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INFLUENCE OF PRECIPITATION AND TEMPERATURE ON THE TURBIDITY OF THE PANKAJOKI RIVER

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Abstract

In Finland, more than half (about 60%) of the drinking water originates from groundwater sources. The Hanhikangas groundwater area is one of the key drinking water sources of Mikkeli, Finland. Since the Pankajoki river flows over the Hanhikangas groundwater area, any variation in the quality of the water in the river might pose risks to the quality of the groundwater in the aquifer. Finding links between the studied parameters might help to make assumptions on the water quality of both the river and the aquifer without further water sampling or continuous water quality monitoring.

The key objectives of this thesis were to investigate and explain the possible influence of precipitation and temperature on the turbidity of the Pankajoki river, to find links between the quality of river water and that of groundwater as well as to investigate the reliability of the data collected by the used water quality probe. Quantitative research methods were used to achieve the objectives of the thesis. Daily means and daily total precipitation were the basis of the first and the second study objectives. The third study aim was examined by comparing the obtained reference samples to the respective real time automatic data. Spearman correlation and Mann-Whitney difference test were the basis of the statistical analyses after finding out that all the samples were non-parametric. The obtained values were later plotted, and the created figures were used for discussion.

The research found that precipitation and temperature influenced the turbidity of the river differently month by month and season by season. In summer, the turbidity of the river did not significantly increase because rain possibly infiltrated into the soil, whereas in autumn and in winter, the increase in the turbidity of the river might be explained by surface runoff and soil erosion. The most significant link between river water and groundwater was seen between their conductivity values, possibly because the river water infiltrated directly into the groundwater area through the riverbed and the riverbank. Finally, the reliability of the real time instrumental data was proven by the reference samples in case of three of the four studied water quality variables, namely turbidity, conductivity, and dissolved oxygen.

Keywords

turbidity, precipitation, temperature, water quality, surface water, groundwater, sampling

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1 INTRODUCTION

Water is one of the most plentiful and essential constituents of living organisms. Besides being vital for life, the importance of water in domestic, agricultural, and industrial activities is also significant. Even though three quarters of the Earth's surface are covered with water, most (about 97 %) of the global water resources is found in saline water bodies, which is not yet suitable for human consumption. Only the remaining three per cent is freshwater, which is distributed unevenly on the planet. Nevertheless, more than two thirds of freshwater are held in glaciers, ice caps and in the atmosphere, therefore only a small portion (less than 1 %) of the global water resources can be found in rivers, streams, lakes, ponds (surface water), and in aquifers (groundwater). (Verma 2016, 1).

In Finland, more than half (about 60 %) of the total drinking water originates from groundwater sources. In the South-Savo region, the number of these sources is limited, thus their protection is extremely important (Nironen & Lehtonen 2020c). In Mikkeli, about 95 % of potable water is groundwater, pumped out of the largest groundwater sources, namely the Hanhikangas and Pursiala groundwater areas, thus groundwater is extremely essential for the Mikkeli citizens (Ylönen 2018, 7). Groundwater is extremely susceptible to contamination. Rainwater and meltwater can filter through course-textured (permeable) soil layers, and reach the aquifers while transporting contaminants to groundwater. (ELY-keskus 2018, 4).

The Hanhikangas groundwater area is one of the most significant drinking water sources of Mikkeli. The Pankajoki river flows over the Hanhikangas groundwater area, therefore any variation in the quality of the river water might pose risks to the quality of the groundwater. Several studies have already been carried out on the Pankajoki river (Lampinen 2013; Viljanen 2016) and the Hanhikangas aquifer (Niemelä 2014; Ylönen 2018), but the influence of precipitation and temperature on the turbidity of the Pankajoki river has not yet been investigated. Finding links between the studied parameters can help to make assumptions about the quality of these freshwater sources without further sampling or continuous monitoring.

Water quality monitoring can be performed in real time, in near real time or offline by different in situ probes or sensors (automatic sampling) or by skilled personnel using laboratory instruments (manual sampling). Both have their advantages and drawbacks depending on the budget constraints and the water quality parameters of interest. Current water management practices require a reliable, cost effective and up-to-date identification of waterborne contaminants to respond to variations in water quality in a short time, therefore automatic sampling is, nowadays, more preferred over manual sampling. However, manual sampling should remain used in water quality monitoring activities to ensure the reliability of the data collected by probes and sensors. (Erickson et al. 2013, 163; Satinder 2013, 2 & 190).

The key objectives of this thesis work are
1. to investigate and explain the possible influence of precipitation (namely rain and snow) and air temperature on the turbidity of the Pankajoki river;
2. to find links between the quality of water in the Pankajoki river and the quality of groundwater in the Hanhikangas groundwater area;
3. to compare the measurement results of manual sampling to automatic sampling, and investigate the reliability of data collected by the probe.

2   THE HYDROLOGICAL CYCLE

According to Collier (2016, 1), the hydrological cycle describes the storage and the movement of water between Earth's spheres, namely the atmosphere, the biosphere (ecosystems), the lithosphere (Earth's crust and upper mantel), the cryosphere (snow and ice), the anthroposphere (the effects of human activities) and the hydrosphere. In other words, the hydrological cycle is the movement of water in different phases from the atmosphere, down on and through the ground, to the water bodies, and then back to the atmosphere. The hydrological cycle is generally driven by the energy from the Sun (Verma 2016, 1). The processes involved in the hydrological cycle are evaporation, transpiration, sublimation, condensation, precipitation, and infiltration, among others. (Brutsaert 2005, 2-3). The main processes involved in the hydrological cycle can be seen in Figure 1.
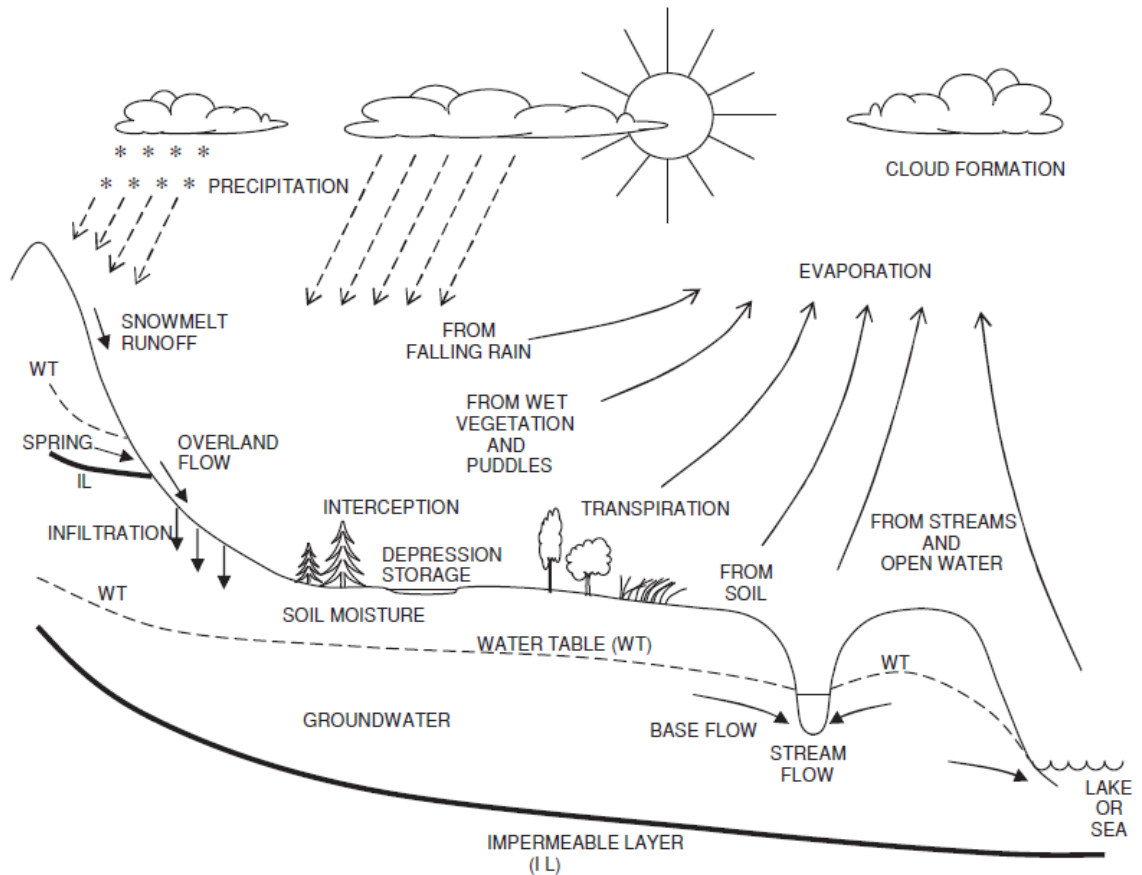
Figure 1. The most significant water sources and the main processes involved in the water cycle (Brutsaert 2005, 3)

Evaporation is the change of phase of water from liquid or solid state to vapour, and refers to the movement of water vapour to the atmosphere. Evaporation generally describes all processes of vaporization including (evapo)transpiration and sublimation. Transpiration is the evaporation of biological water from the stomates (pores) of leaves of plants. It is, however, difficult to separate the two processes in those environments where evaporation from open water surfaces and transpiration from plants take place at the same time, therefore the combined process can be referred to as evapotranspiration. Sublimation is the direct evaporation of ice without turning into liquid form (melting). (Brutsaert 2005, 3).

Condensation is the change of water vapour to liquid state (dew) forming clouds in the atmosphere. The main factors influencing the process are air temperature and the dew point. The dew point refers to the temperature at which dew forms from water vapour in the saturated air. Cooler air can hold less water vapour,

therefore water vapour above the dew point will condense. Fog and mist form when the dew point temperature and the air temperature are even. Additionally, energy is released in the form of heat during the condensation process, since water vapour has a higher energy state than its liquid form. When condensation particles grow large enough through coalescence or collision, so that air cannot hold them anymore, they will precipitate to the ground. (Collier 2016, 3).

Precipitation is the primary source of freshwater. Water can precipitate in forms of rain, drizzle, sleet, hail, or snow, depending on the cloud temperature. According to Collier (2016, 3), the annual average of precipitation is about 980 mm, which is unevenly distributed on the planet. Precipitation can evaporate directly from the atmosphere or from the ground, intercept, or infiltrate into non-saturated surfaces. Interception, by definition, is rainwater temporarily captured by surface storages including plants, soil surfaces, and built structures (roof), which later evaporates (Gerrits 2010, 1). Infiltration occurs when water penetrates and filters through permeable and unsaturated soil layers, which might recharge the underground water tables (aquifers), or might be absorbed by plants. (Collier 2016, 3).

As can be seen from the hydrological cycle, water is in constant state of motion. The origin of each source of water is precipitation. Water can be collected before or after reaching the ground. The quality of water highly depends on its source and the media through which water flows. Water vapour is the purest in nature. Liquid water collects the first impurities as soon as vapour condenses and then precipitates. Water can collect additional impurities in the different stages of the hydrological cycle as well as because of domestic, agricultural, and industrial activities. The sources of water are classified into two main categories: surface water (lakes, ponds, rivers and streams) and groundwater (springs and wells). (Subhash et al. 2015, 1-7).

2.1   Surface water

Surface water generally refers to all sources of saline- and freshwater on the Earth's surface. Surface water can be found in streams, rivers, lakes, ponds, wetlands and glaciers (freshwater) as well as in seas and oceans (saline water).

According to Collier (2016, 1), surface water includes solid precipitation, such as snow and ice, as well.

Lakes and ponds are mostly natural freshwater reservoirs. Lakes can usually be found in mountainous regions into which water flows from streams and springs. Ponds, in contrast, can be seen in lowlands (plains) which collect their water from surface runoff. Surface runoff, or overland flow, is precipitated water that does not infiltrate into soil (Lagadec et al. 2016, 495). The quality of water in these sources might be more uniform than that of springs, streams and rivers. Water from ponds and lakes might not require any additional treatment besides disinfection because of their self-purification. Self-purification includes the sedimentation of suspended matter and the removal of bacteria from still water. This process is more efficient and complete in larger lakes than in smaller ones. (Subhash et al. 2015, 8).

Rivers and streams are also natural sources of freshwater, although their water is much more dynamic than the water of lakes and ponds. The quality of their water depends on the characteristics of the watershed, the extent and nature of their development, the weather conditions and the seasonal variations, among others. Streams from sparsely inhabited regions tend to carry more suspended matter, organic debris, and minerals because of riverbank erosion. Rivers in populated regions are direct to pollution by industrial activities and discharged wastewater. Natural- and artificial pollution result in the variation of colour, odour, hardness, taste, and turbidity as well as the presence of microorganisms in the river water. Rivers are considered the most important sources of public water. The quantity and availability of water significantly depend on the type of the river. Perennial rivers normally provide a continuous flow of water, whereas seasonal rivers require storage facilities to ensure the continuous supply of freshwater also in extreme weather conditions including droughts. (Subhash et al. 2015, 8).

Seas and oceans are saline water bodies that contain most of the Earth's water. Even though plenty of water is available in seas and oceans, the water of these surface water bodies is not suitable for human consumption because of its high salt content, and the separation of dissolved salts from salty water (desalination)

is not yet economically reasonable. The desalination process must be adapted in places where freshwater is not widely available, or saline water is the only source of drinking water for human populations. (Subhash et al. 2015, 8).

2.2 Groundwater

Groundwater is rainwater infiltrating into permeable soil layers forming aquifers beneath the Earth's surface. Groundwater is typically beyond vegetation, and is normally protected from evaporation. During infiltration, the rainwater comes in contact with inorganic and organic substances, therefore obtains physical and chemical properties including hardness due to iron, manganese, arsenic, and fluoride, among others. Additionally, microorganisms are usually filtered out as rainwater percolates into the subsoil. Groundwater is generally colourless and clear, but harder than surface water. By and large, the quality of groundwater is uniform, however oversaturation (waterlogging) and overdraft result in variations. (Subhash et al. 2015, 9).

Springs are the outcrops of groundwater as small water holes along riverbanks and at the foot of hills and mountains, which are either perennial or intermittent. There are two types of springs, such as gravity and artesian. Gravity springs are the result of the outburst of an impervious stratum below an aquifer or the outflow of the water table because of the continuous water flow into the table. In contrast, artesian springs are formed when two impervious strata surround an aquifer, and the water table is under pressure. The quantity of groundwater from both types of springs varies with the amount of precipitation and the position of the water table. (Subhash et al. 2015, 9).

Groundwater can also be accessed using different kinds of wells. Wells are man-made vertical structures driven into an aquifer. Depending on the type of aquifer, either shallow, deep, artesian, or infiltration wells are constructed. Shallow wells receive their water from the subsoil water table, whereas deep wells are supplied by more than one aquifer. Artesian wells, similarly to artesian springs, are formed when two impervious strata enclose a porous aquifer. Infiltration wells are shallow wells which are constructed along riverbanks. Groundwater is filtered by layers of

sand while filtering through the sides of the well. Shallow wells, generally, offer a limited quantity and quality of water, whereas deep wells provide more water with a better quality. The quality and quantity of water in infiltration wells depend on the porosity of the sand medium. (Subhash et al. 2015, 10).

Depending on the construction method, wells can be percolation wells (or dug wells), driven wells, or tube wells. Percolation and driven wells are shallow wells usually confined to soft ground made of sand and gravel. Tube wells are specially driven deep wells. Percolation wells are susceptible to contamination. Percolation wells can provide small localities with adequate amount of groundwater, whereas tube wells can supply larger areas with clean water. (Subhash et al. 2015, 10).

3   WATER QUALITY PARAMETERS

A water quality parameter (also known as variable) is any physical, chemical, or biological property of water that can affect natural ecosystems or limit the use of water by humans. There are hundreds of water quality variables, out of which only a few parameters are usually of interest for a certain use. Water quality standards have been developed to provide guidance on selecting water supplies for various purposes, and to protect natural water bodies from contamination. Ensuring good drinking water quality is a key health consideration. Water quality not only affects human health but also the growth and survival of plants and animals in and near aquatic environments. (Boyd 2020, VIII-IX). Those water quality parameters are discussed in this chapter which are in focus of the thesis.

3.1   Turbidity

Turbidity is the physical indicator of the presence of suspended matter in water (Subhash et al. 2015, 57). Soil particles account for most of the suspended solids in water. Suspended soil particles might originate from the erosion of watersheds by rainfall, stream bed erosion by the water flow, shoreline erosion by waves and the resuspension of bottom sediments in lakes. Particulate organic matter derives from leaf fall, organic particles on watersheds dislodged by overland flow as well as the growth and dead remains of aquatic organisms in water bodies. Turbidity

interferes with the penetration of light that reduces photosynthesis rates and the productivity of aquatic microorganisms. Turbid waters heat up faster compared to clear waters because heat is absorbed by the suspended solid particles. The rate of evaporation of water, therefore, tends to be greater in turbid water bodies than in clear ones. According to McMahon (2016, 4 & 38), the albedo of turbid water is also greater than that of clear water, whereas the backscatter of incident light is reported to be higher in clear water bodies than in highly turbid ones. (Boyd 2020, 47 & 119-120 & 125 & 384).

Turbidity can be measured using a turbidimeter. The turbidity of water was earlier determined by Jackson turbidimeters. This instrument used to have a calibrated glass tube, a tube holder, and a candle. The glass tube in the holder was directly mounted over the candle. The water sample was poured into the glass tube as long as the flame was no longer visible. Silicon dioxide was used to calibrate the glass tube, and its concentration in milligrams per liter was equal to one Jackson turbidimeter unit (JTU). However, this turbidimeter could not determine turbidities below 25 JTU, therefore nephelometric meters have replaced this instrument. A nephelometer passes a light beam through the water sample, and measures the amount of scattered light at a right angle (90 degrees). The higher the amount of scattered light, the greater the turbidity of the sample is. The turbidity of water is expressed in nephelometer turbidity units (NTU). Most natural water bodies have turbidities below 50 NTU, but the value can be lower than 1 NTU or even greater than 1000 NTU. Even though both of the mentioned meters measure turbidities, the measurement results of the Jackson turbidimeter have no direct relationship with that of the nephelometer. (Boyd 2020, 126-127 & 129).

The transparency of surface water bodies can be determined using a Secchi disk. The Secchi disk is a 20-cm diameter disk painted with black and white alternate quadrants, weighted under the bottom. The transparency is measured in meters. The greater the value, the clearer the water is. The Secchi disk provides a fairly reliable estimate on the clarity of water, and is usually in a close relationship with the concentration of suspended solid particles in water. (Boyd 2020, 126 & 129).

3.2 Conductivity

Electricity, by definition, is the flow of electric charges in a closed electrical circuit. The current measured in amperes is the amount of charge flowing in an electrical circuit. The voltage measured in volts is the difference in charge (electric potential difference) between two points of the circuit. The resistance measured in ohms is the opposition within the circuit to the flow of electric current. Conductance is the reciprocal of electrical resistance. Both resistance and conductance depend on the dimensions (length and cross-sectional area) as well as the material of the conductor. Metals are generally good conductors, as they have valence electrons on their outer electron shell that can easily move and conduct an electric current. Conductance, also known as electrical conductivity, is measured in siemens per meter using a conductivity meter. To avoid small decimal numbers, other units of conductance including microsiemens per centimeter (µS/cm) or millisiemens per centimeter (mS/cm) are in use. Specific conductance is affected by temperature, thus the measured value should be adjusted to the temperature in standard test conditions (25 °C). However, the most modern conductivity meters display the specific conductance already for standard test conditions. (Boyd 2020, 89-90).

The formula for the correction of conductivity values can be seen in Equation 1. The temperature correction factor can be found in the EN 27888:1993 "Water quality: Determination of electrical conductivity (ISO 7888:1985)" standard.

$$EC_{25} = \frac{EC_T}{1 + (\frac{\alpha}{100}) * (T - 25)} \tag{1}$$

where EC_{25} conductivity at STC temperature (25 °C)   [µS/cm]

                   EC_T conductivity at the measured temperature   [µS/cm]

                   T measured temperature   [°C]

                   α temperature correction factor   [-]

Electrical conductivity, or the specific conductance of water, is the ability of water to conduct an electric current. The electric current is conveyed by dissolved salts (in other words, dissolved ions) in water. Salts, and also water, are formed when

an acid and a base react with each other in the neutralization process. Electricity is conducted by unbound (free) electrons on the outer electron shell of the atom. The electrical conductivity of water determines the specific conductance afforded by a cubic mass of water with one centimeter. Pure water is considered as a poor conductor as it contains only a low concentration of dissolved ions. Natural water bodies, however, are richer in dissolved ions, therefore better conduct electricity. According to Posudin (2014, 120), the conductance of water from streams ranges from 10 µS/cm to 500 µS/cm. The conductivity of water is roughly proportional to the concentration of dissolved salts. In that respect, the electrical conductivity of water is usually a good indicator of the degree of mineralization. (Boyd 2020, 16 & 90; Subhash et al. 2015, 58).

3.3 Dissolved oxygen

Dissolved oxygen is considered to be the most important water quality parameter in aquatic ecosystems. Aerobic organisms need an adequate supply of molecular oxygen for aerobic respiration in order not to suffocate. Molecular oxygen diffuses into the water bodies from the atmosphere or is released by the photosynthesis of aquatic plants. The source of carbon dioxide for photosynthesis is produced as a byproduct by the respiration of aquatic animals. The photosynthetic production of molecular oxygen is prevented or greatly reduced by ice and snow. Groundwater is often depleted of dissolved oxygen because the carbon dioxide from infiltrated water is not turned into molecular oxygen by means of photosynthesis. (Boyd 2015, 114; Boyd 2020, 36 & 97 & 135-136 & 162).

The rate of diffusion of molecular oxygen into water depends on various factors including the concentration of dissolved oxygen at the given time in the water, the extent of contact between the water and the atmosphere as well as the frequency of turbulence in the water. The transfer of oxygen between the atmosphere and water is caused by the difference in oxygen tension. Oxygen diffuses into the air in case the water is supersaturated with dissolved oxygen. The concentration at which dissolved oxygen saturates in water decreases with a greater elevation, a higher salinity, and a rise in temperature. Even though the diffusion of molecular oxygen between the air and water tends towards equilibrium, the concentration of

dissolved oxygen and carbon dioxide in the water changes because of biological, physical and chemical processes. The concentration of dissolved oxygen in water increases during the hours of daylight, because photosynthesis usually occurs more rapidly than respiration. In the afternoon, the concentration of dissolved oxygen is typically above saturation in water bodies containing healthy aquatic organisms. Although photosynthesis stops at night, aquatic animals continue to use up oxygen by means of respiration, therefore reducing the concentration of dissolved oxygen in water. (Boyd 2015, 113 & 128; Boyd 2020, 152 & 156-157).

The absorption of dissolved oxygen by aquatic animals is mainly controlled by the pressure and the concentration of dissolved oxygen. A low pressure of dissolved oxygen (oxygen tension) can stress or kill aquatic organisms. Excessive or even low concentrations of dissolved oxygen can lead to gas bubble trauma in aquatic animals, too. Aquatic animals generally are productive when the concentration of dissolved oxygen is above 50 % of saturation. Water quality standards for aquatic ecosystems may specify that the concentration of dissolved oxygen should either exceed 5 - 6 milligrams per liter or 80 to 90 % of saturation. The required oxygen concentration in most standards is at least 3 or 4 milligrams per liter. The amount of dissolved oxygen in waters can be reported in many ways including milligrams per liter (mg/L), milliliters per liter (mL/L), oxygen tension (pressure of oxygen), or percentage saturation, among others. (Boyd 2015, 113; Boyd 2020, 135 & 161).

3.4   pH

The water from natural sources can be acidic or basic depending on the nature of dissolved salts and minerals. The acidity of water is determined on the pH scale. The negative logarithm of the concentration of hydrogen ions [H^+] in water is the pH value. The pH scale ranges from 0 to 14, with 7 being neutral. Water is acidic between 0 and 7, and basic between 7 and 14. The pH meter is the instrument designed for pH measurements, which has two specially prepared electrodes. One of the electrodes has a fixed pH value, whereas the other responds to the acidity of the water sample. The potential difference between the two electrodes is measured and displayed. The transfer of hydrogen ions [H^+] between the two

electrodes is what determines the pH of the water sample. (Subhash et al. 2015, 59; Posudin 2014, 253-254).

Freshwater bodies usually have a pH value between 6 and 9, but the pH value of potable water should be kept between 6,5 and 8,5 to be eligible for consumption. Carbon dioxide is considered the main source of acidity in water bodies, however most waters also receive acids from humic substances. Rainwater is naturally acidic (around pH 5,6) because of the dissolution of atmospheric carbon dioxide. The most common cause of extreme acidity (pH < 4) in natural water is often the presence of sulfuric acid from human activities or of natural origin. The alkalinity of water is caused by the presence of carbonates, silicates, borates, phosphates, and hydroxide ions, among others. Besides their mineral origin, these substances either originate from the atmosphere via precipitation or the decomposition of microorganisms. (Subhash et al. 2015, 60; Boyd 2020, 215-216 & 224).

Acidic water bodies, with a high concentration of humic substances, usually have low productivity and biodiversity rates, low nutrient concentrations, and reduced light penetration. The most severe effects of acidic water on the productivity and diversity of species can usually be observed at pH < 5. Fish communities remain diverse in acidic rivers flowing from rainforests because they are adapted to the continuous acidity of water. Acidic water also causes corrosion in water pipes. Acidity can, however, be mitigated using alkaline materials. Pulverized limestone has been used in agriculture for centuries to neutralize acidic water for improving the growth of crops. The conditions for fish production have also improved by the reduction of the acidity of water. (Boyd 2020, 227-229).

4   WATER SAMPLING METHODS

The sources of drinking water including rivers, lakes, springs, and wells are likely to be exposed to a wide range of chemical, physical, and microbial contaminants. Poor water quality, coupled with increasing populations and aging infrastructure, can have a major impact on public health. Present water management practices require a more reliable and up-to-date identification of waterborne contaminants in order to respond to variations in water quality in a short notice. Monitoring can

be performed in real (or near real) time using different in situ probes or sensors (automatic sampling) or offline (non-real time) by collecting water samples and carrying out measurements using laboratory instruments (manual sampling). Depending on the water quality parameter of interest, the most beneficial and accurate sampling method, or the combination of methods, should be considered. (Erickson et al. 2013, 163; Satinder 2013, 2 & 190).

Water sampling should start by defining the key objectives of the measurements. After the sampling objectives are defined, a sampling plan should be established. The sampling plan is a written protocol that describes the sampling location, the sampling equipment (including its calibration and maintenance), the sample containers (if the samples are to be stored), the treatment procedures of the samples prior to measurements (mixing and handling), the method for sample record-keeping (labeling the samples, recording information), among other things. (Yolanda et al. 2007, 294).

4.1   Manual water sampling

Manual water sampling generally refers to the physical collection and analysis of water samples by an individual. Water samples are usually collected following the applicable policies, regulations, directives, and standards. The Water Framework Directive (Directive 2000/60/EC) is one of the most important pieces of legislation in the European Union, which was issued to act as a framework for the protection of all surface- and groundwater bodies (Yolanda et al. 2007, 293). Water samples are analyzed using certain laboratory instruments either on the sampling location (on-site sampling) or in a laboratory (grab sampling). On-site sampling refers to the collection and analyses of water samples on the sampling location. The main difference between on-site sampling and grab sampling is that the water samples are transported to a laboratory for analysis. Water samples need to be analyzed on site if the water quality variable of interest is likely to change during transport. Such parameters are, for example, temperature, pH, and dissolved oxygen. The samples need to be analyzed in a laboratory in case the water quality parameter of interest cannot be measured accurately in the field (for example, phosphorus). The measurement results obtained from manual sampling are considered highly

reliable, but usually time consuming and expensive. Although the set-up costs of manual sampling are small, an individual has to be always sent to the sampling location to collect the samples. Even though reliable measurement data can be produced, the results do not always reflect the present characteristics of water. Certain water quality parameters constantly change in water bodies because of biological, chemical, and physical processes. However, manual sampling should be used as reference wherever and whenever water bodies are monitored using probes or sensors, because in case of contamination, calibration error or sensor malfunction, the obtained instrumental data can be unrealistic and misleading. (Satinder 2013, 190; Erickson et al. 2013, 163-166 & 176-181).

4.2   Automatic water sampling

Automatic water sampling is the collection and analysis of water samples by probes and sensors on the site. The probe or sensor is placed directly in the water at the sampling location. Probes and sensors equipped with a datalogger provide real time or near real time (within 1-4 hours) data on the quality of water which can be accessed remotely as soon as the sampling equipment is installed. Automatic water sampling enables a faster response time to any change in water quality above or beyond the safety limits as defined by standards and legislation so that to reduce the likelihood and severity of potential risks to environmental and public health. Real time and near real time information can also be used to identify trends in water quality (for example, seasonal variations) and achieve a rapid screening of water for toxic contaminants that can be lethal to ecosystems. The main advantage of automatic water sampling is that in situ instruments can provide a more accurate and frequent picture of those water quality parameters that might change during the storage or transport of water samples. Even though personnel are not required to collect and analyze water samples, the equipment must be periodically (for example, on a weekly basis) maintained and calibrated. Automatic sampling instruments have yet limitations, since different probes are required for monitoring different water quality parameters. (Satinder 2013, 190; Erickson et al. 2013, 163-164).

5 MATERIALS AND METHODS

5.1 Description of the study area

The boundaries of the studied groundwater area, the movement of groundwater in the formation, and the location of the studied river can be seen in Appendix 1.

'The River of Seven Names' is a combination of rivers located in Mikkeli, Finland. The name of the river changes along its course from Kelajoki to Naaranginjoki, Heilajoki, Siekkilänjoki, Pankajoki, Hanhijoki and Emolanjoki. The source of the river is Lake Iso-Kirveslampi, located in the southern part of Otava, Finland. The river flows through, inter alia, Lake Oulanki, Lake Naaranki, Lake Iso-Vuolinko, Lake Naistinki, the Pankalampi pond and the Hanhilampi pond before draining into Lake Saimaa. The distance between Lake Kirveslampi and Lake Saimaa is about 22 kilometers. (Nironen & Lehtonen 2020a; 2020d).

The Pankajoki river is one of the parts of 'The River of Seven Names' located in Kalevankangas, Mikkeli. The river flows through the Hanhilampi nature reserve, which is not only a nationally protected conservation area, but also part of the European Union's Natura 2000 network. The water system in the nature reserve receives water from a catchment area of about 65 km^2. The water from Lake Iso-Kirveslampi travels about 20 km before reaching the Hanhilampi pond by the Pankajoki river. Nowadays, the quality of the water in the conservation area is significantly influenced by the drainage of rainwater from settlements and paved roads into the river system. (Nironen & Lehtonen 2020b; 2020d).

The Hanhikangas groundwater area is one of the key sources of drinking water in Mikkeli, Finland (Appendix 1). The Mikkeli Waterworks (Mikkelin Vesilaitos) pump out about 1500 m^3/d of groundwater. The groundwater is pumped out of 20-25 m deep wells from the Hanhikangas groundwater area, which is taken directly to the treatment plant (Nironen & Lehtonen 2020c). The amount of water pumped out of this area is highly dependent on the amount of naturally formed groundwater. The average groundwater produced in the area is about 1700 m^3/d. The Hanhikangas aquifer has been designated as a risk area, because of possible contamination

resulting from human activities related to housing and land use, traffic- and road management as well as from contaminated soil. The Hanhikangas groundwater area is located in a north-south direction, under the Kalevankangas ridge area (including the Hanhilampi nature reserve) and the northern parts of the city center of Mikkeli. About 30 % of the area is constructed, however most of the buildings are located in the southern part of the aquifer. The soil of the groundwater area consists mostly of sand and gravel. The maximum thickness of the aquifer is about 30-35 m. The groundwater in the area originates mainly from the infiltration of water from the Hanhilampi pond and the Hanhijoki river, which receive their water from the Pankajoki river and surface runoff. The groundwater flows mainly from the north, west and south towards the center of the aquifer, and discharges into the Kovalanlampi pond. (ELY-keskus 2018, 4; Appendix 1).

5.2   Data collection

The variations in the quality of water in the Pankajoki river were monitored from the 6th of June 2019 until the 25th of February 2020 using an YSI 6920 V2 probe. The probe was equipped with a KELLER GSM-2 data logger which collected and transmitted real time measurement data to an online database (KOLIBRI Cloud). The studied water quality parameters were pH, turbidity, conductivity, dissolved oxygen, reduction-oxidation potential, and water temperature. The value of these variables was recorded every 30 minutes. The probe was inspected, maintained, and calibrated on a monthly basis. The exact location of the water quality probe was N: 6840441 E: 513476 in the ETRS-TM35FIN coordinate system (Figure 2).

The precipitation- and air temperature data was gathered from the website of the Finnish Meteorological Institute. The location of the observation station was the Mikkeli Airport (Mikkelin lentoasema) (Figure 2). The time interval of the weather observations was 10 minutes. The parameters of interest were air temperature, precipitation intensity, and snow depth. The weather observations were obtained from the 1st of July 2019 until the 31st of December 2019. The time zone of the weather data was adjusted from UTC +0 to UTC +2 (Eastern European Time).

The water quality in the Hanhikangas groundwater area was monitored from the 21st of November 2019 until the 16th of January 2020 using an YSI EXO1 probe. The studied water quality parameters were pH, turbidity, conductivity, dissolved oxygen, and water temperature. The instrument was placed into a groundwater observation tube (H0306), where the surface water filters through the soil. The measured values were recorded every 30 minutes. The probe was calibrated in the beginning of the sampling period. The location of the probe was N: 6840723 E: 513481 in the ETRS-TM35FIN coordinate system (Figure 2).
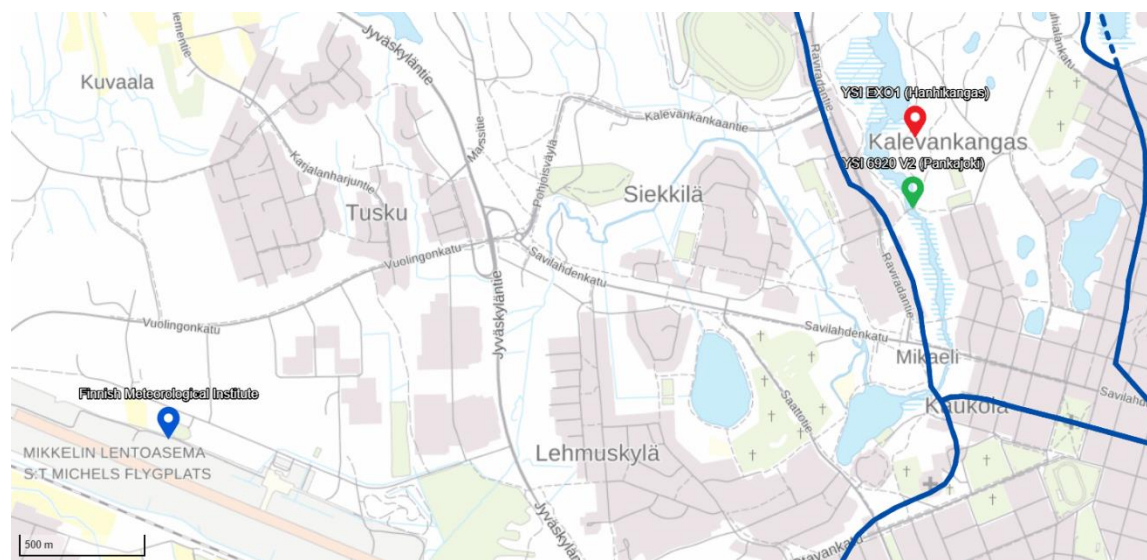
Figure 2. The locations of the instruments for the surface water- (green marker), the groundwater- (red marker) and the weather observations (blue marker) (Maanmittauslaitos & Esri Finland 2020)

Reference samples were collected manually from the Pankajoki river between the 9th of July 2019 and the 30th of December 2019. The measurement results of the reference samples are used to ensure the reliability of the data provided by the YSI 6920 V2 probe. Samples were collected on a weekly basis (once or twice a week), altogether 42 times within the above-mentioned period. The samples were analyzed in the environmental laboratory of the South-Eastern Finland University of Applied Sciences. The parameters studied were pH, turbidity, conductivity and dissolved oxygen using different laboratory instruments. Radiometer analytical PHM210 standard pH meter was used to measure the pH of the water samples which was calibrated using two buffer solutions. The conductivity of the samples was analyzed using WTW Cond 340i and WTW Cond 3310 conductivity meters

with TetraCon 325 sensors. The conductometers were calibrated using a 0,01 M potassium chloride (KCl) solution. Oakton Turbidimeter T-100 was used for the turbidity measurements. The concentration of dissolved oxygen in the samples was determined according to the SFS-EN 25813 (ISO 5813:1983) standard. All the above-mentioned instruments have been calibrated before every analysis.

5.3   Data preparation, selection, and analysis

The variations in the turbidity of the Pankajoki river because of precipitation and temperature are studied from the 5th of July 2019 until the 31st of December 2019. This period of time consists of weeks with little or no precipitation (in the summer months), with frequent rainfalls (in the autumn months) as well as with snowfalls and snow melting (in the winter months). Each of these seasons consists of two months (one month equals 30 days in the thesis). November and December are considered winter months because of low temperatures and variable precipitation of rain and snow. Daily mean turbidity, daily total precipitation, and daily mean air temperature are the basis of every analysis. The daily values were prepared from 30-minute instrumental data (recorded by the YSI 6920 V2 probe) and 10-minute weather observations using Microsoft Excel Pivot Tables. Since precipitation was expressed in millimeters per hour, which represents the intensity of precipitation, the 10-minute values had to be first divided by six and summed in order to obtain the correct amount of daily precipitation. All the daily values were plotted season by season using Microsoft Excel 2016. Daily mean snow depth was introduced in the chart in the winter months in order to investigate whether precipitation is rain or snow. It is considered that whenever the depth of snow increases, snow falls, and whenever that decreases, snow melts.

The relationship between the Pankajoki river and the Hanhikangas groundwater area is studied from the 22nd of November 2019 until the 15th of January 2020. Turbidity, conductivity, dissolved oxygen, and pH are the parameters of interest. The daily means of these water quality parameters are the basis of the analyses. The daily mean values were prepared from 30-minute instrumental data (in case of both probes) using Pivot Tables in Microsoft Excel 2016. The obtained values were plotted parameter by parameter using Microsoft Excel. Linear trendlines and

R-squared values were introduced on the chart to investigate how well the means fit to a regression line. The equations of the trendlines were not displayed on the charts because date was presented on the horizontal axis. Some turbidity values (November 22-24 and December 16-19) were removed from the dataset because groundwater was stirred in the observation tube when the YSI EXO1 probe was pulled out and inserted again, which led to false recordings (man-made outliers). According to Xylem Inc. (2019, 1), turbidity values measured with YSI probes are comparable without conversion, even though turbidity was recorded in different units (in NTU in case of the river water and in FNU in case of the groundwater).

Turbidity, conductivity, dissolved oxygen, and pH are the basis of the comparison between real time automatic data and reference samples. All the manual samples are used in the analyses. The selection of automatic data depended on the exact time of the collection of reference samples. The WTW Cond 340i and WTW Cond 3310 conductometers showed higher values for the calibration liquid (1301 µS/cm and 1413 µS/cm, respectively, compared to 1278 µS/cm) therefore the measured values were adjusted to the correct conductivity of the 0,01 M potassium chloride solution (by 1,77 % and 9,55 %, respectively). The reference samples and their respective automatic data are shown in Appendix 2. The selected automatic data is used only for the statistical analyses, because, for the better representation, the figures are made out of 30-minute observations using Microsoft Excel 2016.

Statistical analyses are performed using IBM® SPSS® Statistics Subscription. The statistical tests selected for the analyses depended on the results of the normality test (Shapiro-Wilk test) and the homogeneity of sample variances (Levene's test) with a confidence interval of 95 % (α = 0,05). Once the significance level was less than or equal to 5 % (p ≤ 0,05), the null hypothesis (H_0) was rejected, hence the homogeneity of variances or the normal distribution of individuals in the sample could not be assumed. These tests were required to find out whether the samples were parametric or non-parametric. The sample was considered non-parametric if the homogeneity of variances or the normal distribution could not be assumed. Based on the test results, in case at least one of the samples is non-parametric,

parametric tests cannot be used for the statistical analyses. The significance level is considered two-tailed in all of these statistical tests.

The selected statistical tests based on the results of the above-mentioned tests can be seen in Appendix 3. Non-parametric correlation and difference tests can only be performed either because there is a statistically significant difference between the sample variances, or the individuals are not distributed around the sample mean (on a bell-shaped distribution curve). The Levene's test was not performed for the parameters of interest for the first research objective because none of the three parameters follows a normal distribution, therefore parametric tests cannot be used anyhow, and the variables represent different parameters whose variance will certainly differ from each other.

Spearman's correlation coefficient is to be used to investigate the relationship between the turbidity of the Pankajoki river, precipitation, and air temperature (with a confidence interval of 95 %). The correlation between these parameters is studied separately for 30 days, 15 days, and 5 days. The statistically significant values ($p \leq 0,05$) will be highlighted in red. The relationship between surface water (Pankajoki) and groundwater (Hanhikangas) as well as the correlation between manual samples and real time automatic data are also tested using the Spearman's correlation. According to Soltész-Várhelyi (2020, 14), the correlation coefficients are interpreted as follows: ± 0,00 – 0,19 (negligibly weak correlation); ± 0,20 – 0,39 (weak correlation); ± 0,40 – 0,59 (medium correlation); ± 0,60 – 0,79 (strong correlation); ± 0,80 – 1,00 (very strong correlation). Regarding the link between surface water and groundwater, the difference between the medians is also investigated using Mann-Whitney's test. If the significance level (p-value) is less than or equal to 5% ($p \leq 0,05$), the null hypothesis is rejected (H_0), hence there is a statistically significant difference between the sample medians. The significance level is considered two-tailed in all statistical analyses.

6   RESULTS AND DISCUSSION

6.1   The links between turbidity, precipitation, and air temperature

6.1.1   Summer months (July 5 – September 2)

During the summer months of the study period, there was no clear link between the studied three parameters. Turbidity tended to increase by precipitation in the first days (July 5 – July 8), and decline when the daily amount of precipitation was negligibly low or none (July 9 – July 15) (Figure 3). No precipitation was observed for ten consecutive days in the first study month (July 20 – July 29), therefore the variations in turbidity during that period cannot be explained by the precipitation data recorded at the weather observation station (Figure 3). The variations in the turbidity of the river might be caused by the erosion of the riverbed (because of the low water level in the river) or by precipitation in the upper parts of the river system. (Appendix 4/1).

The turbidity of the river decreased by precipitation (r_s = -0,894; p = 0,041) in the last five days of the first month (July 30 – August 3), which resulted from the data selection for the analyses (Figure 3). In these five days' period, the turbidity of the river was higher when no precipitation was observed, and the difference in the daily values was nearly identical (an ~1 mm reduction in the daily precipitation caused an ~1 NTU increase in the daily mean turbidity and vice versa) (Figure 3). However, in the same five days' period, the turbidity of the river increased when the air temperature rose, which was also statistically confirmed by Spearman's correlation (r_s = 0,900; p = 0,037) (Figure 3). (Appendix 4/1).

Although some precipitation was recorded during the first ten days of the second summer month (August 4 – August 13), the turbidity of the river declined possibly because rainwater infiltrated into soil, or diluted the water in the river (reducing the riverbed erosion), or directly evaporated before reaching the river (Figure 3). Nevertheless, the turbidity decreased when the temperature increased in the first fifteen days of the second study month (August 4 – August 18), which was also statistically confirmed (r_s = -0,639; p = 0,010) (Figure 3). Rainfalls in the second half of the second summer month (August 19 – September 2) tended to increase

the turbidity of the river, however their link was confirmed (r_s = 0,894; p = 0,041) only for the last five days (August 29 – September 2) (Figure 3). (Appendix 4/1).
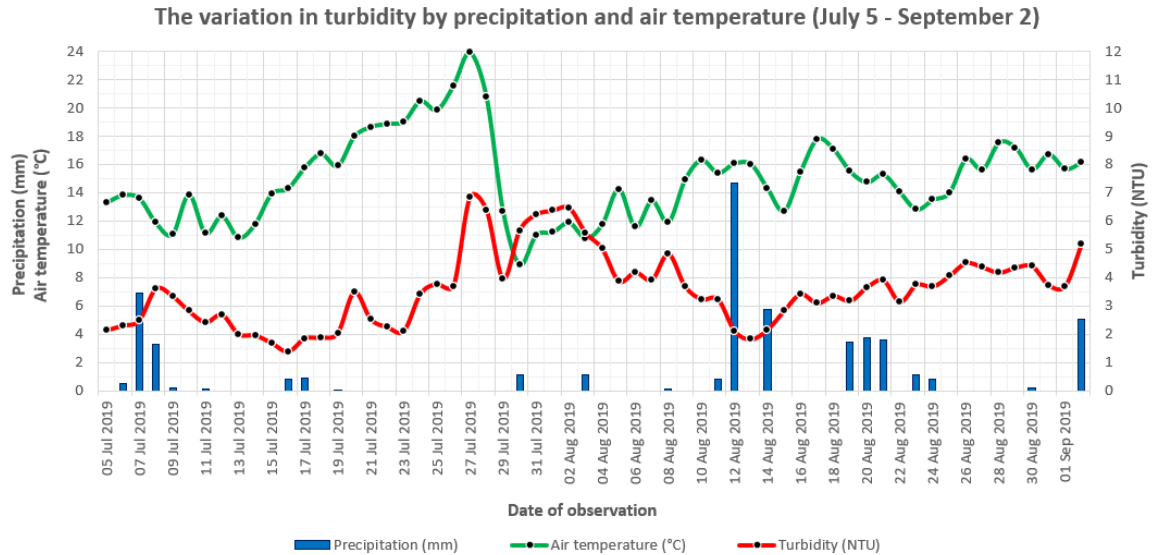

Figure 3. The variation in the turbidity of the Pankajoki river (summer months)

6.1.2 Autumn months (September 3 – November 1)

The link between the increase in the daily total precipitation and the decline in the daily mean turbidity was confirmed statistically (r_s = -0,557; p = 0,031) for the first fifteen days of the first autumn month (September 3 – September 17) (Figure 4). The turbidity of the river decreased when the air temperature dropped (r_s = 0,749; p < 0,001) in the first autumn month (September 3 – October 2), which could be explained by the reduction in the rate of evaporation of water (river water and rainwater) (Figure 4). The downward trend in the turbidity of the river might be explained by the infiltration of rainwater into the soil, the uptake of rainwater by vegetation, or the dilution of water in the river. At this point of the year, the river might have reached a water level that did not allow the water flow to erode the riverbed and the riverbank. (Appendix 4/1).

In the second autumn month (October 3 – November 1), the turbidity of the river doubled because of rainfalls (Figure 4). This might have occurred because the catchment area has already become super-saturated (exceeded its capacity to absorb water), and the excess of rainwater flowed over the land surface causing

soil erosion, therefore increasing the concentration of suspended solid particles in the river water. However, this assumption was not confirmed statistically because the amount of daily precipitation was not proportional to the degree of variations in the turbidity of the river (Figure 4). Turbidity increased when precipitation was less compared that of the previous days (r_s = -0,516; p = 0,049) in the first half of the second autumn month (October 3 – October 17), because the influence of precipitation could be observed in the daily mean turbidity of the following days, therefore the daily mean turbidity of the river was greater on those observation days when little or no precipitation was recorded (Figure 4). (Appendix 4/1).
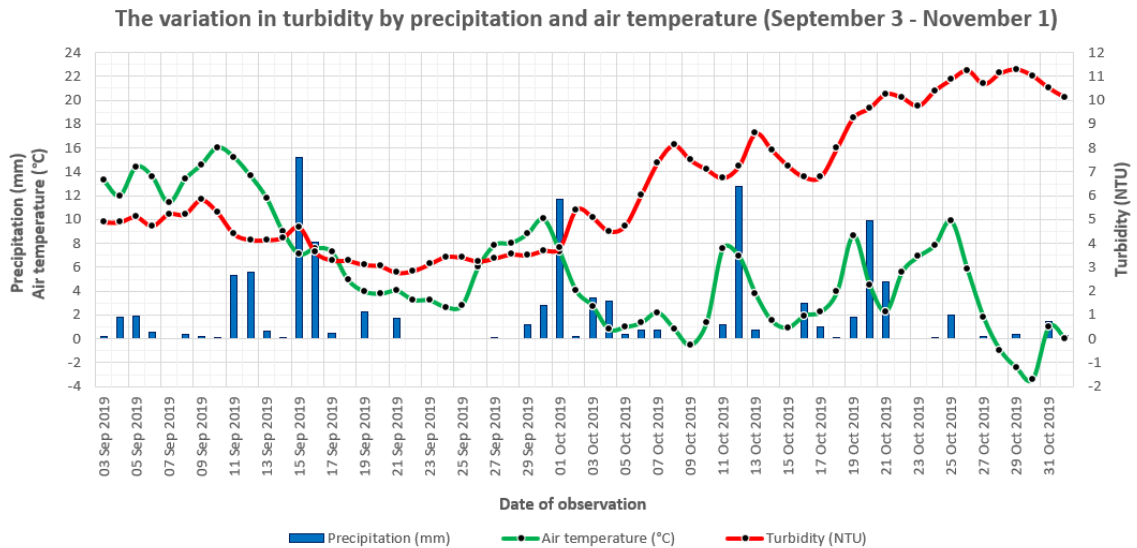
Figure 4. The variation in the turbidity of the Pankajoki river (autumn months)

6.1.3 Winter months (November 2 – December 31)

During the first winter month (November 2 – December 1), precipitation tended to increase the turbidity of the river, possibly because of surface runoff (Figure 5). This assumption was confirmed statistically (r_s = 0,894; p = 0,041) only for the first five days of the fifth month (November 2 – November 6). The surface runoff might have occurred either because the soil in the catchment area was super-saturated (therefore could not absorb rainwater anymore) or was already frozen. The surface runoff could have led to soil erosion, increasing the concentration of suspended particles in the river water. Precipitation was observed altogether for 21 days in the first winter month, out of which snow was recorded only 7 times

(the depth of snow increased on those days). The first snowfalls (November 9 – November 13) were not considered to have a significant impact on the turbidity of the river, since the daily mean snow cover was negligible (< 1 cm), and all of the snow melted in a short time (the snow depth declined) (Figure 5). (Appendix 4/2).

However, from the last days of the first winter month until the end of the research period (November 27 – December 31), the type of precipitation was mainly snow (Figure 5). The turbidity of the river tended to decrease when snow fell (the depth of snow increased), and the air temperature was at or below the freezing point of water (T ≤ 0 °C) (Figure 5). In that respect, when the air temperature was positive (T > 0 °C), snow could begin to melt (the depth of snow declined), and meltwater could drain into the river, therefore increasing the turbidity of the river (Figure 5). During the last days of the second winter month (December 20 – December 31), the turbidity of the river kept decreasing even though the daily mean snow depth declined, possibly because the snow melted in the daytime, and froze again at the night-time (Figure 5). The connection between turbidity and precipitation was not statistically confirmed during the second winter month, possibly because of the presence of snow (Figure 5). (Appendix 4/2).
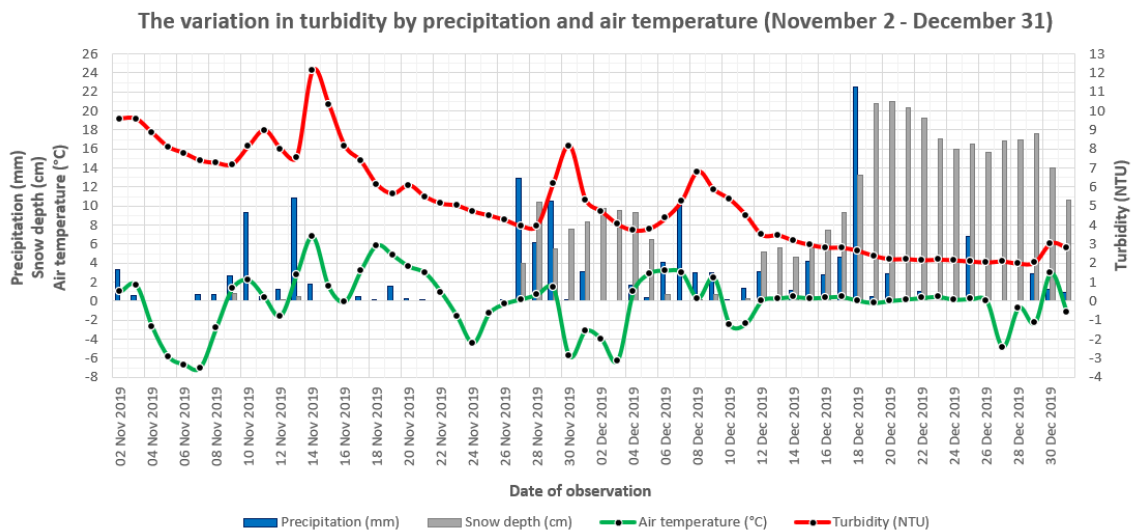

Figure 5. The variation in the turbidity of the Pankajoki river (winter months)

6.2 The links between surface water and groundwater

The link between the water bodies based on turbidity was not significant, neither statistically (r_s = -0,556; p < 0,001) nor graphically (Figure 6; Appendix 4/2). The turbidity of the Pankajoki river showed a downward trend in the studied period (November 22 – January 15). The reason behind the downward trend might be frequent frosts (T < 0 °C), therefore the snow on the catchment area could not melt, which could have led to further soil erosions. The peaks in the turbidity of the river could be explained by soil erosion because of snow melting (Figure 6). The turbidity of groundwater tended to be less sensitive to suspended particles, possibly because the groundwater area did not receive water directly from soil infiltration (the soil in the catchment area could be frozen), or the movement of groundwater was minimal (Figure 6).
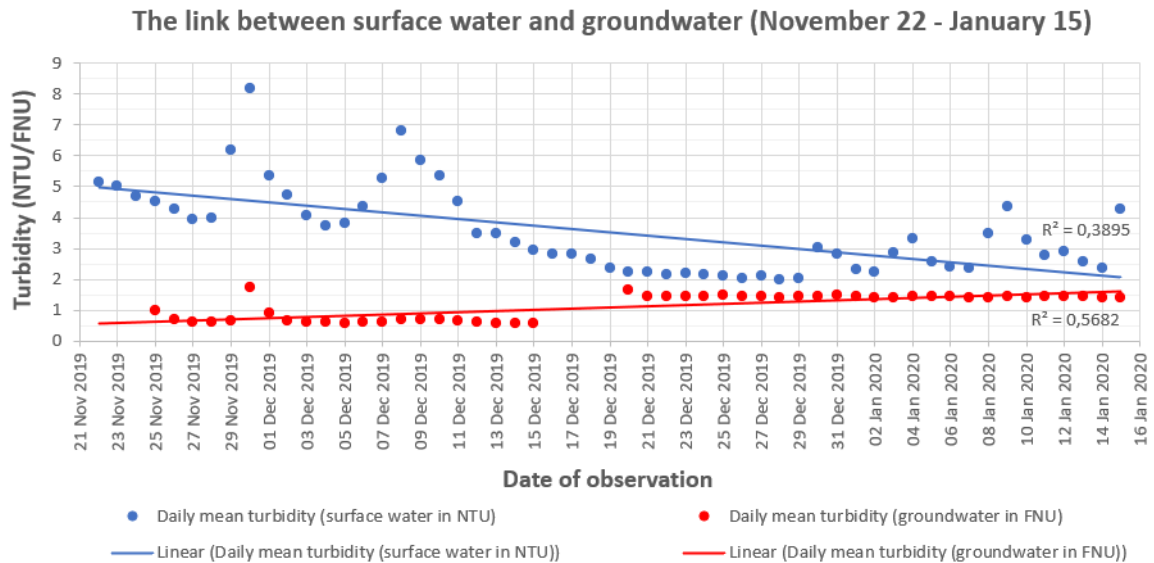
Figure 6. The link between surface water and groundwater (turbidity)

The link between the conductivity of surface water and that of groundwater turned out to be both statistically and graphically significant. The regression lines made out of daily mean values are nearly identical: both follow a downward trend and the daily mean values are around the same scale (Figure 7). The conductivity of river water and that of groundwater declined in the above-mentioned study period (r_s = 0,652; p < 0,001). The difference between the sample median of river water (Mdn = 83,00) and that of groundwater (Mdn = 86,14) based on their daily mean

conductivity values was insignificant (N = 110; p = 0,767). The reason behind the link between the conductivity values might be the infiltration of river water into the groundwater area through the riverbed and the riverbank. The greater variance in the conductivity of groundwater might be explained by the lack of calibration after the water quality probe (YSI EXO1) was inserted again into the observation tube. (Figure 7; Appendix 4/2).
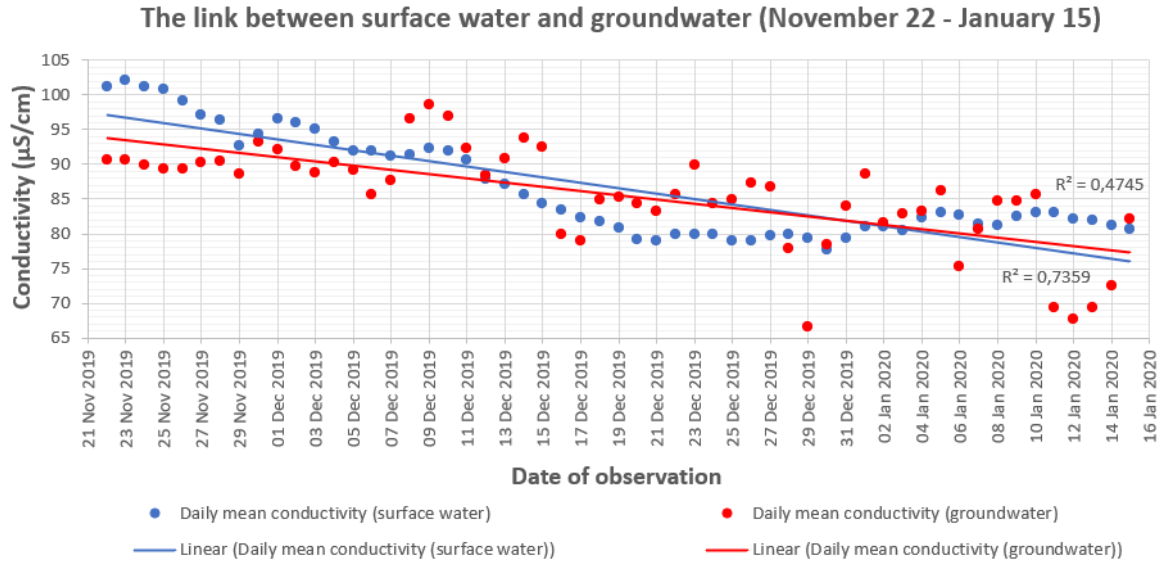

Figure 7. The link between surface water and groundwater (conductivity)

The concentration of dissolved oxygen was significantly higher in the river water than in the groundwater, which might be explained by the presence of vegetation in the river (Figure 8). During the studied period, the daily mean concentration of dissolved oxygen followed an upward trend in both freshwater bodies (r_s = 0,691; p < 0,001) (Figure 8). However, the linear trendline of groundwater had a steeper slope than that of surface water (Figure 8), possibly because of the respiration of aquatic animals and the direct contact of surface water with the atmosphere. The concentration of dissolved oxygen turned out to increase when the conductivity of the river water (r_s = -0,794; p < 0,001) and the groundwater declined (r_s = -0,845; p < 0,001), possibly because of the reduced demand for molecular oxygen in the chemical reactions or the reduced oxygen diffusion into the air (lower saturation) (Figure 7; Figure 8; Boyd 2015, 113; Kennish 2016, 202). (Appendix 4/2).
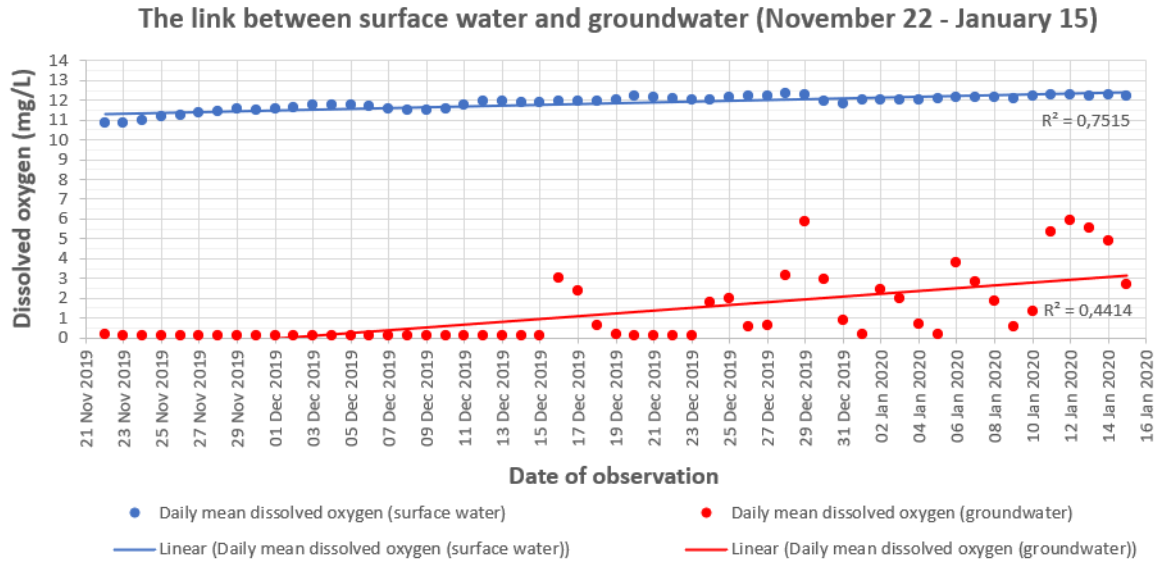
Figure 8. The link between surface water and groundwater (dissolved oxygen)

During the studied period, the groundwater turned out to be more acidic than the river water possibly because of the acidity of the soil in the aquifer (due to humic substances) or the dissolution and infiltration of weak acids from the atmosphere via precipitation (Figure 9; Boyd 2020, 215). Even though the linear trendlines of river water and groundwater followed a downward trend with a similar slope, the pH value of groundwater turned out to be more sensitive to variations (Figure 9). (Appendix 4/2).
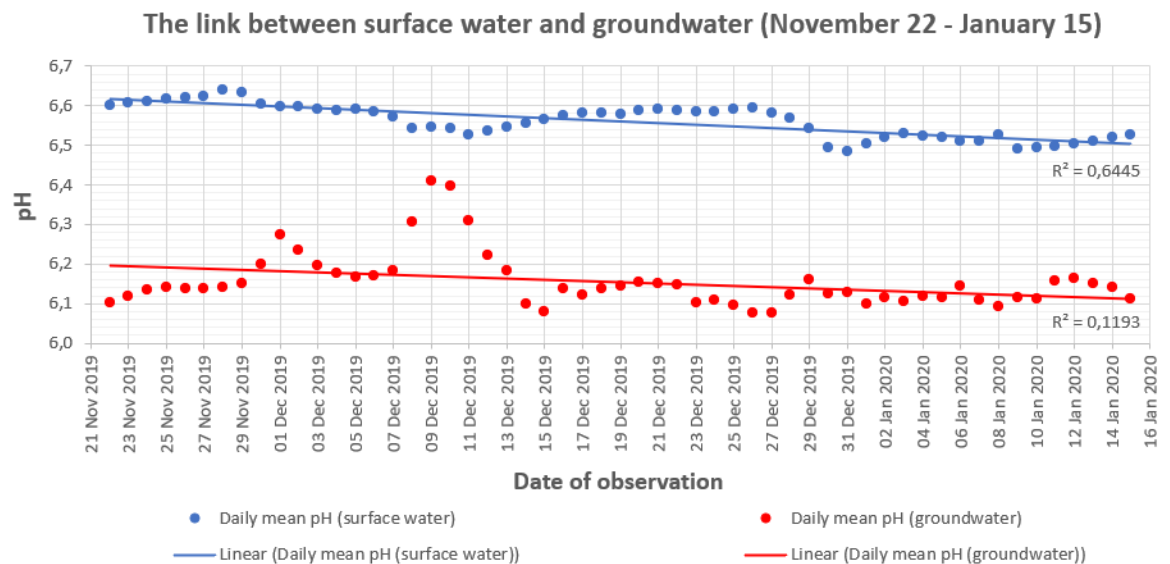
Figure 9. The link between surface water and groundwater (pH value)

6.3   The reliability of real time automatic data through reference samples

The reliability of the real time turbidity data collected by the YSI 6920 probe was confirmed by the reference samples (r_s = 0,892; p < 0,001). The possible reason behind the very strong positive link is that the turbidity of the water sample is not likely to change during transport. The concentration of suspended solid particles, after the sample is stirred in order to resuspend the sedimented particles, can be measured in a laboratory using a turbidimeter. Even though the manual samples showed a greater concentration of suspended matter (Appendix 2), the real time instrumental data provided a more realistic picture of suspended solid particles in the river, whose water is in constant state of motion. (Figure 10; Appendix 4/2).
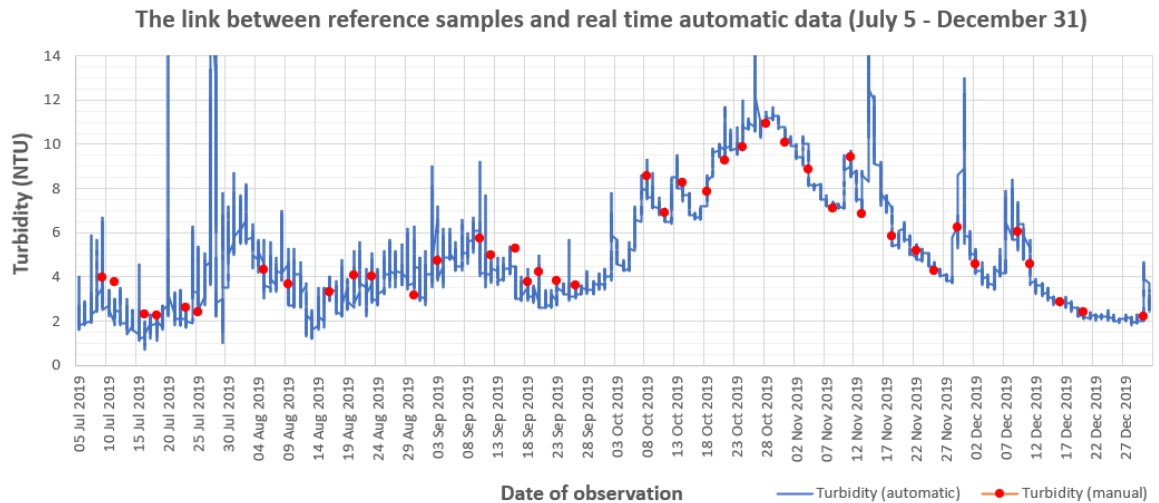

Figure 10. The link between reference samples and real time automatic data (turbidity)

The reliability of the conductivity values recorded by the water quality probe was confirmed by the reference samples using the Spearman's correlation coefficient (r_s = 0,963; p < 0,001). Before the adjustments, one of the used conductometers (WTW Cond 3310) showed significantly higher values for the reference samples (Appendix 2). After the adjustments, the measured values turned out to be more representative however the conductivity of the reference samples measured with the WTW Cond 340i conductometer was mostly lower than that of the automatic samples (Figure 11; Appendix 2). The reason behind the variations might be the malfunction of the sensor (TetraCon 325) of the WTW Cond 340i conductometer or measurement error (Appendix 4/2).
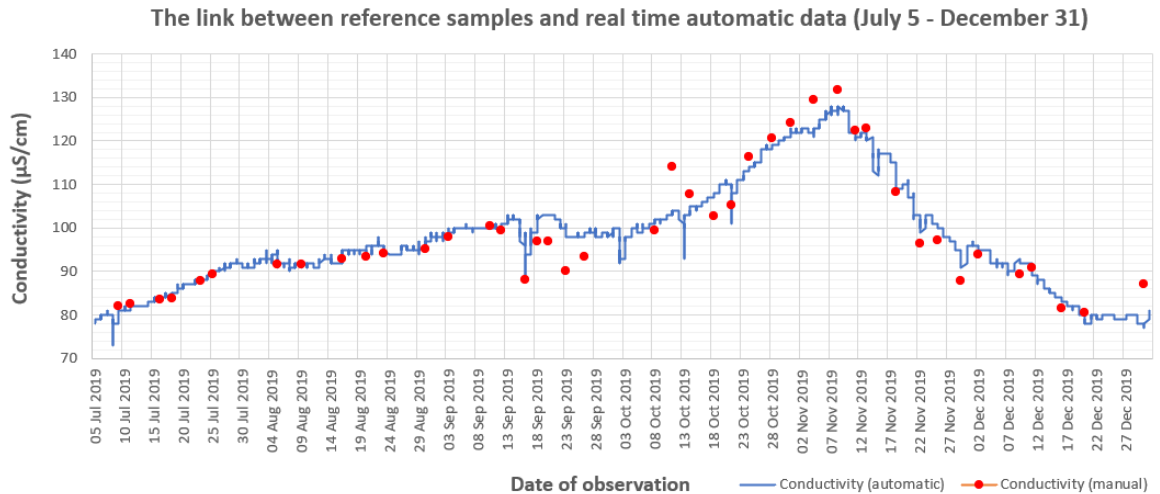
Figure 11. The link between reference samples and real time automatic data (conductivity)

Even though the concentration of dissolved oxygen has the tendency to change during transport, the link between manual samples and real time automatic data is proven to be significant (r_s = 0,929; p < 0,001). However, the results obtained from the reference samples are mostly higher than that of the instrumental data (Figure 12). The explanation is that a laboratory environment is considered to be more sterile compared to a natural environment, because the river is in constant state of motion, and the oxygen transfer between the atmosphere and the water body is continuous. (Figure 12; Appendix 4/2).
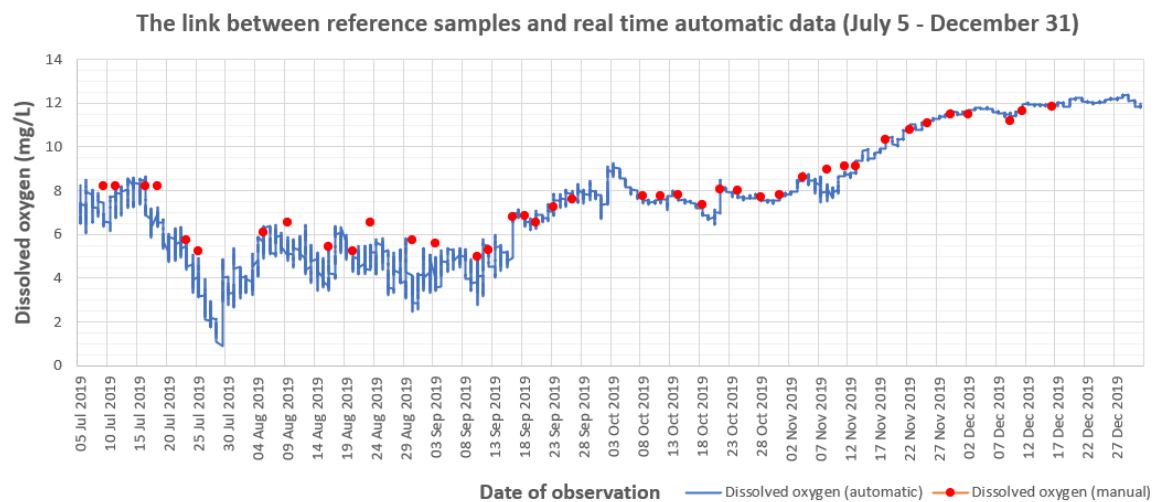

Figure 12. The link between reference samples and real time automatic data (dissolved oxygen)

The relationship between the daily mean pH values of the reference samples and that of automatic samples is not considered too significant (r_s = 0,475; p = 0,001).

The reason behind the medium correlation coefficient (Appendix 4/2) is that pH is temperature dependent and likely to change during transport. This indicates that the pH value of water samples cannot be measured in a laboratory, therefore the meter must be taken to the sampling location instead. During the research period, the river water was slightly acidic possibly because of the dissolution of weak acids from the atmosphere via precipitation, nonetheless the river water could be eligible for human consumption after treatment. (Figure 13; Appendix 4/2).
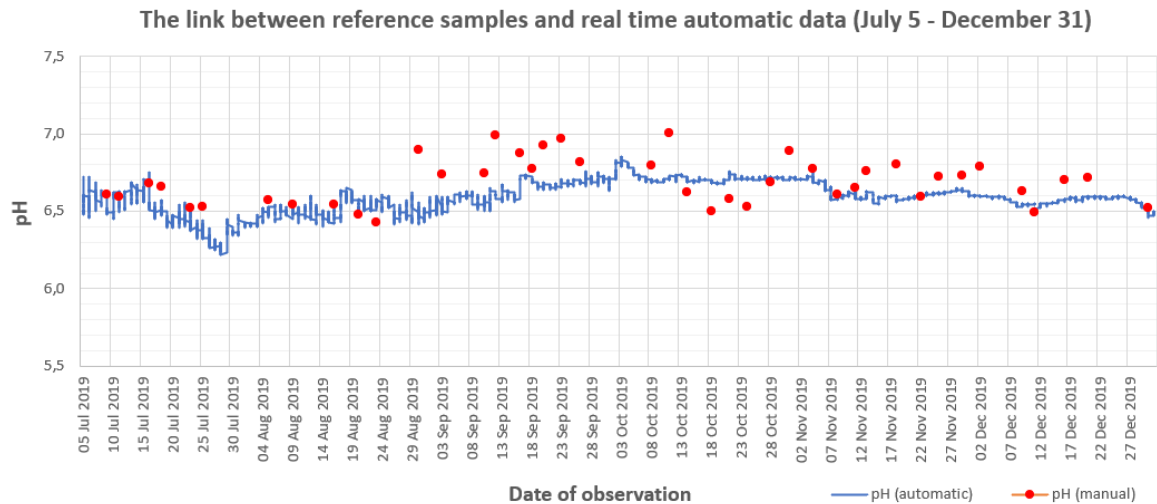

Figure 13. The link between reference samples and real time automatic data (pH value)

7   CONCLUSION

Precipitation and temperature influenced the turbidity of the river differently month by month and season by season. In the summer season, the turbidity of the river did not significantly increase because rainwater supposedly infiltrated into the soil without reaching the river, whereas in the autumn and winter months the increase in the turbidity of the river may be explained by soil erosion due to surface runoff.

The most significant link between the river water and groundwater was observed between their conductivity values possibly because of the infiltration of river water into the aquifer through the riverbed and the riverbank. The groundwater tended to be less sensitive to suspended particles possibly because the aquifer did not receive any water from the direct infiltration of meltwater through the soil, or the movement of groundwater was minimal. The concentration of dissolved oxygen

was significantly higher in the river water than in the groundwater which may be explained by the presence of vegetation in the river. The groundwater tended to be more acidic than river water, possibly because of the infiltration of weak acids.

The reference samples have proven the reliability of the real time automatic data in case of three of the four studied water quality parameters. This study promotes the use of water quality probes whenever possible because automatic sampling provides a more frequent and realistic picture of water quality parameters with a minimal requirement for personnel work.

8   ACKNOWLEDGEMENTS

REFERENCES

Boyd, C. E. 2015. Water Quality: An Introduction. Second Edition. Switzerland: Springer International Publishing AG Switzerland.

Boyd, C. E. 2020. Water Quality: An Introduction. Third Edition. Switzerland: Springer Nature Switzerland AG.

Brutsaert, W. 2005. Hydrology: An Introduction. Cambridge: University Press.

Collier, C. G. 2016. Hydrometeorology. Chichester: John Wiley & Sons Ltd.

Directive 2000/60/EC 23 October 2000. Establishing a framework for Community action in the field of water policy. WWW document. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32000L0060&from=EN [Accessed 24 March 2020].

ELY-keskus. 2018. Esitys Mikkelin pohjavesialueiden luokitus- ja rajausmuutoksista. PDF document. Available at: https://www.ymparisto.fi/download/noname/%7B277CC7A4-9AE7-4E8A-88F2-F9B0B79D3F07%7D/141482 [Accessed 29 March 2020].

ELY-keskus, SYKE, Maanmittauslaitos & Esri Finland. 2019. Mikkelin pohjavesialueet. PDF document. Available at: https://www.ymparisto.fi/download/noname/%7BF9942A14-7981-473C-98DE-EFC999E31044%7D/144359 [Accessed 20 April 2020].

Erickson, A. J., Weiss, P. T. & Gulliver, J. S. 2013. Optimizing Stormwater Treatment Practices: A Handbook of Assessment and Maintenance. New York: Springer Science+Business Media.

Gerrits, M. 2010. The role of interception in the hydrological cycle. Delft University of Technology. Degree programme in Civil engineering. Doctoral dissertation. PDF document. Available at: https://www.researchgate.net/publication/45685037_The_role_of_interception_in_the_hydrological_cycle [Accessed 13 March 2020].

Kennish, M. J. 2016. Encyclopedia of Estuaries. Dordrecht: Springer Science+Business Media.

Lagadec, L.-R. et al. 2016. Description and evaluation of a surface runoff susceptibility mapping method. *Journal of Hydrology* 541, 495-509 [Accessed 13 March 2020].

Lampinen, K. 2013. 7–nimisen joen taajamavaluma-alueet ja niiden aiheuttama kuormitus. Mikkeli University of Applied Sciences. Degree programme in Environmental engineering. Bachelor's thesis. PDF document. Available at: https://www.theseus.fi/handle/10024/63702 [Accessed 29 March 2020].

Maanmittauslaitos & Esri Finland. 2020. Available at:
https://asiointi.maanmittauslaitos.fi/karttapaikka/ [Accessed 1 April 2020].

McMahon, A. D. 2016. Influence of turbidity and aeration on the albedo of
mountain streams. The University of British Columbia. Faculty of Graduate and
Postdoctoral Studies. Master's thesis. PDF document. Available at:
https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0308740
[Accessed 17 March 2020].

Niemelä, S. 2014. Hanhikankaan vedenpumppaamon hankintaveden
laatututkimus. Mikkeli University of Applied Sciences. Degree programme in
Environmental engineering. Bachelor's thesis. PDF document. Available at:
https://www.theseus.fi/handle/10024/79768 [Accessed 3 April 2020].

Nironen, M. & Lehtonen, T. J. 2020a. Hanhilampi ja Pankajoki [Accessed 29
March 2020].

Nironen, M. & Lehtonen, T. J. 2020b. Kalevankankaan luontopolku [Accessed 29
March 2020].

Nironen, M. & Lehtonen, T. J. 2020c. Pohjavesi on juomavettämme [Accessed 29
March 2020].

Nironen, M. & Lehtonen, T. J. 2020d. Vesistö [Accessed 29 March 2020].

Posudin, Y. 2014. Methods of Measuring Environmental Parameters. New
Jersey: John Wiley & Sons Inc.

Satinder, A. 2013. Monitoring Water Quality: Pollution Assessment, Analysis, and
Remediation. Great Britain: Elsevier.

SFS-EN 27888:en. 1993. Water quality: Determination of electrical conductivity
(ISO 7888:1985). Part 2: Definitions.

Soltész-Várhelyi, K. 2020. Korreláció. PDF document. Available at:
https://dl.dropbox.com/s/u1wxrir7cjt3w0f/statgyakGY1_06_korrelacio.pdf
[Referred 3 May 2020].

Subhash, V., Varinder, S. K. & Siby, J. 2015. Water Supply Engineering. New
Delhi: Vikas Publishing House PVT Ltd.

Viljanen, V. 2016. Online-mittausten käyttö veden laatua arvioitaessa. South
Eastern Finland University of Applied Sciences. Degree programme in
Environmental engineering. Bachelor's thesis. PDF document. Available at:
https://www.theseus.fi/handle/10024/105424 [Accessed 3 April 2020].

Xylem Inc. 2019. Turbidity Units and Calibration Solutions – YSI Turbidity
Sensors. PDF document. Available at:

https://www.ysi.com/File%20Library/Documents/Technical%20Notes/T627_Turbidity_Units_and_Calibration_Solutions.pdf [Accessed 2 May 2020].

Ylönen, S. 2018. Pintavesivälitteiset riskit pohjavesialueilla : Esimerkkinä Hanhikankaan pohjavesialue Mikkelissä. South Eastern Finland University of Applied Sciences. Degree programme in Environmental engineering. Bachelor's thesis. PDF document. Available at: https://www.theseus.fi/handle/10024/142183 [Accessed 29 March 2020].

Yolanda, M. & Zayas, Z. P. 2007. Water sampling: Traditional methods and new approaches in water sampling strategy. *TrAC Trends in Analytical Chemistry* 26, 293-299. PDF document. [Accessed 24 March 2020].

LIST OF FIGURES

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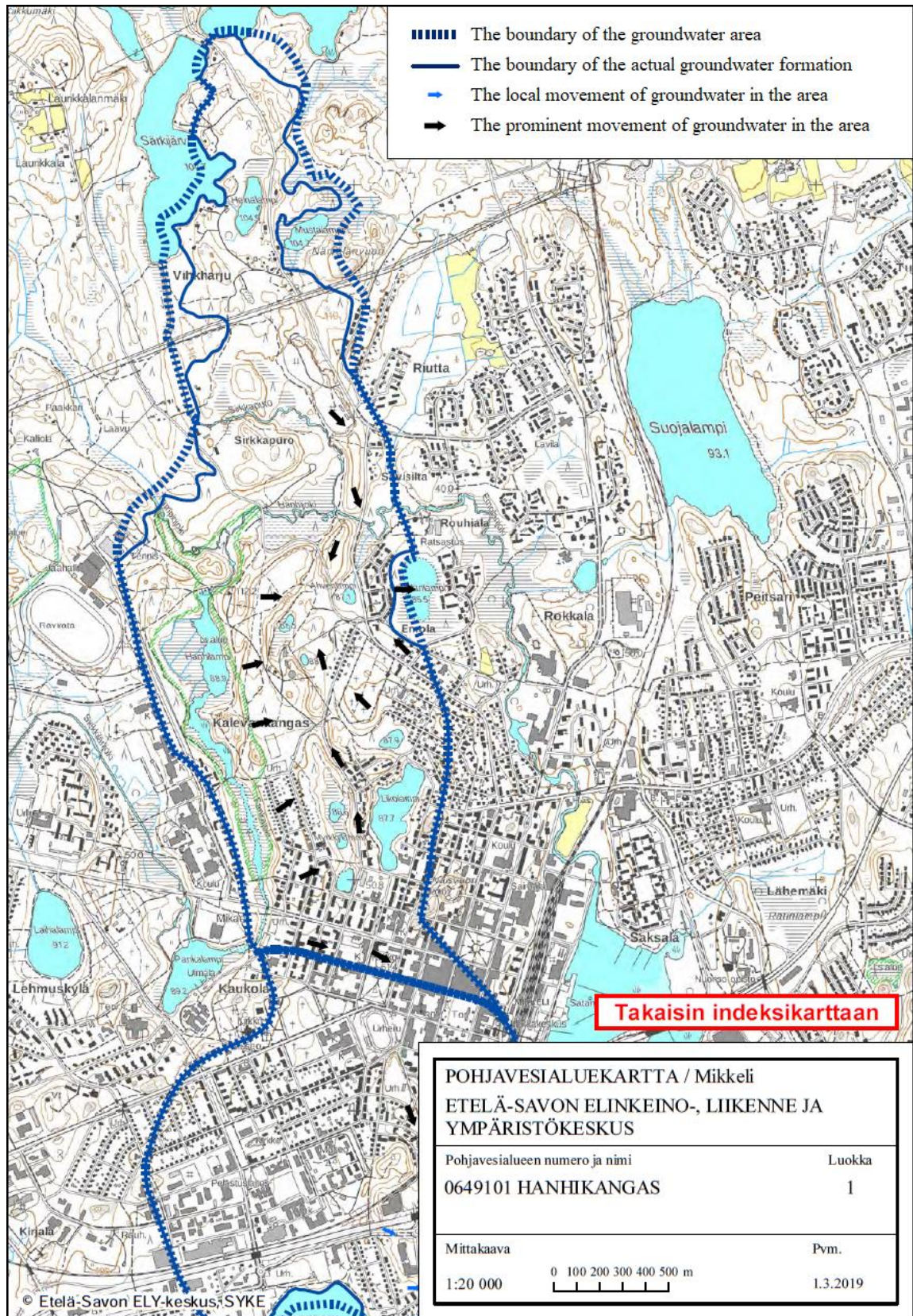# THE GROUNDWATER AREA AND THE MOVEMENT OF GROUNDWATER

Figure 14. The groundwater area and the movement of groundwater (ELY-keskus et al. 2019)

REFERENCE SAMPLES AND REAL TIME MEASUREMENT DATA

Table 1. Manually collected samples and their respective real time automatic data (dates marked with green: the reference sample was collected at the exact same time as the real time automatic data; dates marked with blue: the nearest real time automatic value was selected; dates marked with red: the mean of the two adjacent automatic values was calculated)

		Conductivity (manual) measured / adjusted		Conductivity (automatic)	Turbidity (manual)	Turbidity (automatic)	Dissolved oxygen (manual)	Dissolved oxygen (automatic)	pH (manual)	pH (automatic)
2019.07.09 10:01		90,60	81,94	80,00	3,99	3,30	8,21	6,47	6,61	6,49
2019.07.11 10:01		91,30	82,58	82,00	3,76	2,60	8,21	6,94	6,59	6,51
2019.07.16 10:01		92,30	83,48	84,00	2,31	2,00	8,21	6,97	6,68	6,53
2019.07.18 10:01		92,80	83,93	85,00	2,24	1,80	8,21	6,73	6,66	6,53
2019.07.23 10:01		97,20	87,91	88,00	2,61	2,20	5,75	4,66	6,52	6,40
2019.07.25 10:01	WTW Cond 3310 (new meter)	98,70	89,27	89,00	2,40	5,20	5,25	4,06	6,53	6,39
2019.08.05 10:01		101,30	91,62	93,00	4,32	3,90	6,07	5,24	6,57	6,47
2019.08.09 10:01		101,40	91,71	92,00	3,69	4,20	6,57	5,55	6,54	6,52
2019.08.16 9:31		102,60	92,80	93,00	3,33	3,70	5,42	3,55	6,54	6,44
2019.08.20 10:01		103,40	93,52	95,00	4,09	3,80	5,25	4,47	6,48	6,51
2019.08.23 10:01		104,00	94,06	96,00	4,02	3,90	6,57	4,72	6,43	6,54
2019.08.30 9:10		105,30	95,24	98,00	3,17	4,20	5,74	3,44	6,90	6,48
2019.09.03 9:00		108,27	97,92	99,00	4,71	4,20	5,58	4,98	6,74	6,58
2019.09.10 11:30		111,03	100,43	100,00	5,74	4,50	4,98	4,95	6,74	6,55
2019.09.12 9:20		101,27	99,48	101,00	4,98	4,00	5,31	4,98	6,99	6,60
2019.09.16 15:20	WTW Cond 340i (old meter)	89,63	88,05	89,00	5,31	3,85	6,79	6,62	6,87	6,66
2019.09.18 9:20		98,57	96,82	101,00	3,76	3,15	6,84	6,41	6,77	6,69
2019.09.20 9:55		98,80	97,05	103,00	4,23	2,90	6,57	6,27	6,92	6,64
2019.09.23 11:00		91,80	90,18	101,00	3,83	3,20	7,23	7,13	6,97	6,66
2019.09.26 8:05		95,20	93,52	98,00	3,64	3,10	7,61	7,47	6,81	6,67
2019.10.08 10:15		109,85	99,35	102,00	8,58	8,45	7,77	7,48	6,80	6,69
2019.10.11 8:40		126,10	114,05	103,00	6,89	6,70	7,76	7,54	7,01	6,71
2019.10.14 10:15		119,20	107,81	105,00	8,24	7,90	7,82	7,56	6,62	6,69
2019.10.18 8:25		113,60	102,75	107,00	7,87	7,80	7,33	7,0	6,50	6,68
2019.10.21 8:35	WTW Cond 3310 (new meter)	116,40	105,28	110,00	9,27	9,40	8,05	7,91	6,58	6,75
2019.10.24 8:45		128,55	116,27	114,00	9,85	10,95	7,99	7,72	6,53	6,70
2019.10.28 10:15		133,40	120,65	119,00	10,92	11,10	7,70	7,56	6,69	6,71
2019.10.31 10:00		137,40	124,27	122,00	10,08	10,50	7,83	7,68	6,89	6,71
2019.11.04 10:20		143,20	129,52	122,00	8,86	9,05	8,59	8,62	6,77	6,72
2019.11.08 12:20		145,50	131,60	128,00	7,11	7,20	8,98	8,17	6,61	6,60
2019.11.11 9:50		135,33	122,40	120,00	9,42	9,45	9,14	8,83	6,65	6,60
2019.11.13 10:10		125,13	122,92	122,00	6,84	7,15	9,14	9,02	6,76	6,59
2019.11.18 12:00		110,20	108,25	111,00	5,86	6,20	10,35	10,25	6,80	6,60
2019.11.22 10:45		98,23	96,50	101,00	5,18	5,35	10,78	10,88	6,60	6,60
2019.11.25 10:45		98,83	97,09	101,00	4,26	4,55	11,06	11,13	6,72	6,62
2019.11.29 10:00	WTW Cond 340i (old meter)	89,40	87,82	92,00	6,25	6,20	11,50	11,63	6,73	6,63
2019.12.02 12:20		95,67	93,98	96,00	4,57	4,75	11,49	11,62	6,79	6,59
2019.12.09 8:40		91,00	89,39	93,00	6,04	11,53	11,17	11,55	6,63	6,54
2019.12.11 10:20		92,50	90,86	90,50	4,59	4,65	11,66	11,77	6,50	6,51
2019.12.16 10:10		83,10	81,63	83,00	2,86	2,85	11,83	11,94	6,70	6,58
2019.12.20 9:30		81,90	80,45	79,00	2,40	2,20	-	12,23	6,72	6,59
2019.12.30 9:45		88,70	87,13	77,00	2,23	2,45	-	12,00	6,52	6,50

THE SELECTION OF THE STATISTICAL TESTS

Table 2. The selected statistical tests for the statistical analyses with a confidence interval of 95 %

Parameters of interest	Normal distribution (Shapiro-Wilk test) (α = 0,05)	Homogeneity of variances (Levene's test) (α = 0,05)	Selected statistical test based on disjunction (OR operation)
Turbidity (daily mean)	p < 0,001 (not assumed)	not tested	Spearman's correlation (non-parametric)
Precipitation (daily total)	p < 0,001 (not assumed)		
Air temperature (daily mean)	p < 0,001 (not assumed)		
Turbidity (surface)	p < 0,001 (not assumed)	p < 0,001 (not assumed)	Spearman's correlation + Mann-Whitney test (non-parametric)
Turbidity (ground)	p < 0,001 (not assumed)		
Conductivity (surface)	p < 0,001 (not assumed)	p = 0,122 (assumed)	Spearman's correlation + Mann-Whitney test (non-parametric)
Conductivity (ground)	p = 0,003 (not assumed)		
Dissolved oxygen (surface)	p < 0,001 (not assumed)	p < 0,001 (not assumed)	Spearman's correlation + Mann-Whitney test (non-parametric)
Dissolved oxygen (ground)	p < 0,001 (not assumed)		
pH (surface)	p = 0,020 (not assumed)	p = 0,179 (assumed)	Spearman's correlation + Mann-Whitney test (non-parametric)
pH (ground)	p < 0,001 (not assumed)		
Turbidity (manual)	p = 0,005 (not assumed)	p = 0,322 (assumed)	Spearman's correlation (non-parametric)
Turbidity (automatic)	p = 0,002 (not assumed)		
Conductivity (manual)	p = 0,001 (not assumed)	p = 0,670 (assumed)	Spearman's correlation (non-parametric)
Conductivity (automatic)	p = 0,177 (assumed)		
Dissolved oxygen (manual)	p = 0,017 (not assumed)	p = 0,133 (assumed)	Spearman correlation (non-parametric)
Dissolved oxygen (automatic)	p = 0,034 (not assumed)		
pH (manual)	p = 0,227 (assumed)	p = 0,001 (not assumed)	Spearman correlation (non-parametric)
pH (automatic)	p = 0,313 (assumed)		

THE RESULTS OF THE STATISTICAL TESTS

Table 3. The correlation between turbidity, precipitation, and temperature (summer months)
The statistically significant (p ≤ 0,05) correlation coefficients are highlighted in red

	Precipitation			Air temperature		
	30 days	15 days	5 days	30 days	15 days	5 days
Turbidity (1st study month) July 5 – August 3	-0,125	0,192	0,500	-0,059	-0,511	-0,600
			0,000			0,700
			-0,205			0,800
		0,133	-		-0,154	-0,400
			-			-0,300
			-0,894			**0,900**
Turbidity (2nd study month) August 4 – September 2	-0,119	-0,298	0,354	-0,116	**-0,639**	-0,700
			-0,112			-0,600
			-0,707			0,500
		-0,097	0,500		0,504	0,000
			-0,707			0,700
			0,894			-0,100

Table 4. The correlation between turbidity, precipitation, and temperature (autumn months)
The statistically significant (p ≤ 0,05) correlation coefficients are highlighted in red

	Precipitation			Air temperature		
	30 days	15 days	5 days	30 days	15 days	5 days
Turbidity (3rd study month) September 3 – October 2	0,248	**-0,557**	-0,300	**0,749**	**0,550**	-0,300
			-0,900			-0,300
			0,300			-0,100
		0,318	-0,112		0,482	0,400
			0,000			-0,600
			0,200			-0,700
Turbidity (4th study month) October 3 – November 1	-0,299	**-0,516**	-0,100	0,003	0,046	-0,700
			-0,447			-0,800
			-0,667			0,200
		-0,247	0,200		-0,418	-0,300
			0,205			-0,100
			-0,154			-0,600

Table 5. The correlation between turbidity, precipitation, and temperature (winter months)
The statistically significant (p ≤ 0,05) correlation coefficients are highlighted in red

	Precipitation			Air temperature		
	30 days	15 days	5 days	30 days	15 days	5 days
Turbidity (5th study month) November 2 – December 1	-0,037	-0,200	**0,894**	0,093	0,461	**0,900**
			-0,400			0,100
			-0,359			0,400
		-0,005	0,000		0,346	0,300
			-0,707			0,100
			-0,700			-0,300
Turbidity (6th study month) December 2 – December 31	0,204	-0,023	-0,308	0,250	-0,027	-0,100
			0,200			0,100
			-0,200			-0,700
		0,335	0,600		0,446	0,500
			-0,500			**0,900**
			0,308			0,300

Table 6. Descriptive statistics and statistical tests between surface- and groundwater with a confidence interval of 95 % (α = 0,05)

	Median	Number of observations	Correlation coefficient and significance (two-tailed)	Z value and significance (two-tailed)
Turbidity (surface)	3,2313	48	r_s = -0,556 (p < 0,001) (Spearman)	Z = -8,441 (p < 0,001)
Turbidity (ground)	1,4059	48		
Conductivity (surface)	83,0000	55	r_s = 0,652 (p < 0,001) (Spearman)	Z = -0,296 (p = 0,767)
Conductivity (ground)	86,1434	55		
Dissolved oxygen (surface)	11,9734	55	r_s = 0,691 (p < 0,001) (Spearman)	Z = -9,043 (p < 0,001)
Dissolved oxygen (ground)	0,1517	55		
pH (surface)	6,5724	55	r_s = 0,119 (p = 0,387) (Spearman)	Z = -9,042 (p < 0,001)
pH (ground)	6,1382	55		

Table 7. The descriptive statistics and the correlations of manual and automatic samples with a confidence interval of 95 % (α = 0,05)

	Sample mean	Standard deviation	Number of observations	Correlation coefficient	Significance (two-tailed)
Turbidity (manual)	5,3405	2,4422	42	r_s = 0,892 (Spearman)	p < 0,001
Turbidity (automatic)	5,3829	2,7862	42		
Conductivity (manual)	98,6067	13,7596	42	r_s = 0,963 (Spearman)	p < 0,001
Conductivity (automatic)	99,1548	12,8464	42		
Dissolved oxygen (manual)	7,9578	2,0094	40	r_s = 0,929 (Spearman)	p < 0,001
Dissolved oxygen (automatic)	7,4368	2,5722	40		
pH (manual)	6,6900	0,1499	42	r_s = 0,475 (Spearman)	p = 0,001
pH (automatic)	6,5898	0,0909	42		