of Vaasa). We focused on peer-reviewed books, journal papers, and dissertations written in English. The selected papers were studied in terms of this research’s objectives and then further summarized and cited in this paper.

3. CHOOSING THE GROUNDWATER INVESTIGATION METHODS

Locating a suitable aquifer capable of yielding the quality and quantity of water required at a reasonable economy is the main objective of this investigation. It is a must one investigates the groundwater about the number of aquifers present. The main methods of groundwater investigation are presented in Figure 1. Based on Figure 1, we will choose the best method to identify the current groundwater for the Vaasa region. As the seismic refraction method has been studied in Sweden (Rönkö 1983), the first choice would be the use of seismic refraction for Vaasa region investigations. Depending on the availability of the drilling machine, the second type of investigation would be the test drill method. The seismic refraction method gives an approximate 95% reliable result and will help determine the depth and thickness of the underground water along with the water velocity in different strata. The test drill method will also give a better understanding of the water level and quality. Moreover, remote sensing would possibly reduce the physical groundwork investigations required. Artimo (2003) applied a mixed method, including seismic refraction, test drill method, gravimetric measurements and ground penetrating radar sounding. We believe that such a mixed method can be employed to study the water quality of the aquifer and the groundwater for our site. Regarding water quality testing and sampling, measurements can be conducted (Rönkä 1983, Soveri 1991, Lampén et al. 1993, Karro 1999b). Further, the radioactive determination should be done, on average, every two days.

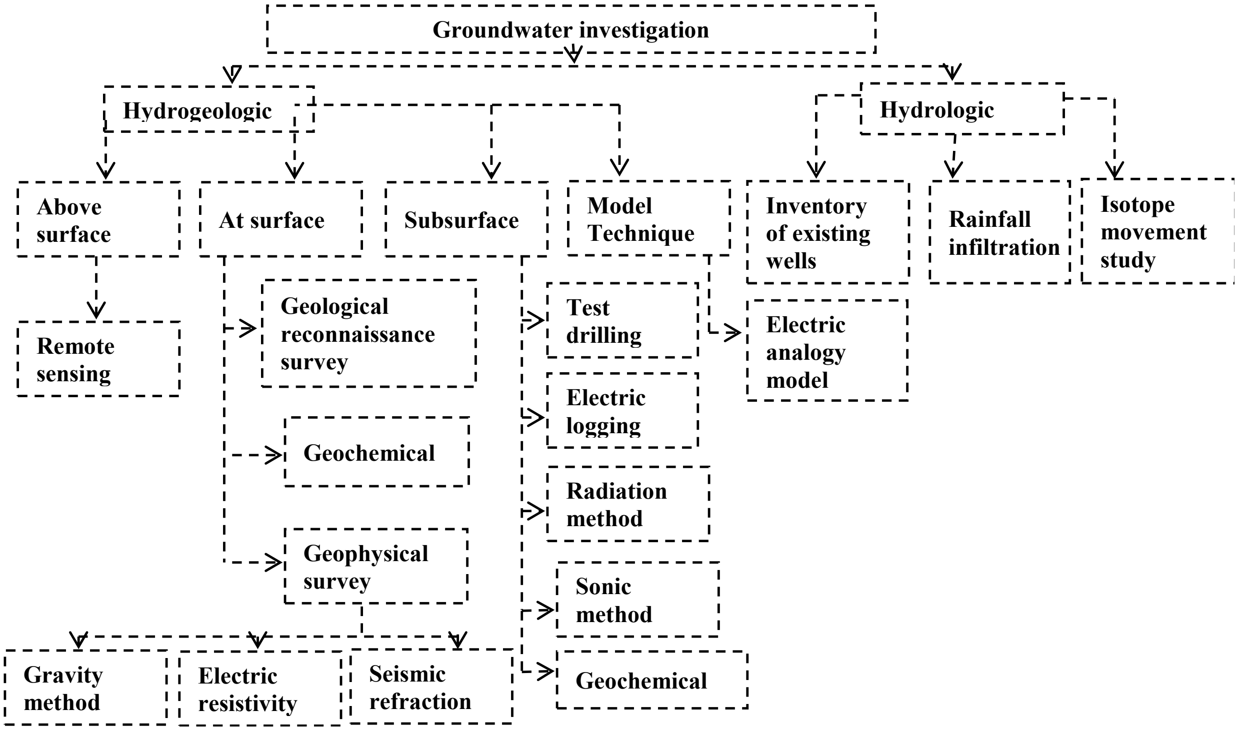

Figure 1. Methods of groundwater investigation (developed by Patra 2000).

4. RESULTS

4.1 Types of water movements present

Bedrock groundwater in the Vaasa region continues in motion and undergoes an annual hydrological cycle (Karro 1999a). The movement slows down with increased depth, and groundwater is most mobile in the surface parts of the Finnish bedrock. From this, we can suggest that there are movements in the Vaasa region's groundwater. The easiest way this can be investigated further is with the use of a flow meter with an anemometer which can process a 0.3 mm/s flow velocity (Martinkauppi 2013a-d). However, precipitation and small flow temperature fluctuations may cause poor performance and limit their use. Another option would be a heat-plus flowmeter, capable of measuring a velocity of 1-240 mm/s and which better manages the problems noticed in other flowmeters. Model flow software such as MODPATH is also applicable when investigating the movements of groundwater (see Martinkauppi 2013; Artimo 2003). Flow nets can also be used to identify the direction of the movement of water, and helps to quantify the water instance under aquifers (Heath 1983). The application of a flowmeter was described by Kearl (1997), who states that it is possible to quantify groundwater flow directions and rates under laboratory conditions by measuring particle velocities in a wellbore using the colloidal bore scope. One of the main functions of groundwater in streams is that it creates an initial source for the stream to start (Jones *et al.* 2000), and its types of movement can be investigated along the stream's course. In presence of a well, the natural movements of groundwater change from laminar to turbulent when it reaches the well (Delleur 1999). In our case, the groundwater is turbulent near the borehole, which means it has much more effect of contact on the borehole exchanger causing a heating or cooling effect. While knowing there is movement and the movement is highly variable; the real notice is that there is a chance of heating and cooling of the borehole by natural groundwater movement. Thus, it is worth considering how we use this natural movement. The first step would be to study the movements thoroughly, and designing the boreholes accordingly would be one suggestion, such as using shorter exchangers. Flow is a three-dimensional concept, and not only vertical (Bear *et al.* 1992).

As noticed in the figures of Canter *et al.* (1987), there are movements between the unconfined aquifer and discharge from lakes and rivers. In the Vaasa region, the location of the groundwater is quite near the sea and not to mention the aquifers might be situated under the sea layers. Therefore, there are movements between them, and it means that any measures affecting the groundwater directly or indirectly affect the seawater. We have to think of the bigger picture. As with climate change and global warming, the current fresh water supply is placed at risk because of the uncontrolled human usage of the past. It is therefore important to consider whether we should risk ignoring the potential of a future generation fresh water source, even though there is an expectation of salinity. Generally, it is quite clean water we encounter, but any effects we may cause while drawing it as an energy source for human use should be considered. Whether the aquifers are charging the groundwater is another possibility mentioned by Brassington (1995). However, it is most probable that the movement is from groundwater to aquifers. Heath (1983) offers more than five illustrations from different books that show that there is movement from groundwater to aquifers. Hence, their proximity to one another seems possible.

4.2 Description of the Vaasa region

Vaasa is a very beautiful town, terribly cold during the wintertime due to the icy winds from the Gulf of Bothnia, but a lovely sunny place during summer. The archipelago is unique with all of its small rocky islands and diverse range of wildlife. The bedrock of the Vaasa region is compiled of folded and metamorphosed Svecofennidic mica schists, phyllites and mic gneisses intruded by granitoids (Karro 1999a). Quaternary glaciation has caused some modifications in the bedrock. The clay which covers the bedrock to a depth of about 100 m characterizes the Vaasa area. The name

Vaasa was given in 1917, and after a few name changes, the Finnish spelt name gained its place in 1930 after the majority of the population became Finnish speakers. There were 69.8% Finnish speakers and 24.8% Swedish speakers (Mikkonen 1975). The place has a population of approximately 169,843 people in 2022. The coverage of the sea influences the groundwater to be salty, with high Mn and Fe. The land area of the province is about 26.119 km^2, which is about 8.5% of Finland's land area. The land is not homogenous; it includes about 300 km of sea coast. From the physical geographical point of view, the administrative province of Vaasa is divided fairly clearly into fertile clayey plains, interspersed with rivers and more barren watershed areas between them, which are slightly higher and covered with till or sand. The eastern and southern parts of the province belong to the agriculturally unfavourable watershed area called Suomenselkä. The density of the population is nearby the river and valleys, for example near Kyrö and in the middle course of the Lapua River. The most sparsely populated area is the northern, eastern and southern edges.

4.3 The connection between the two places

The connection between the aquifers under the sea and the groundwater near the borehole is mysterious. There should be a proper study conducted to determine whether there are connections and water movements between them or not. Isotope movement or tracers (Mälkki 1979) can be used to investigate the groundwater flow, as well the connection between the two places. Within the vicinity of a monitoring well, borehole dilution methods provide a simple and direct way to measure the magnitude of horizontal groundwater flow (Pitrak *et al.* 2007). Based on the literature, there is a connection between groundwater and surface water such as seas, streams and lakes. The groundwater recharges the lakes and streams, and in our case, it is also true for the sea. Therefore, we can say that a connection between the aquifers and the groundwater can reasonably be expected to be found. However, how much of a connection and why it exists must be investigated. There is a connection between the sea and the groundwater, and this may be explained by the fact that, by nature, water is fluid. In addition, there is water in between soil particles, and as water moves continuously, that causes the development of water movements and, so, creates a connection between the two places of the groundwater inland and the aquifers in the sea. As the aquifers are the current groundwater we know to exist in the sea, it is visible that there are connections. However, how much of a connection is something we still have to investigate, and the heat convection that occurs between the aquifers and the groundwater would be our focus of interest.

In summer there is heat in the sea, and that means there is the movement of heat from surface water or the sea to groundwater and the aquifers (Wetzel 2001). If there is a direct connection between the aquifers and the groundwater, then there will be heat development in the boreholes and they will heat up to some extent when the air temperature is 30^{o}C. However, in winter the heat movement might be vice versa, as the boreholes will be heated up by groundwater. The heat movement might also be developed from groundwater by the aquifers in winter. In winter, the bottom of the sea is warmer, while there is ice on the top, and that is why we have liquid water in wintertime, otherwise the coldness will spread to the groundwater, resulting in a fracture of land by ice buildup. This type of heat flux can reverse on shorter even daily time scales, particularly in shallow lakes (Wetzel 2001).

4.4 Kinds of groundwater and aquifer present in the Vaasa region

According to a study done by Karro (1999a) on the quality of bedrock groundwater in Western Finland or the Vaasa region, the groundwater quality is generally good. The results of his analysis are compiled based on 23 drills in 19 locations, where the depth of the wells extends from 20 to 150 m. The Vaasa area is characterized by bedrock which is covered with clay on top to about 100 m. The amount of nitrate is lower than seen in other areas of bedrock groundwater in Finland. However, the nearby sea has contributed to the salinity of the groundwater. Based on his study, we can say that the groundwater we encountered has some salinity, but it would be good to study it more deeply using appropriate sampling techniques. There is no relation between the concentration of nitrogen compounds and the depth of the groundwater. However, there is an expectation of groundwater pollution from surrounding farming or other human activity, as the bedrock neutralizing capacity is very limited. The two main types of pollution sources exhibited are the point source (septic tank systems, underground storage tanks, hazardous waste sites, landfills, surface impoundments, abandoned wells, and drilling mud disposal), and diffused sources of pollution stemming from agriculture, nitrates and agricultural chemicals, acid precipitation, dry deposition and metals contamination (Canter *et al.* 1987; Ullah *et al.* 2022). The current possible contaminates lists were given for drinking water by the World Health Organization (2022). Finnish aquifers are mainly unconfined; therefore, our sea aquifers are also unconfined (Artimo 2003). In addition, there is salinity from ancient seawater that contaminates the groundwater, and this has at least been observed in studies in the Espoo region (Karro 1999b). Thus, groundwater used for drinking water is questionable. While it would be great to determine the minerals and metals present in the groundwater and aquifers, care is needed not to get wrong results, for example by undertaking water sampling in a pumping period when examining the chemical character of the water (Karro 1999b). The phosphorus content of groundwater is quite low (around 20 µg/l) in areas where the phosphorus content of surrounding soil is higher (Wetzel 2001). However, correctly conducted sampling will offer a good insight into the clarity of the water and its availability for drinking purposes. The current standard of drinking water quality is given in detail by the World Health Organization (2022).

4.5 Effects of groundwater in boreholes

The ground source heat pump (GSHP) is a u tube in a closed loop inside a vertical borehole ground exchanger bore (BHE). It works perfectly in the absence of groundwater flow, and the ground works as thermal storage. GHSP is a closed system in which heated fluid circulates in a vertical and horizontal heat exchanger with the surrounding underground, and by it, a huge amount of fossil fuel use is avoided and CO_2 emissions are minimized. It can afford space heating, air conditioning and hot water supply to both commercial and residential buildings. A vertical borehole configuration is often favoured over a horizontal one because of its smaller space requirements and fewer problems with heat loss to the surface. The vertical pipes can be 50 -150m (Molina-Giraldo *et al.* 2011; Lee *et al.* 2012). According to Lee *et al.* (2012), the groundwater flow decreases the temperature of the borehole. The reduction of the required borehole length can be achieved if the presence of groundwater flow helps convey the excess heat away (Molina-Giraldo *et al.* 2011). However, they recommend further investigation to determine the exact effect of the ground flow on the borehole.

There is a higher temperature at a lower velocity, the velocity of 10^{-5} m/s and the relative groundwater table of 0.522 should be similar to that based on a full groundwater velocity of $5 \cdot 10^{-6}$ m/s. However, they differed by more than 1.4°C. The fluid temperature with a full groundwater flow was even lower. This means the temperature change is quite low in different groundwater flows. Unlike the situation with a full groundwater flow, in the ground, the borehole thermal resistance was affected by the temperature variation along the borehole depth, and also varied with the relative groundwater table and the groundwater flows velocity although not to a great extent (Molina-Giraldo *et al.* 2011). Wang *et al.* (2009) said that even at relatively low specific flow rates the groundwater flow may cause significantly enhanced heat transfer. Molina-Giraldo *et al.* (2011) state that without an appropriate way to evaluate the borehole thermal resistance under different ground tables and the groundwater velocity, the correct fluid temperature could not be determined. It is difficult to determine the effect of groundwater flow on boreholes, so further study is recommended. However, the heating and cooling of boreholes is a result of groundwater's effect on the boreholes. Knowing there is movement in the groundwater shows us that these effects are much more casual than seasonal types. Whenever there is movement, the heat loss and gain can be forecasted or noticed as discussed above.

Seasonal heat development and loss are much more accurate to assess based on the findings of previous literature. As Wetzel (2001) states, lake water is heated with indirect heating from groundwater or springs. Therefore, one of the effects of the groundwater in boreholes would be heat coming from hot groundwater to the boreholes in winter. In addition, it is mentioned by Wang *et al.* (2009) that, during winter operation; the heat supply ability of the BHE (borehole exchanger) can be improved with an increasing groundwater velocity. In winter, groundwater is usually hotter than surface water, therefore groundwater contributes to temperature increase (Lee *et al*. 2012; Jones *et al*. 2000). It is possible to say that in summer the groundwater might be colder than the boreholes as atmospheric temperatures can be around 30-degree centigrade, therefore the groundwater might cool down the borehole as the heat will be transported by the moving water (Molina-Giraldo *et al*. 2011). Electric resistivity may be used to detect leaches in refuse disposal sites that cut through loose weathered granite (Young 1973). Leachates have a high pollution potential, but when passing through the soil the impact of load will be reduced by groundwater supplies by way of dilution, sorption and microbial degradation. These effects are much more widespread when there are boreholes, as we are creating direct contact with the groundwater that opens water quality degradation. Vice versa, the groundwater will affect the borehole’s decline in temperature in soil water in summer. Groundwater causes moistening of the soil that causes it not to drill deep especially in nearby sea aquifers (but this is depending on the driller type) and heating up at beginning of winter and wintertime. Both heating and/or cooling are possible, and it depends on the origin of the aquifer and the season if heating or cooling takes place.

4.6 Continuity of the drilling processes

There are 100 m of clay on top of the bedrock in the Vaasa region (Karro 1999a). The drilling process looks like it only needs to make holes in this land cover, which will be good enough to install shorter heat exchangers. The function of the drilling holes is to make a borehole that gives out energy or geo-energy for longer use. However, the problem here is that the movements of the groundwater and aquifers cause a decline or rise in temperature. Mostly it seems to be cooling, but also heating is likely to occur in winter as well. These movements also cause problems while drilling, as the drilling machine does not work when there is water present. The real effect of the groundwater in boreholes is likely to be seen in 10 to 20 years when the groundwater cools the borehole to a much lower level. A forecast can be made after studying the groundwater and the aquifers more deeply. What can be suggested is to place the heat exchanger above the groundwater level, meaning that shorter exchangers can be used. If there is 100 m depth above the groundwater, this should be enough to install shorter borehole heat exchangers as they are usually installed at a 50 – 150 m depth, avoiding drilling into the groundwater level.

If the drilling of boreholes is quite clean such as those used for drinking water, this indicates that the groundwater is also quite clean. However, there is also the situation where there is salt coming from the sea. When planning the details of new materials to be used in wells and boreholes, we have to think carefully, and especially if the water is for drinking, it is important to select only those materials which are specifically approved for drinking water supplies. Other materials may not meet the laid down standards, and might even contaminate the groundwater (Brassington 1995). Therefore, this must be considered while thinking about the continuity of the drilling process. Care must also be taken to avoid any mud dump caused by drilling from being a point source of contamination in the BHE work site. In discussing physical states that reflect their extractive value and in situ value in terms of economy, the use value and nonuse value (existence and bequest) must be identified and a proper value must be given for found groundwater and aquifers. These different values affect our decision-making, and the usage of the groundwater and the aquifers must be given thorough consideration. They are a good source of fresh water for the local community, can be adopted for industrial and agricultural use, and other future usages must be identified. In time, new sources of groundwater and aquifers can be identified by the education sector, and their usage can be studied over time. The values of water stocks and flows also entail an element of accountability, if earning benefits is to be considered a primary objective.

4.7 Suggestion of using groundwater as an energy source

Using groundwater as an energy source can be known as Groundwater Energy Utilization (GEU), which is an open-loop energy system. GEU is especially applicable due to ongoing climate change effects and the need for adequate energy reservoirs. Renewable energy resources such as GEU are much more environmentally attractive and local energy options. Importantly, groundwater creates an essential and significant local renewable energy source in Finland (Arola 2015). Multiple world nations agreed to implement renewable energy programmes. Based on this promise, the EU committed to decreasing its CO_2 emissions to 85% to 90% of 1990 levels by 2050. One of the agreements in the EU was to stop using coal for energy production by 2015 (Princiotta 2011). Satisfying this promise as an EU member, Finland is one of the world's nations that can be seen to be implementing renewable energy sources (RES). The national energy and climate strategy plan to increase the overall share of renewable energy to the total energy production. Statistically, the current renewable energy share in Finland was 35.1% in 2012 (Statistics Finland 2022; referred here mainly to 2013 data). Based on EU directive 2009/28/EU, the plan for Finland's renewable energy consumption will be 38% by 2020. This was an ambitious plan, but it was achieved in 2014 (Finnish energy 2020). In addition, in the year 2018 more than/around 40 % of final consumption was from renewable energy (Findicator 2019).

The GEU technique is called an open-loop energy system or open-loop system. The technique generates energy by extracting thermal energy by pumping groundwater from and discharging it to aquifers (Arola 2015). GEU operates by pumping warm groundwater from one location and then taking the heat to different use (such as heating a house). It then injects the cold water into another location/aquifer until it recharges its heat for the next use. The ground must have a conductivity of high hydraulic potential of soil and rock, ranging from 10^{-5} to 10^{-1} m/s. This is facilitated if the right types of chemical properties are present. However, high concentrations of iron (Fe) and manganese (Mn) together with oxidation that occurs during groundwater circulation may cause clogging of pipes and/or the heat transfer system, and chloride (Cl^-) is the main cause of corrosion and CO_2 might cause acidity (Arola 2015). According to Arola's (2015) description, studies conducted on groundwater energy potential have mostly focused on two specific points: 1) the effects of urbanization on groundwater utilization, and 2) energy storage in aquifers. City areas have much more potential for heat energy development than rural areas, and urban areas come somewhere in the middle. Excessive groundwater flow might be encountered in the passage from the injection well to the abstraction if there is inadequate design or an unfavourable environment, and this may reduce the efficiency of the GEU system. Other energy efficiency declines might occur if the groundwater is at a low temperature. Related to the design, the personnel of several disciplines must work together to establish an optimal design when constructing GEU systems.

Based on the data mentioned in Arola's (2015) dissertation, in Finland, 801 aquifers are categorized for water supply purposes and the exploitable area for groundwater is 293,291 m^3/d. Both in urban and industrial areas, the exploitable amount of heat power in groundwater (GW) is 42,772 KW. Assuming 100% heat energy is produced by the GWHP (groundwater heat pump), 368 aquifers and 365 aquifers under urban and/or industrial land might provide 1000 m^2 of ultra-low energy detached houses and 1,500 m^2 of ultra-low-energy apartments respectively. Groundwater temperature varies between 4.7 and 13.7°C. The seasonal fluctuation is between 1 to 5 m, with the coolest groundwater seen in urban areas and the warmest groundwater found in city centres. The median temperature in rural areas is 6.2°C, in urban areas 7.4°C, and 9.4°C in city centre areas. The peak heat energy is approximately 1.5 times higher in city centres. On other hand, the peak cooling power was 36–50% smaller in city centres than in rural areas. The thermal plume extended to 300 m in approximately 30 months after the pumping started. The effect of taking heat from the groundwater in modelled GEU systems shows a reduction in groundwater temperature of approximately 1 to 2.5°C from its natural temperature at a distance of 300 m from the site.

According to Arola (2015), January is the peak-heat energy consumption month, however, August is cooling. As mentioned previously, groundwater temperature increased from rural to urban areas. The thicker the water column in aquifers, the higher the temperature they possess. But this estimation is limited by the groundwater recharge calculation which poses the biggest error source. Usually calculated based on an assumption that there is a similarity in aquifers regarding precipitation, the hydrology cycle and the porosity, they vary from place to place. Especially, the effectiveness of the heat-transfer system varies over time, mainly in Nordic nations. GEU may be used as an energy source firstly as it is an environmentally friendly (less harmful) freely available renewable energy source with higher capacity in cities. The reduced CO_2 emissions contribute to combating climate change, and climate change makes this system much more suitable for use as the groundwater temperature is increasing due to global warming. The city of Vaasa has a potential groundwater reservoir that can be used as GEU. These suggestions are a part of an ongoing doctoral dissertation study by Girgibo, where this system is recommended as one means of adapting to climate change. However, in Nordic environments, careful planning is a must due to the cold groundwater systems and unconfined aquifers, and careful planning will reduce the environmental risks involved. However, based on the reference year groundwater energy flux demand, 50 years of operation could be achieved. The next paragraphs describe the use of ATES (aquifer thermal energy storage) systems.

The increased water or surrounding earth's temperature due to climate change can be one of the reasons to use groundwater as a heat energy source. There are various types of use of groundwater as heat-energy storage systems. Underground thermal energy storage systems (UTES) can be classified into two types. These are aquifer thermal energy source systems (ATES) open systems, and borehole thermal energy storage systems (BTES) closed systems. The BTES system is based on pumping heat liquid such as water down to boreholes, then pumping it back to the surface. When the heat-to-heat is used, the cooled fluid is pumped back to the same borehole to heat it again for the other round. The ATES system uses the groundwater/aquifer as a heat source. The process is as follows: from one location, hot groundwater/aquifer water is pumped to the surface then the heat will be exchanged in a medium, and then the cold water will be dumped in another location. This cool water will be kept in the new locations until it recharges its heat, then used for the next circulation (Girgibo 2021).

This system can be to store heat in summer or winter. For example, heat generated in solar panels can be used to heat water, and then the hot water is pumped to the porous side of the aquifer. Then in winter, the hot water can be withdrawn when needed and used as a heat source. The third case is to use groundwater to heat boreholes, and the groundwater from inside the borehole will then be pumped to the surface. The nearby groundwater will also heat the boreholes when it moves towards the pumping station. In other words, the water moving from the near-ground water location will be a heat source for the borehole so that the borehole can be used for longer periods, extending its lifetime. All three systems described are renewable energy sources, and in that way, they will minimize the emissions of CO_2.

According to most of the articles reviewed, ATES systems can be used in both winter and summer. In the summertime, the system can be used for cooling purposes as the groundwater in summer is cooler than the surrounding temperature, and therefore ideal to use as a cooling mechanism. On the other hand, in winter the groundwater/aquifer temperature is much higher than room temperature so it can be possible to use this water as a winter heat source. Groundwater can form a thermo-geological environment for both the cooling and heating of buildings (Arola 2015). Banks (2009) stated that groundwater energy has been widely used in some nations such as China for a long period. In the Finnish environment, the demand is more for heating than cooling (Arola 2015). Figure 2 shows the possible use and water flow pattern in both winter and summer from the same aquifer/underground water. As described by Seibt and Kabus (2006), mainly confined aquifers can be used for energy storage. As tested and used in Germany, in summer, water can be heated by any means, for example by solar energy which is absorbed by and stored in 400 m of the ground surface (Banks 2009), then pumped to store the heat in porous aquifers 50-300 m deep. The ideal depth used in Germany is 200 m deep. Moreover, most water-bearing aquifers must afford as high as 10-100 m^3/h flow properties to store a sufficient amount of water. On other hand, hot water from cooling houses can be injected as heat sources into groundwater, in addition to the solar energy system (Arola 2015).

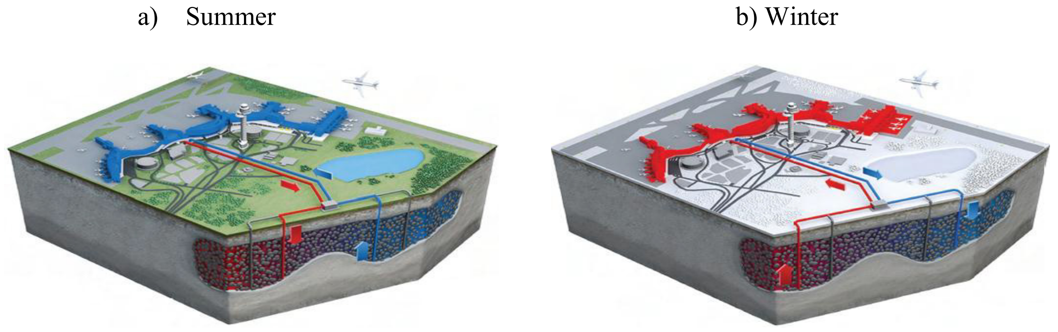

Figure 2. The Aquifer thermal energy storage (ATES) usage system: a) summer time usage and b) winter time usage (reproduced from Worthington 2012).

According to Seibt and Kabus (2006), aquifers planned to store thermal energy should meet the following requirements. The maximum depth has to be 1500 m, and the ideal or the most favourable depth is 200 m in Germany because of its low enthalpy stores in terms of cost. If adequate storage parameters are chosen, then unconfined aquifers can be used. This is useful information for the Vaasa region because according to this paper's findings, most of the Vaasa region aquifers are unconfined. However, the most chosen types of the aquifer are the confined type. The maximum reservoir thickness is 30 m. If it has strong stratification (less homogeneity), this may result in a smaller recovery. The level relative to the top might cause problems when pumping to reuse the water for heating. In addition, based on Seibt and Kabus (2006), a low regional base flow or detailed knowledge of regional groundwater parameters is essential. Knowing the approximate chemical composition of the heat transfer fluid is essential. Moreover, it is a must to avoid store installation from groundwater catchment areas. Based on Worthington's case study (2012) and Seibt and Kabus (2006), both confined and unconfined aquifers can be used for ATES systems. This makes it possible to use the Vaasa region's unconfined aquifer system for heating purposes. This is further supported by Seibt and Kabus (2006) who indicated that there is also the possibility of using unconfined aquifers.

An overall suggestion can be proposed for the city of Vaasa to implement GEU systems as an energy source, where multiple GEU systems can be accommodated in the city area. The city area is preferred to get more heat from groundwater, and there is potential for at least 4 GEU units in the Vaasa region generating (1-100 G (kW)) of energy each, based on figure 3 of Arola's (2015) dissertation. Therefore, the use of GEU in the city of Vaasa is an ideal option which utilizes environmentally friendly free energy. GEU was one of the seaside renewable energy suggested by Girgibo (2022).

5. DISCUSSION

Providing value to the future generation is a point where we ask ourselves why and what we do to the groundwater, in terms of pollution and contamination. The energy borehole is our focus, but we have to give attention to the usage of the area groundwater for future generations or implement solutions such as shorter borehole exchangers to avoid later complications. Furthermore, we have to ask ourselves if there is no chance of contamination and human pollution of the groundwater or the aquifers. This line of thought is essential in decision-making related to energy usage. Valuing the area is important, as water shortage is a possible reality in the far future so we do to ensure groundwater protection is a key issue. Usage is the other focus as establishing whether the groundwater and aquifers can be used for meeting basic needs. Groundwater is the least expensive water source, so there should be other uses for them instead of thinking of groundwater and aquifers solely in terms of being a problem with drilling energy boreholes. The heating and cooling purposes are one usage considered in the current project. Protecting the groundwater and aquifers is an essential role. We must decide whether there is proper protection for them in place, to ensure the continuity of water supplies is balanced realistically against the potential energy use of the area.

Of course, in Finland, there are plenty of lakes and rivers that can be used as freshwater intake, but the future is much more complex. Climate change and global warming might be a reason to think that our lakes maybe not be enough to function as a freshwater source. There will be times in future spent looking for groundwater and aquifers, so their proper protection should start from now. Future economic value is the main point of discussion in the 1997 book on Valuing Groundwater, where TEV (total economic value or use value) = extractive value + in situ value is an essential measure to apply to every groundwater source that is found (National Research Council 1997). Groundwater is a non-market good and there is a strategy to evaluate them such as people's willingness to pay (WTP) or their willingness to accept (WTA) giving it up. However, the contingent valuing method (CVM) must be adopted to give value to groundwater and aquifers. When used correctly in a certain context, CVM has the potential for producing a reliable estimate of groundwater use values. Moreover, knowledge of groundwater values such as its non-use value is essential. Control on not polluting the groundwater, in terms of quality and quantity and avoiding its decline, is a key focus point in related valuing and decision-making processes.

The suggestion made in this paper is to use groundwater as an energy source. The most efficient way of using the groundwater in the Vaasa region is in a groundwater energy utilization (GEU) system. Even though both GEU and ATES (aquifer thermal energy storage) systems are explained in this paper, the main suggestion is to use GEU systems to benefit Vaasa. This is one of the essential ways of using climate change advantageously for current and future generations. The reason to use GEU systems is the fact that the climate change effect is increasing the potential efficiency of energy that can be extracted at present and even more so in future. The other reason is that it will contribute to decreasing the emissions of CO_2, if more of these kinds of renewable energy systems are used. Moreover, this type of system is environmentally friendly [replacing oil heating systems would lead to less soil and groundwater contamination (Arola 2015)], and offers an economical and clean energy source. The possible usage of GEU in the City of Vaasa is ideal. According to Arola (2015), the city area's groundwater potential is much more than its rural areas, and the Vaasa area is one of the good places to implement GEU. The system can be constructed involving various disciplines to develop the most efficient and ideal design for a Vaasa city GEU system.

The other point discussed in this paper is the connection of groundwater with streams, lakes and discharges, and its use is something that affects the surface water; in our case its connection with the sea. The care we extend to groundwater extends to our seas, lakes and streams, so the big picture of limnology appears. Streams have already been eliminated by over-pumping in the American southwest (Columbia Basin Groundwater Management Area 2013). Therefore, we must take special care, and deeply study our current task. The valuation of groundwater is complex and several valuation principles can be used to approach any valuation problem (National Research Council 1997). However, groundwater depletion is irreversible, and some aquifers do not recharge quickly. Therefore, appropriate methods of groundwater investigation must be applied, using the methods described in this paper. The usage of seismic methods is essential, and their use has already been studied in Sweden. The test-drilling method is the other recommendation, along with water quality testing for hydro chemicals, and remote sensing if possible.

The continuity of the drilling process needs further investigation, especially regarding the water movements and the overall heat generation involved. The connection between aquifers and groundwater is quite common and is something expected to appear in our current investigation. The

Vaasa region has mainly unconfined aquifers which have much more connection to the sea, lakes and stream water, and their direct effect on the boreholes is something that needs attention. The choice of material used to drill the borehole has an essential role, especially when we use groundwater as a drinking water supply as there are specifications as to what kind of drilling machine may use. Not using the correct equipment will limit the current groundwater not to be used as drinking water for the local community. However, there is a chance of using it being used for agriculture and industry. The quality of Finland's water has increased over the past 20 years (Lahermo *et al.* 2002), but this must not make us over-confident that there is no pollution in the ground drilling process, and we must still take care to avoid contaminations such as mud collections that result from drilling activities.

A heat flux development may occur at the bottom of lakes and also in the sea. The heat movement from groundwater and aquifers in boreholes is expected to heat processes, especially in winter. Therefore, there is an advantage to keeping boreholes that have been drilled for energy purposes, but we do not know exactly the effects that occur over 10-20 years in the borehole, although it is said it will reduce in energy supply over 30 year time period, so it is a thinking point where the cost visibility of maintaining the borehole operation has to be calculated. The renewal time of groundwater is around 300 years (Table 1-1 of Wetzel 2001) and the water retention time is 600 years (Figure 4-2 of Wetzel 2001), so we should take care of what we do with them. Whether it is possible to continue the drilling of the borehole, if there is an aquifer, was one of the questions we posed during our study. The answer would be that it depends on the machine that is being used. The machine currently being used in the region (Erkki Hiltunen 2022; personal communication) cannot work if there is water present and just jerks rather than carrying out its normal function.

However, in the book 'Finding Water' by Brassington (1995) and 'Drilling Through Groundwater Aquifers' (Djuric 2012), they mention that there are machines which even need water to lubricate them while drilling (e.g. Spud mud which is the most used fluid in the drilling process, and widely seen as the safest process to drill through underground water). Therefore, a deep discussion of this matter with the drilling company might be a solution to allow the drilling process to continue. The kind of water found in unconfined aquifers needs proper investigation, to know their flow and contents. Therefore, tests and analyses such as those described by Mälkki (1979) would be wonderful to implement. Care should be taken that the current aquifers are not perched aquifers where they dry up after stopping the drilling process, so there should be proper identification of all sea aquifers. On other hand, installing the borehole exchange unit above the groundwater and aquifers offers a workable solution to this issue (Molina-Giraldo *et al.* 2011), and they calculated the borehole length could be shorter by 15% when axial effects are considered.

Groundwater is often neglected because it is out of site (so often, out of mind) and it gets little attention even in discourses surrounding compressive water resource management. Degradation is limited, but depletion is common and leads to contamination and other effects. Examining the reciprocal linkages between groundwater and the socio-economic system helps to sustain these resources and gives a fuller understanding of the degradation process. The impact of degradation may be economic, environmental, social, and political, though a clear distinction is not always visible. Particular importance is paid to legal and constitutional frameworks, which often present a barrier to more effective management. However, uncertainty over underground conditions and rates of change is often a considerable obstacle to achieving more effective management. The condition of the resource is therefore clearly important in maintaining values (Artimo 2003).

As described in the film made by the Columbia Basin Groundwater Management Area (2013), aquifers are not connected in-depth, so they dry in a short time while pumping is underway. Therefore, the usage of the aquifers or groundwater must be based on prior studies, to know the associated geology and hydrology of the aquifers. This will help in managing the groundwater effectively without it drying out in a short time, as well as preventing our streams and lakes from drying out due to pumping as seen in the American Columbia district. There is a diffusion between the sea and the aquifers found below the sea. Hence, as the concentration of salt in the sea is much higher, there is a natural movement of salt from the sea to the aquifers, from areas of higher concentration to those of lower concentration. However, the movement of water from the aquifers to the sea is expected. The groundwater recharges the aquifers; then, the aquifers recharge the seawater as it becomes saltier. Thus, there might be seepage from the aquifers to the groundwater that increases its salt content, thus it might not be possible to drink the groundwater directly because of its higher salt contamination (Heath 1983).

6. CONCLUSIONS

The importance of this case study is that it represents the concern of researchers to avoid and overcome the appearance of groundwater in the heat energy storage drilling process. Thus, can show an example to the international community of how much care one must give to freshwater resources such as groundwater even though the field of the research group is a different area. The main novelties of the paper are: 1. The suggestions of the importance of avoiding contamination (valuing groundwater) in the drilling process as a base to make decisions about the continuity of the drilling process, and 2. The use of the GEU system in the city of Vaasa region. The chosen methods seem appropriate for the case study site. However, their accuracy and importance are only confirmed after and/or if the analysis is done. There are movements in the Vaasa region's groundwaters. There is possible movement between the groundwater and the nearby seawater. The groundwater we encountered might have some salinity due to the movement of water from the sea. Most of the Vaasa region aquifers are unconfined. Both heating and/or cooling are possible on the borehole and it depends on the origin of the aquifer and the season that heating or cooling takes place. It was suggested to place the heat exchanger above the groundwater level, meaning that shorter exchangers can be used. Meaning avoiding drilling to the groundwater level with proper investigation, but care must be taken if to continue or stop the drilling process. Valuing groundwater is very important during decision-making. In addition, the suggestion for the city of Vaasa was made to implement GEU systems as an energy source, where multiple GEU systems can be accommodated in the city area. The use of GEU in the city of Vaasa is an ideal option which utilizes environmentally friendly free energy and might even use climate change heat development effects as an advantage depending on the groundwater movement, season and in what depth of the groundwater is located.

What can be said is that the current findings of groundwater and aquifers present a big chance to show how we care for the environment. Decision-making in these matters is not easy, but it is hoped that this paper will give the incentive to make good and continuous decisions. We have to envisage the needs of future generations, where they have as much water as we have been able to enjoy and drink, and better ways to maintain and keep groundwater clean for today, tomorrow, and for future generations to use.

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