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DESIGN, IMPLEMENTATION, AND EVALUATION OF AN ONLINE WATER QUALITY MONITORING SYSTEM IN LAKE SAIMAA, FINLAND

Examiners: Professor Mika Sillanpää
Dr. Sci. Heikki Särkkä

ABSTRACT

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Environmental threats are growing nowadays, they became global issues. People around the world try to face these issues by two means: solving the current affected environs and preventing non-affected environs. This thesis describes the design, implementation, and evaluation of online water quality monitoring system in Lake Saimaa, Finland. The water quality in Lake Saimaa needs to be monitored in order to provide responsible bodies with valuable information which allows them to act fast in order to prevent any negative impact on the lake's environment.

The objectives were to design a suitable system, implement the system in Lake Saimaa, and then to evaluate the applicability and reliability of such systems for this environment. The needs for the system were first isolated, and then the design, needed modifications, and the construction of the system took place. After that was the testing of the system in Lake Saimaa in two locations nearby Mikkeli city. The last step was to evaluate the whole system.

The main results were that the application of online water quality monitoring systems in Lake Saimaa can benefit of many advantages such as reducing the required manpower, time and running costs. However, the point of unreliability of the exact measured values of some parameters is still the drawback of such systems which can be developed by using more advanced equipments with more sophisticated features specifically for the purpose of monitoring in the predefined location.

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List of symbols and abbreviations

ASCII	American Standard Code for Information Interchange
ASTM	American Society for Testing and Materials
ATP	Adenosine TriPhosphate
BOD	Biochemical Oxygen Demand
CCD	Charge Coupled Device
Chl a	Chlorophyll alpha
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
FTP	File Transfer Protocol
GIS	Geographical Information System
GPRS	General Packet Radio Service
GRP	Glass reinforced plastic
GSM	Global System for Mobile Communications
IPxx	International Protection Marking "where xx are two numbers"
IT	Information Technology
ORP	Oxidation-Reduction Potential
PC	Personal Computer
PDA	Personal Digital Assistant

PSS	Practical Salinity Scale
SDT	Secchi Disk Transparency
SI	The International System of Units
SSG	Seawater Specific Gravity
TAN	Total Amount of Nitrogen
TDS	Total Dissolved Solids
TP	Total Phosphorus
USA	United States of America
WHO	World Health Organization
WSN	Wireless Sensor Network

1 Introduction

1.1 Background

""Would you please bring me a cup of water"" the father asked his son, the son went to the tap and opened the valve but surprisingly the water looked greenish. He did not know what to do except telling his father who -by his turn- called the municipality of their city to ask about the problem. The municipality said "we have a big algae bloom in Lake Saimaa which is our water's source, and the treatment plant can't handle it to make the water suitable for drinking, so please avoid drinking that water until we fix the problem". The father went to check from the news on TV and found the same warning, not to drink tap water for cities around Lake Saimaa that uses its water as their drinking source.

This imaginary scenario can happen to any of us, in any city around the world that takes its water from surface sources. The importance of the water's quality that arrives to our houses is becoming to be a more concern for the governmental authorities. They want to assure the quality of water is suitable for drinking and other human's uses, as an essential task. Therefore, they need to have a frequent check for all of the supply-line steps.

Because of this, new trends and technologies are being tried and studied to analyze the water's quality in the raw water sources like wells, rivers, and lakes before being sent to next steps for the treatment in the water supply process. In addition, analysis of water's quality in surface water is important to keep as much clean environment as possible even if the water is not to be used as a drinking water source.

The ability to determine the water's quality and make the results available immediately for authorities is an asset that leads to suitable responses avoiding the supply of polluted water to its last destinations.

Hence, to avoid such the pervious mentioned situation, our current study describes one of the new trends to monitor water's quality. Previously, the conventional method was sampling-in-site and analyzing in lab. This method has many defects as will be seen during the following sections. Therefore, the present research describes the design, the implementation, and the evaluation of an online water quality monitoring system. The implementation takes place in Lake Saimaa, Finland to measure a set of water quality parameter at once. In some parts, this online water quality monitoring system used pre-manufactured parts by a supplier called Trace2O, a UK-based manufacturer.

In addition to being the first time to use such an online water quality monitoring system with this exact set of parameters together in Finland, this system provides valuable data and results for researchers, Finnish authorities, and global organizations. It makes the results available instantly to bodies interested in the determination of these quality parameters in Lake Saimaa. Also, the importance of this research is due to the study area (Lake Saimaa). It is the biggest lake in Finland and the fourth biggest lake in Europe (Kuusisto 1999; Nikkinen 2014; Reinikainen et al. 2001).

Therefore, the novelties of this thesis are:

1. The unique design and modifications of some parts of the system.
2. The first to use online lake-water quality monitoring system in Finland with the parts supplied by Trace2O.
3. The first to implement an online water quality monitoring system in Lake Saimaa in order to measure that exact set of water quality parameters at once.

1.2 Aims & Objectives

This research thesis has several objectives which we aim to achieve. Depending on the core idea of the project and on the benefits of the results, the set of goals are as follows:

1. To design, modify and construct an online water quality monitoring system.
2. To implement this system in Lake Saimaa, Finland.
3. To measure the water quality parameters in Lake Saimaa in different locations in Mikkeli region:
    a. Tuppurala
    b. Pitkäjärvi
4. To take some manual samples from these site by the conventional standard method.
5. To compare the obtained results with the standard values (for some parameters).
6. To compare the online results with the manual results.

7. To evaluate the online system based on the obtained results.
8. To provide recommendations about the applicability of such systems.

By achieving these goals, a previously non-lighted area of knowledge will be clearer. A stronger background for further studies will be available. An encouraging motivation for more improvement will be an asset. A more profound understanding of such systems will be easier. In general, achieving these goals plays its role in improving the world where we live, in taking part in the world's development, and in making the humankind's life better.

1.3 Delimitations

There are some predicted limitations on the online water quality monitoring system implemented in Lake Saimaa, Finland. These predicted delimitations are as follows:

1. Unstable climate in that area during the working period.
2. The dependence on a third party to manufacture some parts of the system.
3. The uncertainty of reliability on the manufacturer to fulfill the demands.
4. Part of the working period of this thesis will take part during summer time where people usually get their vacations. This might lead to some delay.
5. The language barrier, most of the sources about Lake Saimaa are predicted to be in Finnish language.
6. The less number of available articles about online water quality monitoring in general, and specifically in Finland.

With these objectives and limitation ahead, the following research structure is set to achieve the goals and overcome the limitations.

1.4 Research structure

The main structure of the current study consists of three main themes as can be seen in Figure 1. These are the literature theme, the design description theme, and the experimental theme.

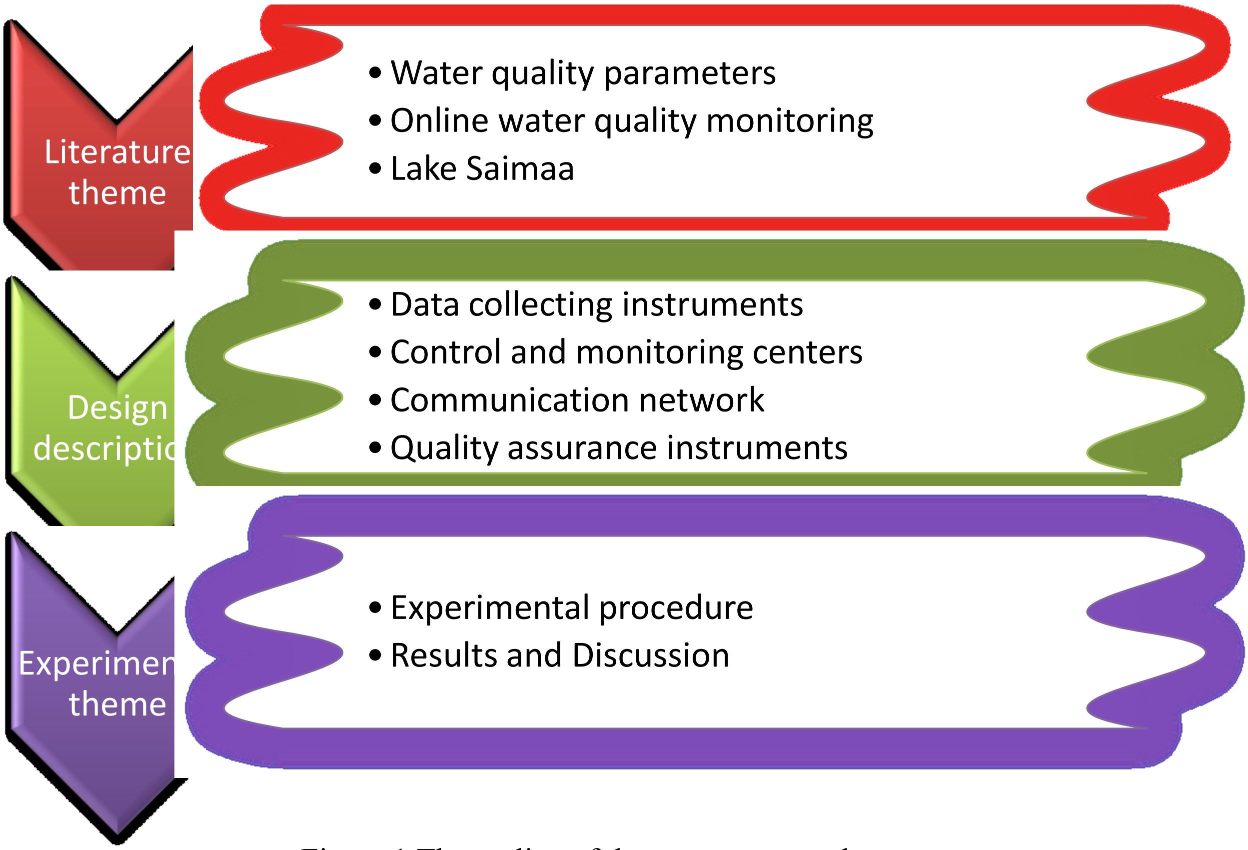

Figure 1 The outline of the current research

The first theme is the literature theme. It includes several sections: the literature information about water quality parameters that were monitored by the current study, the state of art about online water monitoring systems, and the literature information about the study area (Lake Saimaa).

The water quality parameters discussed in this thesis are temperature, pH, turbidity, electrical conductivity (EC), salinity, total dissolved solids (TDS), seawater specific gravity (SSG), chlorophyll a, rhodamine dye, dissolved oxygen (DO), oxidation reduction potential (ORP), nitrate, ammonia & ammonium, and refined oil (BTEX). Online water quality monitoring part shows the structure of online water quality monitoring systems, online monitoring systems features, and the application's trends of online water quality monitoring systems. The Lake Saimaa section states general information about the study area, in addition to some previous researches about it.

The second theme is the design's description. This theme has several parts. It contains the description of data collecting instruments, the description of control and monitoring center, and the description of quality assurance instruments.

The data collecting instruments section describes the design of the ferry and the PaquaStat/PaquaBag. The control and monitoring center illustrates Trace2O and ToMoVaKe servers. The communication network part explains the used data transfer network. The quality assurance instruments part includes location confirmation tools and lab's tools.

The third theme is the experimental theme. It includes the experimental procedure part and the results and discussion part.

The experimental procedure includes the design and construction process, the preparation for the field trips, the actual field trips, and post-field trips. The results and discussion part presents the results for the system's implementation in Lake Saimaa, the water quality parameters' results, and the evaluation of the system.

2 Water quality parameters

There are many parameters that should be investigated, in order to determine the water's quality in any water-system, especially open systems. The quality of water in open systems like rivers or lakes is important to be monitored, especially if the water is going to be used for human or industrial purposes.

The water quality parameters that were studied in the current thesis are presented in this section with some information about each one of them, such as their health effects and their environmental effects. Furthermore, the guideline-values for some of these parameters are reported.

2.1 Temperature

Based on Oxford dictionary, temperature is the degree or intensity of heat present in a substance or object, or the degree of internal heat of a body (Oxford Dictionaries 2013). So it is a way to represent the internal energy of an object, it depends on the kinetic motion of molecules in that substance. When molecules move, they transfer their kinetic energy to thermal energy when colliding. As a water parameter, it shows the status of the internal thermal energy of the water which is mostly caused by the molecular motion.

Temperature has several essential effects on the status of the water (Wilde and Radke 1998). It affects the solubility of dissolved solids and gases, more solids and less gas can be dissolved with higher temperature (U.S. Geological survey 2014a). Also it affects conductivity, chemical reaction rate - increases at higher temperature (U.S. Geological survey 2014a)-, pH, and biological and organisms activity. In addition, temperature fluctuation affects the uses of that water for other human purposes such as dams or power stations (U.S. Geological survey 2014a).

Several scales are used to measure the temperature. Celsius, Kelvin and Fahrenheit are the most common ones.

There is always a range in which the waters' temperature occurs. It depends on the ambient temperature, weather and climate, and the location of the water open system.

2.2 pH

The pH is a measure of the hydrogen-ion (H^+) activity (Wagner et al. 2006). It is also defined as the negative logarithm of (H^+) activity (Ebbing and Gammon 2009). It is a value that describes the acidity of the water, and since the (H^+) concentration values may be very small, the trend was to use the logarithm of the base 10 to make the description clearer. The (H^+) is formed by the dissociation of any compound that includes a dissolvable (H^+) in water.

The importance of pH lies because of its effect on organisms living in the water. pH change can be an indicator of increasing pollution (U.S. Geological survey 2014b). In addition, pH value of water affects the solubility and biological availability of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium) (U.S. Geological survey 2014b).

Although the most common range of the pH is between 0 representing the acidic medium and 14 representing the basic one, in open systems the range is between 6.5-9 in fresh water systems such as lakes, and 6.5-8.5 in salt water systems such as seawater (U.S. Environmental Protection Agency 1986).

The conventional measurement of the pH takes place by the usage of an electrometric method by using a hydrogen-ion electrode (Wagner et al. 2006). The typical sensors are two combined electrodes. One is immersed in a reference buffer solution, and the other in an electrolyte. The electrolyte exchanges (H^+) ions with the medium through a glass membrane. Based on the (H^+) concentration in the medium, the sensor measures the potential difference between the two electrodes. It represents this potential difference as an electrical signal. The calibration step defines this specific signal with a pH value. After that, the device translates the signal to a pH reading.

2.3 Turbidity

Turbidity expresses the optical properties of a sample which cause light to be scattered and/or absorbed, instead of being transmitted in a straight line (U.S. Geological survey 2014c). Also, ASTM International (2012) goes further by describing turbidity as the presence of any suspended or dissolved matters, such as plankton, clay, finely divided organic matter, organic acids, other microscopic organisms, and even dyes.

High turbidity caused by solids can increase temperature and reduce light available for photosynthesis. If the turbidity is caused as a result of suspended sediment, it can be an indicator of erosion (Clean Water Team 2004a).

The turbidity is measured by Nephelometric Turbidity Unit (NTU) which is a measure of the light scattered at 90 degrees. The recommended criteria values for turbidity should be less than 5 NTU (U.S. Environmental Protection Agency 2002). Or for water bodies with moderate plant and animal life the turbidity should be (1-10 NTU) and water bodies enriched with nutrients turbidity is (10-50 NTU) (Clean Water Team 2004a).

There are several methods to determine the turbidity in water (Clean Water Team 2004a) such as Secchi disc, transparency tubes, dual cylinder kit, and turbidity meter. They all depend on the same principle, they are all optical measurements, and the only difference is in the turbidity meter where the observer is an optical sensor, whereas for the rest, human observation is needed. However, the wavelength of the used light, the size, the shape, and the composition of the substance that causes turbidity, all have an effect on the sensors (Wagner et al. 2006).

2.4 Electrical Conductivity and Resistivity

Electrical Conductivity (EC) is a measure of the water's capacity to conduct an electrical current and is a function of the types and quantities of dissolved substances in water (Wagner et al. 2006). Based on this, conductivity depends mostly on ions' concentrations, in addition to temperature (U.S. Environmental Protection Agency 2014). The measuring unit for conductivity is Siemens (S) or its smaller subunits (mS, µS). Also, conductivity can be presented as specific conductivity as (µS/cm). The range for freshwater conductivity values is between (100-2000 µS/cm) (U.S. Environmental Protection Agency 2014).

The importance of EC is generally because it is related to the total solute concentration, it is considered as a quantitative expression of salt concentration in the water; even it is affected by the charge and relative concentration of each individual ion in the solution (Johnsson et al. 2005). Furthermore, it makes an indication for the geology of that area; areas with granite bedrock tend to have lower conductivity whereas areas with clay soils tend to have higher conductivity (U.S. Environmental Protection Agency 2014). In addition, sudden increase or decrease in conductivity in water can indicate pollution such as agricultural runoff or a sewage leak (Kemker 2014).

Conductivity is usually measured by conductivity meters (Wagner et al. 2006). They give reliable, accurate, and durable measurements but they are susceptible to fouling from aquatic sediment and organisms.

The other used term is resistivity. It is the reciprocal of conductivity (1/EC); therefore, it quantifies how strongly a substance opposes the electrical current flow.

2.5 Salinity

Salinity is the salts' content in the water. Or, it is the total concentration of all dissolved salts in water (Kemker 2014). Technically, it is difficult to measure the salinity directly because of the number of different salts, and the difficulty in determination of the exact content. For these reasons, salinity is being derived from specific conductivity.

The salts in water bodies are primarily sodium chloride (NaCl). However, there is a combination of dissolved ions including sodium, chloride, carbonate and sulfate (Clean Water Team 2004b).

The importance of determination of salinity becomes out from the fact that fresh water is used as irrigation water for agriculture activities. Therefore, the amount of salt will determine which crops, plants or trees can be planted. Salinity affects crops by reducing the yield (Henschke and Herrmann 2007).

Also, the salinity level has an influence on aquatic biota. Every kind of organism has a typical salinity range that it can tolerate. In addition, salty water can cause problems with the health (Clean Water Team 2004b).

Salinity is commonly reported with the Practical Salinity Scale (PSS) which was developed in relation to a standard potassium-chloride solution based on temperature, conductivity, and barometric pressure measurements (Wagner et al. 2006). It is a dimensionless value nearly equivalent to parts per thousand which used to be the standard unit before (Kemker 2014). In fresh water systems, the water quality criterion for salinity is 250 mg/L (U.S. Environmental Protection Agency 1986).

2.6 Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) represents the water's content of all dissolved inorganic solids and small amount of organic matters (Bartram and Ballance 1996a; U.S. Environmental Protection Agency 1986; WHO 2003a). It includes the sum of all ion particles that are smaller than 2 µm (Kemker 2014). The main constituents are calcium, magnesium, sodium, and potassium cations and carbonate, hydrogen-carbonate, chloride, sulfate, and nitrate anions (WHO 2003a).

The conventional method to measure TDS is by evaporating a sample of filtered water and then measuring the weight of the remaining solids (Kemker 2013). However, because determination of TDS by evaporation is time-consuming, TDS is usually measured by converting conductivity values to TDS values by means of a factor (Kemker 2013; WHO 2003a). The most common approximated factor for conversion is 0.6532 (Kemker 2013).

The drinking water standards are 500 mg/L as the maximum TDS concentration (U.S. Environmental Protection Agency 1986), and it is used by some states and regions as instead of a conductivity limits (Kemker 2014).

Although these are the drinking water standards, U.S. Environmental Protection Agency (1986) put a rating for the quality of water bodies as in the Table 1.

Table 1 The rating of water's bodies as the level of TDS
(U.S. Environmental Protection Agency 1986)

Rating	**Level of TDS** (mg/L)
Excellent	Less than 300
Good	300 - 600
Fair	600 - 900
Poor	900 - 1,200
Unacceptable	Above 1,200

The limits of TDS are set because excessive TDS may produce toxic effects on fish (Kemker 2014), physiological effects such as laxative effects, unpalatable tastes, and higher costs due to corrosion of pipes used with this water (U.S. Environmental Protection Agency 1986).

2.7 Seawater Specific Gravity (SSG)

Seawater Specific Gravity (SSG) is just another way to represent water density. Its unit is σ_T which is defined as the subtraction of water density -at standard condition- from the water sample density. For example, if SSG is (2 σ_T) this means the density of water is 2 kg/m^3 more than the standard water density.

Usually the density of open water systems is calculated by colorations between temperature and conductivity. And then the representation of SSG takes part.

2.8 Chlorophyll a

Chlorophyll is the green pigment found in chloroplasts of algae and plants (Offiong et al. 2014), as well as in cyanobacteria. It allows them to create energy from light (to photosynthesize the food) (Michaud and Noel 1991).

While Chlorophyll is a measure of all green pigments, Chlorophyll a is a measure of the part that exists in organisms that are still active (alive) (Michaud and Noel 1991).

Therefore, the definition of Chlorophyll a appears to be the measure of living organisms that have this pigment in a water column (Offiong et al. 2014). In addition, chlorophyll's concentration monitoring is used to manage the eutrophication (over-enrichment of Phosphorus and Nitrogen) in water bodies (Ritchie et al. 2003). Eutrophication is considered the longest-standing water quality problem (Hanmer et al. 2003). Also, chlorophyll a is considered as a good indicator of phytoplankton biomass (Markogianni et al. 2014); therefore a measure of the primary food source of aquatic food webs (Hanmer et al. 2003). For these reasons, the Chlorophyll a concentration that is found in water's body, affects the chemical, physical, and biological characteristics of that water (Michaud and Noel 1991).

Chlorophyll a is usually reported in µg/L. Although of its importance but the value of chlorophyll's concentration differs from one water system to another, hence there is no water quality standard for chlorophyll a (Michaud and Noel 1991). However, there are some local criteria for chlorophyll a concentration in some areas such as (10 µg/L) in Queensland (Department of Environment and Heritage Protection 2009).

The common chlorophyll concentration monitoring is based on radiation of narrow bands of wavelengths that have empirical relationships between radiance/reflectance and chlorophyll concentrations (Ritchie et al. 2003).

2.9 Rhodamine Dye

Rhodamine dye is a red colored highly fluorescent dye which can be detected in very low concentrations. The fluorescent properties mean that when it is irradiated with a light of a specific wavelength it emits a higher wavelength light (Aquaread Ltd 2014a; RsHydro 2014; YSI Inc. 2014). There are several uses for this dye such using it as a tracer dye in water flow (RsHydro 2014), a measure of the time of travel (YSI Inc. 2014), or studying the reactions and the irrigation uptake by plants (Aquaread Ltd 2014a; YSI Environmental 2001).

The value of measuring rhodamine in water systems lies on the fact that it is a good indication of pollutants. Rhodamine dye has the ability to color some organic materials that causes water pollution. Hereby, it indicates how polluted the system is. As well, it provides the chance for tracing those pollutants (Aquaread Ltd 2014a).

The standards values for rhodamine dye concentrations is 10 in µg/L for fresh waters used as drinking water supply, and 0.1 in µg/L for direct consumption drinking water (Bencala and Cox 2005).

Rhodamine is detected by using fluorescent meters which measure the light fluoresced by the rhodamine after being irradiated with light. The concentration of the dye in the water has a relationship to the fluorescence, so this measurement gives an indication of the rhodamine levels in the water, and hence the pollution level (Aquaread Ltd 2014a).

One of the used rhodamine dyes is rhodamine WT which is highly recommended to use, because of its usage's easiness (YSI Environmental 2001).

2.10 Dissolved oxygen (DO)

Oxygen is a soluble gas in water. When it dissolves in water it forms the dissolved oxygen (Wagner et al. 2006). Therefore, dissolved oxygen refers to the level of non-compound oxygen present in water as O_2 (Kemker 2013).

In open water systems, sources of DO in surface waters are usually from atmospheric aeration and photosynthetic reactions of aquatic organisms (Wagner et al. 2006).

Dissolved oxygen is one of the most essential monitored factors for early warning systems in water bodies (Kemker 2013; Mariolakos et al. 2007). It is a critical parameter for water's quality (Mariolakos et al. 2007). As well as for the survival of living organisms because aquatic organisms need oxygen in order to live (Michaud and Noel 1991). Also, dissolved oxygen is needed for some chemical reactions that occur in the water system (Michaud and Noel 1991).

There are several factors that affect the DO concentration. First, the atmosphere pressure, DO increase when pressure increases (Kemker 2013; Mariolakos et al. 2007; Michaud and Noel 1991). Second, temperature, DO decreases when temperature increases (Kemker 2013; Mariolakos et al. 2007; Michaud and Noel 1991). Third, pollution level, DO concentrations decrease when water is more polluted (Michaud and Noel 1991). Fourth, salt concentration, when salt level increases in a water system DO decreases exponentially (Kemker 2013).

Because of its importance, sensors' technologies are produced to measure and detect the dissolved oxygen concentration. The most common one is the amperometric method (Wagner et al. 2006). It measures the dissolved oxygen concentration with a temperature-compensated polarographic membrane-type sensor.

In this method, oxygen is transferred through the membrane to a cathode-anode system with an electrolyte -usually KCl-.An electrical potential is applied from electrical source driving the oxidization-reduction reaction to take part. The oxygen is reduced on the cathode to hydroxyl ions which causes a pressure difference through the membrane. This pressure difference is the driving force for oxygen to diffuse through the membrane. By then, the pressure difference is measured and is translated to show the dissolved oxygen concentration. (Eutech Instruments Pte Ltd 1997)

DO concentrations can vary in water system from less than 1 mg/L to more than 20 mg/L (Kemker 2013). But the water criterion for DO is set to be 4 mg/L as the minimum limit (U.S. Environmental Protection Agency 1986).

Moreover, DO can be presented by either mg/L or percentage representation where 100 % is the saturation value. This saturation value in mg/L depends on the previous mentioned parameters as can be seen in Appendix I. In some cases, DO is reported to be more than 100%. This means, DO concentration in mg/L is more than the saturation concentration based on the temperature and salinity. It can be easily understood by the rapid condition change such as photosynthesis, where more oxygen is produced when light exists, or rapid temperature changes. Because the equalization of water is a slow process the value of DO in water can be more than 100%. (Kemker 2013)

2.11 Oxidation-reduction potential (ORP)

Oxidation-Reduction Potential (ORP) or Redox potential, as called sometimes, is a measure of the equilibrium potential that is developed at the interface between a noble metal electrode and an aqueous solution containing electro-active species (Nordstrom and Wilde 2005). Yet, another more simple definition, ORP is a measure of an aqueous system's capacity to either release or accept electrons (Bier 2009).

Potential energy is the stored energy that is ready to be put to work. It's not actually working, but it is there if needed (Lowry and Dickman 2010).

An oxidizing system is a system which has plenty of electro-active species that can oxidize other matters and accept electrons. On the other hand, a system is a reducing system when it has the electro-active species that tend to release electrons.

The importance of ORP in water system comes out because ORP is a practical method to electronically monitor the ability of a water body to remove harmless chemicals and unwanted plants, animals, and microorganisms (Lowry and Dickman 2010).

When the system is an oxidizing system it is considered to be a clean system because the oxidizing species can attract electrons from the harmful substances. This means practically to remove their harmfulness.

The used unit for the ORP is mV, because it is measured by the potential difference between the species in the system and a noble metal electrode. A positive value of OPR means the system is oxidizing system, whereas a negative value of ORP means a reducing system.

2.12 Nitrate

Nitrate is a nitrogen-oxygen chemical ion (Eldridge et al. 2014). It is formed by one atom of nitrogen (N) and three atoms of oxygen (O) having the chemical formula as (NO_3^-) (McCasland et al. 2012). It is a naturally occurring ion as is part of the nitrogen cycle (WHO 2011). It is essential for all living things where it is the primary source of nitrogen for plants (Eldridge et al. 2014).

Sources of Nitrate in the water bodies are fertilizers, wastewater treatment effluent, industrial wastes, animal wastes, food processing wastes, nitric oxide discharges from automobile exhausts, leaking from septic tanks, sewage; erosion of natural deposits (Eldridge et al. 2014; U.S. Environmental Protection Agency 1986; WHO 2011).

The importance of nitrate concentration in water bodies is due to its health concerns. Its excess levels can cause potential health risks (Eldridge et al. 2014). Infants under 3 months of age could become seriously ill, or might die with high levels (U.S. Environmental Protection Agency 1986). Also, it can cause methemoglobinemia or "blue baby" disease (McCasland et al. 2012; WHO 2011).

Methemoglobinemia is the most significant health problem associated with nitrate (McCasland et al. 2012). When it is present in addition to its derivative (Nitrite), hemoglobin can be converted to methemoglobin, which cannot carry oxygen like hemoglobin (McCasland et al. 2012).

Furthermore, some researchers have suggested that nitrate may play a role in birth defects, thyroid disorders, spontaneous miscarriages, and in the development of some cancers' types in adults. (Eldridge et al. 2014)

However, the nitrate concentration in surface water is normally low (0–18 mg/l) (WHO 2011) and the water criteria for Nitrate is 10 mg/L NO_3^--N (U.S. Environmental Protection Agency 1986). Therefore there are some methods to treat water supplies to meet these criteria such as ion exchange, reverse osmosis and electrodialysis (U.S. Environmental Protection Agency 1986).

2.13 Ammonia & Ammonium

In addition to the previously discussed Nitrate, other Nitrogen-base compounds affect the water's quality in water systems. Ammonia is a unionized compound with the formula (NH_3) and Ammonium is the ionized form with the formula (NH_4^+) (WHO 2003b).

Although ammonia is formed naturally by the combination of nitrogen and hydrogen by diazotrophic organisms such as cyanobacteria, it might enter the water systems' environments through other means like anthropogenic discharges such as municipal discharges, or agricultural runoff (U.S. Environmental Protection Agency 2013).

The two forms (NH_3 and NH_4^+) exist in natural water system but their ratio depends on pH, temperature, and salinity (U.S. Environmental Protection Agency 2013; WHO 2003b). The ratio of (NH_3/NH_4^+) increases by 10-fold for a single pH unit raise, and two-fold for 10°C rise in temperature (U.S. Environmental Protection Agency 2013).

The importance of ammonia results from the fact that it is used in fertilizers, manufacturing of fibers, plastics, paper, and rubber (WHO 2003b). Also, it is used as a starting material for many nitrogen-containing products (WHO 2003b). Furthermore, ammonium salts are used in food additives, cleansing agents and as diuretic (WHO 2003b).

However, NH_3 - not (NH_4^+) - has been demonstrated to be the principal toxic form of ammonia in the water bodies (U.S. Environmental Protection Agency 1986). Therefore, ammonia is considered among the most important pollutants that exist in the water's systems (U.S. Environmental Protection Agency 2013).

Even there is no evidence that ammonia is carcinogenic (WHO 2003b), the toxicity of ammonia applies on aquatic organisms such as on fish or humans and other creature that uses the water directly. Its toxicity causes damaging on the gills. Also, it causes reduction in blood oxygen-carrying capacity, depletion of adenosine triphosphate (ATP) in the brain, and disrupting normal functioning of the liver and kidneys (U.S. Environmental Protection Agency 2013). Furthermore, the presence of ammonia at high levels is an indicator of fecal pollution (WHO 2003b).

For these reasons, the criteria for ammonia and ammonium are set at pH of 7 and 20°C to be (17 mg /L) of the total amount of nitrogen (TAN) in both forms (NH_3 and NH_4^+) for a one-hour period (U.S. Environmental Protection Agency 2013). And for four-day period, the criteria is (1.9 mg /L) TAN (U.S. Environmental Protection Agency 2013).

Detection of ammonia and ammonium in water systems can take place by titrimetry which is less accurate, indophenols' reaction, or ammonia-selective electrodes (WHO 2003b).

2.14 Refined oil (BETX)

Refined oils are volatile organic compounds that are found in petroleum derivatives (Aquaread Ltd 2014b). BTEX is the acronym name given to benzene, toluene, ethylbenzene and the xylene (Wang et al. 2003).

BTEX is quantified usually by analytical methods. Benzene, ethylbenzene, toluene and the xylene are colorless liquids, immiscible with water but miscible with organic solvents. They have strong odor and are highly flammable (European Environment Agency 2014).

The concern in the BTEX complex is the health effects. For example, benzene has been classified as a known human carcinogen by U.S. Environmental Protection Agency (2013).

The need to determine the BTEX traces in water is essential to prevent its harmful impacts on nature. Although there are analytical methods to measure BTEX (Wang et al. 1995) but the field method to measure the refined oil is usually by using a fluorometer that uses UV radiations.

3 Online water quality monitoring

Water pollution is threatening the whole world as one of the serious problems (Wang et al. 2011). Therefore, determination of the water's quality is an indispensable attitude for water resources' management and water's pollutants control (Jiang et al. 2009). For this, water analysis – whether chemical or physical analysis- is the goal for water quality monitoring systems (Wu et al. 2010).

The ultimate purpose of water's quality determination systems is to provide authorities and responsible bodies with the needed valuable informations. These informations allow them to build their decisions on, and to take actions as fast as possible, if needed. However, the purpose is slightly different in different places around the world. For example, in United States, the focus is more on determination of water's quality in distribution systems, to protect them from terrorist attacks, mainly biological ones (Storey et al. 2011). Whilst in

Europe, for instance, the emphasis is more on the protection of source waters such as rivers and lakes (Storey et al. 2011).

Generally, water quality monitoring systems are based on four main methodologies (Jiang et al. 2009):

1. The conventional system of sampling on site and analyzing in laboratories following the standard procedures (Wagner et al. 2006). This method is very slow in dealing with and delivery of data. Also, it collects small amount of information, because of the difficultness to access natural widely distributed waters' bodies (Tie-zhu and Le 2010).
2. Automatic monitoring of water parameters by sensors, followed by data transmission via a telecommunication unit. This method has several advantages, with different techniques. It is the base method for the system used in this thesis.
3. Water quality parameters determination by remote sensing technologies without any contact to the water body. It is done mainly by detection of the spectrum of some electromagnetic waves, for example, satellites imagining for finding the transparency of a water system.
4. Detection of water quality parameters by analyzing the change in activities of sensitive aquatic organisms like some kind of fish that is affected by the presence of some substance in the water body.

While those are the existing possible methods to monitor the water quality the term "online" can be only used for the last three methods. The word online means connected to a network or to internet (Oxford Dictionaries 2013). Thereby, the following sections will describe the structure of these online monitoring systems in general, in addition to their advantages and disadvantages.

3.1 The structure of an online monitoring system

Any online water quality monitoring system has three main parts (Capella et al. 2010; Jiang et al. 2009; Wu et al. 2010) :

1. Instruments that collect the data and measure the parameters from the water's body, they consist of hardware and software, for example, they can be sensor-electrodes with telecommunication unit (Wang and Zhang 2009), or a camera (Sawaya et al. 2003).
2. Data processing and monitoring center which usually has a server to receive and store the data, in addition to making them available for user, also, it includes a user interface program to show the results or simply they can be made available on internet where people from all around the world can access with authentication.
3. The network that is used to transfer the data between the data-collecting instruments and monitoring center, it can be GPRS (Jian et al. 2007), Zigbee (Regan et al. 2009), or Radio waves (Sawaya et al. 2003).

3.2 Features, advantages and disadvantages

To well understand the features of online monitoring systems, there is a need first to spot out the issues with the conventional systems that affects their use. The existing method of sampling on site with laboratory-based analysis of water quality parameters has several defects that reduce its efficiency. First, the test cycle is time-consuming which results in poor precision (Mou et al. 2011).

Then, as the data gathering is slow, the collected amount of information is very small (Tie-zhu and Le 2010). In addition, it is difficult to develop operational response that provides protection for the public health in the real time (Storey et al. 2011). Thirdly, the conventional method is cumbersome if large set of samples is necessary to be collected and stored in certain conditions (Capella et al. 2010).

For these reasons, this method poses a determinant financial burden (O'Flynn et al. 2010) which affects the whole process of water quality monitoring and drives to find other methods. The online water monitoring systems arise as the solution for these defects, having the following features.

3.2.1 Advantages

The need to overcome the previous mentioned defects in conventional monitoring systems resulted in the developing and implementation of the online water quality monitoring systems. These systems have the following advantages:

- Reducing the required manpower (He et al. 2008; Mou et al. 2011; Offiong et al. 2014; Wang et al. 2011), minimizing therefore the human errors (Glasgow et al. 2004).
- Minimizing the cost of data collection (Glasgow et al. 2004) due to reduction in sampling, handling, and analyzing time (Capella et al. 2010), which results in low operation cost (Grönlund and Viljanen 2003; Tie-zhu and Le 2010) .
- Increasing the quality of collected data (Glasgow et al. 2004; Grönlund and Viljanen 2003), by elimination the possible contamination of the samples during their transfer from the site to the laboratory (Capella et al. 2010).
- Limitlessness of such systems to different geography and climates (Tie-zhu and Le 2010). Resulting in the ability to collect detailed temporal and spatial data sets of complete ecosystems, even from locations that are difficult to access by conventional means (Capella et al. 2010).
- Streamlining the data collection process, in which, increases the quantity of obtained data (Glasgow et al. 2004; He et al. 2008).
- Having a faster and more efficient response to different pollution's problems because of rapid discovery of pollutants (Capella et al. 2010; Grönlund and Viljanen 2003). This leads to cope with the threat of water pollution (Mou et al. 2011) by taking the appropriate actions and sitting up required plans (Dehua et al. 2012).
- Providing useful data that can be used in multi-purposes, like environmental protection, water resources management, and natural hazards warning (Dehua et al. 2012; Mariolakos et al. 2007).

3.2.2 Disadvantages

Despite the previously mentioned advantages, online water quality monitoring systems have disadvantages which affected their wide application. Some of these disadvantages can be summarized as follow (Regan et al. 2009; Storey et al. 2011):

- The need of practical utilities for the system such as long-term electrical power source.
- Data unreliability, since sensors need to be calibrated frequently in order to provide accurate results.
- The requirement of regular maintenance.
- Disability to translate, to evaluate, and to analyze the huge number of collected data in the progress of making suitable operational actions.
- In some cases, the sensors' materials are weak which results breakage of the sensor.

Scientific research and development addressed these challenges. The next section will provide an overview of some of the proposed solutions, trends and applications for online water monitoring systems. Also, the use of different methods and techniques will be described and discussed.

3.3 Trends and applications of online water quality monitoring systems

In several countries around the world, such as USA, France and China, real-time monitoring data are collected and provided to the public through the internet (Mariolakos et al. 2007). However, next will be a brief description of previous applications of online monitoring for water quality parameters divided into three categories depending on the method that is used in the application.

There is the automatic online water quality monitoring systems which is the focus of this current thesis. Then, the second method is by using remote sensing to monitor some water quality parameters. The last method is an indirect method to determine the water quality depending on some creatures' behaviors and reaction.

3.3.1 Method of automatic monitoring with capacity for transmitting data

This method uses sensors that measure the water's parameter, devices that transmit the data over a network and an interface for representing the results to the observers as can be seen in Figure 2. However, there are several techniques for this method which differ only in minor details, for example the network platform used to transfer the data. Some of the previous applications of this method are presented in this section.

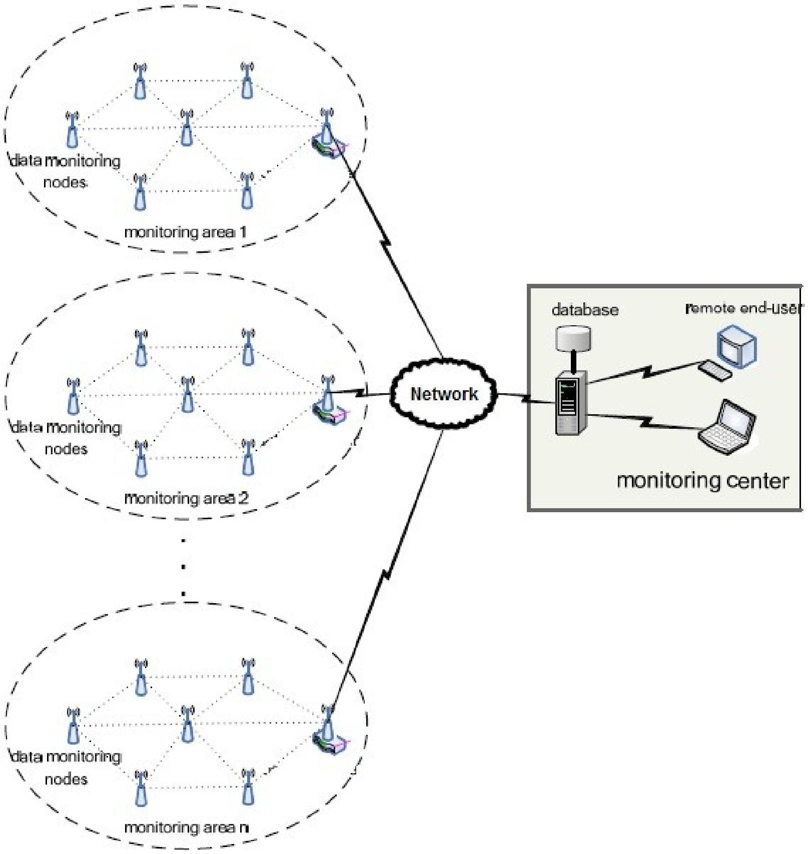

Figure 2 The components of the automatic online water quality monitoring system, adopted and modified from (Jiang et al. 2009)

Capella et al. (2010) had a chemical analysis system for nitrate, ammonium and chloride in fresh water. They used ion selective electrodes and a wireless network with a secondary data transmission. The data transmission unit depends on mobile phone operator to send the data to internet. The purpose was to control the quality of the water that is poured into Lake Albufera, which is a few kilometers from the city of Valencia, Spain.

They used Wireless Sensor Networks (WSNs) which have low consumption prevail over bandwidth and coverage. Although the paper described the WSN in details but the main idea was to use several transducers. Each one has a node which sends the obtained data to a sink node. The sink node sends the data over a private network to a server which makes them available on internet. These data are accessible at a user interface page that can be reached anytime.

However, the main conclusion they came up with is that, such approach of monitoring will lead to lower expenses, better accuracy and higher performance in the future.

Another application was done by Wu et al. (2010).They proposed a system to monitor water quality parameters based on GPRS in one reservoir called "XueYe reservoir". This reservoir is located in town of XueYe (Shandong, China). The choice of this reservoir was because of its bad current situation regarding water's quality. The bad quality of this reservoir is due to fish raising and sand-gravel extracting, in addition to pollutants from nearby restaurants and hotels.

Like any other online monitoring system, there are three parts. First, the data collection instrument which collects the data and receives instructions from the monitoring center. It has several subparts such as the multi-parameter sensors, processor, and telecommunication unit which sends the data by GPRS. The second part is the monitoring center. A server takes place there to receive the data from the nods, and saves them in the database for the user's query. In addition, it evaluates the water quality result and produces alarms in the suitable time. The third part is the GPRS network where data are transmitted between the data collection instrument and the monitoring center.

Although, results showed the changes in pH and dissolved oxygen (DO) over time, but it is clear that the focus was not on the water's quality parameters as much as the description of a GPRS-based system.

Nevertheless, the authors concluded that these systems can be used to evaluate water quality, can detect any urgent water pollution accidents quickly, and can provide references to the decision-making departments as the abnormal water quality information will be available from the monitoring center.

Another description of a system in details regarding the used hardware and software along with the obtained results regarding water quality parameter was provided by Jiang et al. (2009). Their concern was on the design and building the system. The researchers proposed a wireless online monitoring system that measures the temperature in a range of 0 to 80 °C and the pH of water in an artificial lake at HangZhou DianZi University (China). They described the structural design of the used monitoring system in addition to the design of hardware and software of the data monitoring nodes. These nods are responsible for measuring water parameters and then their communicating by Zigbee to a data base station. Also, they described the design of hardware and software of this data base station which sends the data to a control center via GPRS. Even more, they illustrated the software design for the remote monitoring control center. It consists of a server that saves the data and an interface that permits the user to get the saved data.

They used WSN which is an ad-hoc network composed of a number of small and low cost sensing nodes. These nodes are capable to sense, collect and send data.

At the end, they got some results and analysis of how this system is applied for pH monitoring. In addition, these systems have useful features such as large monitoring ranges, low power consumption, flexible configuration, and low cost.

Also, a project was held by O'Flynn et al. (2010) called "Deploy project". In this project, they were monitoring the water quality parameters in the river Lee which flows through Cork, Ireland.

Deploy is a project that uses on-line real time monitoring technology to show mainly how this technology could be used for cost-effective, real-time, and continuous monitoring of the river's catchment. There were five monitoring zones in different sides along the river to monitor pH, temperature, depth, conductivity, turbidity and dissolved oxygen by using a multi-sensor system. Data were collected by the multi-parameters sensors in the five locations. These sensors sent the data via GPRS to a server. The server makes the data available for a user interface by an internet website.

The results showed the benefits of having a continuous monitoring of water by showing the pH results in one location comparing them with the results that would have been achieved by just sampling once every day. It is clear that there are some events which could not be known with conventional sampling methods.

In addition, another result was about how having different locations of the sensors can provide reliable assessment of the exact situation. Indeed, in some cases, results from one site cannot be explained without the data collected from other sites.

As conclusions, O'Flynn et al. (2010) concluded that such projects have the potential of enabling scientists to observe and monitor environmental variables of interest making them able to take the proper actions.

However, with the whole advantages of the system, it does not mean that there will be less fieldwork carried out. Still, it will be required to design, install and maintain the sensor systems from time to time by the operator.

Ji et al. (2011) designed a monitoring system for water quality parameters consisting of the main three parts. First, the data monitoring subsystem which included the sensors for water parameters and the transmitter of collected data. The second part is the communication subsystem, mainly the GPRS network. The last part was the master station subsystem which has the server and the user interface.

Nevertheless, they dealt with the system's architecture, software and hardware design, and Information Technology (IT) details more than the results of water's quality. The reported results showed that, the quality of water can be monitored with such systems with very efficient, stable and reliable performance.

In addition, the built system by Wang et al. (2011) to monitor the water quality was divided into several nods measuring the parameters and then sending them to a base station by ZigBee network. The base station plays the role of coordination between the nodes. It sends the data to the monitoring center via GPRS. Furthermore, the monitoring center has a server that receives the data and stores them, in addition to a user interface platform to show the data for the user. It has to be noted that the paper just describes the system in details for the point of view of IT. Actually, it would have been more interesting if such system was applied to monitor the water quality in a real case scenario, thus enabling the readers to have a wide perspective on the systems' performance.

Furthermore, Offiong et al. (2014) made an investigation about the feasibility of real time monitoring for situations in developing countries like Nigeria. They decided to use the Zigbee technology because of its affordability, low maintenance, and performance (speed, precision and accuracy). They used it for sensors that measure turbidity, pH and DO.

The data from several randomly distributed sensors nods were transmitted by Zigbee technology and then are made publicly available on a server.

Also, Mariolakos et al. (2007) used an on-line water quality monitoring in the Evrotas River in Laconia, Greece. They installed a set of different sensors for pH, temperature, turbidity, DO, and conductivity in seven sites along the river. The distribution of the sensors depended on the geological, hydrological, and hydro-geological conditions throughout the river.

After the data gathering by sensors, they were sent and transferred via GSM modems to a server at the University of Athens and to servers in the Local Union of Municipalities. The choice of GSM instead of GPRS was due to the fact that, the existing GPRS networks in Greece were not reliable for data transfer at that time.

The obtained results showed the relationships between DO and temperature in different sites. But, some of their conclusions stated that fouling is a problem and sensors need to be cleaned and re-calibrated very often. They estimated the time to be 2 months in their project. Also, another conclusion was that the sites' selection is critical. Different sites have different conditions that can affect the precision of the set up.

Because of weak sampling capability for water quality in China with the conventional sampling-in- site method, Tie-zhu and Le (2010) designed an on-line water quality monitoring system based on GPRS.

As usual, the system has three components: the first part, the water quality monitoring stations which collect the data and measure the water quality parameters. The second part is the GPRS network and the modem which are responsible of transmitting the data and sending them to the third part of the system (the monitoring center). The last part monitoring center which consists on a server and a user interface, it can receive, store, and analyze data, in addition to alarming capability.

Furthermore, Mou et al. (2011) developed a system for monitoring water in wells where there were 72 source water wells in total. But, only 46 of them were in use as a water source for Dongzhou water-plant in Zhengzhou, China.

The used system had several end-terminals which sense the water parameters in wells, such as chemical oxygen demand (COD), nitrogen, ammonia, turbidity and pH values. After that, the collected data are sent via GPRS over the phone network to a web server. The server stores the data and makes them available for users in a user interface program. It was a unique approach to monitor wells making it applicable to monitor the ground water quality by using this method.

A different approach was done by Wang and Zhang (2009) to measure different parameters. They were not interested in the chemical composition of the water, but rather, the water level. Their purpose was to prevent flooding in Yangtze River, China. Therefore, the collected data were made available to different responsible bodies who can take an action.

With the aid of GPRS technology, the water level and the rainfall were measured in one reservoir in China (Huangbizhuang Reservoir). The system, as any regular online water quality monitoring system, had the sensors for measuring the water quality conditions the GPRS network that sends and transmits the collected data to a web server, and the monitoring center that receives the data and stores them making them available for a user in a user interface.

Also, Dehua et al. (2012) had a description of an automatic on-line monitoring system using GPRS for transmitting the data. The system is used to determine different water quality parameters such as temperature, pH, conductivity... etc. It has three main parts, the data acquisition part, the monitoring center, and the network platform between them. The water quality parameters are collected with a multi-parameter probe. Then they are sent via GPRS to a server in the control center making them available after that for a user interface.

3.3.2 Method of remote sensing technologies

This is the second method to determine the water quality. It is based on the use of imaging at different wavelengths. The resulted spectra and images are then analyzed against actual measurements sampled in-situ. The aim of this analysis is to correlate the relationship between the parameter and the obtained spectra. Such simulation provides the ability to determine the level or the concentration of any substances able to change the optical properties of water. The idea of the remote sensing is illustrated in Figure 3.

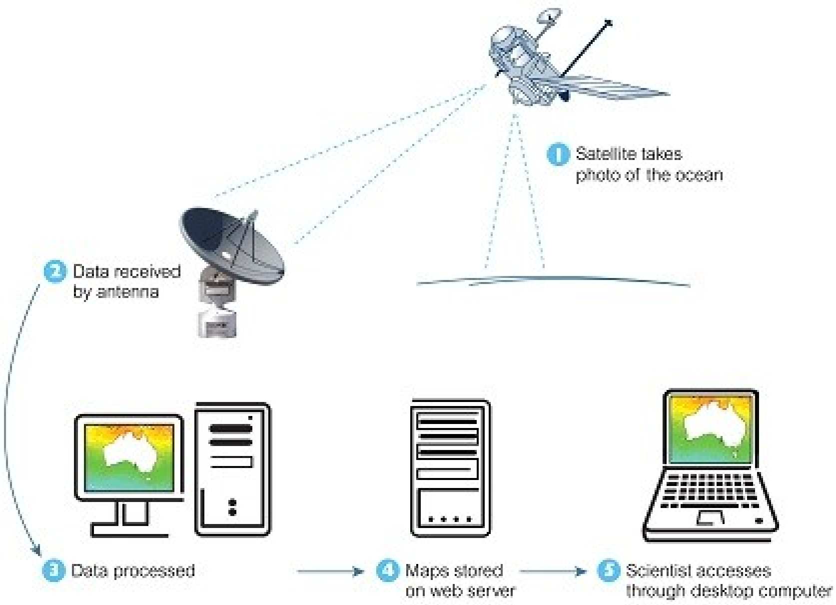

Figure 3 The process of remote sensing method to determine the water's quality, adopted and modified from (IMOS, Integrated Marine Observation System 2014)

One application of this method was done by Sawaya et al. (2003). They used satellite imaging of IKONOS and QuickBird satellites to determine and analyze the water quality in some lakes in the City of Eagan Minnesota, USA. Their objectives were to determine different variables such as Secchi disk transparency (SDT), chlorophyll a (chl a), and the total phosphorus (TP). Then they went through to analyze the obtained data via mathematical correlations.

Also, Ritchie et al. (2003) described some technologies that use satellite imaging with different wavelengths to determine the water quality. Their main focus was on the parameters depending on the optical properties (chlorophyll, temperature, and turbidity). Also, they discussed some in situ sensors that use optical water features by emitting a light and measuring the interactive of the light with the water. The related study showed that some limitations with this remote sensing method. For instance, the difficulty to take high accurate imaginary with spectral resolution by satellites imaging sensors is one of these limitations. This restricts the wide application of the obtained data for monitoring the quality of water.

Another study aimed to test if the combination in ENVISAT MERIS and TERRA MODIS satellites is feasible to monitor the water quality in Finnish lakes and coastal areas. In addition, satellite LANDSAT Thematic Mapper (TM) data were simulated and tested (Härmä et al. 2001). At first, they used data from those satellites to make a simulation using semi-empirical algorithms. Then, they evaluated the simulation by using field measurements that were gathered from several lakes in the southern Finland and the coastal waters of Baltic Sea during May 1997, August 1997, and August 1998. After that, the accuracy of these algorithms was tested with the simulated data from LANDSAT TM. As a result, they found that band combination enables better ability to monitor and interpret the water quality. Also, they found MERIS to be the satellite which provides the best band combination to determine water quality in Finnish lakes and coastal areas. However, they faced some problems such as having a variety of optically active matters with different concentration, the number of the lakes is huge but the size of each one is very small, and the inability to have many cloudless images because of Finnish weather. They suggest that, those obstacles should be addressed and dealt with to have better results.

Furthermore, another application of LANDSAT 5 TM was done by He et al. (2008) in which they aimed to make a model that analyzes eight water parameters (turbidity algae content, ammonia, nitrate, total nitrogen, COD, dissolved phosphorus, and total phosphorus). Their study area was Guanting Reservoir which is located in northwest Beijing, China. This application was part of a bigger project for controlling the Yongding River. The river -in addition to the reservoir- is the water resource for industry, urban, and agriculture in Beijing.

They took 76 samples in two days during 2005 and used LANDSAT TM images to match the sampling data. Then, they used multiple linear regression analyses to make a model for each parameter. At the end they found that there was a significant correlation between each water quality parameter and remote sensing images. Thus, monitoring the water quality with remote sensing was useful to establish an effective method for measuring those parameters.

Also, Kallio et al. (2001) studied 11 lakes in southern Finland in 1996 and 1998 regarding their water quality. They used an airborne imaging spectrometer for application (AISA) which is a pushbroom imager with a charge coupled device (CCD) with a sensor matrix of 286384 cells. Their aim was to determine the best empirical algorithm for the obtained water quality data from the AISA in these lakes as an example of typical Finnish lakes. So, they went through algorithms that are taken from previous literatures and their own developed ones, to determine the best one among them. Based on their research, the results showed that, water quality parameters such as chlorophyll, turbidity and total suspended solids can be determined by remote sensing technology in Finnish lakes.

This was some of the remote sensing application, but in real life there are more applications and even, commercial applications. The main concerns of this method are the accuracy and the need to have some field sampling to build up the algorithms.

3.3.3 Method of analyzing the change in activities of sensitive aquatic organisms

This is the less common method to determine the water's quality. It depends on determination of the behavior of the living organisms. Or more precisely, it measures the change of the behavior due to the change in the water's quality. At the beginning the attitude of the living organisms is monitored under the normal circumstances, and then the response for a controlled change is recognized and recorded. The next step is to monitor the same organisms in the nature, and if the recorded behavior is found, it means the recorded change in the water's quality for this behavioral change occurred.

The reason behind this method is less common lies on the fact that this method needs an intermediate (the living organism). This intermediate can have some different activities not because of the water's quality but rather because of other factors like the environment or other organisms. However, usually researchers try to avoid any other factors by conducting the experiment in a controlled environment.

An example of this method is introduced by Ma et al. (2010). They used a CCD camera to monitor and analysis the motion trajectory of live fish. Their goal was to determine the swimming patterns of fish in normal circumstances for a period of time and then determine if there is a change in these patterns under abnormal situations like higher or lower pH. They used a neural network mapping for archiving and comparing the obtained different patterns in the normal and in the abnormal situations.

The results from their work showed how pH values can change the motion patterns of the fish. Also, vice versa, the change of the motion if archived before can be used to determine the change in the pH. They observed a change in the pattern of fish's motion when they changed the pH (5 – 9) by injecting commercial solutions to the system.

4 Lake Saimaa

4.1 General information

Saimaa is a lake system with approximately 4400 km^2 (Kuusisto 1999; Nikkinen 2014; The Columbia Encyclopedia 2013). Its location can be seen in Figure 4. The bedrock of the Lake Saimaa region dates back to 1900 million years as part of Eurasian tectonic plate (Kuusisto 1999). It occupies the heavily glaciated plateau of south Finland at 76 m above sea level (Reinikainen et al. 2001). It is considered as the largest lake in Finland (Kuusisto 1999; Nikkinen 2014; Reinikainen et al. 2001; The Columbia Encyclopedia 2013). It comprises more than 120 connected lakes that are connected by straits where the largest is the southern basin of 1290 km^2 (Reinikainen et al. 2001). Even more, it has altogether 13710 islands and skerries with islands' area of about 1850 km^2 (Kuusisto 1999; Nikkinen 2014; Reinikainen et al. 2001).

Figure 4 Location of Lake Saimaa and some of the cities on its shoreline in Finland's map, also, Lake Ladoga can be seen southeast of Lake Saimaa (World Atlas 2014).

The system drains southeast into Lake Ladoga in Russia through the Vuoskijoki River which is 160 km long, and then through river Neva into the Baltic Sea (Nikkinen 2014; Reinikainen et al. 2001). The mean water discharge is 596 m^3/s (Kuusisto 1999).

The length of its shoreline is almost 14800 km (Grönlund and Viljanen 2003; Kuusisto 1999; The Columbia Encyclopedia 2013), on which more than 10 cities lie on such as Joensuu, Kuopio, Savonlinna, Lappeenranta, and Mikkeli (Grönlund and Viljanen 2003; Nikkinen 2014; The Columbia Encyclopedia 2013). Along the shoreline there are 396 harbors and landing stages whether in or out cities (Nikkinen 2014).

Lake Saimaa is mainly clear with low nutrient content. But, there are some areas affected by mankind activities alongside some, and non-point sources of effluent from agricultural activities (Grönlund and Viljanen 2003). Therefore, the best approach is to deal with each location of Lake Saimaa individually (Kuusisto 1999).

Water quality in different areas of Lake Saimaa is shown Figure 5. The map is based on an environmental survey from 1994 to 1997 (Kuusisto 1999). Over 61.5% of the surface water of Lake Saimaa is classified as excellent, 31.6 % as good, 6.2 % as satisfactory, 0.5 % as passing, and only about 26 hectare as poor nearby Kaukas. The used classification has the following meanings:

- Excellent: very pure water
- Good: slight eutrophication is permitted , low humus content
- Satisfactory: the water body has been polluted to minor extent by waste water
- Passing: more serious pollution, highly eutrophic
- Poor: badly affected by pollutants

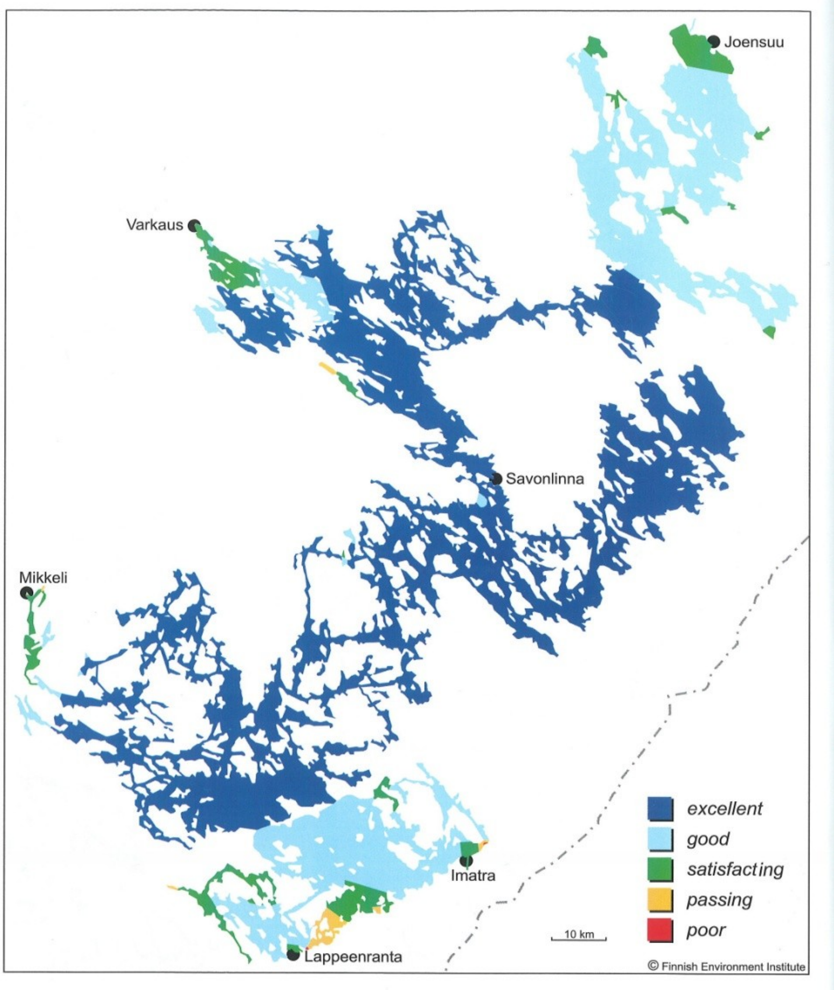

Figure 5 Water qualities in different locations of Lake Saimaa (Kuusisto 1999)

Furthermore, as can be seen in Figure 5, in Mikkeli (the study area), most of the areas were classified as satisfactory. Only small areas around the waste water discharge point got the classification as passing. The farther the distance from the city of Mikkeli to the main body of Like Saimaa, the purer the water is. The water there gets the good or excellent classification in the main body of the lake.

Lake Saimaa is considered as the most valuable lake in Finland for Finnish people (Kuusisto 1999). The reason does not lie only behind being a great reservoir of surface fresh water as Nikkinen (2014) states or its ecological values but also economical values such as the following (Kuusisto 1999):

- Hydro-electrical power facilities
- Lake traffic and log floating
- Tourism
- Fishing
- Water supply for human and industries uses

Thereby, it is a great approach to apply online water quality monitoring system in this lake for the benefit of people live nearby Lake Saimaa area, and people live farther. However, the following section will provide more details about previous studies about Lake Saimaa.

4.2 Previous studies

Several studies were done regarding Lake Saimaa from different aspects such as ecology, climate, and wildlife. The first research about Lake Saimaa dates back to 1847 to determine the water's level (Kuusisto 1999). Most of the published researches are in Finnish language, whereas the sources in English language are very few.

Many sources focused on Saimaa ringed seal (Hyvärinen et al. 1995; Hyvärinen et al. 1998; Käkelä et al. 1993; Kokko et al. 1998; Sipilä 2003), because it is classified as highly endangered species (Nikkinen 2014).

Although, the first statutory monitoring program in Lake Saimaa started in 1970's (Kuusisto 1999), there were some other studies regarding the water quality in Lake Saimaa. These sources handled the topic from different points of view. Some of these approaches are described in some details. They are presented chronologically where old approaches are first then newer ones.

One of the earliest studies was the one done by Simojoki (1955). He studied the variation of water's level in Lake Saimaa, Finland. First, the measurements of water's level were taken in the southern part of Lake Saimaa. After that the level variations were compared with the fluctuations in precipitation, pressure, and temperature in Helsinki (Finland's capital).

As a result, he showed that the rhythm of water's level variation in Lake Saimaa is the same as the precipitation in Helsinki with a period of 30 years long.

Based on these results, he concluded that the water's level can to be estimated for Lake Saimaa for the future by using the 30 years cycle that was found previously and which he noticed from his study.

Also, another old study was done by Kettunen (1979). The research aimed to investigate the effect of waste waters from cellulose factory drained into Lake Saimaa. The method was by measuring the oxygen concentration. There was a prediction that the water quality beside the shore is different than the main body of the water.

They followed four streamlines in the lake and took samples from each of them to a laboratory for analysis. The reason of the choice of these four streamlines is the fact that, pollutants usually follow their own paths in the lake due to the difference in density between their effluent and non-polluted lake water. Therefore, those paths were chosen and followed.

The result which they found was as they predicted, there is a difference in oxygen concentration from 5.4 mg/l beside the shore and 1.9 mg/l in the main body. Also, as a conclusion, that if any investigation is going to take part in such systems, occurrence of horizontal differences should be taken into consideration.

Furthermore, Kukkonen et al. (1996) tracked the streamline of a pulp and paper mill located in Lappeenranta, Finland. They have chosen four points along the effluent gradient in southern part of Lake Saimaa, in addition to two points upstream the discharge point.

They used sediment traps to collect settling particles on a monthly base from May to October 1991. Their aim was to measure Chlorophenolic and isotopic composition of organic nitrogen and carbon.

They got some results about how the effluent is diluted in the lake. They found the organic carbon content of the particles in one month and similarly in the other months to vary from 10.5% to 22.1%. Also, not surprisingly, they found the highest organic carbon content to be at the station nearest to the mill.

The conclusion was that the waste of the pulp mill is precipitating as sediments within a short distance and then the rest is transported through into the lake's system.

Another approach in Lake Saimaa was done by Reinikainen et al. (2001). They used one of the modeling methods (4-way Candecommp-parafac) to model previous data collected from Lake Saimaa in five different places, obtained from 1972-1995. The used data were the water quality parameters data such as Turbidity pH, and conductivity. The mainly considered source of pollution was from pulp mills in two cities (Lappeenranta and Joutseno).

They got some results by just using the collected data over the time and fitting a model for them. The main result they got was that, there is a variation in water's quality over time; some are due to natural changes and some because of the human activities.

Furthermore, Grönlund and Viljanen (2003) aimed to evaluate and compare results of temperature, oxygen concentration, conductivity, pH, and chlorophyll, between automatic measuring system on one hand and laboratory analyses on the other hand. The automatic system included probes located on the Finnish research vessel R/V Muikku. Their research took place during the period 15.5.2001 - 1.8.2001.

They used linear regression analysis to obtain their result. The consistency between the automatic measurements and laboratory analyses was shown to be significant. The use of automatic probes allowed frequent measurements, and these are useful for observing spatial differences in Lake Saimaa, as an example of large lakes.

They showed the result by linear regressions, it was used for water temperature (C), oxygen (mg/L), conductivity (mS/m) and pH against the corresponding laboratory analyses at 54 sampling points in Lake Saimaa.

However, this can't be considered as online live monitoring since all of the data from the probes are analyzed on the ship by the same equipment. It means, if any significant hazardous situation is faced, this research vessel needs more steps to go through to have a proper reaction. Also, it reduces the access to the collected information only to people on board. Nevertheless, if obtained results are being sent on a frequent manner to a land center, responsible authorities can take fast reaction depending on those available results.

5 The design of the online water quality monitoring system

As any online water monitoring system, our system has the main three parts; the parameters' measuring instrument that collects the data from the lake, the control and monitoring center, and the communication and network platform. These parts are described in details in following sections. Figure 6 shows the outline of our system with the three subdivisions marked in three different colors.

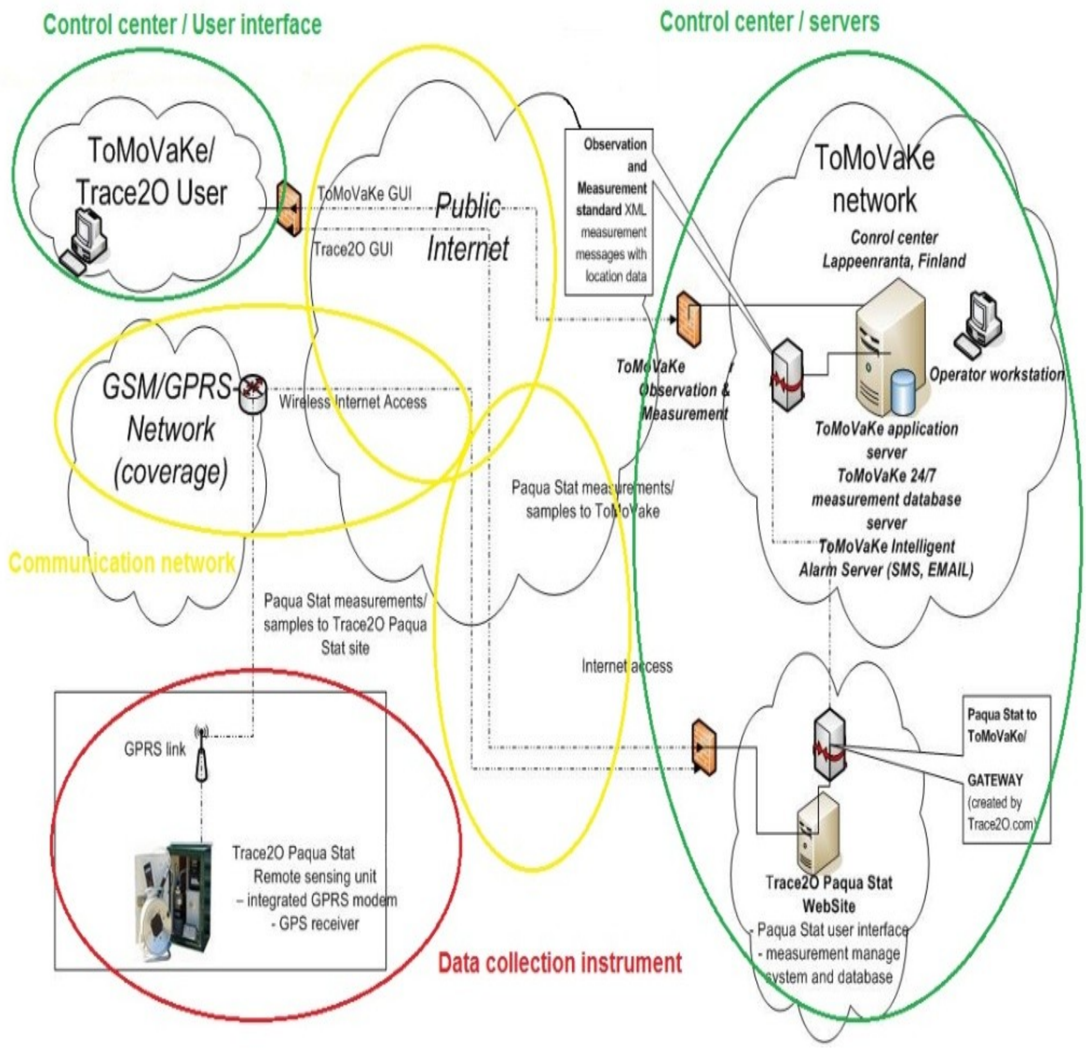

Figure 6 Description of the whole system

5.1 Data collecting instruments

The data collecting instrument consists of two main parts. The first part is the PaquaStat/PaquaBag system. It is the main device for monitoring the water quality parameters. The second part is the Ferry. It is the station where the monitoring system is installed. It plays the role as the host-place for operators, devices, and utilities. Both parts are illustrated in the following sections.

5.1.1 The PaquaStat & PaquaBag

The PaquaStat is the core of our online water quality monitoring system. It is multi-unit equipment that consists of several components. The PaquaStat is manufactured by a UK-based company called Trace2O. Trace2O provides environmental monitoring solutions (Trace2O 2014). They manufacture and supply environment's monitoring equipment to many places around the world (Trace2O 2014). The system which we received from them is housed in a weatherproof cabinet made of GRP (Glass reinforced plastic). The system and its units are illustrated with some details.

The PaquaStat consists of the following (Trace2o Ltd. 2014):

- Control Unit: the control unit is a waterproof enclosure with IP67 rate. It means, it is totally protected against dust and against the effect of immersion between 15cm and 1m. It includes the telemetry data transfer unit, solar power regulator, relay board, black box and battery charging unit.
- Charge regulator: the solar charge regulator is responsible of managing the incoming charge from the solar panels. Thereby, it directs the energy from the solar panel, either to recharge the batteries or to direct consumption. The aim of this regulator is to achieve optimum energy performance from the batteries and the solar panels.
- Lead-acid charger light: the lead acid charger light is an indicating light for the batteries' status. It shows whether the batteries are connected to AC source of electricity or not. Also, it shows the energy level in the batteries.
- Telemetry unit: the telemetry unit is also the processing unit. This device communicates with the black box to get the ready formatted data and then transmits these data. It transmits the data over the cellular phone network using the GPRS. Also, it has a SIM card from one of the Finnish mobile phone operators (Elisa). Moreover, the telemetry unit provides the PaquaStat with the location. The location information is added to collected data before being sent. So, when being sent the location of these data is sent too.

- Isolators: the isolators are on/off switches to switch the power supply source between batteries, AC and Solar panels.
- Thermostat: the purpose of this thermostat is to ensure the temperature inside the PaquaStat is suitable. If the ambient temperature drops below -20 C or any other specified temperature, the thermostat switches the battery heaters on.
- Batteries: the batteries are sealed lead acid batteries which are safe for transport under special provision of the dangerous goods regulations. They are 80Ah each. The batteries are fitted with snap on terminals for ease of removal
- External connections: the connections for the solar panels, AC power and the probe. In addition, there is a cable roll of 50 m to provide the ability to measure water's quality in depths up to 50 m. This cable-roll is shown in Figure 7 with its two endings.

Figure 7 The 50m cable roll with the two endings

- The solar panels: the solar panels are solar energy source for the PaquaStat. They collect the solar energy and transfer it to the solar charge regulator, where it can be used to recharge the batteries or for the direct consumption. One of the solar panels is shown in Figure 8.

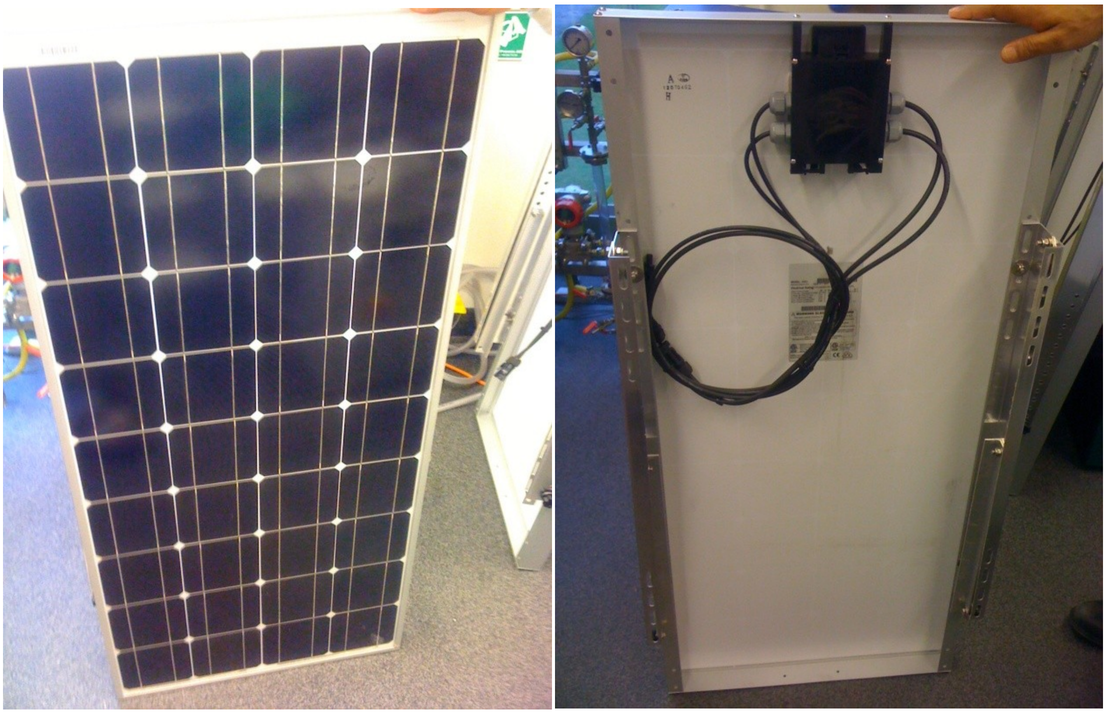

Figure 8 Front and back views of one solar panel, they are the sun-side and the connection-side

- The probe: the probe is a multi-sensor multi-parameter probe that is designed to measure different water quality parameters. Table 2 represents the parameters that can be measured by these sensors. The probe is a cylindrical metallic tool that accommodates the multiple sensors. Figure 9 shows the probe and the different sensors included in it.

Table 2 Parameters which the probe can measure, their units, ranges, and accuracy

Parameter	Units	Range	Accuracy
Barometric Pressure	mb	850 - 1100	±0.1mb
Temperature	degC	-5 – 50 (water)	±0.5
pH	pH Units	0 – 14	±0.1
ORP	mV	±200	±0.1
Electrical Conductivity	µs/cm	0-200000	±1
Resistivity	Ω.cm	5-1000000	±1
Salinity	PSU	0-70	±0.01

TDS	mg/l	0-100000	±1
SSG	σt	0-50	±1
DO	mg/l	0-50000	±0.01
Depth	cm	0-10000	±1%
Rhodamine Dye	µg/l	0-500	±2%
Chlorophyll	µg/l	0-500	±2%
Turbidity	NTU	0-3000	±2%
Refined Oil	µg/l	0-10000	±2%
Ammonium NH4+	mg/l	0-1000	±10%
Ammonia NH3	mg/l	0-1000	±10%
Nitrates NO3	mg/l	0-1000	±10%

Figure 9 The probe and the multiple sensors inside

- Black Box: the black box is the unit which communicates directly with the probe. It formats the data collected by the probe to match the requirements of the communication platform in order to make them available to be transmitted by the telemetry unit.
- The calibration meter: it is a hand-held tool used for the probe's calibration process. The device is shown in Figure 10.

Figure 10 The calibration device, used for calibration of the probe

However, this PaquaStat was the device delivered from the manufacturer (Trace2O). We modified the whole system in a way to suite our needs. The PaquaStat is too heavy (around 100 kg). The cabinet, the batteries, and other units cause this big weight. Also, in its current situation, the PaquaStat has a very big size (around 0.33 m^3). These two factors (weight and size) make the transportation of PaquaStat very difficult, make it inconvenient to handle, and make it risky to use on a floating ferry.

To overcome these obstacles, we designed a more sophisticated system, giving it a name (PaquaBag). This system was designed as a modification of the original PaquaStat and was implemented in this current research. It is easy transportable, it is easier to use, and it is a more convenient to use.

The idea of PaquaBag is to fit the main needed sub-units of the PaquaStat control unit into a back-bag. As can be seen in Figure 11, in addition to the black box, the telemetry unit, and their connections, there are other parts. These are a second GPRS location-determination unit, a battery, on/off switch, and a voltage gauge to show the battery's voltage.

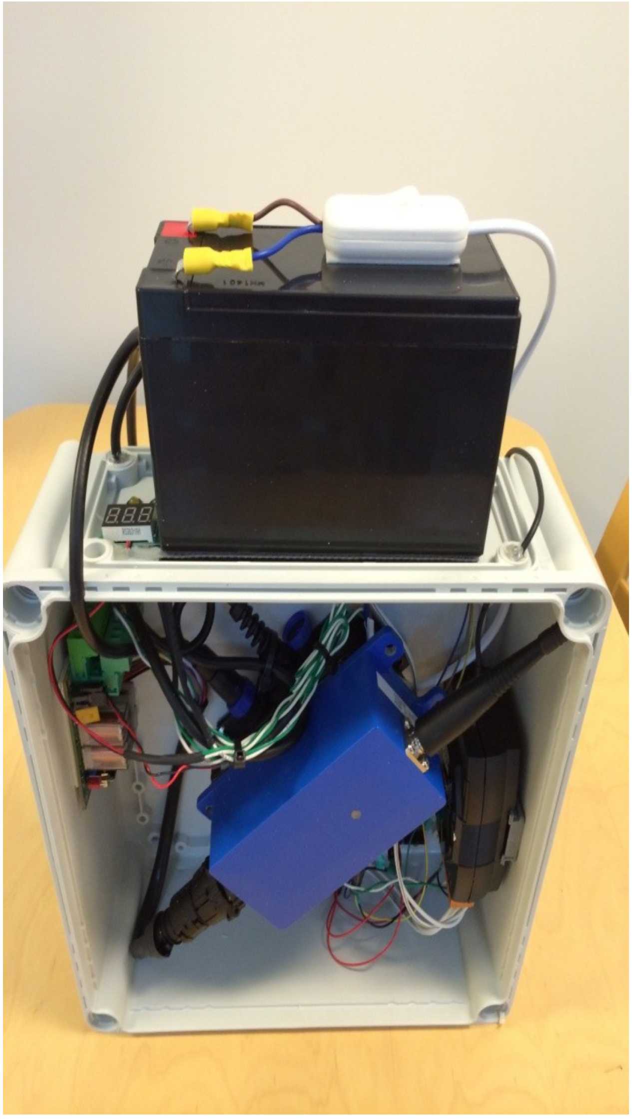

Figure 11 The main component of the PaquaBag

The whole system is then put in a back-bag as in Figure 12 the probe connection has its place out of the bag in a way to be connected to the probe very easily. Also, the USB connection to the control unit is accessible at the top of the bag. The final look of the bag within the system inside it is shown in Figure 13.

Figure 12 The location of the designed unit inside the bag

Figure 13 The PaquaBag, the cable, and the probe

The needs for more sophisticated, easy to use, and transportable system were the reasons behind the modification and the design of the PaquaBag

One counter-argument might arias about our modified system regarding the battery life. The battery can only run the system for 24 hours before being in need to be recharged, because it is smaller than the original one. To answer this, the PaquaBag is designed to provide the ability to test and evaluate the system. The PaquaBag is designed for operators being with the system not a self-running system. The point of PaquaBag is to evaluate both the online monitoring system, in addition to the water quality in as mush places as possible. When doing so, the result will be useful for being analyzed to determine which place needs a permanent installation of a PaquaStat. In addition, the analysis of the results is supposed to show the efficiency and the reliability of the system which can be achieved with the PaquaBag. Therefore, the PaquaBag does not need to have long-life batteries.

5.1.2 The ferry

The idea of the ferry is to have a medium-size station that can be used as a floating station or a stationary station. The purpose of this ferry station is to host all needed devices, utilities, and operators. In addition, this ferry provides the operators with the opportunity to reach several points in Lake Saimaa. It allows traveling within the lake to measure the water quality parameters at non-shorelines sites. The ferry's 3D design can be seen from Figure 14.

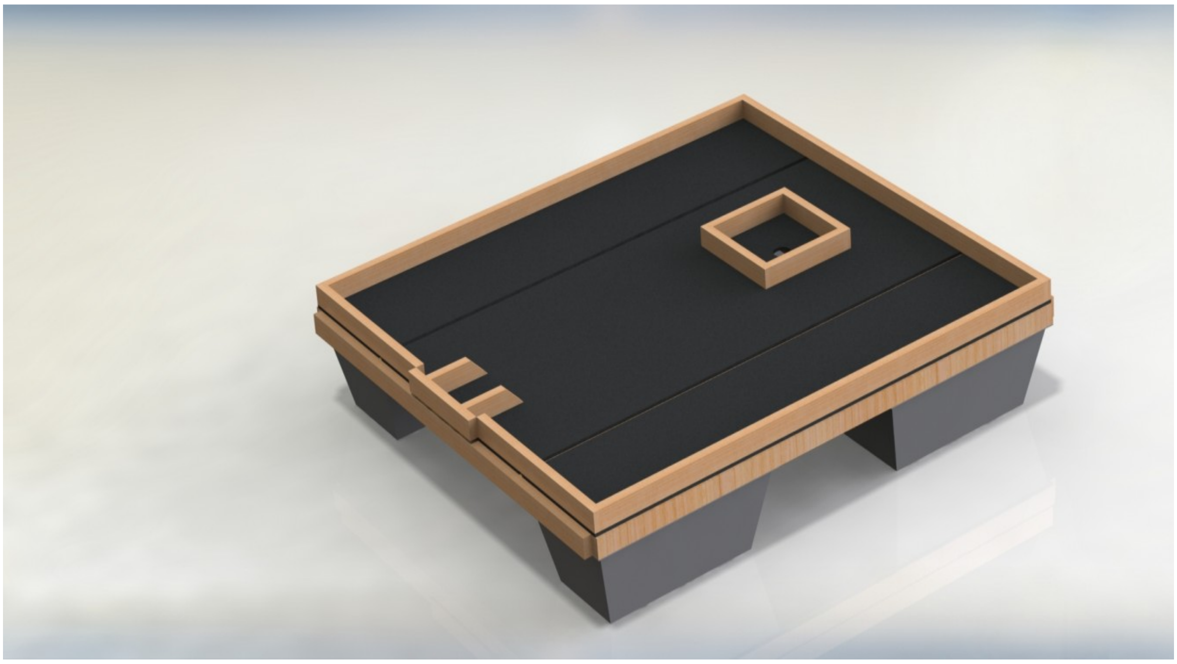

Figure 14 The ferry's design

The ferry, after being built up has some accessories to make the trips safe and applicable. Theses accessories added to the ferry after being constructed are shown in Figure 15 and Figure 16. The added accessories were a motor, sonar, motor batteries, safety vests, anchor and two paddles.

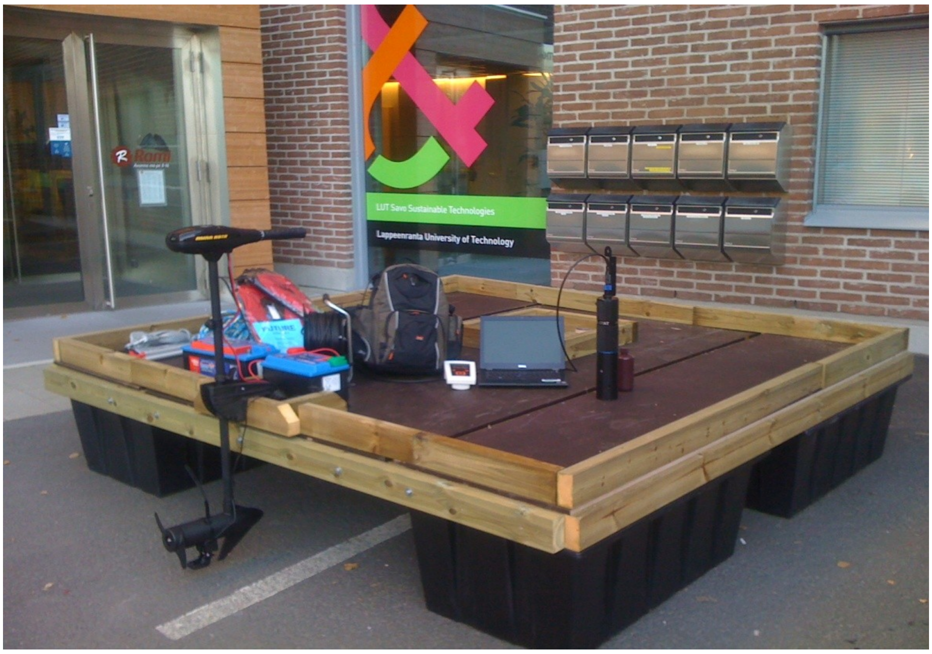

Figure 15 The last shape of the ferry and the needed accessories

Figure 16 The added accessories

The utilized accessories (Figure 15 and Figure 16) and the reasons behind using them are as follow:

1. The motor: it is used to drive the ferry to the wanted destination on a speed of 3 km/hr. The grounds for using electric motor rather than a petrol fueled motor is to prevent influence of potential residuals of petrol (redefined oil remnants).
2. Sonar: it is used to provide a detailed picture of the underwater geography and the presence of different creatures and the exact depth of the place where the ferry is located at. Figure 17 shows the sonar connected to the motor engine.

Figure 17 The sonar and the engine of the motor

3. Motor batteries: they are used to provide the motor with required electricity to operate.
4. Safety vests: they are used by the operators for safety reasons.

5. Anchor: to eliminate the waves' effect on the location of the ferry, to have the same location all over the sampling session, and to provide the ferry with more stability for the operators.
6. Peddles: they are mainly for emergency purposes, if there a shortage of the motor's batteries happens, the hand power is to be used by peddles.

The ferry's design was to meet the demands and the needs. Having a flat big surface was to achieve the stability while floating and the operation-ability for the operators to move and the facilities. The hole in the body of the ferry was made to provide the operators with the ability to submerge the probe into the water's body though it instead of the different sides of the ferry. By this, the weight distribution will be balanced, most of the weight will be close to the middle rather than the sides which might cause the ferry to flip. The utilization of the probe to let the probe through it can be seen in Figure 18.

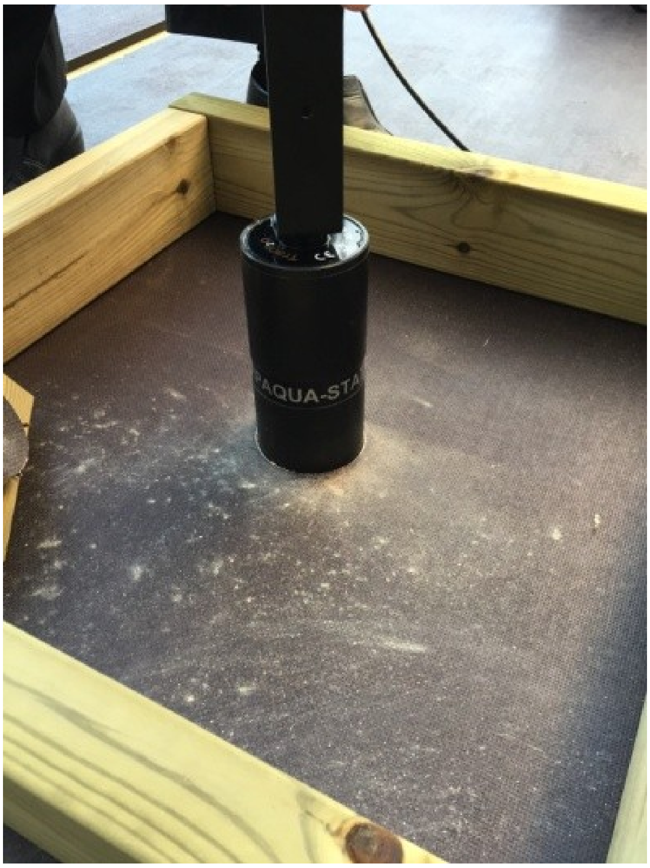

Figure 18 The use of the hole to leave the probe down to for the sampling processes

Furthermore, the design of the three parts in a way they are built in the site was in order to have a suitable method to carry and transfer the ferry from one place to another in three pieces instead of one. Otherwise it will be difficult to move a ready-built ferry on land between two places.

5.2 Control and monitoring center

The monitoring and controlling center has two main parts: the Trace2O server and the ToMoVaKe server. They both have an interface for users with different features and properties. There was a need to use two servers and two interfaces. This is mainly because the manufacturer of PaquaStat (Trace2O) programmed the unit to be connected to their server with smooth communication. It was difficult to modify the program in the unit to be directly connected to the second part (ToMoVaKe), mainly because of the files type used in the PaquaStat. The solution was to use both servers but with a gateway in Trac2O server that directs to ToMoVaKe server. In the following sections, each part is described.

5.2.1 Trac2O server

Trace2O server is the first part of the monitoring center. It is a UK-based server. The main role of this server is to receive the information from the PaquaStat, process and interpret them to a meaningful form, and then to send those to the next part of the monitoring center (ToMoVaKe). The information is transferred from PaquaStat in ASCII files via FTP (file transfer protocol) to the Trac2O server through internet.

Also, the server has a user interface which is used with authentication as can be seen in Figure 19. This authentication depends on the customer who uses the PaquaStat unit. After singing in, the user can choose any of the units that are assigned to the user's ID by locating the wanted device on a map, as can be seen in Figure 20. After that, the results from the chosen unit are shown against time for each measured parameter as in Figure 21. They can be shown for different time intervals, but cannot go to old readings.

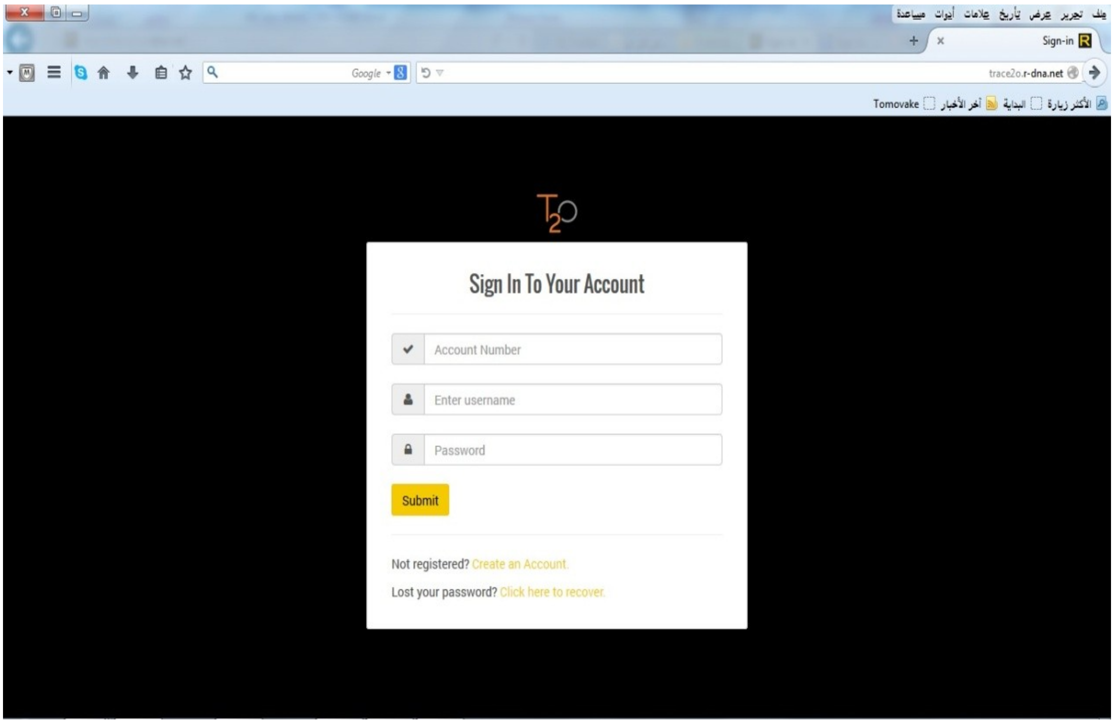

Figure 19 The home page of the user interface for the Trac2O server

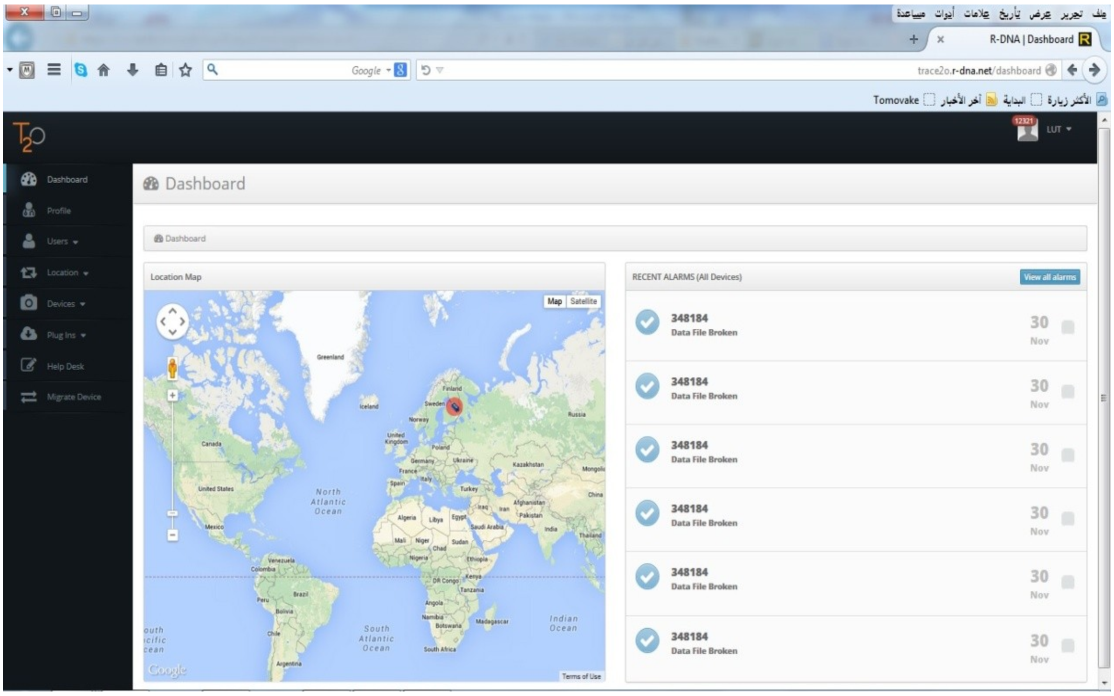

Figure 20 The Trace2O server map where users can choose the wanted device

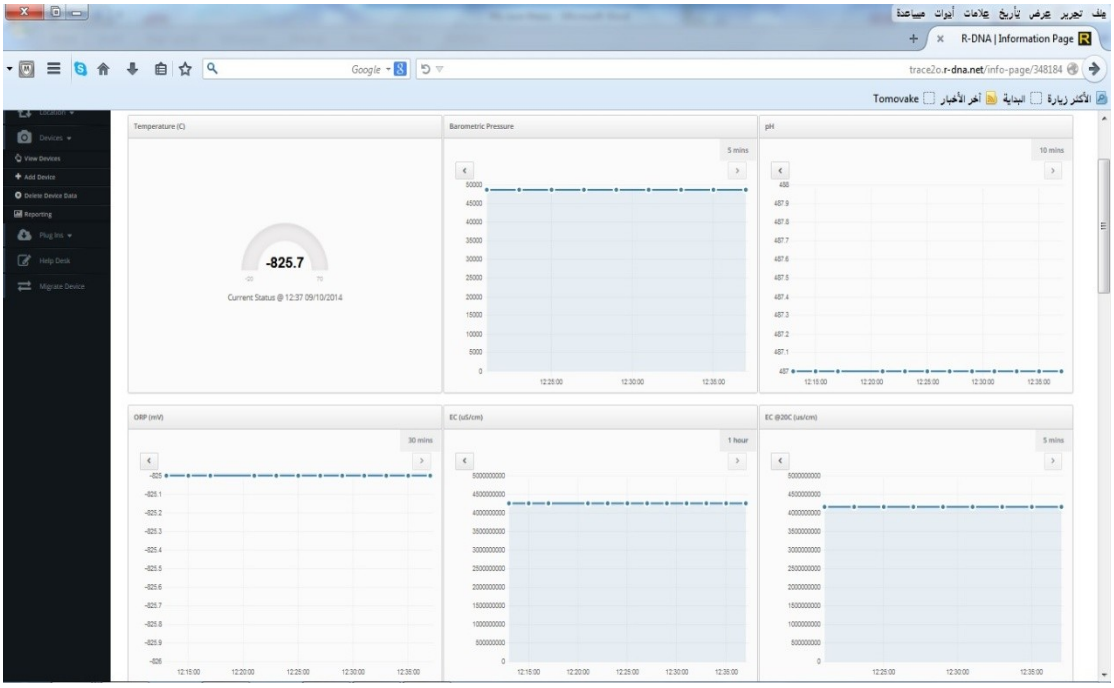

Figure 21 The reading parameters against time with 5, 10, 30, and 60 time intervals

Trace2O made the server available to all of its customers with different IDs. Even though the server is connected to all PaquaStat units all around the world but users can access the units that are used by them.

As the PaquaStat measures the water's quality every two minutes and sends the readings to Trac2O server every 3 minutes, the ASCII files are stored in a file store as files-data-base.

When Trac2O server receives the data from the PaquaStat it processes the data included in each ASCII file -after saving them in the file store- to make an XML file. This XML file is sent to the ToMoVaKe server. Every ten minutes, there is a gateway in Trac2O server that opens, sends the data as XML file to ToMoVaKe over internet, and then closes.

5.2.2 ToMoVaKe

ToMoVaKe is a server located in Lappeenranta, Finland with a data base and a user interface. It receives the data from Trace2O server as XML files, stores them, and makes a history for 36 months. Thereby, it plays the role of database that keeps all of the information from previous measurements accessible for users.

Furthermore, ToMoVaKe's user interface makes the data accessible for users at (http://157.24.188.113:8080/tomovake/tomovake.html). In addition, it has the ability to analyze these data and to make graphical representation of them.

ToMoVaKe is a part of a project developed by Lappeenranta University of Technology (Laboratory of Green Chemistry). The aim is to build a platform to monitor the environment with a 24/7 on-line access through internet. In addition, one goal was to use this platform to promote research in institutes and small firms.

The use of ToMoVaKe user interface is easy. The first thing is to access the homepage as in Figure 22 and then to use the authentication given by the programmer to login.

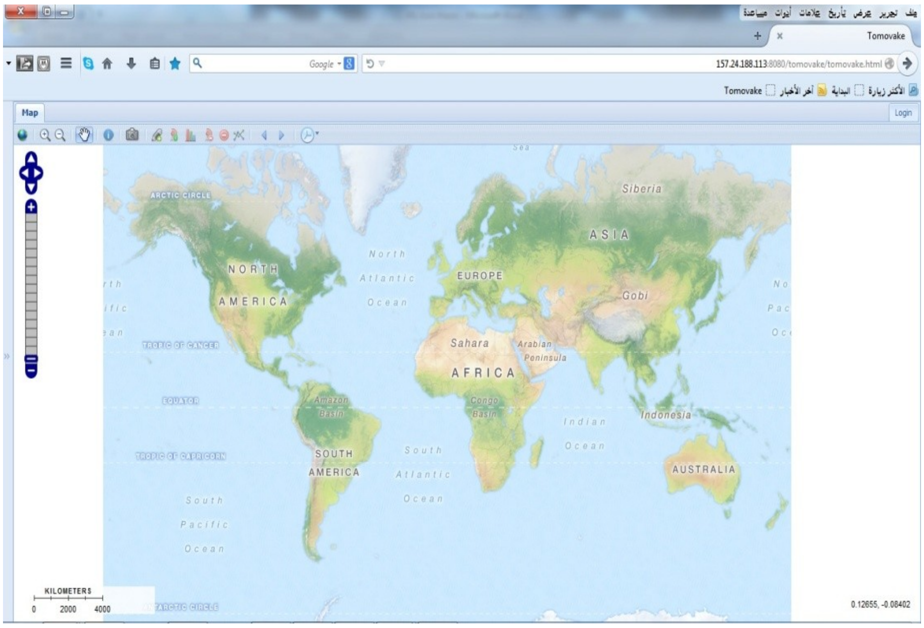

Figure 22 The homepage of ToMoVaKe user interface

After logging in, the user shall choose the study area, in the current research it is "ThesisMikkeli". The third step is to locate the assigned sensors on the map by selecting the sensors layer as can be seen in Figure 23. At this point, there are several tools that can be used with ToMoVaKe like zoom in, zoom out, selecting tool, device info, and statistical tools. By these tools, the user can choose the desired sensors and check their up to date information, their status, and the situation of the environment where they are.

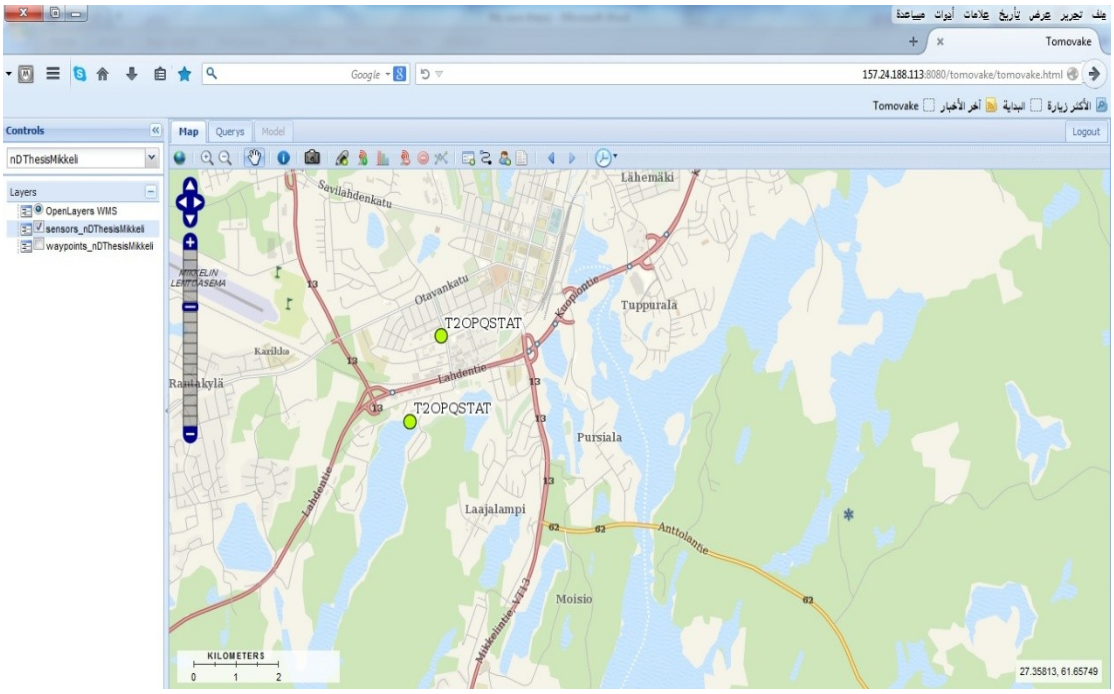

Figure 23 ToMoVaKe interface after selecting the area to be "ThesisMikkeli" and choosing the sensor layer to be active

Also, there is another feature of ToMoVaKe for researchers. It is the ability to define the study area with a description of that area and the study plan. In addition, there is ability to determine specific points in that area where measurements are going to be taken or where they were taken already. It provides the exact position of these specific points with their longitude and latitude values.

After the measurement are taken, the results from the history data base can be retrieved for any period the user wants as can be seen from Figure 24. The query page is accessed in ToMoVaKe. Then the user determines the output format of the data (XML or CSV), the time period in which the results are wanted, and the sensors by which these data measured. When all of the options are chosen, ToMoVaKe generates the required file making it possible to be downloaded to the computer.

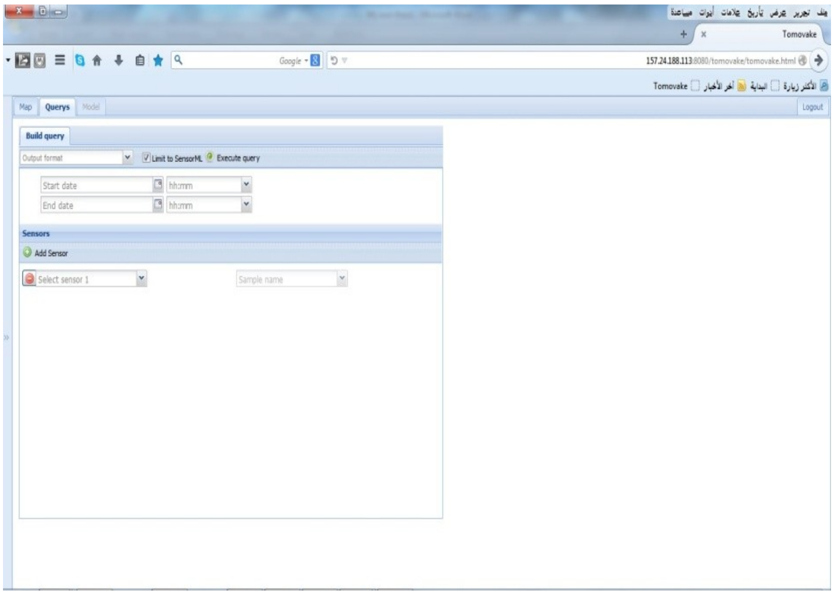

Figure 24 The results retrieval and query page

Another way to represent the data from the history data base is the graphical representation. It is done by using the statistical tool after using the selecting tool to select the desired sensor on the map. The statistical tool looks as in Figure 25. The user chooses the desired period that is wanted to be shown and the parameters wanted to be represented (more than one parameter can be added and each one of them is represented by its own graph).

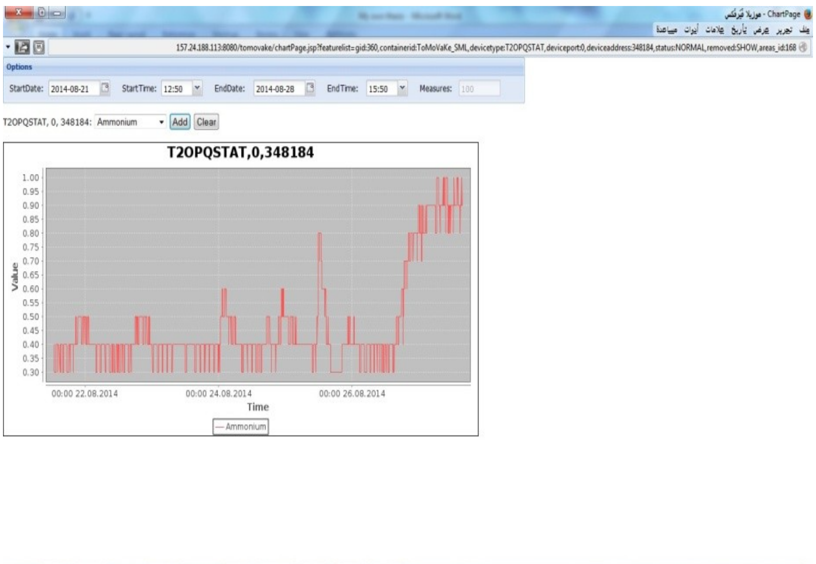

Figure 25 Retrieval of result using the statisitical tool, Ammonuim results as an example

In addition to all of this, ToMoVaKe has an advance alerting system. ToMoVaKe is programmed to send alert-messages by email or SMSs to assigned people if there is any measurement over a specific limit. When any new device is identified and connected to ToMoVaKe, some limits for different parameters are defined with the set of contact-details of the people whom to inform. In this way, when ToMoVaKe receives a measurement form PaquaStat for a parameter and the value is over the designed limit, it sends an alert to those people. By this feature, ToMoVaKe is suitable to be used for early warning and awareness online monitoring systems.

The choice of (Trace2O and ToMoVaKe servers) was due to their features that were illustrated above.

The advantages of using these servers and interfaces are obvious. The use of standard web browser to access them makes the use more convenient for all types of users since they are already familiar with them. In addition, the access to theses servers does not need specific software; it needs only PC or laptop connected to internet.

Furthermore, the authentication step provides the service with touch of trust. No harmful programs and individual can get access to the server. Therefore, the user will deal with the information as reliable information.

Those are some of the reason, but of course, the whole features of the control center given above can be valid reason

5.3 Communication network

The communication between the data collection unit (PaquaStat/PaquaBag) and the monitoring center (Trace2O) is done by using GPRS (General Packet Radio Systems) through internet. The PaquaStat is supplied with the ability to use the mobile phone network.

A SIM-card from Elisa network operator was used and was introduced to PaquaStat's system. The collected data from the PaquaStat is sent to internet through the mobile phone network by using the GPRS. Trac2O server receives these data and processes them as mentioned before and again sends them to ToMoVaKe server via internet.

The choice for GPRS in our system as the communication network was due to the following facts:

1. No need for extra network, only to use of the public mobile network.
2. The high coverage of the coverage of the public mobile network.
3. The cheapness of using GPRS over the public mobile network,
4. The high transmission rate in comparison to other network platforms such as Zigbee or GSM.

These reasons were the same that made Wang and Zhang (2009), Jing (2011), and Wu et al. (2010) to utilize GPRS in their systems.

6 Quality assurance instruments

The quality assurance instruments are the instruments used to test and evaluate the online water quality monitoring system. The first instrument was used for location confirmation. Other instruments were laboratory based instruments which were used to make some laboratory's tests in order to make sure the readings of the PaquaStat/PaquaBag are correct. The following sections will discuss these instruments.

6.1 Location confirmation

As described in the PaquaStat sub-units, there is a GPRS-based location determination system, included in the telemetry unit. To confirm the readings of latitude and longitude obtained by this system, a location confirmation method was followed.

A mobile phone with location determination option was used. One app was used to confirm the location. It uses the local mobile phone network to locate the phone's location.

By this location confirmation method, the exact location found by the PaquaStat was confirmed.

6.2 Laboratory tests

Some laboratory tests were used to confirm the readings of the field readings. Collecting the samples was done by following the standard methods (Bartram and Ballance 1996b; U.S. Environmental Protection Agency 2010). After the samples were transported back to the laboratory, the following two instruments were used to conduct different tests.

6.2.1 Spectro-photometrical analysis

The laboratory's device that was used for spectrophotometrical analysis is a product from Hach-Lange, Figure 26. The product's name is DR 2800 spectrophotometer. It is a VIS spectrophotometer with a wavelength range of 340 to 900 nm. It comes with a different set of programs for example, the pre-installed tests, or barcode programs. The technical details can be found in Appendix II. (Hach-Lange 2013)

Figure 26 DR 2800 device with the several vials (Hach-Lange 2013)

For each parameter this device can measure, there are special vials. Samples are added to these vials allowing the required time for the reaction to take place. After that, a barcode reader reads automatically the barcode on the vial. DR 2800 uses the barcode identification to set the correct wavelength for the analysis, therefore to calculate the result immediately with the use of the stored factors by the manufacturer (Hach-Lange 2013). In this current research, this device was used for analysis of nitrate and ammonium.

6.2.2 Electrochemical analysis

For laboratory electrochemical analysis, inoLab® Multi 9310P device was used (WTW 2014). It uses intelligent digital sensors (IDS) for measuring pH, conductivity, and dissolved oxygen. The IDS technology enables measurements and efficient documentation (WTW 2014).

The inoLab® Multi 9310P (Figure 27) with its single digital input is an outstanding to digital multi-parameter-measurement with IDS electrodes. It has measuring consistency, error-free measurements, ability for storage of measured parameters, and high-quality sensors for all application areas (WTW 2014).

Figure 27 inoLab® Multi 9310P

The device can measure several parameters listed in Table 3 with their ranges. Although some of these parameters have to be measured in the field as the standard methods state (Bartram and Ballance 1996b; U.S. Environmental Protection Agency 2010), but the usage of this device was to give an indication about the accuracy of the obtained readings.

Table 3 The parameters that can be measured by
inoLab ® Multi 9310P and their ranges

Parameter	Range
Conductivity	0 - 1000 mS/cm
Salinity	0.0-70.0 (acc. to IOT)
TDS	1 - 1999 mg/L

7 Experimental procedure

There were many steps to be followed during the experimental procedure. Some of them took role in the design and construction process, some were done as preparation steps, some were followed during the field trips and some were after the field trips, mainly laboratory's tests. In this section, the procedure for each part will be described.

7.1 The design and construction process

The design of the ferry started with consideration of the needs for such a floatable station. The needs were to have stability while floating, to have enough space area for operators to move, to have a design that can host the facilities, and to have a convenient way to install and use the system onboard.

The first 3D model was made by SolidWorks 2014® and then the wooden parts were cut and arranged together to give the last design. To make the ferry easy to transport, it was design to have three main parts that can be built and constructed easily onsite.

The construction of the ferry was the next step after the transportation to the desired destination. The ferry was constructed by putting the three parts together using the crews as can be seen in Figure 28.

Figure 28 Construction and building up of the ferry

When the ferry was ready, the motors and batteries were added. After that, the ferry was pulled by the robe to the lake to start the field trip measurements. Figure 29 shows the ferry before pulling it to the water. A real driving test took place in Anttola area as an implementation of the system in Lake Saimaa, which was one of the objectives. It will be discussed in the ""Actual field trips"" section.

Figure 29 The ferry with the motor for the driving test

7.2 Preparation for the field trips

The start was by charging the batteries of the PaquaBag for sufficient time until they are fully charged and ready to be used. Also, the probes were fully calibrated as the instructions in the manufacturer's manual guide (Trace2o Ltd. 2014). Then, the icebox and ice-packs were prepared for the manual samples. In addition, the empty dark plastic bottles are brought out from the storage room and made ready to be used. Furthermore, sulfuric acid, droppers, tissues, and gloves are arranged to be ready and easy to carry them.

Furthermore, all of the required accessories for the ferry are checked and prepared for the trip. For example, the motor's batteries for the motor were fully charged and made ready to be used.

7.3 Actual field trips

The field trips started by arranging everything needed in a car, driving to the desired destination. The dock arm was far in water in the first two locations (Tuppurala and Pitkäjärvi), so the whole system was installed there without the ferry. In addition, the ferry needs some time to be built which was avoided.

The fields' trips to Tuppurala and Pitkäjärvi had several steps. The first step was to put the PaquaBag on, until the GPRS gets the exact position. At that point, when the exact location was acquired, the PaquaBag was connected to a laptop to set up the time stamp into the system (Figure 30), because it loses its memory when the power is switched off. The USB wire connection was used to connect the PaquaBag to the laptop.

Figure 30 Connecting the PaquaBag to the laptop to set the time

When the time stamp and location were ready, the system was ready to be used. The probe was submerged to the water and its depth was fixed by a robe connected to the body of the dock (Figure 31).

Figure 31 Installation of the probes in Tuppurala

The next step took place on the laptop. The ToMoVaKe interface was used to set a waypoint with recording the location and the purpose of this way point by a description text as can be seen in Figure 32. Then, a session time for this waypoint was sat. Also, the ToMoVaKe interface was used to confirm the exact altitude and latitude of this waypoint, and to check everything regarding the internet connection between the PaquaBag and the ToMoVaKe server was OK.

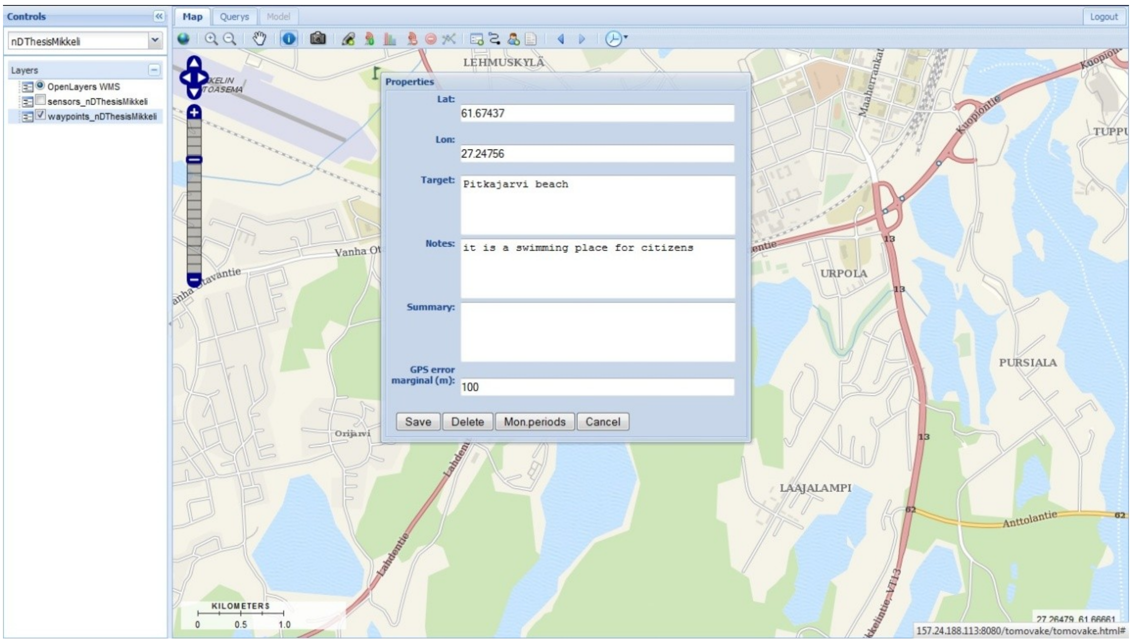

Figure 32 The set up of the waypoint for Pitkäjärvi

As specified by the design of the PaquaStat, the probe takes measurements each two minutes. Meanwhile, the operators started taking pictures for the area as physical observation to be included later to the waypoint.

For the quality assurance, some samples were in need to be taken. The samples bottles were brought out from the icebox and then were washed by the water in the sampling site three times withdrawing the used water to another side. The standard methods for taking samples were followed (Bartram and Ballance 1996b; U.S. Environmental Protection Agency 2010). Then the samples were stored in the icebox until the end of the field trip. Some pictures from the manual sampling are presented in Figure 33.

Figure 33 Manual sampling in bottles

Furthermore, a second probe similar to the online-connected probe was submerged into water beside the online-connected probe at the same depth. It was connected to the calibration device where the readings can be seen. Therefore, the use of calibrating device was to read the values only not to make a calibration. The readings for the same parameters were added to ToMoVaKe as manual readings to make a comparison between them and the online obtained data. The use of the calibration device to read the values of the parameters can be seen in Figure 34.

Figure 34 Manual readings using a similar probe but connected to the calibrating device

The next steps were to include the physical observation to ToMoVaKe, to close the session of the waypoint, to take the probe out from the water, to clean the used stuff, to pack the tools and to drive back.

The same steps were followed in both locations. However, the following planned trips were supposed to have the usage of the ferry which was not accomplished because of the obtained results as will be described later.

The use of the ferry should have taken part as the following process: when arriving to the destination, the build-up process of the ferry to take place, and the utilization of the ferry as floating station to host the system. After that the ferry can be driven by a motor to the desired area. The approximate time for the construction of the ferry with installing all of the tools and accessories was approximated to be 45 minutes.

But however, the construction and implementation of the ferry took place in Lake Saimaa in an area called ""Anttola"" nearby Mikkeli. Figure 35 shows the drive-test where the ferry was implemented in Lake Saimaa.

Figure 35 The implementation of the ferry in Lake Saimaa, Anttola, Finland

The choice of Anttola area to build up and implement the ferry rather than in Mikkeli was for several reasons. The first one was the population. The number of inhabitants in that area is less than in Mikkeli, it led to have less questions than if it would have been in Mikkeli. The second reason lies behind the area itself, there are more open space to Lake Saimaa than in Mikkeli. The third reason was due to the fact it was in the testing period. There were some uncertainty of the exact needed steps; it went through some trials to get the confirmation of how the construction and implementation steps of the ferry should go.

However, as stated before, the ferry was constructed, tested and implemented in Anttola but the usage of the ferry for further trips did not take place because of the system's testing results from the first two locations.

7.4 Post-field trips laboratory's tests

When returning back from the field trip, the samples were analyzed in the laboratory for some parameters. Nitrate and Ammonium were tested using DR 2800 device (Figure 36), following the manual instructions of that equipment (Hach-Lange 2013). Also, some other parameters were checked by inoLab® Multi 9310P, such as EC, TDS, and salinity. The instructions in the manual guide (WTW 2014) were followed.

Figure 36 the use of DR 2800 device

After the second trip and analyzing the obtained results, a need for more laboratory tests raised. These laboratory tests were used to test the functionality of the system by using standard solutions. Therefore, standard solutions were prepared for Nitrate because it had one of the worst results as will be seen in the results section. Trace2O system was tested with them. Again further tests were needed because of the obtained bad results. Re-calibration of the system, testing with the standard solutions (provided by Trace2O), and comparing the results with the laboratory devices showed non-functionality of the probes.

The next step was to contact the manufacturer (Trace2O) to report the issue about the system by a failure report. Trace2O asked to have the system back to make the required tests on the system and repair.

8 Results and discussion

There were many results that were obtained during this thesis. The results show the accomplished achievements regarding the objectives and goals' set. This section will introduce the achieved results with some discussion about them.

The main result was that an online water quality monitoring system was designed and built on reality. Although some parts of the systems were purchased or used as pre-manufactured parts, the design of some parts and the modification of other parts took place. Also, the online water quality monitoring system was tested and implemented in Lake Saimaa. Furthermore, it was evaluated whether the pre-manufactured system (Trace2O's PaquaStat) or the whole system in general.

The design and the construction of the system were presented in the design section in details. The implementation of the ferry in Lake Saimaa was illustrated in details in the experimental procedure section as part of the goal (stated earlier) to implement the system in Lake Saimaa.

Moreover, the implementation of the system as the second part of the implementation-goal of this thesis was achieved. The online water quality system was implemented in two locations (Tuppurala and Pitkäjärvi) in Lake Saimaa, Finland. Figure 37 shows the exact location of the waypoints for both locations in Mikkeli area.

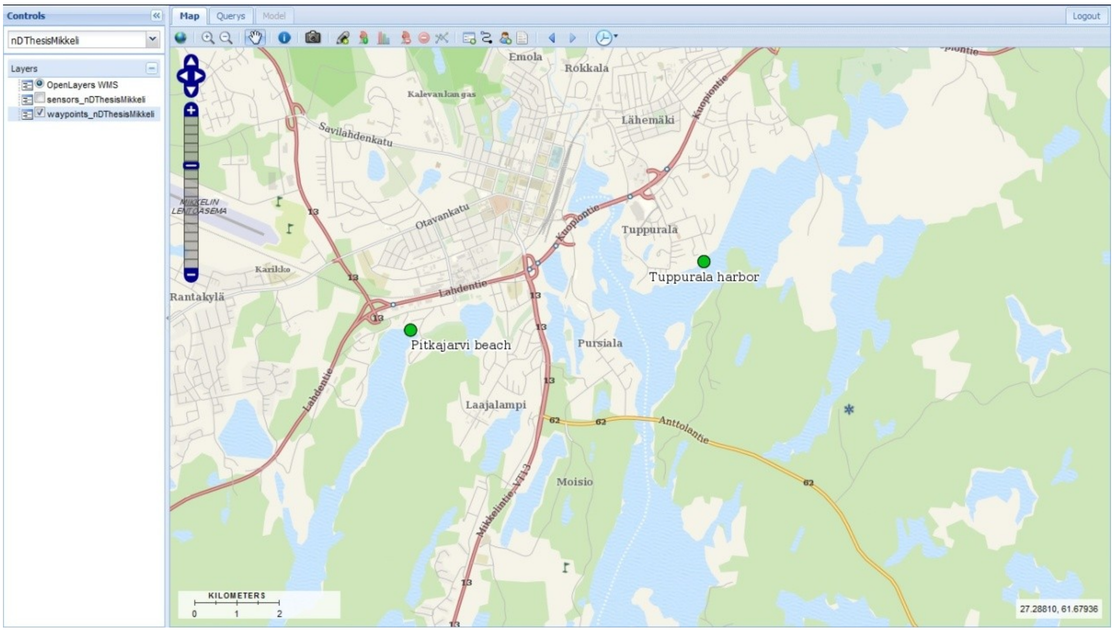

Figure 37 The exact location of the two sites (Tuppurala and Pitkäjärvi)

Both sampling sites were close to the shoreline. Therefore the use of the ferry was not utilized. In addition, the main point of the first two trips without the ferry was to check the procedure of how the latter trips and process should go. The assessment of water quality in these two locations is presented in the following section.

8.1 Water quality parameters assessment

The assessment of the water quality parameters in Lake Saimaa was another objective of this thesis. The whole set of the obtained results from the two visited sites can be seen in Appendix III. The results for each parameter from the two locations are presented by figures and discussed in details in this section.

The results are presented in XY diagram. Y-axis represents the value of the parameters. X-axis represents the time. The blue points show the online readings. The res points show the manual reading that were obtained by the second probe manually with the calibrating device. The green point in Pitkäjärvi results represents the manual reading with the calibrating device but with the probe that was online. The probe was dethatched from the online system and then connected to the manual reading device.

Some of the parameters are compared to the standard values with comments about them as an achievement of the comparison objective.

8.1.1 Temperature

The temperature in these two locations of Lake Saimaa in two sequence days was almost the same. Figure 38 and Figure 39 show the temperature versus time in Tuppurala and Pitkäjärvi.

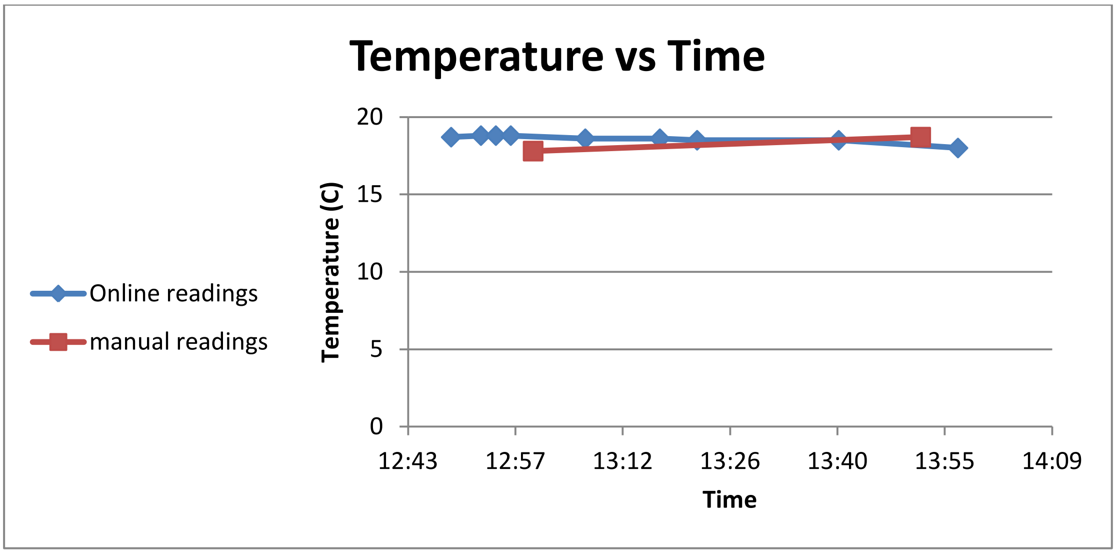

Figure 38 The temperature change over time in Tuppurala, online and manual readings

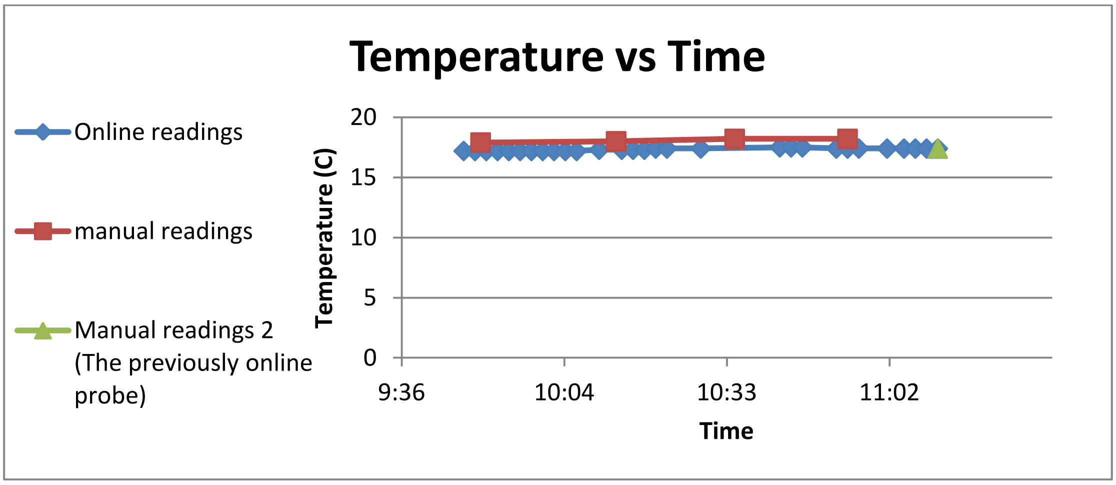

Figure 39 The temperature change over time in Pitkäjärvi, online and manual readings

As shown in Figures 41 and 42 the temperature in the Lake Saimaa is not significantly changed by different sampling area. In the case of Tuppurala (Fig. 38), the temperature was 1 C higher; this is due to the sampling time. In Tuppurala the sampling time was closer to the midday rather than the morning as in Pitkäjärvi, the more time under the sun shine played a role that the temperature is higher, especially, both samples were for the surface water where the sun shine has a noticeable impact.

The trend of the temperature in Tuppurala was to have lower readings over time; this can be reasoned to the weather change. At the end of the sampling session, it was cloudy and there was no sun shine, which might have affected the water temperature.

Another remark for the both sites was the difference between the manual and the online readings which will be met in most of the other parameters as well. The differences were mostly within the accuracy range of the device

8.1.2 pH

Also, pH in the two locations of Lake Saimaa in two sequence days is almost the same. Figure 40 and Figure 41 show the pH versus time in Tuppurala and Pitkäjärvi.

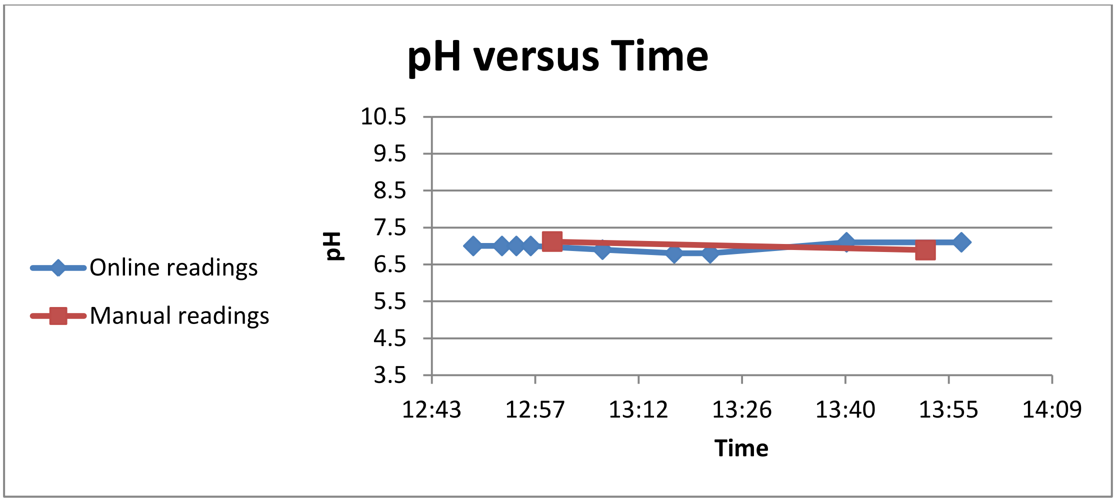

Figure 40 The pH change over time in Tuppurala, online and manual readings

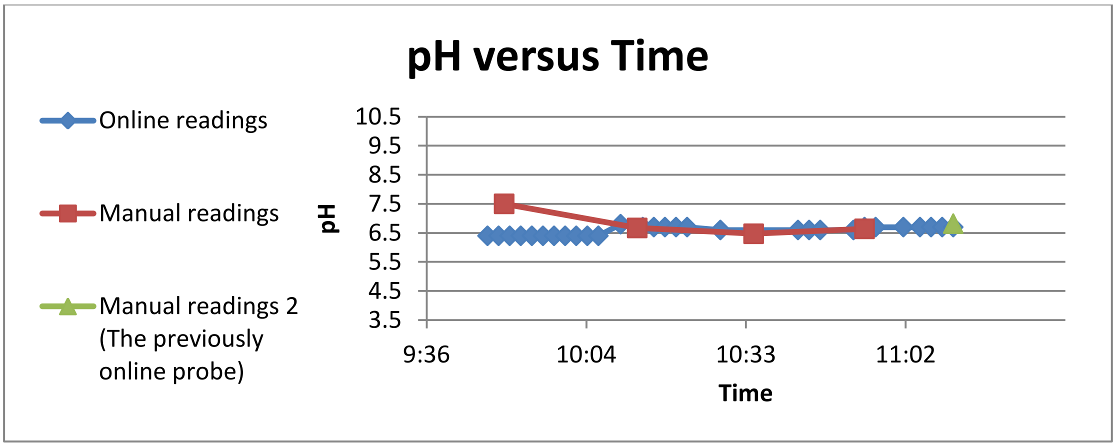

Figure 41 The pH change over time in Pitkäjärvi, online and manual readings

The pH readings showed a steady behavior in both sites, but the values in Pitkäjärvi were below those in Tuppurala. The difference between them is less than one unit; the reason of this difference can be referred to the rain effect. The rain amount that is received by the more open area (Tuppurala) plays a role to neutralize the water body.

In both sites, the online and manual readings were very close together as an indication of the functionality of the pH sensor within the probe. However, there was the first point in the manual readings different than the online readings in the Pitkäjärvi area (Fig. 41). The reason of this - as can be seen from the trend of the value – is the time needed for the sensor to stabilize. It seems there was a period of time needed for the pH sensor to be ready for providing reliable data.

8.1.3 Turbidity

The turbidity in the two locations of Lake Saimaa in two sequence days is shown in Figure 42 and Figure 43.

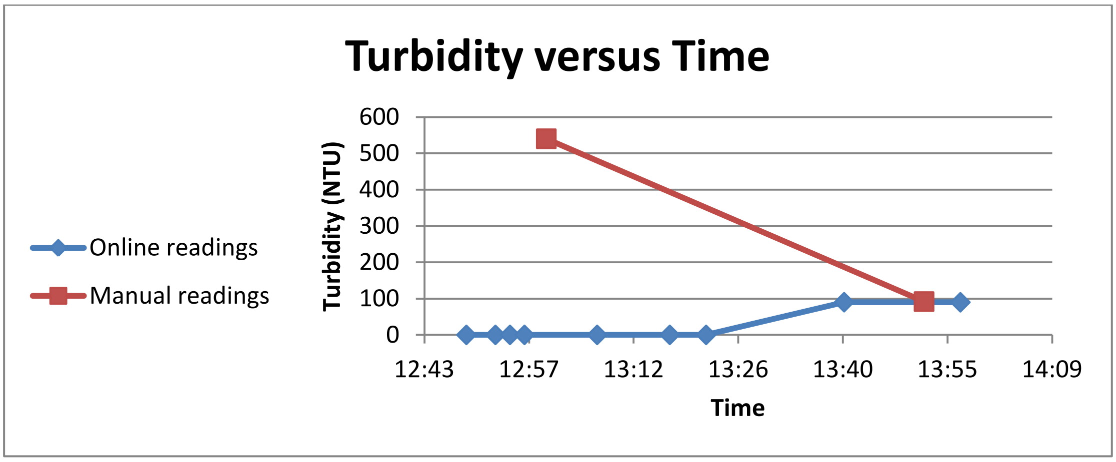

Figure 42 The turbidity change over time in Tuppurala, online and manual readings

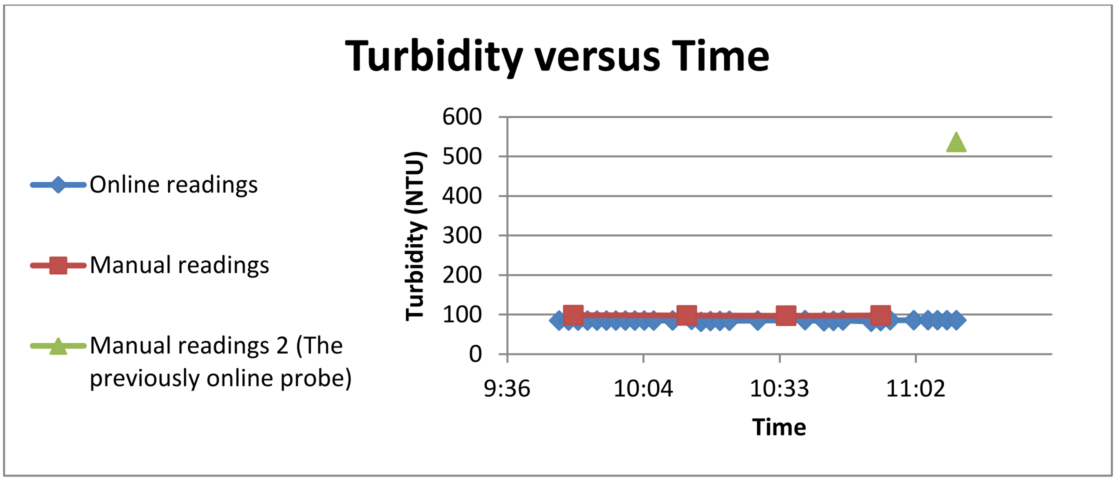

Figure 43 The turbidity change over time in Pitkäjärvi, online and manual readings

The results of turbidity showed strange outcomes for the online system and the manual readings in both sites. In Tuppurala the first point of the manual readings was very far from the online readings, both probes were localized beside each other, there cannot be this huge difference between the values, therefore the suspecting of the readings started to arise. One explanation can be as previous; there was a need for some time for the manual readings to stabilize because the next point was very close to the online readings.

Even more, there is a jump in the online readings from zero to around 100 NTU. If this value from the online system reflects the true situation, it means the system took long time before being able to provide reliable values. In addition, the value itself is very high as seen before in the standard values; it shows that this water in Tuppurala is over enriched with nutrients (Clean Water Team 2004a). On the other hand, if both online and manual readings with 100 NTU do not reflect the actual situation, the whole system fails to proof its reliability to measure this parameter in such a location.

In Pitkäjärvi, the online and manual readings were close to each other the whole run at around 100 NTU except the last point Again, as seen in Tuppurala, this value for a surface lake water means the area is over enriched with nutrients (Clean Water Team 2004a).

The last manual reading was taken by the same probe that was online. The huge difference in the values between the manual and the online values cannot be referred to a sudden change in an open system like this current system, neither referred to a malfunctioning within the probe. This situation can be due to a problem with the data communication either in the wires for the manual sampling or in the GPRS system for the online one.

8.1.4 Electrical conductivity and resistivity

The electrical conductivity in the two locations of Lake Saimaa in two sequence days is shown in Figure 44 and Figure 45.

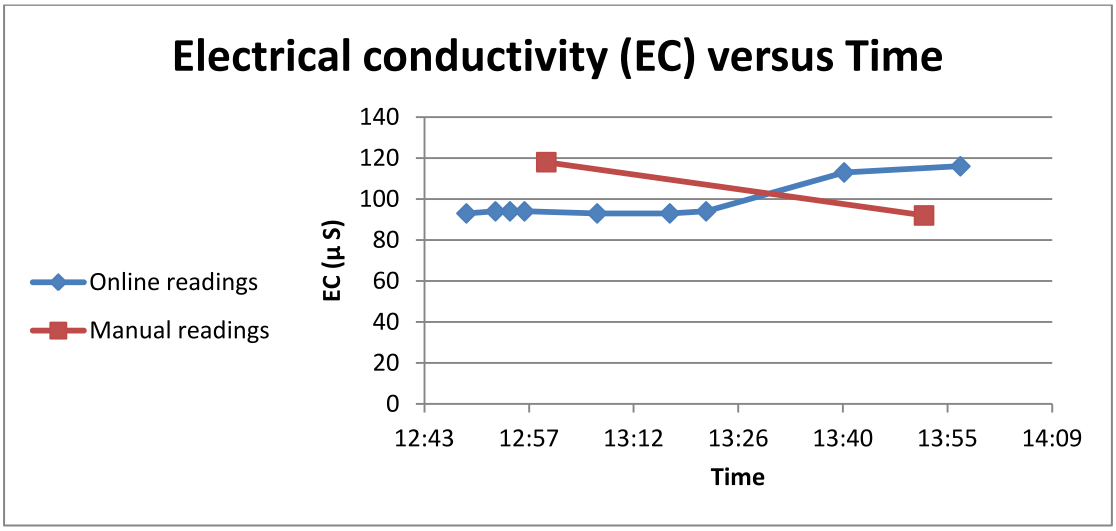

Figure 44 the EC change over time in Tuppurala, online and manual readings

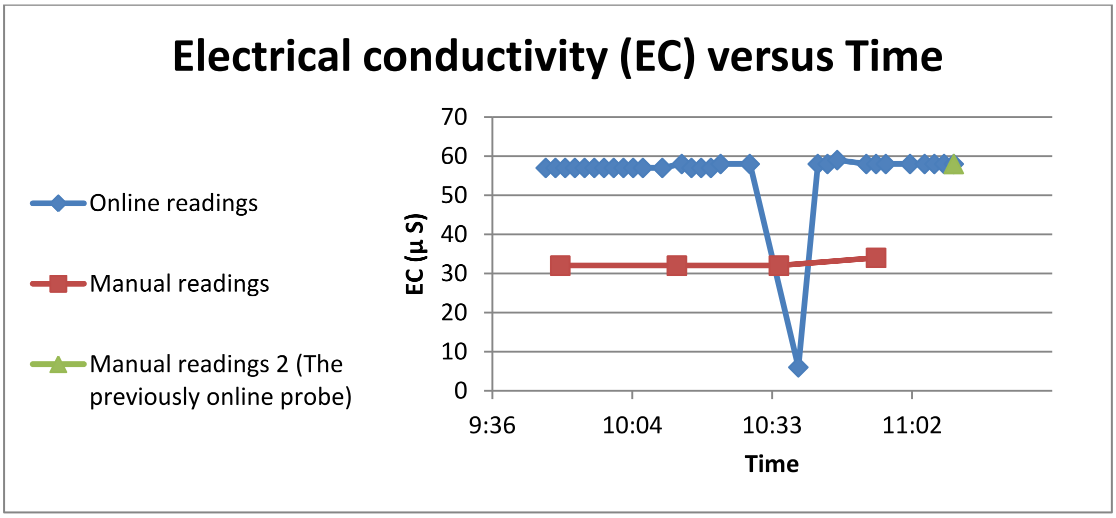

Figure 45 the EC change over time in Pitkäjärvi, online and manual readings

In both site the values of manual samples were different than the online readings, but the last point of manual samplings in Pitkäjärvi showed that the differences are due to the use of different probes. The last point of the manual sampling shows the same probe used for the online readings and both values were almost the same. This gives a suspecting of how two copies of the same probe behave differently, if one of them shows the real value the other one which is supposed to be exactly the same has to show the same value. Specially, if both were manufactured by the same company and went through the same calibration steps as instructed by the manufacturer.

The difference between 95 and 120 µS in the online readings (Fig. 44) can be explained by a water underflow of in the lake or some plankton fouling on the EC sensor. Whereas in Pitkäjärvi (Fig. 45) the one point of the EC reading with 6 µS cannot be explained by fouling, it represents a value of very pure water such cannot be just an isolated point from the rest of other online measurements. The strongest reasoning of the drop is a fail in the system whether the communication path or the EC sensor.

Regarding the obtained values, in Tuppurala (Fig. 44) the EC can be considered close/within the range of the freshwater bodies (U.S. Environmental Protection Agency 2014). Also, the samples which were taken to the laboratory for post-trip analysis showed 125 µS/cm. It is very close to the measured making the indication that it is a reliable value.

On the other side, in Pitkäjärvi (Fig. 45) the readings of either online or manual sampling were below the range specified by U.S. Environmental Protection Agency (2014). There is one valid reason out of two; the water in Lake Saimaa is very pure or the system does not have the ability to reflect the real situation. However, the post-trip laboratory -analysis showed a value of 72.8 µS/cm which is very close to the measured value by the online system. The laboratory analysis value and the online readings outbalance that the Lake Saimaa is more pure than U.S. Environmental Protection Agency (2014) values.

8.1.5 Salinity

The Salinity in the two locations of Lake Saimaa in two sequence days is shown in Figure 46 and Figure 47.

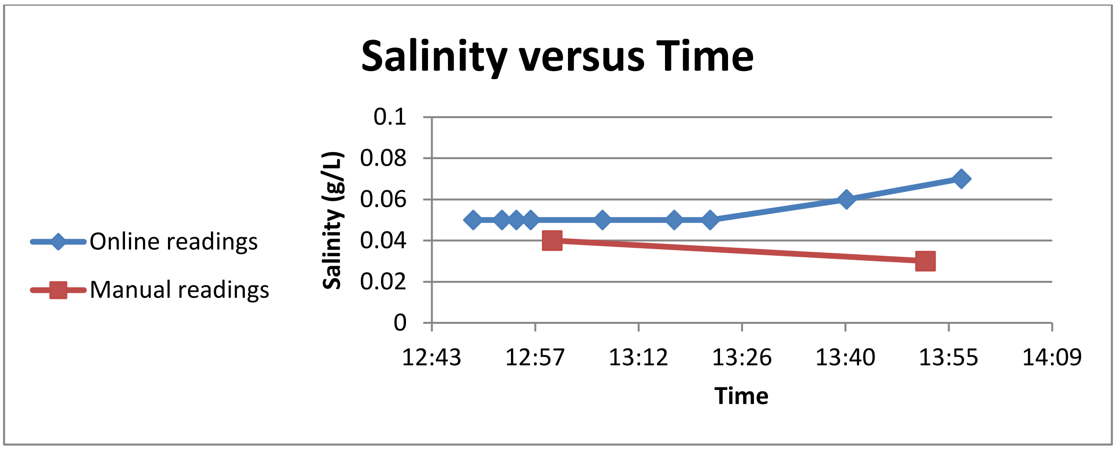

Figure 46 The salinity change over time in Tuppurala, online and manual readings

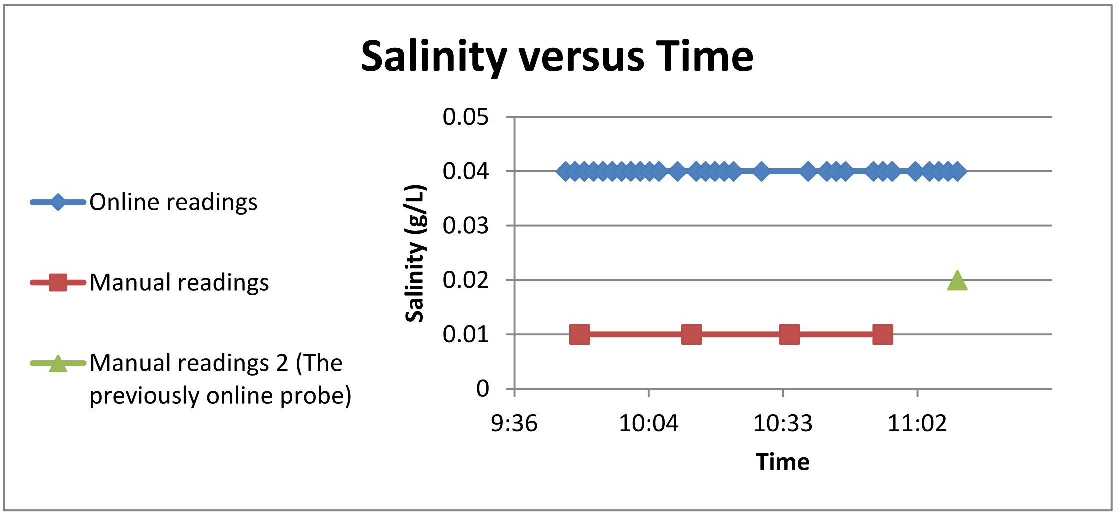

Figure 47 The salinity change over time in Pitkäjärvi, online and manual readings

In Figure 46 for the readings in Tuppurala, the online and manual readings kept showing offset, and even a trend of diverse. This gives more indication that the system cannot be reliable, and its functionality needs more testing. The trend for the online readings to increase has the same explanation as for the EC value change in Fig. 44, either a water underflow stream or fouling.

In the second site (Pitkäjärvi Fig. 47) the manual and online readings have a constant offset during the whole session they gave totally different readings from each other. Even more, when the same probe of the online system was connected to the manual readings device it gave a different value represented by the last point of the manual readings in Fig. 47. The same problems discussed before, the same probe cannot give the same results for the same sampling area mean there is a problem with the communication platform (wires or GPRS network).

Results from both sites showed that Lake Saimaa has pure water that is below the criteria of 250 mg/L set by U.S. Environmental Protection Agency (1986).

8.1.6 Total Dissolved Solids

TDS in the two locations of Lake Saimaa in two sequence days is shown in Figure 48 and Figure 49.

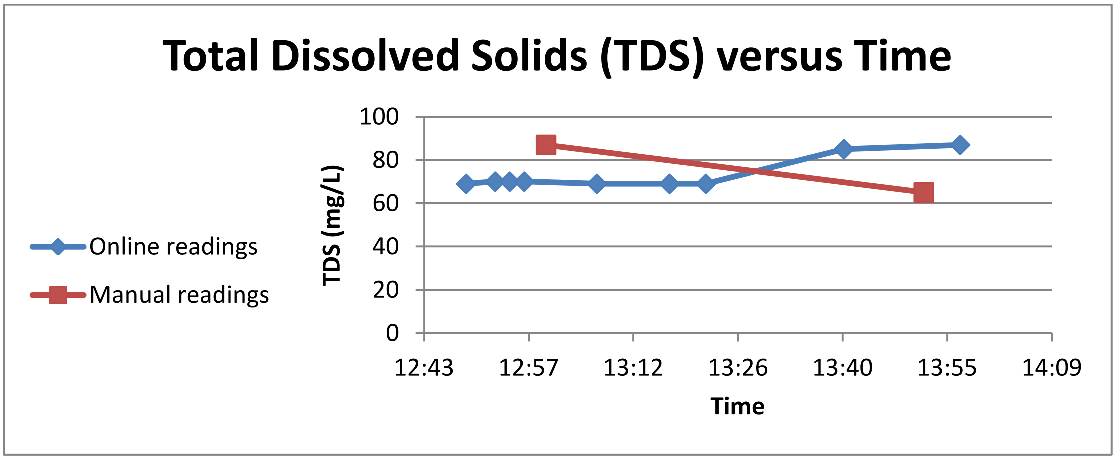

Figure 48 TDS change over time in Tuppurala, online and manual readings

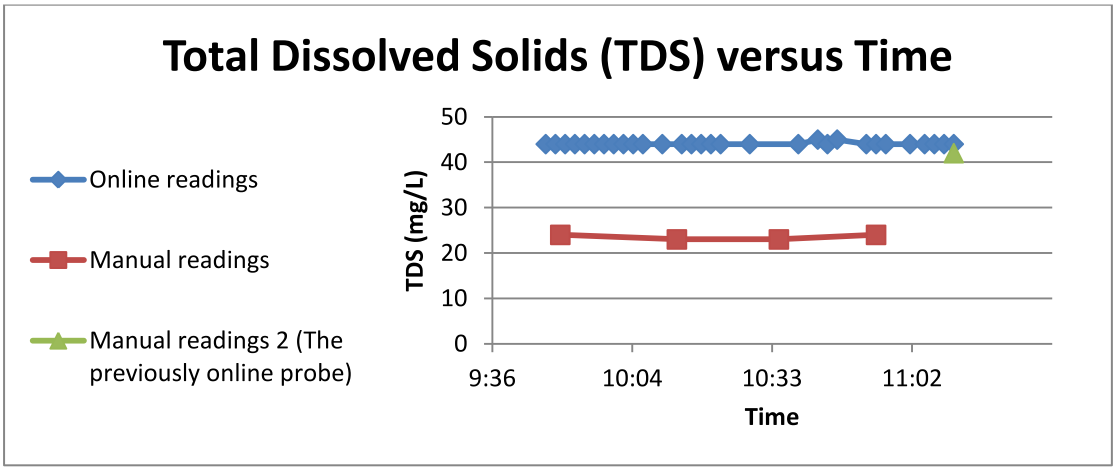

Figure 49 TDS change over time in Pitkäjärvi, online and manual readings

All of the arguments and reasoning that were used for EC and Salinity applies on the TDS because this parameter depends on the EC sensor. It seems the values of TDS are calculated from EC values.

Regarding the results of TDS in Lake Saimaa, the lake can be considered to have pure water because the TDS values are less than 300 mg/L stated by U.S. Environmental Protection Agency (1986). The lake lies under the excellent rating for the surface water bodies.

8.1.7 SSG

In the two locations of Lake Saimaa in two sequence days, SSG is shown in Figure 50 and Figure 51.

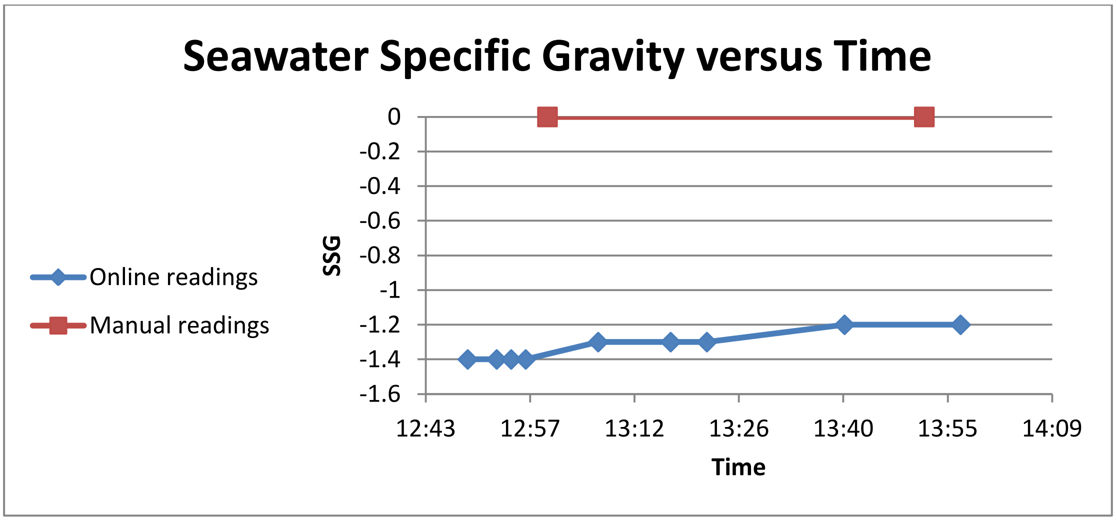

Figure 50 SSG change over time in Tuppurala, online and manual readings

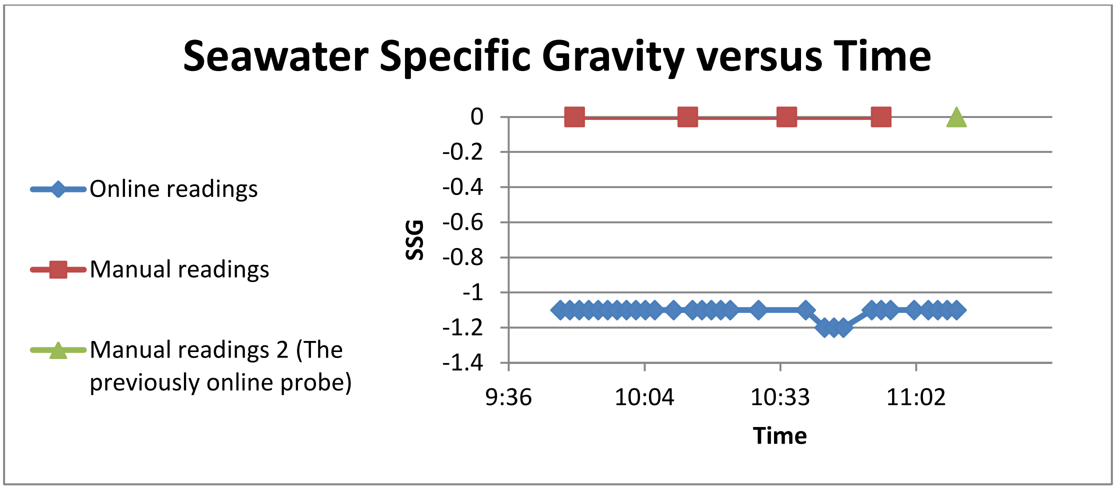

Figure 51 SSG change over time in Pitkäjärvi, online and manual readings

In both locations (Fig. 50 and 51), the offset between the online and manual readings continues. The manual readings kept showing zero for the value of SSG with no change, even when the same probe in the online sampling was connected to the manual reading it gave a value of zero (last point in Fig. 51). This means whatever the situation is the manual readings cannot provide a trustable value for the water density.

The negative values for SSG in both sites represent that the water in these locations of Lake Saimaa has less density than the water density under the standard condition. This can be referred to the gas content of the water, since it is in an open system and more gases dissolves in the water. The same approach can be used to explain the increase-trend in Tuppurala (Fig. 50). The increase in temperature due to exposure of sun light in the midday resulted in the loss of the dissolved gases from the water and hence decreasing the volume which results in the density increase.

In Pitkäjärvi (Fig. 51) the online readings showed steady values overtime. There were couple of point below the average of the readings but because this difference is within the accuracy range of the probe (Trace2o Ltd. 2014), they can be neglected.

8.1.8 Chlorophyll a

Chlorophyll a concentration is shown in Figure 52 and Figure 53 for the two locations of Lake Saimaa in two sequence days.

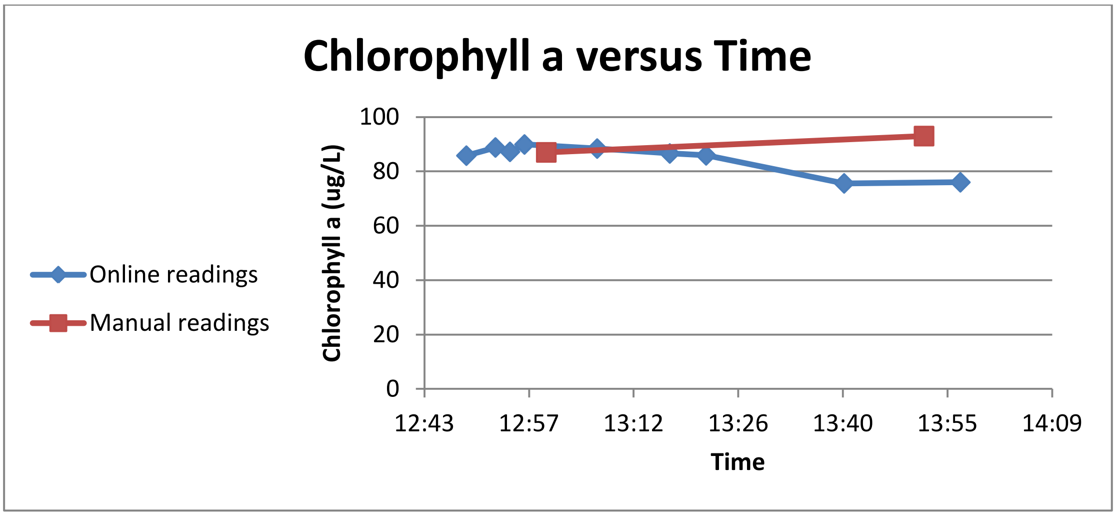

Figure 52 Chlorophyll concentration change over time in Tuppurala, online and manual readings

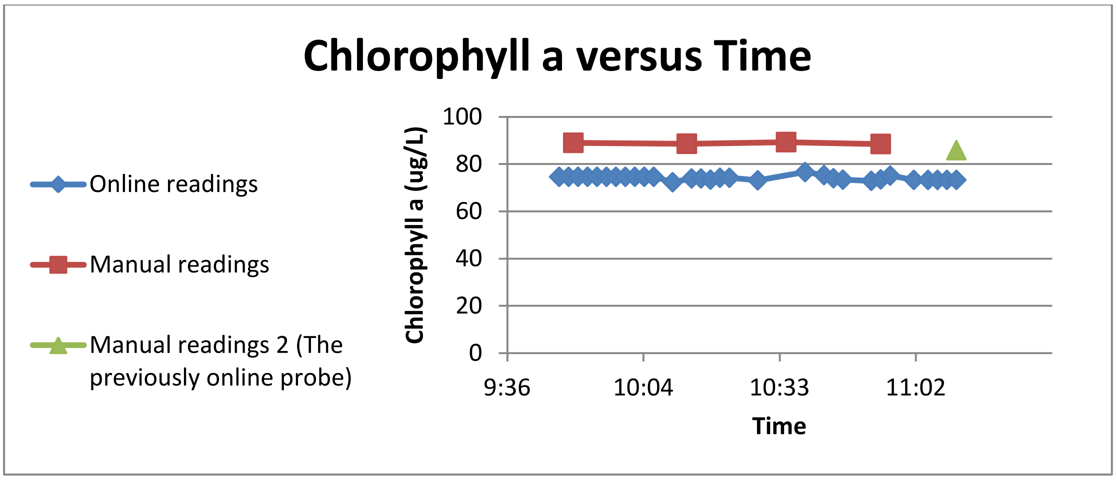

Figure 53 Chlorophyll concentration change over time in Pitkäjärvi, online and manual readings

In pitkajarvi (Fig. 53), online and manual readings showed consistency at the beginning of the session of a value close to 90 µg/L. But after that a diverse between the two readings was observed. Although the manual readings were steady around 90 µg/L but the change happened to the online readings. The online readings decreased around 10% of the first value. This can be because of fouling or a water underflow stream as discussed before. The chlorophyll sensor depends on the photochemical properties of the water sample, if it is face with fouling the sensors' operation-ability will be affected which means to provide different readings.

On the other hand, the next day of operations in Pitkäjärvi gave an offset result between the online and manual readings (Fig. 53). Also, from the same figure, the last point of the manual sampling was taken by the probe that was online before during the session. This point shows that the manual reading of the same probe gives a different result than the online one. As explained before, this is due to a malfunctioning in the network connection either for the online or manual system.

The readings of the chlorophyll a concentrations in Lake Saimaa in both locations (Tuppurala Fig. 52 and Pitkäjärvi Fig. 53) shows that the chlorophyll content whether from plankton or from other green-pigment species is high in comparison to other fresh water open systems such as the one in Queensland, (Department of Environment and Heritage Protection 2009). This high level of chlorophyll a concentration can be referred to the high content of nutrients resulting in a bloom of the planktons, or the drifting from nearby plants and organic matter having the chlorophyll a to the water causes this high level in the water.

8.1.9 Rhodamine Dye

Rhodamine dye in the two locations of Lake Saimaa in two sequence days is shown in Figure 54 and Figure 55.

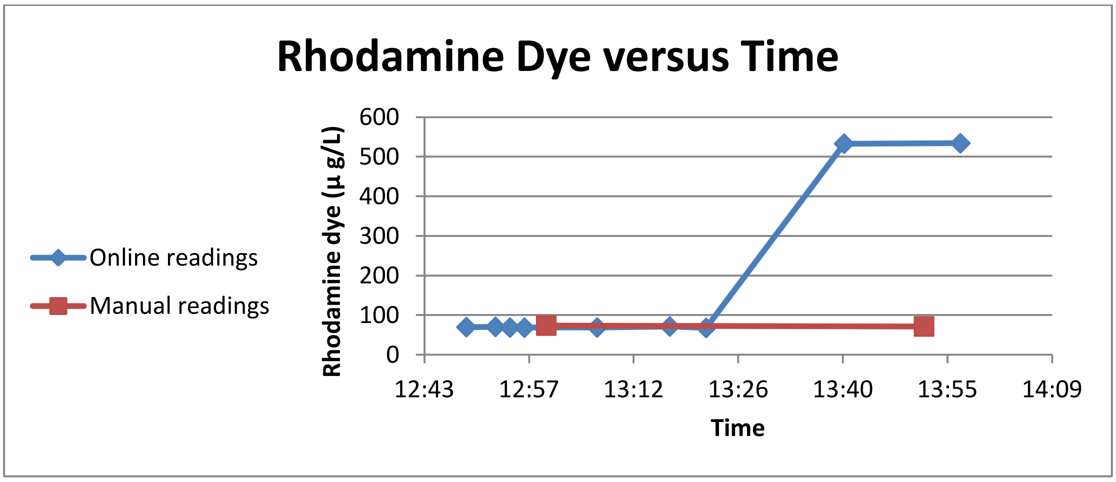

Figure 54 Rhodamine dye change over time in Tuppurala, online and manual readings

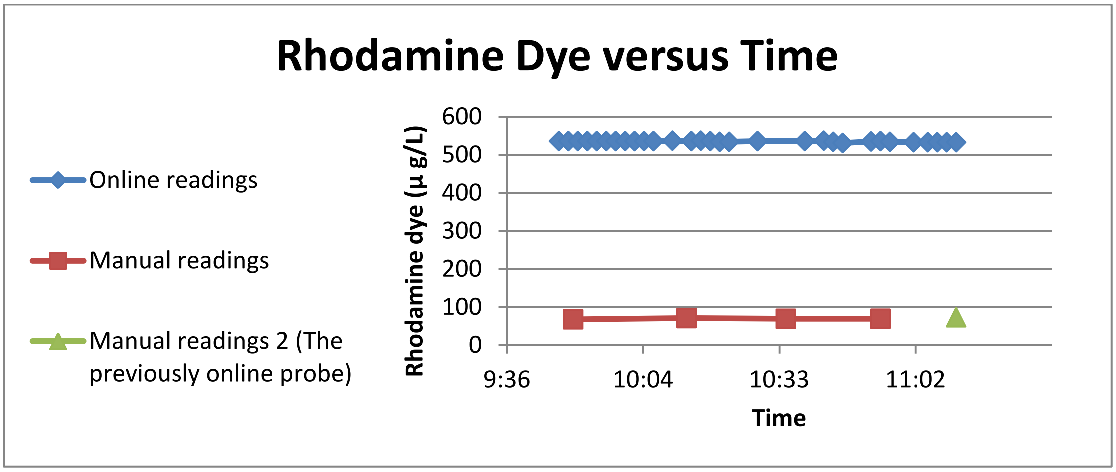

Figure 55 Rhodamine dye change over time in Pitkäjärvi, online and manual readings

As said for the chlorophyll a, Fig. 54 (Tuppurala) shows steady readings for the manual readings of 70 µg/L, the same as the online readings at the beginning of sampling session. The last two points show a big difference, a difference of 5 times the value. This can be reasoned to the effect of the turbidity and chlorophyll a change. The increase in turbidity in the same exact two points results in an impact on the other photochemical sensors such as the rhodamine dye sensor. But what makes the readings unreliable is the manual readings. If the actual sampling area situation was truly changed the manual readings should have changed in the same manner as the online ones which was not observed.

The Tuppurala (Fig. 54) shows the same behavior that was noticed and discussed before, the offset between the manual and online readings and the difference in the same probe's results between online and manual systems.

Furthermore, the values as they are measured whether by the online or manual systems are very high in comparison to the value for fresh water systems (10 µg/L) (Bencala and Cox 2005). This result gives an indication of the inability of the system to reflect the truth regarding the rhodamine dye in the sampling area.

8.1.10 Dissolved Oxygen

DO in percentage is shown in Figure 56 and Figure 57 for the two locations of Lake Saimaa in two sequence days.

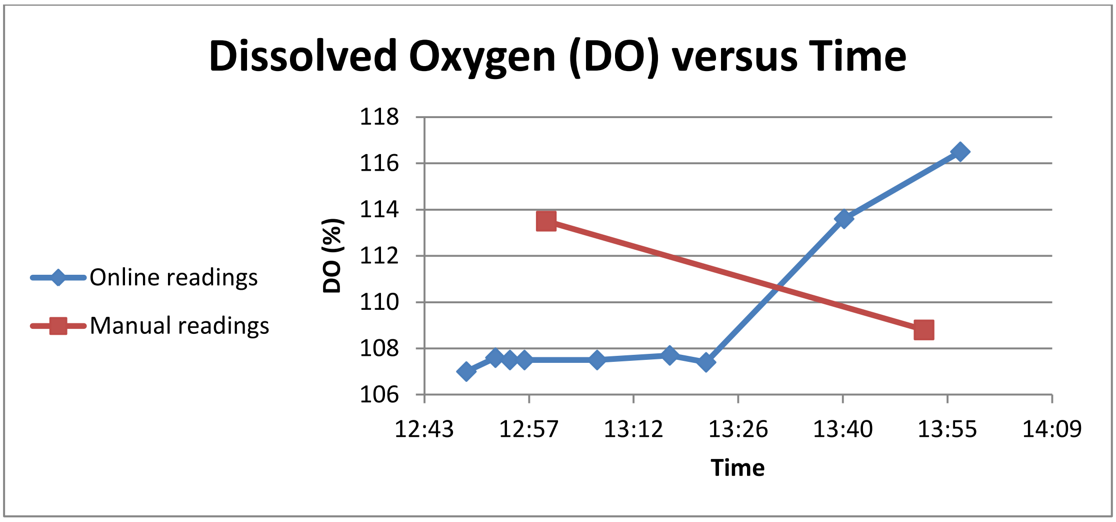

Figure 56 DO change over time in Tuppurala, online and manual readings

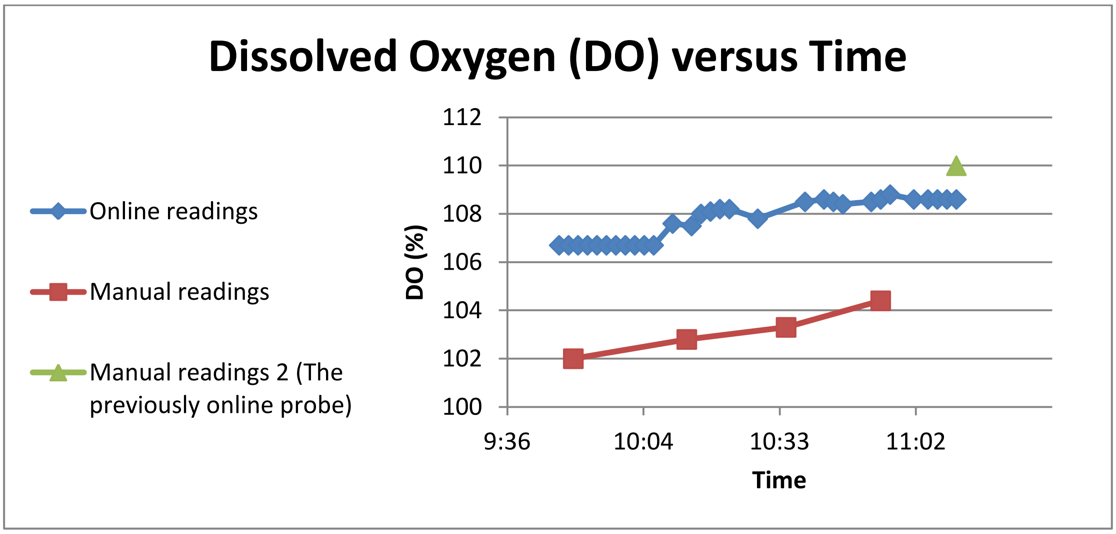

Figure 57 DO change over time in Pitkäjärvi, online and manual readings

The results from both locations (Fig. 56 and 57) show that the DO concentration is in the oversaturation status with values above 100%. The results are not surprising, especially for an open system like Lake Saimaa. The reason of the Oxygen oversaturation is the big surface area of the Lake Saimaa; more Oxygen gets the chance to dissolve into the water body. The winds motion over the surface water of the Lake Saimaa provides more turbulence needed for the dissolving of the oxygen into the water. Even more, the water in Lake Saimaa depends heavily on the rain level, the rain water is mixed with air and when it comes to the water it brings this oxygen. Furthermore, the existence of photosynthesis process produces more oxygen inside the water system. the reason as stated before of having values of more than 100% is that big systems need some time to get to the equilibrium status which applies to Lake Saimaa.

In Fig. 56 for Tuppurala, the manual readings showed a big difference than the online readings. Manual readings decrease when online readings increase. There should be a problem with the system. Furthermore, the sudden change in the DO values in the last two point of Fig. 56 represent a turbulence caused by winds for example resulted in more oxygen to be dissolved in that specific sampling area.

On the other hand, in Pitkäjärvi Fig. 57 there was a steady increase in the value of DO. This is due to the depth of the probe where samples were taken close to the surface of the water meaning a huge impact of the atmosphere on that water. The increase in the sunlight means more photosynthesis processes and more oxygen in the water. Also, as stated for the Tuppurala, the wind at that area was noticeable and caused more oxygen in water. Because the temperature was almost steady as was seen in Fig. 39 the more DO in the water means a more supersaturation values.

However, the offset between manual and online readings in Fig. 57 is still observable but with the same trend this time, when the online readings increased the manual readings did the same. Also, the last point in the same figure which represents the manual readings with the probe that was online was much closer to the online readings. However, the same probe was not able to reproduce the same readings; the resulted value is much higher than the accuracy range given by the manufacturer (Trace2o Ltd. 2014).

Furthermore, if to compare the values between the two location (Tuppurala and Pitkäjärvi), Tuppurala has a higher DO than Pitkäjärvi. This is due to the area openness of Tuppurala where more sunlight hits the water and more wind mixes the water surface.

8.1.11 Oxidation-Reduction potential

Oxidation Reduction Potential in the two locations of Lake Saimaa in two sequence days is presented in Figure 58 and Figure 59.

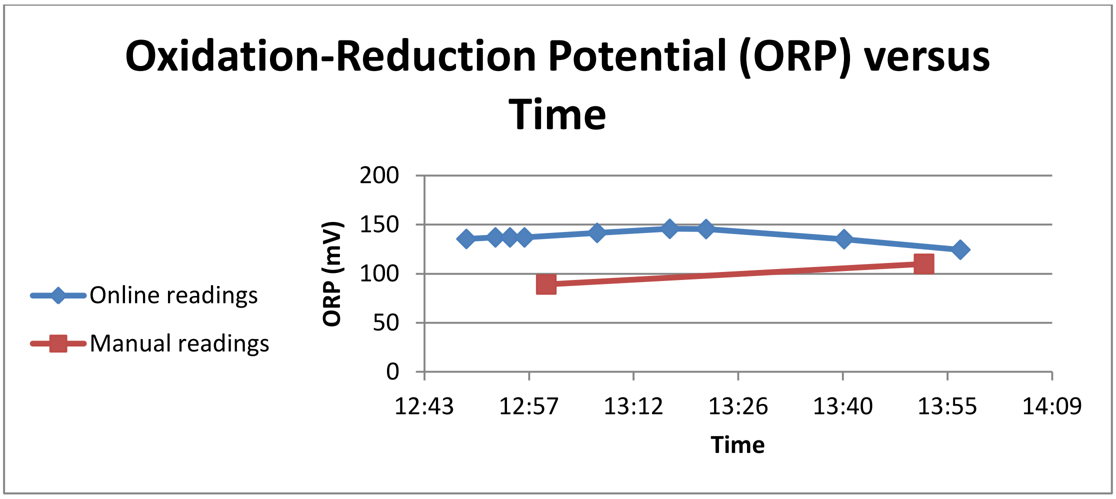

Figure 58 ORP change over time in Tuppurala, online and manual readings

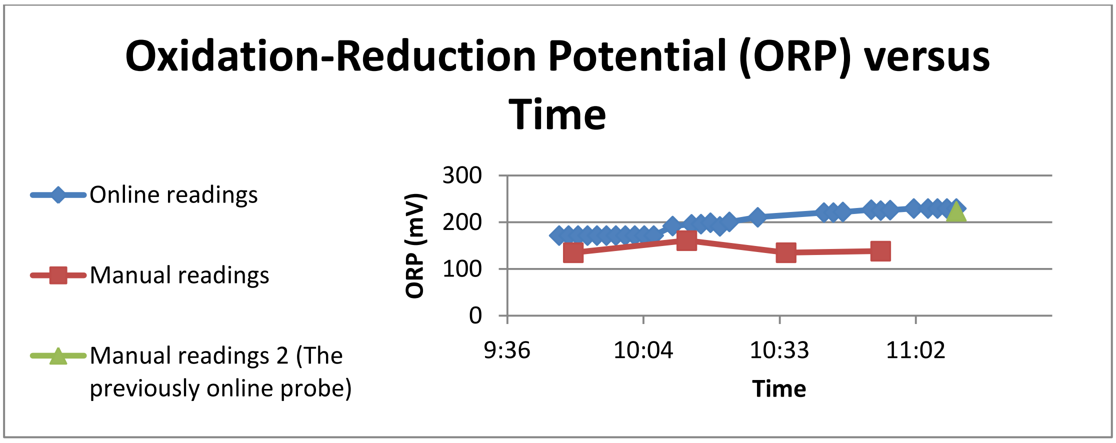

Figure 59 ORP change over time in Pitkäjärvi, online and manual readings

In both locations as can be seen in Fig. 58 and 59 the ORP values are positive values meaning the system of Lake Saimaa is an oxidizing system. As discussed before about the ORP, Lake Saimaa has the potential to self-clean and remove the harmful matters. The electro-species are able to oxidize bacteria and harmful microorganisms. Although both locations have a positive value for ORP but it is clear in pitkajarvi (Fig. 59) that ORP is much higher (around 200 mV) than in Tuppurala (Fig. 58). The reason can be the nearby withdrawal point of the waste water treatment plant which results in consumption of these oxidizing electro-species, resulting in a lower value of ORP.

In Tuppurala Fig. 58, the offset between online and manual readings is significantly big at the beginning of the measuring session. However, the readings from both systems stated to have a converging trend around 120 mV (Fig. 61). On the other hand, the offset between the manual readings in Pitkäjärvi (Fig. 59) shows no relation between the online and manual systems.

There is another one point to mention here, in Pitkäjärvi (Fig. 59) the last point of the manual sampling showed the same readings of the online sampling system, this means the difference between the online and manual readings is due to differences between the probes. When one probe gives the same value whether it is on online or manual system and the other probe gives another value, this means there are difference in the two probes that are supposed to be identical and both from the same manufacturer.

8.1.12 Nitrate

In two sequence days with the two locations of Lake Saimaa, Figure 60 and Figure 61 show Nitrate concentration versus time in Tuppurala and Pitkäjärvi.

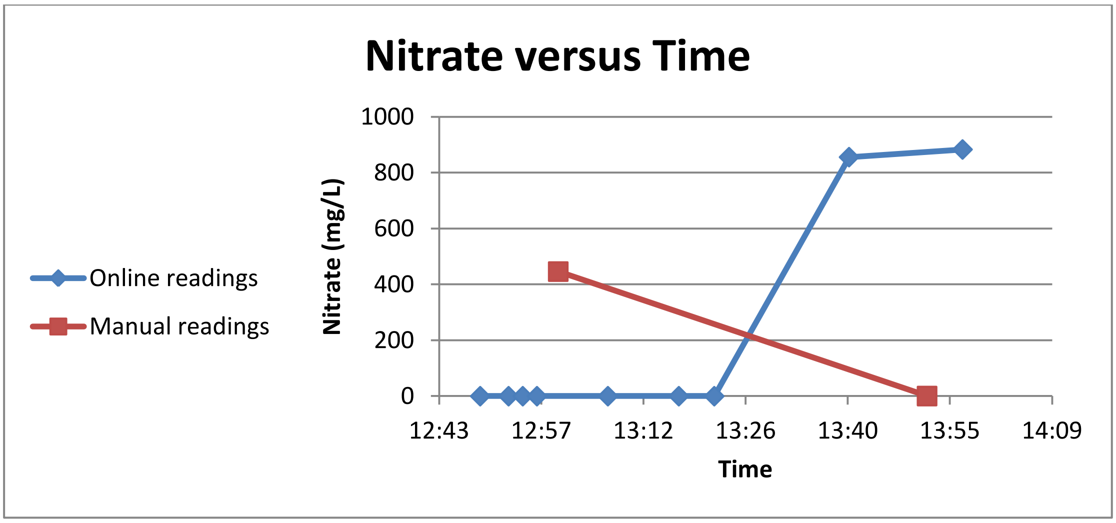

Figure 60 Nitrate concentration change over time in Tuppurala, online and manual readings

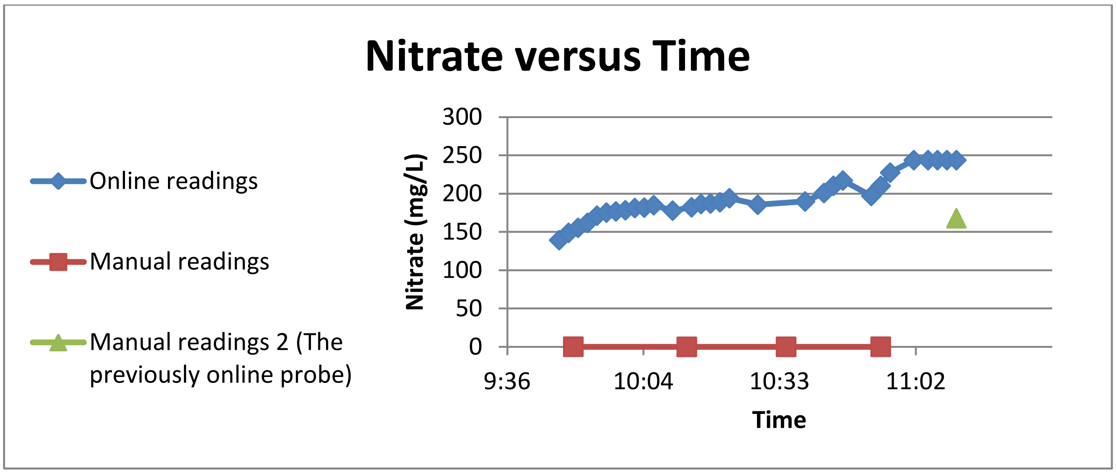

Figure 61 Nitrate concentration change over time in Pitkäjärvi, online and manual readings

The nitrate results were the most unreliable, unpredictable, unreasonable results. In both locations (Tuppurala Fig. 60 and Pitkäjärvi Fig. 61) the offset between the online and manual readings was very huge; there was no explanation of this offset. During the online readings of the nitrate in Tuppurala (Fig. 60) the manual readings were much higher. When a sudden change happened in the online readings up to 900 mg/L the manual readings dropped to zero. This cannot be a reflection of the real situation since the values have a huge difference than the values of how nitrate shall be in surface water (U.S. Environmental Protection Agency 1986; WHO 2011).

In Pitkäjärvi (Fig. 61), the manual readings showed value around zero until the probe was changed. When the online probe was disconnected and used for manual sampling it showed a value for the nitrate rather than zero as can be seen from the last point, but not as the online readings. This means, one probe was reading very low values whereas the other probe read some values for the nitrate.

Even more, Fig. 61 shows a trend for nitrate concentration increase. The readings were not steady and constant, they kept increasing. This situation cannot be a representation of a real situation in an open system like Lake Saimaa, Nitrate concentration cannot move from 150 mg/L to 250 mg/L within short time (2 hours), Further as stated before, this value is considered very high value which cannot be true in this current case.

Also, the post-trip laboratory -tests showed different values than both online and manual readings in both locations. For Tuppurala the water samples tested in the laboratory showed a result of 6 mg/L NO_3^- which is a result within the limits of WHO (2011) but it does not match with any of the obtained result whether by online or manual readings.

Analysis of samples taken from Pitkäjärvi showed differences too. The obtained value from the laboratory photometrical analysis was 0.85 mg/L NO_3^-. This value is closer to the manual readings but very far from the online readings (Fig 64).

According to the laboratory results, Pitkäjärvi is cleaner than Tuppurala regarding the nitrate concentration. This is due the point-source of pollution (waste water treatment plant discharge point) nearby Tuppurala. This pollution causes higher nitrate concentrations.

Those results proved that nitrate sensors are not reliable and cannot be trusted.

8.1.13 Ammonia & Ammonium

Ammonium concentration in Tuppurala and Pitkäjärvi in two sequence days is shown in Figure 62 and Figure 63.

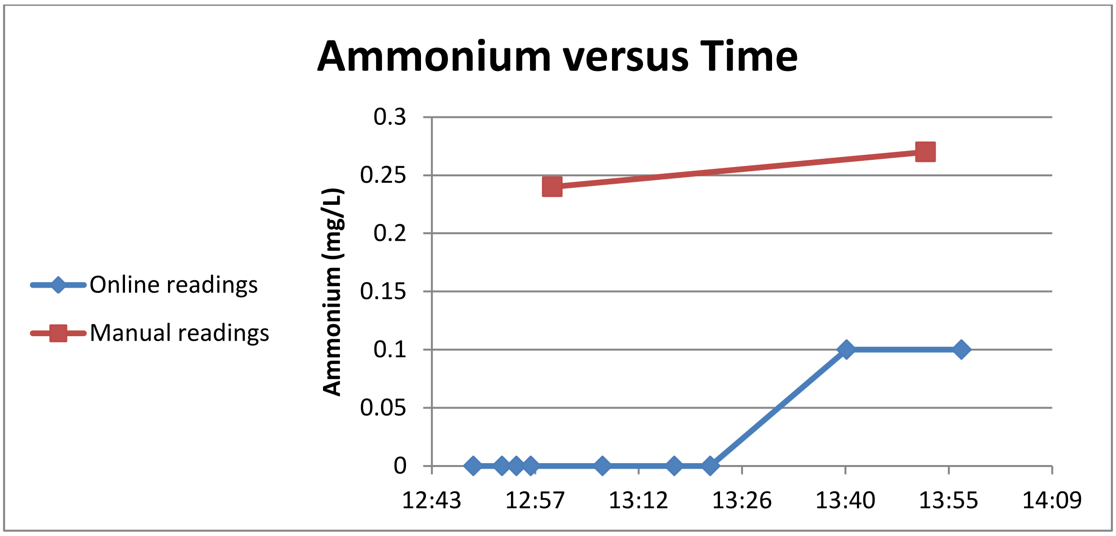

Figure 62 Ammonium over time in Tuppurala, online and manual readings

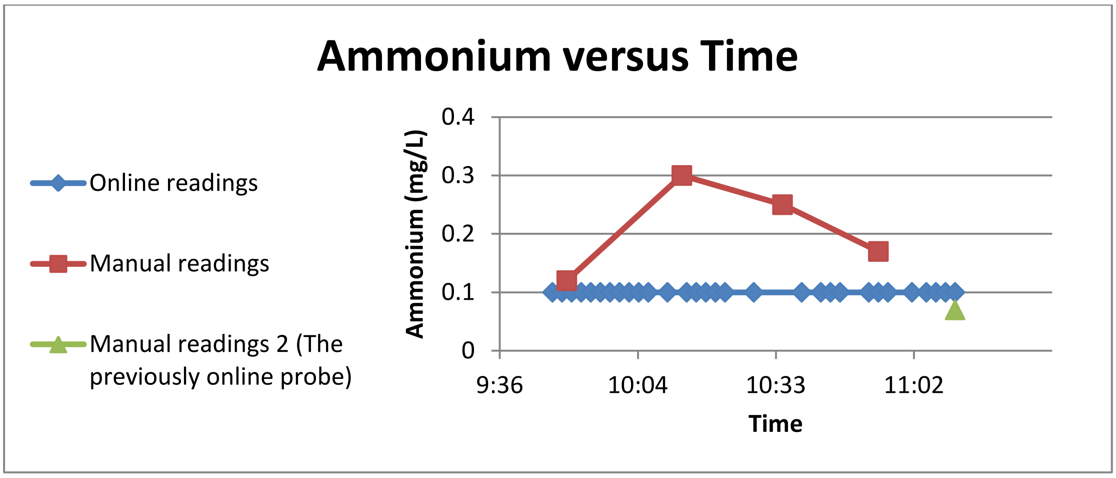

Figure 63 Ammonium change over time in Pitkäjärvi, online and manual readings

In Tuppurala (Fig. 62) the offset between manual and online readings is seen again. Also, the last two points in the online readings showed a different behavior than the rest of the points. This change has been noticed in other parameters before. It can be reasoned to the interference between sensors. The values of both online and manual systems are below the limits (U.S. Environmental Protection Agency 2013). But the laboratory tests showed different results, the ammonium concentration was 0.02 mg/L NH_4^+ which is very less than the measured values.

In the second location (Pitkäjärvi Fig. 63), the manual readings showed a strange behavior against the steady vales of the online readings, even when the other probe was used for the manual sampling the strange behavior continued. Again, the same probe failed to reproduce the same results in manual sampling as it showed in the online sampling. As stated for Tuppurala, both readings showed values under the criteria limits (U.S. Environmental Protection Agency 2013). However, the laboratory tests showed a value of 0.01 mg/L NH_4^+ for the samples taken from that location. This value is lower than the obtained values by the online and manual systems.

The laboratory results showed that Pitkäjärvi is cleaner than Tuppurala regarding the ammonium concentration. The reason (as discussed for nitrate) is the waste water treatment plant withdrawal point.

The results of ammonia showed zero in both locations by both online and manual sampling, therefore the results were not graphically presented.

8.1.14 Refined Oil

Refined Oil in the two locations of Lake Saimaa in two sequence days is presented in Figure 64 and Figure 65.

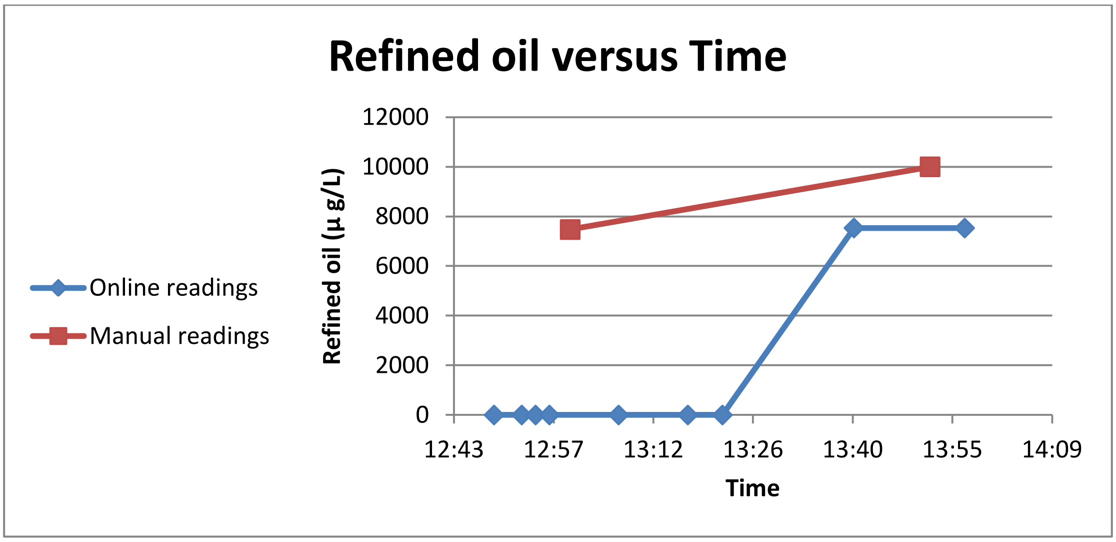

Figure 64 Refined oil change over time in Tuppurala, online and manual readings

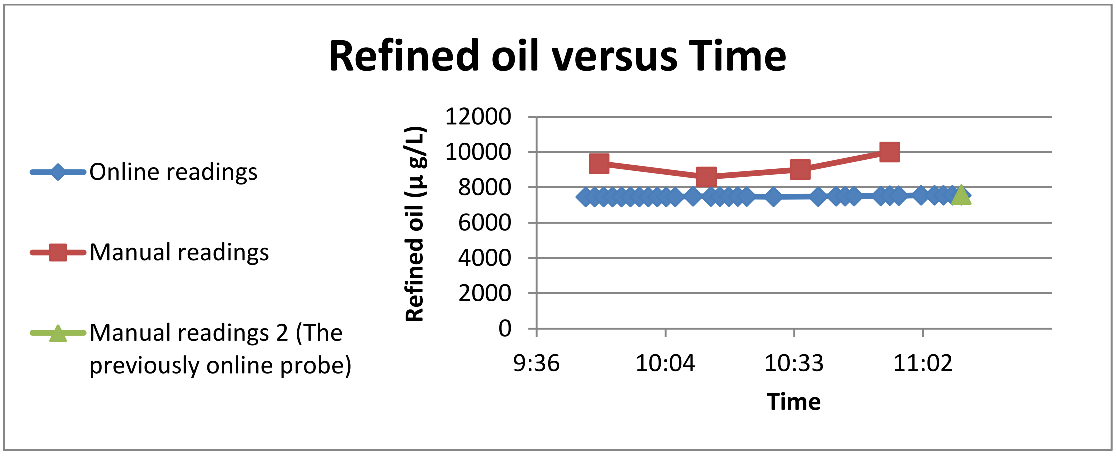

Figure 65 Refined oil change over time in Pitkäjärvi, online and manual readings

In Tuppurala (Fig. 64), differences between online and manual readings are obvious. The huge sudden change in the online readings in the last two points represents a failure in the sensor caused by interference with other sensors. But, since the increase-trend is seen in both online and manual readings, the reason can be pollutions stream passing through the sampling point resulted in the increase but the response to this situation change differs between the manual and online systems.

In Pitkäjärvi (Fig. 65), the online readings showed steady values in contrast to the manual readings which showed a fluctuation. However, some times the manual readings were closer to the online readings but still more than the accuracy range specified by the manufacturer (Trace2o Ltd. 2014).

This parameter (refined oil) results for the last point in Fig. 65 for the manual readings showed that there is a problem with the connection data transfer (cables or GPRS network), because the same probe was not able to reproduce the same values as when it was on the online system.

8.2 Evaluation of the online water quality monitoring system in Lake Saimaa

To evaluate the online water quality monitoring implemented in Lake Saimaa two-step evaluation is needed. The first one is to evaluate Trace2O system. The second step is to evaluate the general concept, applicability and results of online water quality monitoring systems.

8.2.1 Evaluation of Trace2O system

After the two trips to Tuppurala and Pitkäjärvi, intensive testing of the Trace2O system in the laboratory took place. Because the most suspected results were for the Nitrate, standard solutions of nitrate were prepared in the laboratory using Sodium Nitrate. Two standard solutions of 10 mg/ L NO_3 and 100 mg/L NO_3^- were prepared. They were used to isolate the problem in Trac2O system that produced the before-obtained results.

First, the probes were used to measure the nitrate concentration in the standard solutions with the online system manual system. Both failed to show the real concentration. Suspecting raised for the calibration process, therefore, the calibration process was repeated with the same solutions and after that the probes failed to read the correct concentration values, again.

The system was run several times for periods between one hour and overnight test, but it kept giving wrong reading. Based on these results, the manufacturer was called to report this issue with their device. Then, upon agreement with Trace2O, the probe, the cable, and the calibrating device were sent to the manufacturer to test them and do the needed reparations. The results regarding the system which were confirmed by the manufacturer were as follow:

1. The sensors cannot be used as research sensors.
2. The ionic strength of pH (calibration) solution can affect other sensors.
3. High salinity levels (of water samples) may cause an interference of the order of 10mS or higher.
4. The system has interference issues
5. Trace2O probes are designed for trend analysis not for absolute accuracy.
6. The sensors become saturated with ions and will drift rapidly.
7. Fouling on the sensors will cause a drift over time
8. The sensors cannot be relied on to give extremely accurate readings in a continuous monitoring application.
9. Low voltage output from the handheld meter.
10. The 50m cable should not be used during calibration.
11. The need to fit an inline voltage converter in the cable.
12. Some of the sensors have failed themselves.
13. The guarantee of the Nitrate and ammonium sensors is 4 months in water.
14. Interferences issue between sensors
15. Limitation in pH range for the operation-ability of Nitrate and Ammonium sensors
16. Optical sensors can be affected by air bubbles.
17. Chlorophyll sensor can be affected by interference from other microbiological compounds and species, difference in fluorescence response between different species, differences in light and temperature, or interference caused by turbidity.
18. Chlorophyll sensor is not designed to give accurate laboratory grade results.
19. The need of laboratory analysis to establish correlations for a particular water source

20. Refined oil readings suffer from interference of flour and some Bacterial spores, ambient light and temperature differentials, turbidity, or Fluorescent response from different types of oil.
21. Rhodamine Dye readings can suffer interference caused by microbiological species ambient temperature, or turbidity

These defects of Trace2O system affect the reliability. Results cannot be trusted to represent the real values. However, the next section evaluates the online water quality monitoring system in general based on the obtained results.

8.2.2 Evaluation of the whole online system

The system proved its advantages as a result of it implementation in Lake Saimaa. In here the evaluation of the system's efficiency and performance takes place.

1. The systems proved that it reduces the manpower and the human errors. All the required manpower to operate the system in our case was two or three people. If the same number of samples is to be taken during the same period, it will need more people for operation.
2. Also, if the same number of samples is going to be collected with by the same number of operator manually, it will cost more as wages payments.
3. As have been noticed with the EC and TDS the manual samples taken to the laboratory do not give 100% trustful results because of the suspicion of contamination or evaporation which change the results. By using the online monitoring system the values can be trusted that they represent the actual situation of the sample.
4. The utilizing of the ferry with the PaquaBag results in the ability to reach different points in the Lake Saimaa and measuring the water quality there regardless the weather conditions.
5. The quantity of the data collected from Pitkäjärvi for example, needs much more time to be collected by the conventional method. There was one data point for nitrate and ammonium collected by the conventional method and 5 data point by the manual sampling on-site in comparison to around 30 data points by the online system.

6. The ability to determine any rabid change to the water quality, providing with the capability to react in a proper way. For example, in Pitkäjärvi Fig**** DO change in time was easy to track. If manual laboratory -testing is to take place and the samples are collected once a day this change will not be noticed except after a long time. The ability to discover the pollution instantly and react with them is another result for using the online water quality monitoring systems
7. The data which were obtained can be useful for different bodies, for example, Mikkeli municipality, Mikkeli water, or research centers interested in Lake Saimaa.
8. The use of the standard web browser to access the two servers provides the easiness for end-users to handle the system.
9. GPRS showed the ability to be the fast reliable communication network for such applications because of its wide range coverage and data transfer speed.

All of these results are true in only one case, if the readings are reliable. The reading unreliability results from the sensors or the communication network as was seen in the application of Trace2O system. Or it can result from the need of maintenance and regular calibration steps.

9 Conclusions and recommendations

Upon the accomplishment of this work, it was obvious that the needs for regular monitoring of the water quality have to be fulfilled. There are several parameters that can be assessed to determine the water quality. In Lake Saimaa, Finland the need for online water quality monitoring is stronger. The design of the system should suit the area where the system to be implemented. The results of the different parameters measured in this thesis and the evaluation results show the need for more development and improvement in the system to solve the face problems. The future needed solutions and recommendations are as follow:

1. There should be more focus on main parameters. Some of the measured parameters refer to the same water condition, for example chlorophyll a and rhodamine dye. Therefore, reduction in the capital and maintenance costs can be achieved.

2. There should be more considerations for the area/location where to implement the online water quality monitoring systems. Climate and geography of the area has to be studied and then the system has to be modified accordingly.
3. Furthermore, the climate and the geography should be considered when designing the different part of the system.
4. Testing of any online water quality monitoring system has to take place in the laboratory first before running the field tests. Otherwise, time consumption will be the case.
5. The evaluation of the online water quality monitoring system show that the biggest limitations are with the hardware (mainly the data collecting instruments) supplied from third parties. To solve this, following point should be considered regarding the sensors:
    a. There should be deep discussion with the manufacturer about the conditions where their devices are going to be used and installed.
    b. There should be more research for development of new sensors that are able to handle different ambient conditions.
    c. There should be less number of sensors and parameters measured with the same probe to kill off or at least to reduce the interference between sensors.
    d. If the same number of sensors and parameters are needed for some reasons, there should be division of these sensors to different probes to avoid the interference.
    e. If the interference is resulted from the nature of the measured value, for example, photochemical properties of the water body, then the sensors for these parameters should not be coupled together but separated in different probes.
    f. On the other side, the interference results from different types of measurements, such the interference between physical parameters and electrical parameters, then, there should be coupling between sensors which are alike together in one probe.
    g. There should be long-period tastings with extended warranty for any system to assure its reliability before being implemented for open systems.
6. In general, there is a need to get certifications from a neutral party that the manufactured system is ready for implementation according to the needs of the

customer and the conditions of the location. Therefore, each online monitoring system is assessed individually as concluded by Storey et al. (2011) too.

At the end, the train from Lappeenranta stopped in its last destination (Central railway station) in Helsinki. One passenger wearing a black coat and carrying a diplomatic bag was preparing himself to ride off. His intention was to take a taxi directly to one of the Finnish authorities responsible for the environmental protection in Lake Saimaa. He was reading this master's thesis during his trip from Lappeenranta to Helsinki in order to make sure he remembers all of the conclusions and recommendations included there. Once this master's thesis came to his hands he decided that he has to carry these conclusions and recommendation to responsible people. Therefore, he took the trip to Helsinki for the sake of keeping a clean environment and to prevent any catastrophe situation that might occur, as the imaginary described situation in the introduction, between the father and his son.

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Appendixes

Appendix I: The saturation values in mg/L according to temperature and salinity (Kemker 2013)

TEMPERATURE (°C)	SALINITY (g/kg)								
	0	5	10	15	20	25	30	35	40
0	14.621	14.120	13.636	13.167	12.714	12.277	11.854	11.445	11.051
1	14.216	13.733	13.266	12.815	12.378	11.956	11.548	11.154	10.773
2	13.829	13.364	12.914	12.478	12.057	11.650	11.256	10.875	10.507
3	13.460	13.011	12.577	12.156	11.750	11.356	10.976	10.608	10.252
4	13.107	12.674	12.255	11.849	11.456	11.076	10.708	10.352	10.008
5	12.770	12.352	11.947	11.554	11.175	10.807	10.451	10.107	9.774
6	12.447	12.043	11.652	11.272	10.905	10.550	10.206	9.872	9.550
7	12.139	11.748	11.369	11.002	10.647	10.303	9.970	9.647	9.335
8	11.843	11.465	11.098	10.743	10.399	10.066	9.744	9.431	9.128
9	11.559	11.194	10.839	10.495	10.162	9.839	9.526	9.223	8.930
10	11.288	10.933	10.590	10.257	9.934	9.621	9.318	9.024	8.739
11	11.027	10.684	10.351	10.028	9.715	9.412	9.117	8.832	8.556
12	10.777	10.444	10.121	9.808	9.505	9.210	8.925	8.645	8.379
13	10.537	10.214	9.901	9.597	9.302	9.017	8.739	8.470	8.210
14	10.306	9.993	9.689	9.394	9.108	8.830	8.561	8.300	8.046
15	10.084	9.780	9.485	9.198	8.921	8.651	8.389	8.135	7.888
16	9.870	9.575	9.289	9.010	8.740	8.478	8.223	7.976	7.737
17	9.665	9.378	9.099	8.829	8.566	8.311	8.064	7.823	7.390
18	9.467	9.188	8.917	8.654	8.399	8.151	7.910	7.676	7.449
19	9.276	9.005	8.742	8.486	8.237	7.995	7.761	7.533	7.312
20	9.092	8.828	8.572	8.323	8.081	7.846	7.617	7.395	7.180
21	8.914	8.658	8.408	8.166	7.930	7.701	7.479	7.262	7.052
22	8.743	8.493	8.250	8.014	7.785	7.785	7.561	7.344	6.929
23	8.578	8.334	8.098	7.867	7.644	7.426	7.214	7.009	6.809
24	8.418	8.181	7.950	7.725	7.507	7.295	7.089	6.888	6.693
25	8.263	8.032	7.807	7.588	7.375	7.168	6.967	6.771	6.581
26	8.113	7.888	7.668	7.455	7.247	7.045	6.849	6.658	6.472
27	7.968	7.748	7.534	7.326	7.123	6.926	6.734	6.548	6.366
28	7.827	7.613	7.404	7.201	7.003	6.810	6.623	6.441	6.263
29	7.691	7.482	7.278	7.079	6.886	6.698	6.515	6.337	6.164
30	7.558	7.354	7.155	6.961	6.772	6.589	6.410	6.236	6.066
31	7.430	7.230	7.036	6.846	6.662	6.483	6.308	6.137	5.972
32	7.305	7.110	6.920	6.735	6.555	6.379	6.208	6.042	5.880
33	7.183	6.993	6.807	6.626	6.450	6.278	6.111	5.948	5.790
34	7.065	6.879	6.697	6.520	6.348	6.180	6.017	5.857	5.702
35	6.949	6.767	6.590	6.417	6.248	6.084	5.924	5.768	5.617
36	6.837	6.659	6.485	6.316	6.151	5.991	5.834	5.681	5.533
37	6.727	6.553	6.383	6.218	6.056	5.899	5.746	5.597	5.451
38	6.619	6.449	6.283	6.121	5.963	5.810	5.660	5.513	5.371
39	6.514	6.348	6.186	6.027	5.783	5.722	5.575	5.432	5.292
40	6.412	6.249	6.090	5.935	5.783	5.636	5.492	5.352	5.215

Appendix II: The technical details for DR 2800 (HACH-LANGE 2013)

Performance Specifications	
Operating Mode	Transmittance (%), Absorbance and Concentration
Source Lamp	Gas-filled Tungsten (visible)
Wavelength Range	340–900 nm
Wavelength Accuracy	± 1.5 nm
Wavelength Reproducibility	< 0.1 nm
Wavelength Resolution	1 nm
Wavelength Calibration	Automatic
Wavelength Selection	Automatic, based on method selection
Spectral Bandwidth	5 nm
Photometric measuring range	± 3.0 Abs in Wavelength Range 340–900 nm
Photometric Accuracy	5 mAbs at 0.0–0.5 Abs 1% at 0.50–2.0 Abs
Photometric Linearity	< 0.5%–2 Abs < = 1% at > 2 Abs with neutral glass at 546 nm
Stray Light	< 0.2% T @ 340 nm with KV450/3 < 0.1% T @ 340 nm with $NaNO_2$
Data storage	500 measured values (result, date, time, sample ID, user ID)
User programs	50
Physical and Environmental Specifications	
Width	220 mm (8.6 in)
Height	135 mm (5.3 in)
Depth	330 mm (12.9 in)
Weight	4.06 kg (8.95 lbs) without battery 4.38 kg (9.66 lbs) with battery
Operating Requirements	10–40 °C (50–104 °F), max. 80% relative humidity (non-condensing)
Storage Requirements	-40–60 °C (-40–140 °F) max. 80% relative humidity (non-condensing)

Appendix III: The set of data obtained from Tuppurala on 9/Sep/2014 and from Pitkäjärvi 10/Sep/2014.

Tuppurala 9/Nov/2014

		SamplingTime	Temperature (C)	pH	Turbidity (NTU)	EC (µS)	Salinity (g/L)	TDS (mg/L)	SSG	Chlorophyll a (µg/L)	RhodamineDye (µg/L)	DO (%)	ORP (mV)	Nitrates (mg/L)	Ammonia (mg/L)	Ammonium (mg/L)	RefinedOil (µg/L)
Online readings	1	12:49	18.7	7	0	93	0.05	69	-1.4	85.8	69.9	107	135.4	0	0	0	0
	2	12:53	18.8	7	0	94	0.05	70	-1.4	88.8	70.5	107.6	137	0	0	0	0
	3	12:55	18.8	7	0	94	0.05	70	-1.4	87.2	68.8	107.5	137	0	0	0	0
	4	12:57	18.8	7	0	94	0.05	70	-1.4	89.9	68.6	107.5	137	0	0	0	0
	5	13:07	18.6	6.9	0	93	0.05	69	-1.3	88.4	68.9	107.5	141.6	0	0	0	0
	6	13:17	18.6	6.8	0	93	0.05	69	-1.3	86.6	71.5	107.7	145.7	0	0	0	0
	7	13:22	18.5	6.8	0	94	0.05	69	-1.3	85.9	67.8	107.4	145.5	0	0	0	0
	8	13:41	18.5	7.1	90	113	0.06	85	-1.2	75.6	533	113.6	135.2	855.8	0	0.1	7535
	9	13:57	18	7.1	89.8	116	0.07	87	-1.2	76	534	116.5	124.4	883.2	0	0.1	7531
Manual readings	1	13:00	17.8	7.12	540	118	0.04	87	0	87	74	113.5	89.1	446.1	0	0.24	7472
	2	13:52	18.7	6.89	91.7	92	0.03	65	0	93	71.7	108.8	110	0.53	0	0.27	10000

Pitkäjärvi 10/Nov/2014

		SamplingTime	Temperature (C)	pH	Turbidity (NTU)	EC (µS)	Salinity (g/L)	TDS (mg/L)	SSG	Chlorophyll a (µg/L)	RhodamineDye (µg/L)	DO (%)	ORP (mV)	Nitrates (mg/L)	Ammonia (mg/L)	Ammonium (mg/L)	RefinedOil (µg/L)
Online readings	1	9:47	17.2	6.4	85.1	57	0.04	44	-1.1	74.6	536	106.7	171.5	139.3	0	0.1	7456
	2	9:49	17.2	6.4	85.1	57	0.04	44	-1.1	74.6	536	106.7	171.5	148.9	0	0.1	7456
	3	9:51	17.2	6.4	85.1	57	0.04	44	-1.1	74.6	536	106.7	171.5	155.4	0	0.1	7456
	4	9:53	17.2	6.4	85.1	57	0.04	44	-1.1	74.6	536	106.7	171.5	161.9	0	0.1	7456
	5	9:55	17.2	6.4	85.1	57	0.04	44	-1.1	74.6	536	106.7	171.5	171.3	0	0.1	7456
	6	9:57	17.2	6.4	85.1	57	0.04	44	-1.1	74.6	536	106.7	171.5	175.3	0	0.1	7456
	7	9:59	17.2	6.4	85.1	57	0.04	44	-1.1	74.6	536	106.7	171.5	176.8	0	0.1	7456
	8	10:01	17.2	6.4	85.1	57	0.04	44	-1.1	74.6	536	106.7	171.5	178.3	0	0.1	7456
	9	10:03	17.2	6.4	85.1	57	0.04	44	-1.1	74.6	536	106.7	171.5	181.2	0	0.1	7456
	10	10:05	17.2	6.4	85.1	57	0.04	44	-1.1	74.6	536	106.7	171.5	181.8	0	0.1	7456
	11	10:07	17.2	6.4	85.1	57	0.04	44	-1.1	74.6	536	106.7	171.5	184.9	0	0.1	7456
	12	10:11	17.3	6.8	85.3	57	0.04	44	-1.1	72.3	537	107.6	191.9	177.8	0	0.1	7494
	13	10:15	17.3	6.7	87	58	0.04	44	-1.1	73.9	536	107.5	195.6	182.2	0	0.1	7477
	14	10:17	17.3	6.7	81.9	57	0.04	44	-1.1	73.9	537	108	196	186.5	0	0.1	7472
	15	10:19	17.3	6.7	83.8	57	0.04	44	-1.1	73.4	536	108.1	199	187.1	0	0.1	7470

	16	10:21	17.4	6.7	84.2	57	0.04	44	-1.1	74.2	534	108.2	191.2	188.8	0	0.1	7477
	17	10:23	17.4	6.7	84.6	58	0.04	44	-1.1	74.2	534	108.2	200.8	194	0	0.1	7476
	18	10:29	17.4	6.6	85	58	0.04	44	-1.1	73.1	536	107.8	210.6	185.5	0	0.1	7464
	19	10:39	-238	15.9	86.2	6	0.04	44	-1.1	76.6	536	108.5	1562	189.8	0	0.1	7472
	20	10:43	17.5	6.6	83.3	58	0.04	45	-1.2	75.3	537	108.6	220.7	200.8	0	0.1	7497
	21	10:45	17.5	6.6	84.3	58	0.04	44	-1.2	74	534	108.5	220.7	210.2	0	0.1	7499
	22	10:47	17.5	6.6	85.3	59	0.04	45	-1.2	73.4	531	108.4	222	217.1	0	0.1	7504
	23	10:53	17.4	6.6	82.2	58	0.04	44	-1.1	72.9	535	108.5	226.9	197	0	0.1	7511
	24	10:55	17.4	6.7	83.8	58	0.04	44	-1.1	73.5	536	108.6	225	210.1	0	0.1	7531
	25	10:57	17.4	6.7	86.1	58	0.04	44	-1.1	75.1	534	108.8	226	227.4	0	0.1	7524
	26	11:02	17.4	6.7	86	58	0.04	44	-1.1	73.3	533	108.6	229.4	243.7	0	0.1	7552
	27	11:05	17.4	6.7	86	58	0.04	44	-1.1	73.3	533	108.6	229.4	243.7	0	0.1	7552
	28	11:07	17.4	6.7	86	58	0.04	44	-1.1	73.3	533	108.6	229.4	243.7	0	0.1	7552
	29	11:09	17.4	6.7	86	58	0.04	44	-1.1	73.3	533	108.6	229.4	243.7	0	0.1	7552
	20	11:11	17.4	6.7	86	58	0.04	44	-1.1	73.3	533	108.6	229.4	243.7	0	0.1	7552
Manual readings	1	9:50	17.9	7.5	98.8	32	0.01	24	0	89	68	102	134.8	0.18	0	0.12	9340
	2	10:14	18	6.67	98.2	32	0.01	23	0	88.6	71.1	102.8	160.6	0.05	0	0.3	8589
	3	10:35	18.2	6.47	97.5	32	0.01	23	0	89.3	69.1	103.3	134.8	0.08	0	0.25	9011
	4	10:55	18.2	6.64	98.1	34	0.01	24	0	88.5	69.2	104.4	138.1	0.14	0	0.17	10000
Previously online probe		11:11	17.4	6.82	537	58	0.02	42	0	85.9	73.3	110	223.5	168	0	0.07	7598