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## Abbreviations

| | |
|---|---|
| ADSL | Asymmetric Digital Subscriber Line |
| BH | Borehole |
| DWAF | Department of Water Affairs and Forestry |
| GSM | Global System for Mobile Communications |
| IoT | Internet of Things |
| JMP | Joint Monitoring Programme |
| JTU | Jackson Turbidity Unit |
| NTU | Nephelometric Turbidity Unit |
| pH | potential hydrogen |
| SANS | South African National Standards |
| SDGs | Sustainable Development Goals |
| TCP | Transmission Control Protocol |
| TDS | Total dissolved salts |
| THMs | Trihalomethanes |
| TSS | Total Suspended Solids |
| TWAD | Tamilnadu Water Supply and Drainage Board |
| UDP | Transmission Control Protocol |
| UNDP | United Nations Development Program |
| UNICEF | United Nations Children's Fund |
| WHO | World Health Organization |
| WPAN | Wireless Personal Area Network |
| WSAs | Water and Sewer Authorities |
| WSP | Water and Sanitation Program |

| | |
|---|---|
| WUC | Department of Water Utilities Corporation |
| WASA | Water and Sanitation Authority |

# 1 Chapter 1 Introduction

## 1.1 Introduction

Water is an essential element in our lives. It is one of the most important substances on earth. It is a basic necessity for all living organisms including human beings, animals and plants. People not only use water for drinking, they also use water for cooking, washing their bodies, washing clothes, rinsing kitchen utensils and gardening. Water is also used in agriculture and in industries for product manufacturing. There is no life without water on earth. Furthermore, water is a vital nutrient for human beings and it is critical to sustaining life [4]. Most of the fresh water comes in the form of rainfall, hail, fog and snow. Approximately seventy percent of the earth is covered with water (most of it is saline) occurring in different oceans of the world [34].

Human bodies are made of seventy-five percent water. In a body, water has many functions, such as, supporting the digestion system, absorption, transportation, use of nutrients and the elimination of toxins from the body [3]. The organs of a healthy body normally need one to eight glasses of water per day to function properly [2]. The quality and quantity of water intake are both important for humans and animals. For example, dehydration occurs in a body when it takes in less water than normal consumption. The quality of water affects our health and other activities of life. When a person drinks water from a source that is contaminated they open themselves up to numerous health risks. Water supplying authorities need to make sure that the water supplied is free of toxins and other harmful contaminations [5, 8]. For the safe use of water by all organisms on the planet, the quality of water must be acceptable and standards for water quality are the responsibility of public water departments.

In some developing countries, a large proportion of the population suffers from health problems associated with the lack of good quality drinking water and the presence of contamination in water sources [12]. It is estimated that around five million children die annually around the world due to the poor quality of drinking water [13]. This problem is more aggravated by the rapid increase in population in some areas resulting in extra pressure on the existing water resources [15].

In many parts of the world, such as Kenya for example, a decade of drought has been a major issue causing poor water supply. There are approximately seventeen million people in Kenya out of a population of forty million people who do not have access to the clean water. According to the World Bank, less than half of the rural population of Kenya has access to clean water, as opposed to the urban population where eighty-five percent of people have access to safe water [16]. In addition, seventy percent of the industrial waste in the developing countries are disposed of into the water channels leading to contamination of water supplies [10].

To improve public health, a call to action was made in 2000 in the form of the Millennium Development Goals approved by the World Health Organisation (WHO). It includes a set of eight goals proposed to improve lives and provide basic rights to human beings. The seventh goal is related to the water issue. It calls for environmental sustainability as well as good drinking water quality. In this goal, there are several targets, such as to reduce the percentage of global population without access to safe water and sanitation. A survey was conducted by WHO/UNICEF under the Joint Monitoring Programme (JMP) to monitor water supply and sanitation. This was needed because most people do not know the quality of water they are drinking [55].

The Sustainable Development Goals approved by the United Nations Development Program (UNDP) mentions that since 1990, 2.6 billion people have been able to get access to cleaner sources of water. Another figure published in the Sustainable Development Goals by the UNDP, estimated that at least 1.8 billion people globally use a source of drinking water that is faecesally contaminated [9, 14]. Water quality is also decreasing due to human activities such as increase in population and expansion of industry and agriculture. The World Health Organization (WHO) and United Nations Children's Fund (Unicef) announced in 2006 that ninety five percent of urban people had access to safe drinking water while in developing countries this was seventy-three percent [11]. The problems of water quality do not only exist in the developing world. In France, the water supplied to three million people did not meet the WHO standards for drinking water and 97% of ground water samples did not meet the nitrate standards [50].

It is a major challenge for municipalities and water authorities in many parts of the world to provide access to safe and clean drinking water for domestic use with growing demands [37, 40]. In developing countries, the demand for safe and clean drinking water has become more serious with rapidly growing population [38].

## 1.2 Water situation in South Africa

Many countries on the African continent are situated on a hydrographic network, however, the availability of fresh water differs from country to country. For instance, South Africa is largely a semi-desert country. The weather, global warming, poor rainfall, and wastage of water affects the reliability and variability of river flow accounting for most of the fresh water resources [33, 34, 35]. South Africa is a water scarce country with respect to fresh water [5, 17]. The quality of raw water that is available for drinking and other uses varies both temporally and spatially. This variation changes substantially with seasons as well as being source dependent [23]. For example in a river the amount of dissolved oxygen may vary due to runoff. Drinking water quality may also depend on location and climate in an area. [24, 25, 26].

In South Africa, more than seven million people, which is approximately seventeen percent of the population, do not have access to safe drinking water [30]. They are forced to consume water from low quality water sources. Non-potable water causes numerous health risks in the form of waterborne diseases. For example, of these deaths, approximately 20% are young children up to the age of five years [32]. Thus it’s important to understand that unclean water in household is not good for drinking [7]. Hence, it is important to improve the monitoring of drinking water quality through proper management and holistic approaches [31]. In South Africa, research and historical data sets have demonstrated that eighty-one percent of urban communities had potable water in 1990, while in 2008 ninety nine percent people in urban areas had access to safe drinking water. In comparison, only seventy eight percent of people in rural areas had safe drinking water in 2008 [5].

Many governments are working on legislation to ensure that consumers are provided with safe drinking water. In South Africa, the government has also recognized the impact of poor quality water on the health of citizens. This has resulted in the government passing substantial legislation. Some of this has been included in the Constitution as well such as, section 24 of the Bill of Rights, (Constitution of the Republic of South Africa, Act No. 108 of 1996), the National Water Act (36 of 1998), the Water Services Act (108 of 1997) and the National Health Act (61 of 2003). As a result of these efforts, the South African Government has set up one of the largest government departments, namely the Department of Water Affairs and Forestry (DWAF); to regulate drinking water quality [35]. The main objective of this governmental department is to ensure that consumers are provided with safe drinking water. Water should be treated and made suitable before it is supplied if there was a problem with the water quality at source [56].

DWAF also maintains and follows the South African National Standards (SANS) for water quality aligned with recommendations from WHO. Local authorities regularly monitor the quality of water. These authorities are also rated according to the Blue Drop Certification System. People are advised to avoid drinking water from streams and rivers, especially in areas where there is human habitation, since it causes contamination resulting into water-borne diseases [47].

The South African Government has implemented regulations and policies to deliver safe water, but the local municipalities have not necessarily caught up with the national guidelines. This is particularly true for rural communities and municipality where water supply is only partially reticulated and treated, and a majority of the population still rely on individual boreholes. The low compliance rate is generally explained using reasons of under-resourcing, skill shortages, lack of understanding of required standards, lack of intervention to address problem areas, inadequate management, and limitations on finances, assets and fiscal accountability [49. 115].

High incidences of poor water quality are common in rural areas of South Africa, therefore it is evident that non-metro Water and Sewer Authorities (WSAs) of local government in South Africa are struggling to provide safe drinking water to their communities. Rural water monitoring and management is also difficult due to remote locations and vast areas. Water in rural areas is often supplied through borehole (BH) schemes accessed by poor roads. This makes monitoring difficult due to travel times and in some instances, boreholes are not directly accessible by road [46]. The South African Government has also implemented many rural water supply schemes under the National Reconstruction and Development Program (RDP) to provide clean and safe water. However, clean and safe drinking water is still a dream in many rural areas of South Africa [45].

The primary objective of the Water and Sanitation Program (WSP) is to ensure that supplied water has minimum containments or harmful particles. It is also required to reduce or remove contamination through treatment and prevent drinking water from contamination during storage, distribution, and handling. These objectives are also applied to household systems, large piped drinking water supplies, and small community supplies [46].

## 1.3 Objective of work

1. Identify the set of critical quality parameters that are most important to monitor in a water sample.
2. Propose an idea to develop a system that is cheaper and efficient to check the quality of water.
3. The system should be capable to insure real time quality monitoring and enabling properties for the authorities to take timely corrective action.
4. Develop and test a prototype for proof of concept and to verify the hypothesis.
5. Discuss the results.
6. Conclude with future recommendations.

## 1.4 Organization of dissertation

**Chapter 2:** The chapter 2 includes a review of relevant research conducted in relation to water quality and safe water supply to the ever growing human population especially in the rural areas of the South Africa.

**Chapter 3:** Chapter 3 covers the details about the research question and describes the methodology used for answering the question. Under section 3.3 a proposed solution has been presented and discussed.

**Chapter 4:** Chapter 4 is about to proposed different systems (system that is proposed in chapter 3). At the end selected one system that is suitable for this research question.

**Chapter 5:** Chapter 5 is about the implementation of a proposed system (systems that are proposed in chapter 4). The main content of this chapter is about the proposed system's design and its implementation.

**Chapter 6:** Chapter 6 is about to provide the details about how the experimentation was conducted in laboratory and in proof of concept purposes.

**Chapter 7:** Chapter 7 is about to analyses these results and concludes with some recommendations for the electricity utilities.

# 2 Chapter 2 Literature Review

## 2.1 Introduction

Water quality is a serious concern in today's world. The population is increasing at a rapid rate and putting pressure on the natural resources and one of them is clean drinking water. Water quality depends on many factors, and the factors resulting in the deterioration of water quality are increasing with time. These include industries, mining, agriculture, human and environmental f.actors. This chapter includes a review of relevant research conducted in relation to water quality and safe water supply to the ever growing human population especially in the rural areas of the South Africa.

## 2.2 Sources of drinking water

There are many ways to collect water for household use. The main sources of fresh water are surface water, ground water, river or lake water, rock catchment areas and rock holes, excavated dams, rainwater tanks, boreholes, springs and wells. [39].

There are two major sources of drinking water [41].

1. Surface water that comes from wetlands, rivers, streams, lakes, and dams. This also includes snow and ice as solid forms of water. Surface water is easiest to access, it does not require any mechanical operation, as ground water does, and it also does not require collection of rain water. Therefore, it requires treatment before it becomes usable for domestic needs.
2. Ground water which is the water under the surface of the ground includes springs, wells and boreholes [42]. A large portion of this water is a form of surface water that has seeped down. It is stored in and absorbed slowly through geologic formations of the soil, sand and rocks called aquifers. Soil acts as a natural filter for ground water.

The other sources of water are non-potable and treatment has to be done to make sure that water is potable before it is supplied for domestic usage. People who live in urban areas, mostly have access to surface water, which is supplied by local municipalities and goes through some treatment before the point of consumption. Municipalities treat and distribute water through networks of pipes to their consumers [43]. In contrast to urban areas, rural areas mostly are supplied with water from underground sources [44].

## 2.3 Water quality

Water that looks safe and clean may still contains microbiological organisms or pathogens that can lead to different diseases. Water is a good solvent and picks up impurities very easily. In 1969, when Neil Armstrong landed on the moon, he described Planet Earth as "a shining blue pearl spinning around in space". This shinning blue colour represents water [17]. Approximately, seventy percent of earth is covered by water, out of which 97.5 % is salt water. Furthermore only 3% is fresh water and of this 3%, two-third water is in a frozen form such as glaciers. Only about 1% of fresh water is available for life on Earth [17, 18].

"Water quality is defined in terms of chemical, physical, and biological content of the water" [19]. According to the World Health Organization, good water quality is defined as water that is safe to drink and free from contaminants and does not represent any significant risks to health over a lifetime of consumption [21, 36]. Over the last decades access to safe water has improved in every part of the world. However, in developing countries, one billion people still do not have access to clean drinking water. In 2010, 884 million people in the world used polluted drinking water and in 2015 672 million people still used water from polluted sources. It has also observed that existing fresh water resources are becoming polluted due to human and industrial activities. The increase in pollution and rapid industrialization is causing water pollution in many countries [21].

## 2.4 Drinking water parameters

Drinking water suppliers are always responsible for the quality and safety of the water that they are providing [71, 114]. Drinking water quality refers to physical, chemical, and microbiological content of water dissolved or suspended [71].

### 2.4.1 Physical parameters

The physical parameters of drinking water quality include physical properties of water that includes taste, colour (cloudiness of the water) and odour [58]. These properties do not cause a direct health risk but could be the sign of a potential problem. The presence of dissolved organic carbon (DOC) increases the amount of organic material in the water [5]. The dissolved, organic carbon if combined with chlorine to form trihalomethanes (THMs) can cause cancer [71]. Therefore, it is important to monitor the physical factors of water. Authorities generally monitor pH, turbidity, dissolved solids and electrical conductivity to check the physical drinking water quality. The physical properties and their effects in water are listed in Table 1 [59].

*Table 1: Physical properties of water*

| Physical Properties of Water | | |
|---|---|---|
| **Key Substances** | **Ranges** | **Physical effects** |
| Electrical conductivity | 0.005-0.05 S/m | Total dissolved salts (TDS): Serves as a general indicator of change in water quality and affects the taste and "freshness" of the water. |
| pH | 6-8 | Affects the taste and corrosiveness of water. Water is either acidic or alkaline. |
| Turbidity | 5 NTU/JTU or less | Indicates the colour of water (cloudiness), usually as the result of colloidal material. |
| Temperature | $15^0$C -$25^0$C | Indicates the level of bacterial activities. If the temperature is low, the bacterial activity is slow. Otherwise bacteria growth and production is fast. The toxicity increases with increases in temperature. |
| Taste/Odour | ___ | Taste can be influenced by temperature, TDS, and pH. Normally taste becomes sour (hydrochloric acid) or bitter (caffeine). Odour can also be caused by organic substance (THMs). |
| Colour (TCU) | 15-20 | Colour and turbidity influence the appearance of water. It changes due to dissolved (true colour) or colloidal (apparent colour) material i.e iron, manganese and clay. |
| Hardness | 50 mg/l CaCO3- 150 mg/l CaCO3 | Indicate the amount of dissolved calcium and magnesium in the water. Hard water is high in dissolved minerals, both calcium and magnesium. |
| Note: These are the basic physical factors, which are normally measured. There are many other factors that affect the quality of water | | |

### 2.4.2 Chemical parameters

Chemical parameters of drinking water quality are affected through nature and concentration of dissolved substances like salt, metal and organic compounds. The dissolved chemicals can cause serious health risks and aesthetic problems [27]. South African Nation Standards (SANS) divide the chemicals into three categories which are macro, micro and organic. The chemicals that can cause major health risks are arsenic (As), nitrate (N), and fluoride (F). If the values of these chemicals are more than allowed in South African Nation Standards (SANS), it could cause cancer, methemoglobinaemia, and mottling of teeth [6, 57]. The chemical properties and their effects are described in Table 2 [48].

*Table 2: Chemical properties of water*

| **Chemical Properties of Water** | | |
|---|---|---|
| **Key Substance** | **Ranges** | **Effects** |
| Arsenic | 0.01 mg/l - 0.05 mg/l | Excessive amounts can make the water poisonous and may also cause cancer |
| Cadmium | 0.003 mg/l - 0.005 mg/l | May affect the toxicity of the water |
| Calcium | ___ | Causes scaling in pipes; affects taste of water |
| Sodium and chloride | 150 mg/l -200 mg/l (Sodium)<br>250 (Chloride) | May impart a salty taste to the water |
| Fluoride | 1.5 mg/l -2 mg/l | Excessive amounts stain teeth and cause crippling skeletal deformities |
| Iron and manganese | 0.3 mg/l (iron)<br>0.5 mg/l (manganese) | May discolour water; excessive amounts may be toxic |
| Magnesium | ___ | Excessive amounts make water bitter and may cause diarrhoea. |
| Nitrate and nitrite | 10 mg/l | May be toxic to infants |
| Potassium | ___ | Imparts a bitter taste; toxic in large amounts |
| Zinc | 1-5 mg/l | May affect the taste of water - makes the water bitter |
| Note: These are the basic chemical factors, which are normally measured. There are many other factors that affect the quality of water | | |

### 2.4.3 Microbiological parameters

The presence of microbiological contents in the water indicates the presence of disease causing organisms (pathogens). These organisms mainly come from faecal origin (enteric pathogen) which includes virus, bacteria and protozoan that cause waterborne diseases such as gastroenteritis, infectious hepatitis and dysentery [68]. In developing countries, diarrhoea is the major cause of illness and death [65]. Because of this, it is important to monitor the microbiological parameters of drinking water. South African Nation Standards (SANS) recommends the microbiological parameters that are important to monitor are, E. coli and total coliforms (rod shaped, gram-negative, non-spore forming, lactose fermenting bacteria). Both of these microbes indicate the faecal pollution in domestic water. The microbiological properties and their effect on water quality is listed in Table 3 [48].

*Table 3: Microbiological properties.*

| Microbiological properties of water | |
|---|---|
| **Key Substance** | **Effects** |
| Total coliforms | Indicates biochemical and growth characteristics. Bacteria multiply at 37º C |
| Thermo-tolerant Coliforms | Bacteria can grow at higher temperature, ie. 44- 45º C |
| Escherichia coli | Thermo-tolerant species that specifically have facial origin. Will grow at 44-45ºC on complex media |
| Faecal streptococci (enterococcl) | Indicate faeces of human and animals. There is a sub-set which is relatively tolerant of sodium, chloride and alkaline pH. |
| Total bacteria and viable bacteria | Indicate the activity of micro-organisms, useful in assessing general microbial content of water. |
| Heterotrophic bacteria | Does not represent all bacteria in water. It only grows and produces visible colonies under prescribed condition of temperature. Colonies generally thrive at 22º C to 31º C |
| Free residual chlorine | Indicates the adequacy of disinfection using chlorine |
| Note: These are the basic microbiological factors, which are normally measured. There are many other factors that affect the quality of water | |

## 2.5 Measuring water quality

Lack of safe water is the single most important reason for the high rate of mortality among young children due to preventable water-related diseases [67]. It is evident from earlier discussion that the monitoring the water quality is important for providing safe and clean drinking water which is still a major challenge in the 21st Century.

In a system the method of monitoring could be continuous or periodic. There are many types of monitoring equipment available in the market using different measurement methods. The equipment could be portable (manual or automated) or fixed. The testing of water could also be done in a laboratory or remotely using portable or permanently installed equipment. There are several technologies available for water testing and monitoring. These technologies vary in cost depending on the parameters measured. The use of a technology also depends upon the parameters and its suitability due to many factors such as location, etc.

Traditionally, chemical and biological parameters are monitored in laboratories. Water samples are sent to the laboratory for analysis. Trained staff test the water quality with care and by applying acceptable quality assurance procedures. These procedures give accurate results. However, laboratory analyses is expensive and time consuming [73].

Automated methods are more appropriate for remote and continuous monitoring of water quality since a low level of skill is needed to operate the equipment. Automated analysis can be fixed at a particular time and frequency in the case of permanently installed equipment. In the case of handheld equipment, the duration of testing is fixed thus eliminating human errors. In manual monitoring, it is difficult to maintain the sampling frequency whereas in automated methods this is controlled by predefined procedures [73].

Many of the water quality parameters can be measured on site however, some of the physical parameters can be accurately checked in the laboratory environment only. The parameters like temperature, conductivity/salinity, pressure/depth, pH, turbidity, transparency, dissolved oxygen, and colour can be successfully checked on site by the automated or handheld systems. Since the required skill level of the person performing the testing is low the cost of labour and time is minimised [73]. Factors such as pathogens and other organic contaminants are generally measured in laboratories.

Portable water quality monitoring systems reduce the time spent collecting samples and providing results. Modern portable devices are sufficiently accurate for field water testing. Individual or integrated instruments can be used to test water to measure temperature, conductivity, dissolved oxygen, pH (alkalinity or acidity of water), turbidity (colour or suspended particles) etc. These portable devices use sensor or electrode technologies. These have improved over the years and light-weight high accuracy sensors are now available to test the water at a significant accuracy. They give fast results with sufficient accuracy. These sensors are generally designed for small scale monitoring and accurate results. The accuracy of these sensors is reduced when used in large scale measurements but still produce acceptable results. Biosensors are generally used in laboratories. These sensors are delicate and expensive and produce highly accurate results. Such biosensor devices are heavier and delicate, therefore their application in the field is difficult.

There are many water quality measuring field kits available in the market which are discs, test strips, drop test kits and dip slides. Generally these kits are used to monitor the presence of E-coli and bacterial contamination, dissolved oxygen, pH, electrical conductivity, temperature difference, turbidity and level of nitrite, nitrate and orthophosphate ions, arsenic, fluoride, iron, residual chlorine, chloride, alkalinity, hardness, aluminium, etc. Portable water monitoring devices provide immediate results and are useful in areas where drinking water safety is compromised.

## 2.6 Related works in water monitoring systems

With the advancement of technology in the recent past much research has been conducted in the area of remote water monitoring systems. There are many researchers who have proposed different systems using the sensors available in the market to monitor the quality of water quickly and efficiently [72, 70, 69, 60, 61, 62, 63 64, 65]. There is also research available where researchers have monitored fewer parameters in a given water sample to conclude whether or not the given sample was safe for drinking. This research has met with limited success.

One example of such research was conducted in South Africa in 2012 [60]. In order to decide the difference between good or bad quality of water, Rivett et al [60] built a cell phone application that was tested in four rural communities in South Africa. The application was installed on the cell phones of the people responsible for supplying water. The application contains a number of questions about the water quality, safety plan and best practices of water. The user's answers, provide guidance to the authority responsible for water quality. A comment box is also available where the user provides information about the physical parameters of tested water such as pH, turbidity, and electric conductivity. Once the form was completed it was then sent to a central server using the cell phone network. The integrity of the data was checked before storing the data into the database. The system also provides a spreadsheet of the data that can be downloaded via an internet application [60].

In Botswana, the employees of the Department of Water Utilities Corporation (WUC) use handheld meters to test water quality [65]. In residential areas tests on water samples are conducted once or twice a week. However, in the industrial and agricultural areas these tests are conducted daily. These tests are generally based on the chemical and microbiological properties of the water. However, this approach is not efficient. It is expensive, needs more human resources, and results are not in real time. The advancement in Micro-Electro-Mechanical Systems (MEMS) and wireless communication systems made it possible to monitor the water quality remotely and in real-time. In 2016 Mompoloki Pule et al [65] introduced a wireless sensor monitoring water quality. The sensor monitors the physico-chemical water quality parameters. These parameters include temperature, pH, electrical conductivity, chloride, nitrates, oxidation reduction potential (ORP) and turbidity [65].

In 2012 Basavaraja et al [70] proposed a set of parameters (from the set of physicochemical parameters) that they claimed was adequate to monitor a water sample. However, there is insufficient scientific evidence to prove their hypothesis. The list of their proposed parameters includes chloride, alkalinity, phosphate, nitrate, total hardness, turbidity, total dissolved solids, temperature, pH, free carbon dioxide and dissolved oxygen. They used their proposed system on a perennial tank. Normally, tank water is used for irrigation in India. Perennial tanks are the source for drinking water for human, livestock, and fish culture. Due to the increase in human population the use of fertilizer has increased in agriculture. This heavily affects the quality of water and depletion of aquatic biota. Therefore, it is important to monitor drinking water quality at regular interval. This system recorded temperature and pH at the time of sample collection using a thermometer and pH meter while all other parameters were monitored in a laboratory [70].

In 2009 Haron et al [72] proposed and developed a remote water quality monitoring system using wireless sensors for a prawn farming pond. They identified three critical water quality parameters relevant to the health of prawns. Those three parameters were pH, temperature, and dissolved oxygen. The team developed a prototype system that checked the water quality through wireless sensors and delivering an alert to the farmers in the form of Short Message Service (SMS) if there is any problem. [72].

In 2009 Marco Zennaro et al [69] described access to safe and clean drinking water as a basic human right. Clean drinking water reduces the global burden of diseases that are caused by waterborne pathogens. To overcome these problems it is necessary to monitor drinking water quality automatically. The list of parameters that Zennaro et al monitored are acidity (pH), dissolved oxygen, and turbidity (a measure of the clarity of the water). They sent the water samples to laboratories for chemical examination. The proposed system monitored the water quality through a wireless sensor monitoring system in Malawi. The sensors are used to collect the data. The communication between node and the back-end systems was established through wireless communication. This system showed two benefits, one is low energy consumption by sleeping and wake up function and another one, is inter-network (gateway used) for the communication [69].

In 2010 Mariana Jurian et al [61] discussed that when the issues in the quality of water are raised, especially for the drinking water quality then, there is a need to have a water quality monitoring system. In their research they propose that the following parameters from the different categories are important to monitor. The physical and chemical parameters are colour, smell, taste, aluminium, free residual chlorine, iron, sulphides and sulphureted hydrogen, pH, conductivity, nitrates, and turbidity. The bacteriological parameters include Coliform bacteria, Escherichia coli, and Colony count at 22°C, Sulphite reducing clostridia, Colony count at 37 °C. In the implementation however they developed a system that is able to monitor pH, electric conductivity, turbidity, temperature, dissolved oxygen and oxidation reduction potential. The parameters are monitored through multi sensors and then values are transmitted to the server through radio connection at regular intervals. At the server side, the values are displayed on a screen and server also stored the received data values in a database for clients' reference [61].

There are many continuous monitoring systems but these systems are extensive at high temporal and spatial resolution. The objective of Aravinda and his team [62] (2013) was to propose a low-cost wireless water quality monitoring system that could monitor the quality of water continuously. Their proposed system monitored pH, temperature, light intensity, electric conductivity, dissolved oxygen, total dissolved solid, salinity and oxidation reduction potential. The system also has an Autonomous Live Animal Response Monitoring (ALARM) component attached with it [62].

Pradeep Kumar et al (2016) develops an Internet of Things (IoT) based on the water quality monitoring system, which monitors the temperature, pH, and turbidity with IoT based technologies. The system detects the values through the sensors and if any value is higher or lower than the pre-set values the system then sends a message to the relevant authority [63].

Pandian D R et al (2015) proposed a system that minimizes the human intervention by using IoT platform. The proposed system monitors temperature, turbidity, and pH. The sensors are connected to Arduino board. The values are sent to the cloud which is Tamilnadu Water Supply and Drainage Board (TWAD) test laboratory. The employees of the TWAD laboratory monitor the data remotely and save this data in the cloud. If any employee requests for data they can securely provide required information to the requested user through cryptography techniques [64].

# 3 Chapter 3 Research question and methodologies

## 3.1 Problem statement

Several researchers have shown that the parameters related to the quality of drinking water can be monitored effectively in the field as well as bringing samples to a laboratory for testing. Many researchers agree that laboratory testing is more comprehensive but is costly and requires a long time to get results. There is also research available where researchers have proposed remote monitoring of water quality based on fewer parameters in a given water sample to conclude whether or not the given sample was safe for drinking. This has met with limited success. There is however limited or no scientific evidence available to validate the effectiveness of the selected fewer parameters to determine the quality of drinking water. The aim of this research is to fill that gap. The research presented in this dissertation proposes a list of fewer parameters that will be monitored to determine the quality of water. The effectiveness of those parameters in determining the quality of drinking water will be verified by conducting a detailed analysis on a number of water samples in a laboratory environment.

## 3.2 Research Question

a) What is the minimum set of measurable parameters that will give an adequate measure of acceptable water quality?

b) What is the lowest cost and most practical device that can be developed to measure this minimum set?

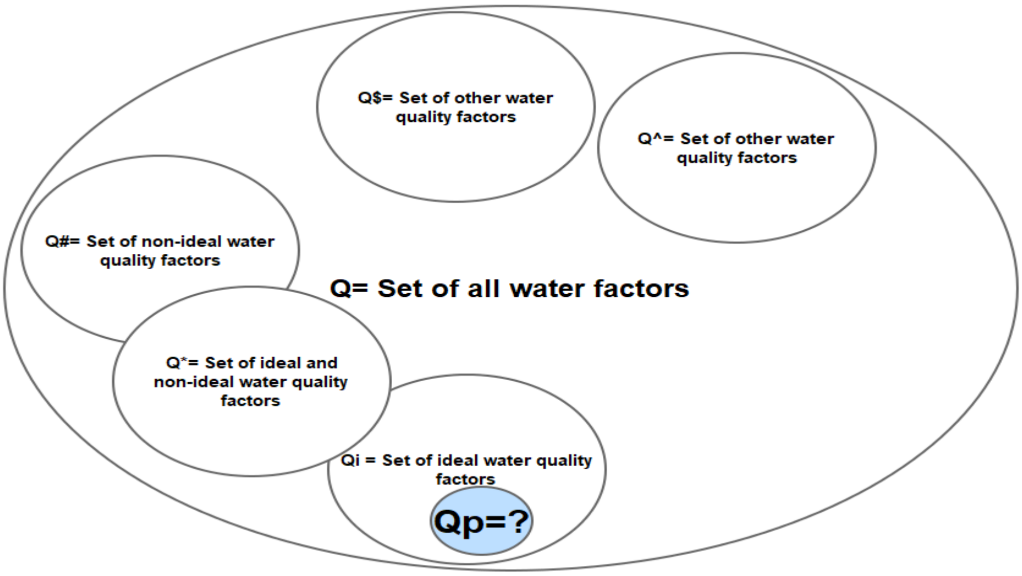


*Figure 1: Set of water factors*

## 3.3 Methodologies

The proposed methodology for conducting this research is as follows:

1. Survey of available research on the topic.
    a. Conduct extensive survey of the available research in the area of water quality management.
    b. Study factors that can degrade the quality of drinking water.
    c. Identify mutual dependence of the factors impacting the quality of the water.
2. Analysis of available sensors.
    a. Study technologies to measure the quality of water.
    b. Compare sensors broadly used to measure the quality of water for their cost, effectiveness, and accuracy
3. Design and implementation of a number of subsystems.
    a. The system is divided into multiple subsystems. Each of those components are separately discussed and designed.
4. Testing the system in real world environment.
    a. The developed proof of concept are tested in the context of a domestic water consumer
5. Comparing the results generated by the system with a detailed analysis done in the laboratory environment.
    a. Compare the results produced in the laboratory with the results obtained from the proof of concept system.
6. Analyse the effectiveness of the system.
    a. In the last section of the report the effectiveness of the system will be discussed.

# 4 Chapter 4 Proposed Solution

## 4.1 Introduction

As indicated in Section 3 this research deals with determining the minimum list of parameters that can generate sufficient information about the quality of drinking water. The research then leads to the proposal of a system that can monitor these parameters automatically and store this information within a back office system for later usage. Finally the research needs to then determine the effectiveness of the chosen parameters by carrying out detailed water analysis within a laboratory environment. In order to achieve these goals the project has been broken into the following phases:

1. Determine, via a literature review the minimum number of parameters which can give sufficient information to determine the water quality at the point of consumption.
2. Propose a cost-effective system that can measure these parameters and transmit the information back to a central server for reporting and decision making.
3. Compare the effectiveness of parameters with detailed laboratory analysis.

## 4.2 Guideline for determining the list of parameters

The review of the existing research literature in Section 2 showed that there are parameters that are absolutely critical to determine the quality of the drinking water. Water will not be considered fit for human consumption and may cause numerous health risks if the value of these parameters are out of acceptable range. The objective of this work is to choose the minimum number of these critical parameters to confirm the quality of the water. The other objective is that the parameter should be measurable with relatively inexpensive electronic sensor devices. The measured results will then be transmitted to a central server. The following factors are considered in choosing the parameters to be tested:

1. Mutual dependency of parameters
2. The effects on drinking water due to industrial and mining factors
3. Speed of measurement
4. Monitoring in field
5. Cost

### 4.2.1 Mutual dependency of parameters

There are many parameters that are mutually dependent. The change in one parameter produces a change of values in other parameters. For example, the value of the pH not only indicates the acidity and alkalinity of the water but also affects the hardness. The inter-dependent parameters can be predicted with a reasonable accuracy if one of the parameters is measured. Therefore an attempt is made in this work to choose a minimum number of parameters that can give an indication of water quality without the measurement of mutually dependent parameters. Another example of this relates to the microbiological parameters. The microbiological factors are monitored in a carefully controlled environment to determine the presence of the microbial load in water. This process is tedious, expensive and requires a longer time to complete. However, temperature levels are directly proportional to bacterial activities and can be used as an indicator of microbial loads since bacteria growth increases at higher temperatures [4, 48]. Monitoring temperature can enable authorities to decide if they need to get the water analyzed for microbiological properties especially in tanked or long term stored water.

The physical factors that are dependent on the microbiological and chemical properties of water, for instance, the presence of faecal streptococci can be determined by the value of alkalinity in a water sample. The value of alkalinity is measured by pH in a given sample. Similarly, the taste of the water can also vary based on the value of pH. The colour, suspended solids as well as some of the other impurities can be monitored successfully by monitoring the value of turbidity. Due to the above factors a high value of turbidity makes the water unsuitable for human consumption. The mutually dependent factors are listed in Table 4 [51].

*Table 4: Parameters dependency on other parameters.*

| **Parameters** | **Depend on** |
|---|---|
| Total Coliforms | Temperature |
| Thermo-tolerant Coliforms | |
| Escherichia Coli | |
| Heterotrophic Bacteria | |
| Taste | Temperature, pH and Total dissolved solids. |
| Water Hardness | pH |
| Faecal Streptococci | |
| Total Dissolved Solids | pH, electric conductivity |
| Pseudomonas Aeruginous and Aeromonas spp | Turbidity |
| Colour | |
| Pathogen (cyst & oocyts) | |
| Suspended Solid | |

### 4.2.2 The effect on drinking water due to industrial and mining factors

There are many factors affecting water quality because of human activities such as industrial, non-industrial and mining activities. For example, the temperature of the water is not directly affected by industrial and mining activities. However, microbiological properties are affected by temperature in areas where there is high human activity. In a warmer area with high human activities, the monitoring of the water temperature can give an indication of possible microbiological load. Furthermore, electrical conductivity, pH, dissolved oxygen, and water hardness are affected in the areas where there is higher industrial and mining activities.

Non-industrial activities such as agricultural activities can also affect the quality of drinking water. Parameters such as electrical conductivity, pH, dissolved oxygen, faecal coliforms, and microbiological parameters are significantly affected by non-industrial activities. The higher value of nitrates is also a common factor due to agricultural activities and can be monitored by pH as conductivity.

Other sources of contamination such as, leakage of waste water pipes and sewerage pipe bursts can deteriorate water quality significantly. This can add suspended particles into water changing the colour and suspended particle count (organic and non-organic). This can be detected by turbidity measurement. Turbidity also has an effect on the pH.

### 4.2.3 Speed of measurements

It is important that the proposed system is capable of monitoring the quality of water effectively in the shortest possible time. To achieve this parameters that can be measured quickly are selected. Furthermore, it is also believed that the system needs to have minimum human intervention. The list of parameters which can be measured quickly are listed below in Table 5 [5].

*Table 5: Water quality parameters according to speed.*

| Parameters | Speed (time to produce result) |
|---|---|
| Total coliforms | Medium |
| Faecal coliforms | Medium |
| Faecal streptococci | Medium |
| Total bacteria | Slow |
| pH | Fast |
| Ammonia | Fast |
| Solid(total & dissolved ) | Medium |
| Organic matters(TOC, BOD, COD) | Medium |
| Colour | Fast |
| Temperature | Fast |
| Turbidity | Fast |

### 4.2.4 Monitoring in field

The proposed system should be capable of monitoring the quality of drinking water remotely since the proposed parameters are measured using sensors or probes. These sensors are simple and are suitable to be used in field monitoring. The system measures and sends the result to the backend system for storage. The backend system then generates required reports or alerts for the relevant authority in case of any abnormality detected. The parameters that are measured using sensors and probes are listed below in Table 6 [48].

*Table 6: Water parameters with online possibilities*

| Parameters | Possibility of online monitoring |
|---|---|
| Total coliforms | Yes/No |
| Faecal coliforms | Yes/No |
| Faecal streptococci | Yes/No |
| Total bacteria | Yes/No |
| pH | Yes |
| Temperature | Yes |
| colour | Yes |
| Turbidity | Yes |
| Conductivity | Yes |
| Ammonia | Yes/No |
| Solid(total & dissolved ) | No |
| Organic matters(TOC, BOD, COD) | Yes/No |
| Note: Yes=Suitable; Yes/No=Can be done; No=Not suitable. | |

### 4.2.5 Cost

The proposed system should be of reasonable initial and operation cost and should have acceptable accuracy in measuring the proposed parameters. In addition the system should be stable, robust and cheap to maintain.

The sensor or probes used to measure the parameters of Table 7 are easily available at a reasonable cost. The proposed system should also be fit for purpose and accurate.

*Table 7: Water parameter with cost detail.*

| Parameters | Cost |
|---|---|
| Total coliforms | Medium |
| Faecal coliforms | Medium |
| Faecal streptococci | Medium |
| Total bacteria | Medium |
| pH | Low |
| Solid(total & dissolved ) | Medium |
| colour | Low |
| Turbidity | Low |
| Conductivity | Low |
| Ammonia | Medium |
| Organic matters(TOC, BOD, COD) | Medium |
| Temperature | Low |

## 4.3 Proposed parameters to measure the quality of water

All the factors involved in measuring the quality of drinking water are discussed in the earlier sections. In the process of determining the parameters, the guidelines listed in the Section 4.1 were considered. The selected parameters for the proposed system are listed below.

1. Temperature
2. pH
3. Turbidity
4. Electric conductivity

The reasons for selecting the listed parameters are given below.

### 4.3.1 Temperature

Using the temperature of water to determine its quality is very common. Temperature of the water depends on its surroundings such as, geographical location, season, time of the day, weather, body size and the depth of the water source. Temperature does not have any direct impact on the quality of water. However, many quality-related factors can be affected by it. In addition to this, there are some factors which are monitored at certain temperature values (pH is one example of this) since they vary significantly with temperature. Temperature at which the water is transferred or stored can also affect its quality. Temperature levels are also directly proportional to microbiological properties of water. Bacteria, such as Legionella, multiplies in water at temperatures ranging from $20^o$ to $45^o$ Celsius. These bacteria are dormant below $20^o$ and do not survive above $60^o$ Celsius [4]. It is not possible to monitor in detail the microbiological properties of water at the point of consumption. However, temperature value (over time) can indicate if the water should be sent for microbiological abnormalities to a laboratory.

According to the American College of Sports Medicine (ACSM), the normal temperature for drinking water should be $15^o$ to $25^o$ Celsius [4]. Water hotter or cooler than this can have negative effects on our bodies and health.

Industrial and mining activities in an area can affect the temperature of water. Temperature can also fluctuate seasonally, daily and even hourly especially in the outdoor water storage sources and smaller sized streams [5, 11 and 48].

**Effect of temperature on other factors**

As discussed earlier, temperature of water does not have any direct impact on the quality of water. It can, however, affect the water in many ways. Electric conductivity is dependent on the temperature since ionic activity increases with the increase in temperature resulting in higher water conductivity. The electrical conductivity of water increases by 2-3% for an increase of $1^o$ Celsius. Many electric conductivity meters available standardize the readings to $25^o$ Celsius [20].

The value of pH can vary with the fluctuations of temperature. It is advised that the pH meters or sensors should be calibrated on a specific temperature. The pH should then be monitored on that calibrated temperature [22, 51].

The microbiological factors are also affected by the temperature of water. For example:

- ❖ Total Coliform (represents the whole group) and other bacteria multiply in water temperature ranging from $20^o$ to $45^o$ C. For example:
  - ➢ The thermo-tolerant coliforms are the bacteria that grow at the high temperature of $42^o$C.
  - ➢ Escherichia coli grows at $44^o$ to $45^o$ C.

- Strain E. coli finds temperature around 37$^{o}$ C ideal for its growth.

Low cost sensors are available to monitor the temperature easily in real-time. These sensors can provide accurate results at a high speed data availability [66].

### 4.3.2 pH

pH is a very common parameter monitored to access the physical qualities of a water sample. The pH is measured to determine the acid balance of a solution and is defined as "negative of the logarithm to the base 10 of the hydrogen ion concentration". The pH runs on the scale from 0 to 14 (i.e. highly acidic to very alkaline). The imbalance in the value of pH affects the taste and corrosiveness of water. The ideal value of pH in drinking water is between 6.5 to 8. For underground sources of water, the ideal value ranges between 6 and 8 [5, 11 and 48]. If the value of the pH is under 7 the water source is called:

a) Acidic,
b) Soft, or
c) Corrosive.

However, the water source with the pH values above 7 are called:

a) Basic,
b) Alkalized water, or
c) Hard water

In principle, water with a pH value less than 7 has more $H^{+}$ activity than $OH^{-}$ activity. If the water in a source is too acidic or basic, the $H^{+}$ or $OH^{-}$ activity may harm the health of consumers.

**Health risks**

An abnormality of the pH value can cause health risks to human life. The World Health Organization states that most health risks are associated with the extreme values of pH on both sides of the scale. pH values above 11 can cause eye and mucous membrane irritation. On the other side of the scale, pH values below 4 can also cause irritation due to the corrosive effects. Acidic drinking water can cause serious health problems since high acidity in the water can damage the pipes used for plumbing resulting in leaching of heavy metals from plumbing systems. Toxic metals such as lead can leach into the water and makes it dangerous for consumption. The consumption of substances like lead can cause neurological and reproductive problems, such as miscarriages, and hearing loss etc. The overconsumption of heavy metals can also cause damage to the gastrointestinal system. Zinc from corroded pipes can cause nausea, vomiting, and diarrheal [20, 22, 48].

**Mutual dependency of pH on other factors**

The value of pH is inversely proportional to the temperature of water. As the value of temperature increases; water becomes more acidic. If the temperature of water is increased by 25°C, the pH level decreases by 0.45.

Water hardness can also be determined based on the value of pH. If the values are higher than 7, the water is considered as hard water. When water is derived from soil, it dissolves many minerals. Water hardness is due to Calcium and magnesium because these are easily dissolved in the water. The minor contribution to the total hardness of water is also made by other polyvalent ions, such as aluminium, barium, iron, manganese, strontium and zinc.

The value of total dissolved solids can also change the pH values of water, resulting in the change of the taste of water [22, 48, 51].

### 4.3.3 Turbidity

The amount of cloudiness or murkiness of the water is called "turbidity". This can vary from a river full of mud and silt where it would be impossible to see through the water (high turbidity), to spring water which appears to be completely clear (low turbidity). Turbidity can be caused by:

- Silt, sand and mud
- Bacteria and other germs
- Chemical precipitates.

It is very important to measure the turbidity of domestic water supplies, as these supplies often undergo some type of water treatment which can be affected by turbidity. For drinking water supplies, the following guidelines should be taken into consideration:

- Drinking water should have a turbidity of 5 NTU/JTU or less,
- Where water is chlorinated, turbidity should be less than 5 NTU/JTU and preferably less than 1 NTU/JTU for chlorination to be effective [48].

**Health risks**

Like temperature, turbidity also does not have any direct health risks. However, the higher values of turbidity can provide an ideal environment for the growth of bacteria, viruses and parasites. These organisms can cause gastrointestinal diseases. Based on the values of turbidity the authorities can decide whether or not a sample should be tested for the presence of microbiological growth of bacteria in a source of water. *Cryptosporidium Parvum* is a parasite that causes gastrointestinal illness. It is generally transmitted by ingestion of oocysts excreted in human or animal faeces. In 1993 Milwaukee was affected by the largest documented health emergency triggered by drinking water quality in the history of US [1]. Over four hundred thousand people were affected by the outbreak which cost over 96 million US dollars in combined healthcare and productivity losses. Increase in the turbidity values over the period of one month was the only indication of the decrease in water quality [1].

**Mutual dependency of turbidity on other factors**

The value of turbidity can indicate the potential presence of microbiological organisms in the source of water such as,

- Pseudomonas Aeruginous and Aeromonas spp,
- Increased turbidity can indicate the increase in pathogen numbers (cyst and oocyts),
- Suspended solids in a water sample can also be measured indirectly as turbidity
- Furthermore, by knowing the clarity of water, the value of turbidity can also indicate the effectiveness of the water treatment process [11, 22, 51].
- Electric conductivity can also be dependent on turbidity.

### 4.3.4 Electric conductivity

The value of electrical conductivity of a water sample can estimate the total dissolved impurities in water. Pure water is not a good conductor of electricity. The solubility of water changes with the change in the temperature of water. The ideal temperature to measure the electrical conductivity in a water sample is 25ºC. Water becomes a good conductor for electricity when salts dissociated into positively and negatively charged ions are present in water. The normal range of electric conductivity in drinking water is between 0.005 to 0.05 S/m. While the electrical conductivity is a good indicator of the total salinity, it still does not provide any information about the ion composition in the water [22, 51].

**Mutual dependency of electric conductivity**

It is hard to measure Total Dissolved Solids (TDS) in the field. The electric conductivity can give an indication as the measure of TDS. However, at a certain level of salt concentration, the electrical conductivity is no longer affected [48, 51].

## 4.4 Proposed system to measure water quality

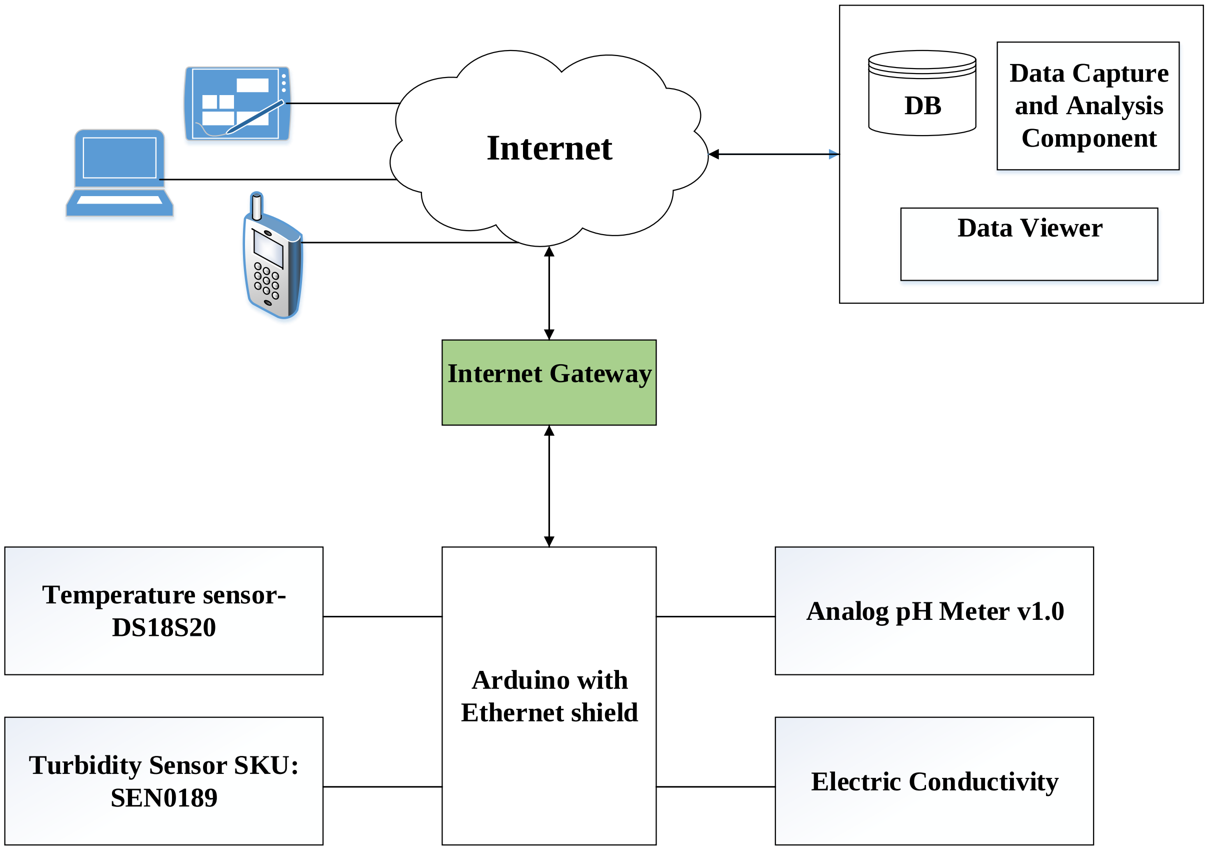


*Figure 2: Proposed system abstract diagram*

The second part of this research is to propose a cost effective system that can be used to monitor the water quality in real-time (as discussed in section 4.1). The proposed system needs to employ low cost technologies. In addition to this, it needs to be able to measure the selected parameters and transmit that information back to a central server for reporting and decision making. An abstract view of the proposed system is shown in figure 2. In this section some of the available technologies that can be used to develop different components of the system are discussed.

### 4.4.1 Sensors

In the proposed system different sensors are needed to measure the respective parameters (discussed in section 4.3) in the source of water. There are many types of sensors available in the market. Some of those sensors and their functionality are discussed in this section.

#### 4.4.1.1 Temperature sensor

Monitoring the temperature of water to determine the quality is a common practice. The value of the temperature of the water depends on its surroundings such as, geographical location, season, time of the day, weather, body size and the depth of the water source. The temperature of the water can be continuously measured using different types of sensors and probes available in the market. In the proposed system a cost effective sensor is needed. The sensor needs to offer adequate accuracy and also needs to operate in the range of field temperatures. A comparison of different sensors available in the market is provided in Table 8. Since the system is targeted to be used in a domestic environment the selected sensor does not necessarily need to have operating capabilities in extreme environments. For the proof of concept purposes the DS18S20 temperature sensor has been used. This type of temperature sensor provides 9 bit Celsius temperature measurements. It has an alarm function with non-volatile programming for upper and lower triggered points. It has a 1-wire bus for communication. By definition it has only one data line for communication with the central microprocessor. Furthermore, DS18S20 gets power directly from a data line "parasite power" and minimizes the need for external power supply. Parasite Power Mode Requires Only 2 Pins for Operation (DQ and GND). Each DS18S20 has a unique 64-bit serial code, which allows multiple DS18S20's to function on the same 1-wire bus. This sensor is suitable for applications including HVAC (heat, ventilation and air conditioner network) environment controls, temperature inside the buildings, machinery or equipment and process monitoring and control systems. The sensor is capable to measure temperature ranges from -55°C to +125°C (-67°F to +257°F) ±0.5°C and accuracy from -10°C to +85° C. The cost of the sensor is around $6 (USD).

*Table 8: Temperature sensors*

| Sensor Name | Temp. range (Celsius) | Accuracy | Applications | Rugged | Interface | Cost (dollar) |
|---|---|---|---|---|---|---|
| DS18S20 | -55°C to +125°C | ± 0.5°C | heat, ventilation and air conditioner (HVAC) | NO | Serial | $6 |
| ENV-TMP-Field ready temp sensor | -20°C to 133°C | ±1°C | extreme environment (all weathers and submersible | | Digital | $18 |
| Pt100 | -200°C to 850°C | ± (0.15+ (0.002*t)). | operate in the extreme environments (such as maximum temperature $15^{0}$0C and minimum -$55^{0}$C) | No | Analog | $100 |
| SH10 | -10°C to 80°C | ±0.5°C | Temperature and Humidity Sensor (calibration) | No | Digital | $27 |
| 109 temperature probe for CR200X- series Data loggers | -50° to +70°C | ±0.5°C | air, soil and water temperature | Yes | ___ | ___ |

#### 4.4.1.2 Turbidity sensor

It is very important to measure the turbidity of domestic water supplies, as these supplies often undergo some type of water treatment which can be affected by turbidity. The value of turbidity can vary from a river full of mud and silt where it would be impossible to see through the water (high turbidity), to spring water which appears to be completely clear (low turbidity). The value of turbidity can indicate a potential problem associated with the presence of microbiological organisms in the source of water. There are many types of sensors available (Shown in Table 9) in the market that can monitor the turbidity levels in a water source effectively. Since turbidity does not have a direct impact on the quality of water a sensor with the reasonable amount of accuracy is sufficient in a water quality monitoring system. For the proof of concept the Turbidity Sensor SKU: SEN0189 by DFROBBOT has been used. The sensor works on the principle that, when light is passed through a sample of water, the amount of light transmitted through the sample is dependent on the amount of soil and containments in the water. The amount of total suspended solids (TSS) in water is directly proportional to the amount of transmitted light meaning, as the TTS level increases, the amount of transmitted light also increases resulting in increased turbidity values. The sensor is able to be used in the domestic environment and is cost effective as well. There are other cheaper sensors also available such as, TSD-10 Turbidity Sensor, and Turbidity Amphenol -TSW10, but their primary application is in the measuring water in washing machines and dishwashers. However, one of these sensors can also be used in a low cost water monitoring system where the value of turbidity is not of significant importance.

*Table 9: Turbidity sensors*

| Sensor name | Range | Accuracy | Operating temp | Application | Calibration | Cost |
|---|---|---|---|---|---|---|
| Turbidity Amphenol - TSW10 | 0 NTU - 1000 NTU | ±2NTU | -30°C- 80°C | Water quality in rivers and streams, wastewater, Washing machine, dish washer, research and lab. | Turbidity level Calibration -> Master NTU standard liquid | Around $15 |
| TSD-10 Turbidity Sensor | 0 NTU-4000 | ±2NTU | -10°C - 90°C | Washing machine, dish washer, | Turbidity level Calibration -> Master NTU standard liquid | Around $5 |
| Turbidity sensor TRB-BTA | 0 to 200 NTU | ±2 NTU under 25 NTU and ±5% above 25 NTU | 0°C - 85°C | Education purpose and not appropriate for industrial, medical, research, or commercial applications. | Yes | Around $153 |
| Turbidity sensor SKU: SEN0189 | | | 5°C - 90°C | water quality in rivers and streams, wastewater | No | Around $14 |

#### 4.4.1.3 pH sensor

pH is a very common parameter monitored to access the physical qualities of a water sample. The pH is measured to determine the acid balance of a solution. The value of pH can vary based on the change in the temperature of the water. This is one of the reasons why measuring the temperature of the water is also important in establishing and measuring the value of pH. The imbalance in the value of pH affects the taste and corrosiveness of water. The abnormality of the pH value can cause health risks on human life such as, eye and mucous membrane irritation etc. Like other parameters, the value of pH can also be monitored continuously using many sensors available in the market. Some of those sensors are noted in the table 6. For the proof of concept purposes Analog pH Meter v1.0 is used. It connects to the microcontrollers (such as Arduino, and Raspberry Pi) through BNC connector that then connects to the Analog port of the Microcontroller of choice. Following are the cautions that need to be considered before using pH sensor:

- Before the electrode is applied in continuous use it needs to be calibrated with the standard solution for more accurate results. The best environment temperature for measuring pH is about 25 °C. If one is calibrating the sensor using the acidic sample, the pH value of the standard solution should be 4.00. If the sensor is calibrated with the help of the alkaline sample, the pH value of the standard solution needs to be around 9.18.
- Before the pH electrode measures different solutions, it needs to be washed with a water solution. For the better accuracy deionized water is recommended for the wash [28, 29].

*Table 10: pH sensor*

| Sensor name | Ranges | Accuracy | Operating Temp | Connector | Application | Calibration | Cost |
|---|---|---|---|---|---|---|---|
| Analog pH Meter v1.0/ SEN0161 | 0 to 14 | ± 0.1pH (25 °C). | 0-60 °C. | BNC | Not for extreme environment | Yes (for accuracy) | 572.00 |
| 3550_0-ASP200-2-1M-BNC | 0 to 14 | ___ | 0-80°C | BNC | Field and lab. | Yes | $25 + $30 |
| PC2121-5M pH Industrial Electrode | 0 to 14 | ±10mv (25 °C) | 0-110°C | pH/ORP adopter | Industrial purpose as well as suitable for pool, sea and ground water | Yes (for accuracy) | $100.00 |

#### 4.4.1.4 Electric conductivity sensor

The value of electrical conductivity of water sample can estimate the total dissolved impurities in water. Pure water is not a good conductor of electricity. It is hard to measure Total Dissolved Solids (TDS) in the field. The electric conductivity can give an indication as to the measure of TDS. There are many sensors available in the market to measure the conductivity of the water. However, Analog Electrical Conductivity Sensor / Meter for Arduino is a cost effective and suitable sensor that can be used in a low-cost water quality monitoring systems [52, 53]. However, because of the limited availability of the funding, for the proof of concept purposes the electric conductivity was not measured using the proposed system. To measure the electric conductivity the instrument from the laboratory was barrowed and was used to measure the electric conductivity. The details about that instrument are provided in Appendix 3.

*Table 11: Electric conductivity sensors*

| Sensor name | Ranges | Operating temp | Environment | Application | Cost |
|---|---|---|---|---|---|
| Conductivity probe K 0.1 | from 0.07 to 50,000 S/cm | 1-110$^0$C | Submerged in fresh and salted water. | Lab, field, aquarium, Hydroponics, Food Safe, Soil Samples, Strong reducing agents | $144 |
| Conductivity Probe K 1.0 | 5 − 200,000 µS/cm | 1-110$^0$C | Submerged in fresh and salted water. | Standard Lab use, field use, fish keeping, ,Samples containing Heavy metals, soil Samples, | $126.00 |
| Analog Electrical Conductivity Sensor / Meter for Arduino | 1ms/cm-20ms/cm | 5-40$^0$C | ___ | Water quality monitoring, Aquaculture, Hydroponic and Aquaporin. | $69.90+ $30 (probe+BNC) |

### 4.4.2 Microcontrollers

A microcontroller contains memory, programmable input/output peripherals as well as a microprocessor. It is a single integrated circuit that is designed to perform a single task and execute specific applications. It is specially designed for embedded applications and can control all functions of an electronic device such as a cell phone, microwave or camera. In the proposed solution a microcontroller platform is needed to interact with the sensors to get the values and post them to a server for later usage. There are many microcontroller platforms available on the market that can be used to design such a system. Some of those are listed below.

**I. Arduino**

Arduino is a low-cost open-source electronics development platform that is used to develop prototypes as well as final electronics products. Arduino boards can read inputs using several input pins available on the board. It can process those inputs using the given instructions and generate outputs. The Arduino board can also use Ethernet, WiFi, or GSM add-on shields to transmit data to the back office systems. It has a USB connection that can be used to deploy the software program onto the board and can also be used to log output to a connected computer [74, 76].

### II. Raspberry Pi

Raspberry Pi is a credit-card sized computer powered by the Broadcom BCM2835 system on a chip (SoC). It is low cost and small in size and can be used for prototyping as well as final electronics products. It can plug into a monitor or TV and can use a standard Keyboard and mouse. Raspberry Pi is capable of doing everything that one would expect from a desktop computer including browsing, playing high definition videos, running a spreadsheet or word processor, and playing games. Currently, on the software side, three Linux-based operating systems are supported by the Raspberry Pi. It is powered by 5V micro USB AC charger or at least 4AA batteries [74, 77].

### III. Nanode

Nanode is an open-source microcontroller and allows experimentation with Internet of Things (IoT) technologies. Nanode is a low cost and on-board internet connectivity module that is the next generation logical creation of open source hardware Arduino projects. Once one is an expert in Arduino, it is easier to program for the Nanode platform. It provides a simple means of communication via the Internet using applications such as an online browser or through open source APIs such as Cosm. Nanode can serve a simple webpage, and interact with its hardware using a browser interface. It can also be used as a sensor environment such as temperature, weather or air quality and is able to send data to a cloud-based open data service such as Cosm. The data could then be visualized and graphed as needed [75].

## 4.4.3 Communication channels

Communication channels refer to a medium through which a message is transmitted in an application or organization. In the proposed solution as shown in Figure 2 there is a need for a communication channel that can help the microcontroller platform transfer the values of monitored parameters to a server setup in the cloud.

### 4.4.3.1 Short range communication

### I. Ethernet cable

Ethernet is a popular form of network communication. It is used to form a wired network. The Ethernet cable connects different devices in a local area network such as PCs, routers and switches. It has a limitation in distance of up to 100 meters. Modern microcontroller platforms such as Arduino, Raspberry Pi etc. has Ethernet interfaces to connect the microcontroller with a Local area network [78].

## II. Bluetooth

Bluetooth is a wireless communication channel. It is used to transmit data and voice through radio waves. It is a short range of radio communication network between different types of devices such as mobile phones, computers, cameras and other electronic devices. The data transfer rate is approximate 2Mbps. Devices need to be within 10 meters of each other for a reliable connection. Every device has a small microchip that is used to send data and voice signals. In Bluetooth one device behaves as master and one or more devices act as slaves. The master device is used to create a link with other devices. The devices can transmit data once a connection between master and slave is established [80].

## III. Wi-Fi

Wi-Fi is usually used as a wireless local area network. The data sent between sender and receiver through radio waves instead of cable. It allows computer and other electronic devices to communicate wirelessly with one another in a particular area. The speed of Wi-Fi depends on devices for example if people use 802.11g device its average speed can be 2.4 GHz and 802.11b people can get a maximum speed 54Mbps [79].

## IV. Zigbee

Zigbee is designed to carry small amount of data over a short distance while consuming very little power. It uses mesh networking standard where each node is directly connected. In a Zigbee based network you don’t need to rely on a router and the endpoint. Zigbee has a low-channel bandwidth of 1MHz. It is restricted to wireless personal area network (WPAN) and reaches an average of 10 to 30 meters for usual applications. The data transfer speed is much slower than Wi-Fi. The maximum speed is 250kbps that is much lower than the lowest speed Wi-Fi offers [79].

### 4.4.3.2 Long range communication

## I. ADSL

Asymmetric Digital Subscriber Line (ADSL) runs on a fixed line that transmits digital information at a high bandwidth on existing phone lines for homes and businesses. ADSL provides continuously available services. Therefore, it is not necessary to pay or buy a regular dial-up connection. Generally, a fixed charge is added to your telephone bill every month that depends on your package. It sends high amount of data through existing telephone lines. ADSL is more stable than other connections and best for location-bound users. ADSL modem works better if people are closer to the service provider offices [82].

### II. 3G network

3G stands for "third generation network". It enhances the wireless mobile telecommunication network. 3G network is better than older wireless networks and offers faster data transmission rate, advanced multimedia access, and global roaming. The normal speeds are in the range of 7.2 Mbps to 52 Mbps. This technology is mostly used in mobile phones and handsets as to connect the phone to an internet or another IP network in order to make voice calls, video calls or to download and upload data [81].

### III. 4G and LTE network

4G stands for "fourth-generation network". 4G technology is a successor of 3G technology. 4G technology is becoming increasingly popular globally due to their fast speeds. 4G allows users to use fast and reliable web browsing and music streaming. The speeds can go up to 100 Mbps in high mobility like service from a moving car.

LTE stands for "Long Term Evolution" that is relatively new cellular network and has not been fully built out yet. Currently, 4G and LTE mobile technologies have similar connection speeds and are substantially more advanced than 3G [81].

## 4.4.4 Communication protocol

Communication protocols a set of rules and syntax to send a message in an application. The protocol may be implemented in hardware and software or both. There are different types of protocols available for example TCP/IP HTTP, HTTPs, XMPP, MQTT etc.

### I. HTTP

Http stands for "Hyper Text Transfer Protocol". It has request and response architecture. It runs over UDP. The message size is Large and is in ASCII format. HTTP based REST API is good enough for request and response sort of applications. HTTPs is stands for "Hyper Text Transfer Protocol secure". This protocol is a secure version of http and is used to send data between browser and websites securely. All communication is encrypted and it is used for high confidential online transactions for example online shopping orders and online banking [83].

### II. MQQT

MQTT stands for “Message Queue Telemetry Transport”. MQTT is a lightweight messaging protocol used for IoT based applications. It has publish and subscribe architecture. The devices can publish any topics or data and can also subscribe to any topics or data for any updates. It runs over TCP protocol. The message size is small and in binary, with 2Byte header. This is a suitable protocol for the applications where we need bi-directional communication [83].

### III. XMPP

XMPP is an Extendible Messaging and Presence Protocol. It is a set of open technologies for instant messaging, presence, multi-party chat, voice and video calls, lightweight middleware, content syndication, and generalized routing of XML data. This protocol is open, free and public for everyone. The multiple implementation is in form of client, server, server component and libraries [84].

## 4.4.5 Database management systems

Database management systems (DBMS) is a set of programs that are used to interact with end-users. DBMS enables the users to store, retrieve and manipulate the data in a database.

### I. RDBMS

A relational database management system (RDBMS) is program or engine that are structured in a database table, field and record. Generally, RDBMS uses the Structured Query Language (SQL) to access the database. The most important feature of the relational database includes an ability to use tables for data storage and manipulate the stored data. The most popular RDBMS are MS SQL Server, DB2, Oracle and MySQL, PostgresSQL etc [85].

### II. Mango DB

MongoDB is a cross-platform and open source document-oriented database and a link to NO SQL database. MongoDB supports dynamic schema design which allows the documents in a collection to have different fields and structures. The document storage and data interchange format in a database called BSON. It provides a binary representation of JSON like documents. It is built for scalability, high availability and performance for a single server deployment to large and complex multi-site infrastructure [85].

### 4.4.6 Single node VS Multi node proposed system

Figure 3 shows an abstract view of a single node water monitoring system. In Figure 4 an abstract diagram of a system that is consisted of multiple nodes is shown. This kind of system can be used on sites where there is a need of water monitoring at the multiple points. Designing and modelling such a system is not the scope of this report however a brief discussion and ideas for future research are discussed in chapter 7.

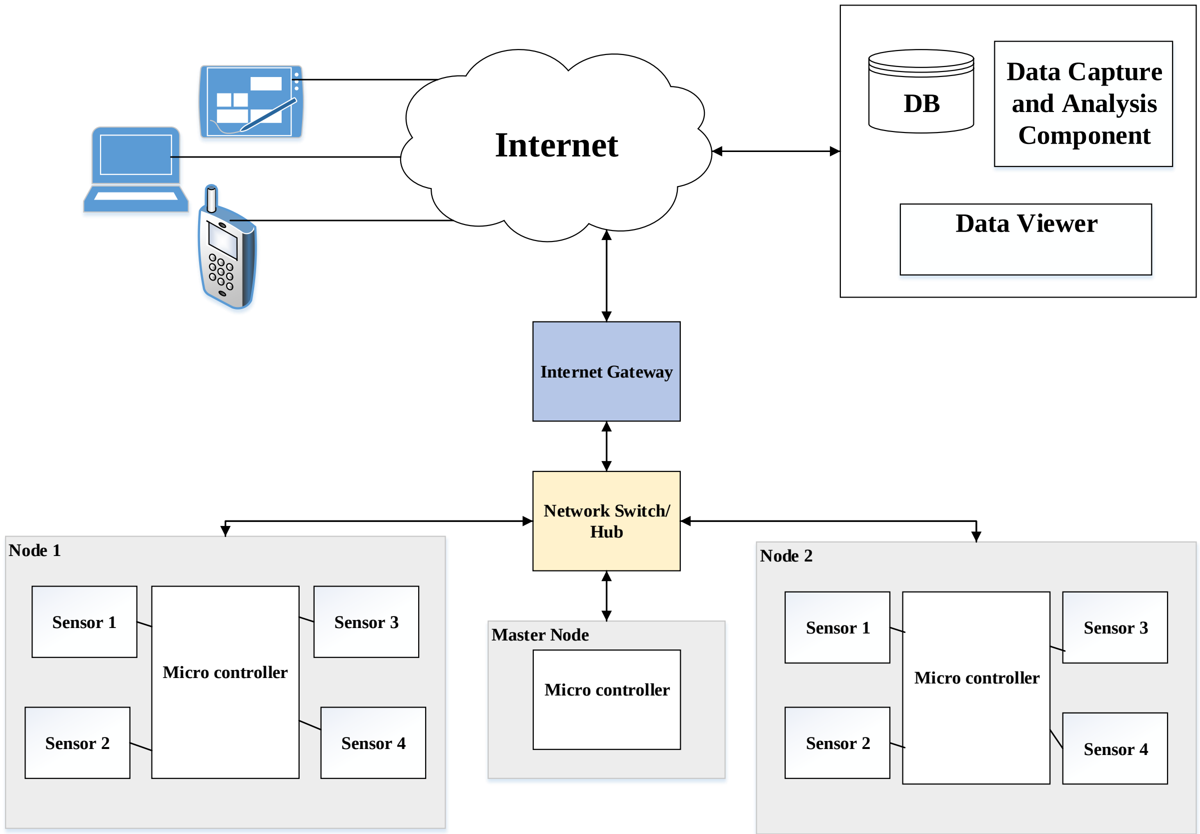


*Figure 3: Multi-node water monitoring system abstract diagram*

# 5 Chapter 5 Proof of concept and implementation

## 5.1 Introduction

With the growth of the modern telecommunication systems of today, advancement in the field of microcontroller platforms, and availability of sensors based systems it is possible to develop an embedded system that can gather the water quality information and transmit this to back office system. In the proposed system (shown in figure 3) the same idea will be implemented. The system will monitor water parameters and will post that information to a back office system in real time. This will enable the responsible people to receive water quality information in-time without any human intervention. This can then ensure that the authorities will be better equipped to provide clean and safe drinking water for the people living in rural areas.

## 5.2 System design and implementation

The proposed system of smart water monitoring node is built using an open-source electronics prototyping platform called Arduino. “Arduino is a flexible and easy-to-use hardware and software platform. It is an open-source physical computing platform based on a simple microcontroller board, and with a development environment for writing software for the board”. Physical and logical diagram developed for the proof of concept is shown in figure 4 and figure 5 respectively.

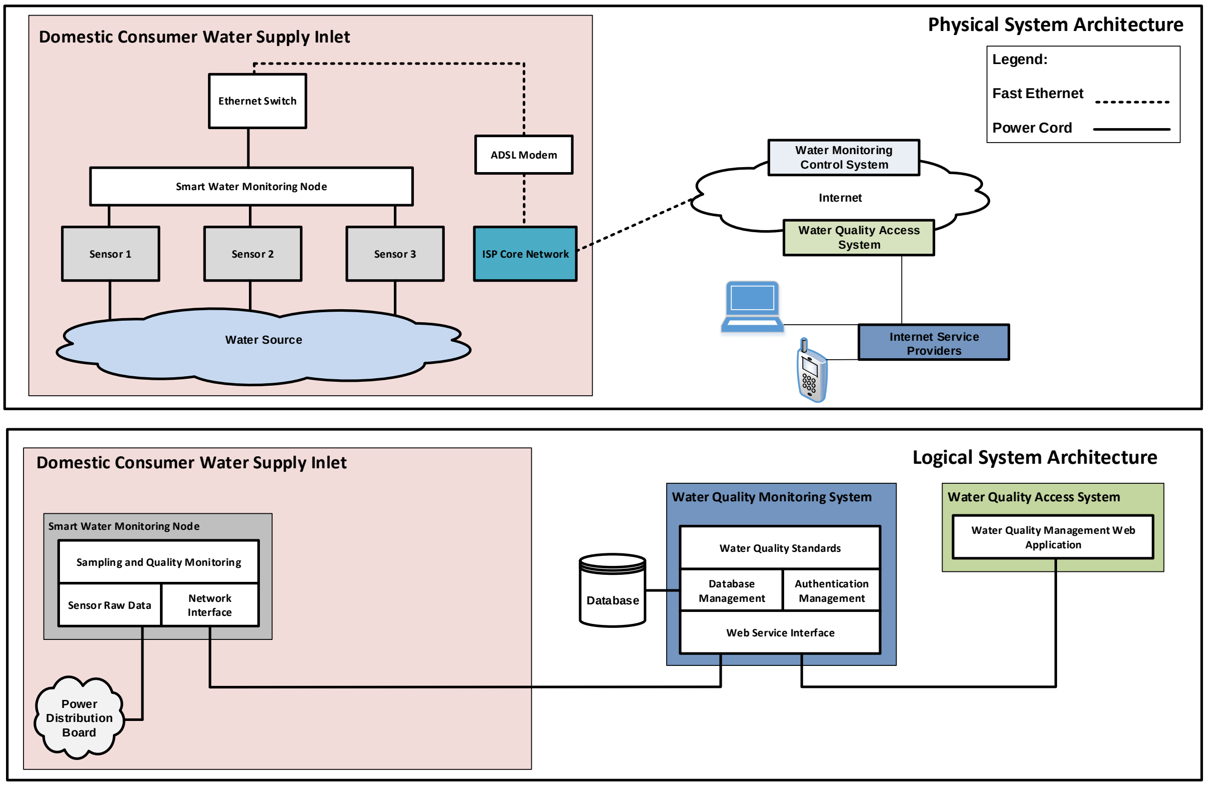


*Figure 4: Physical and Logical System diagram*

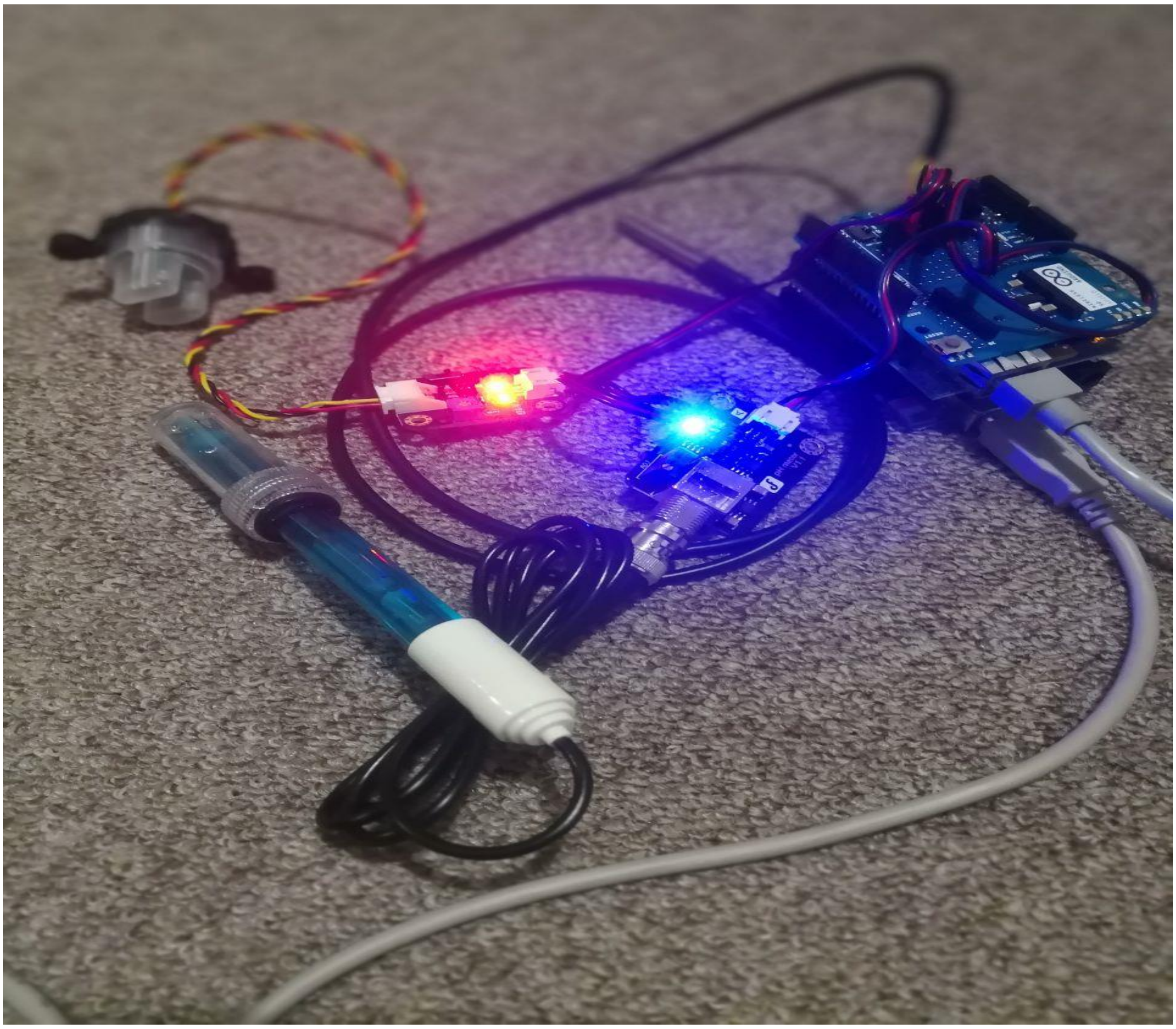

*Figure 5: Proposed system circuit*

The proposed system has been broken down into the following three physical components: Smart water monitoring node is installed in the domestic consumer's home premises. The sensors are to be installed at the main inlet supply of water. This is core of the system that monitors the values of selected parameters using the sensors, and sends that information back to the Water quality monitoring system (explained later in this chapter). Smart water monitoring node consists of a microcontroller (Arduino) and different sensors (discussed below). Arduino board is connected with an Ethernet switch (which also serves as ADSL Modem) using the Ethernet shield (Ethernet shields as additional plugin boards for Arduino are easily available).

### 5.2.1 Smart water monitoring node

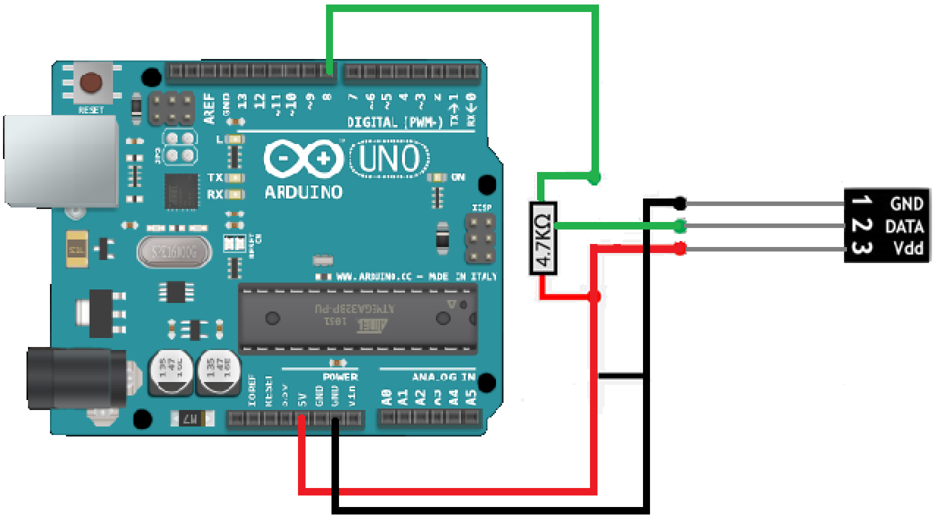


*Figure 6: Temperature sensor circuit diagram (taken from the user manual)*

#### 5.2.1.1 Temperature sensor component

For the proof of concept purpose DS18S20 temperature sensor is used. This type of temperature sensor provides 9 bit Celsius temperature measurements. The sensor is connected to the pin 8 of Arduino board as shown in figure 6. The sensor can be accessed using the OneWire library available for Arduino platform. The circuit was developed exactly how it has been shown in the figure 6. The Arduino board gets the values of temperature and stores it in its memory to send to the back office system later during the process. Figure 7 is the actual circuit designed and used for the proof of concept purposes.

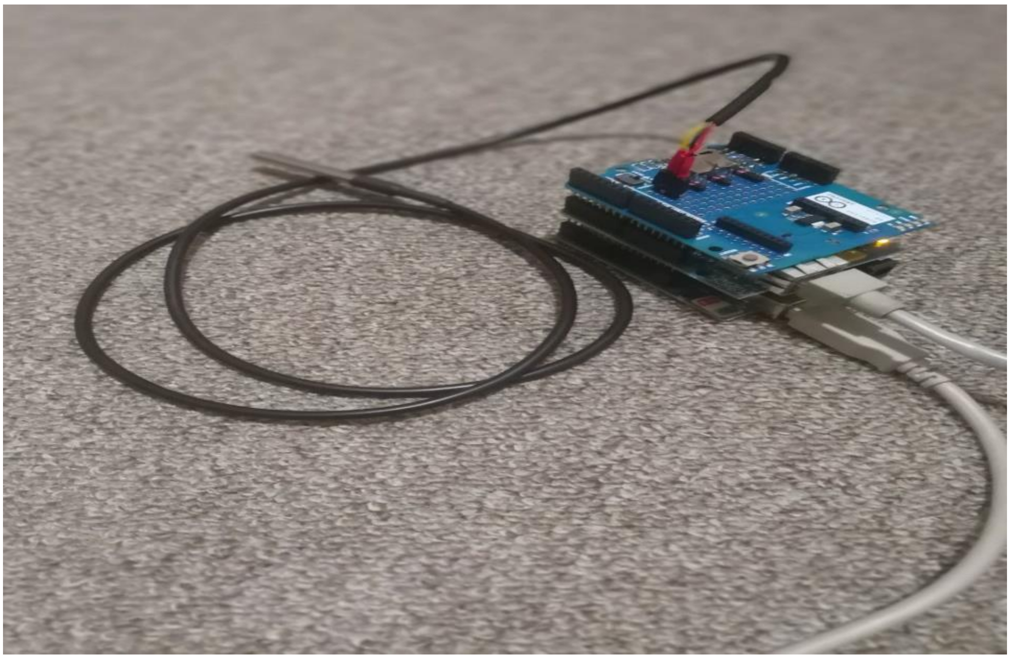

*Figure 7: Proposed temperature sensor*

#### 5.2.1.2 Turbidity sensor component

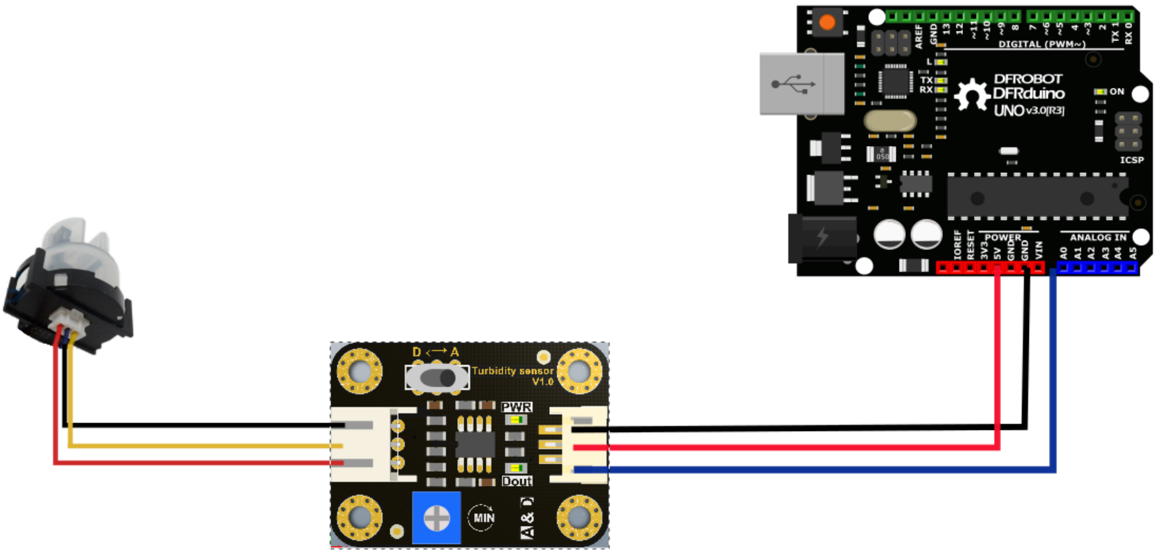


*Figure 8: Turbidity sensor circuit diagram (taken from the user manual)*

Turbidity Sensor SKU: SEN0189 by DFROBBOT has been used for building the proof of concept system. The sensor works on the principle that, when light is passed through a sample of water, the amount of light transmitted through the sample is dependent on the amount of soil and containments in the water. The sensor is connected to the Arduino board as shown in the Figure 8 (taken from the user guideline document available for the sensor). The Arduino board reads the sensor values from the analog pin A0. It then converts the analog reading (which goes from 0 - 1023) to a voltage (0 – 5V) using the following formula:

$$resultVoltage = sensorValue * \left(\frac{5.0}{1024.0}\right)$$

Figure 9 is the actual circuit designed and used for the proof of concept purposes. This measured the turbidity in a water sample.

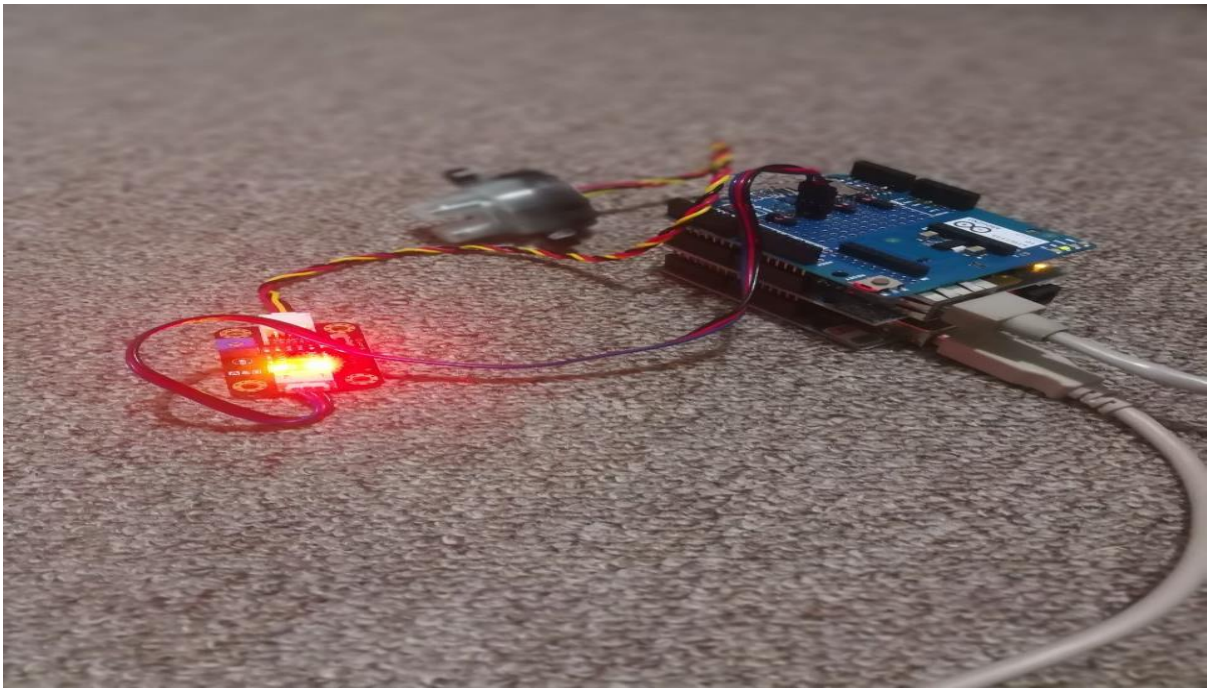

*Figure 9: Proposed turbidity sensor*

#### 5.2.1.3 pH sensor component

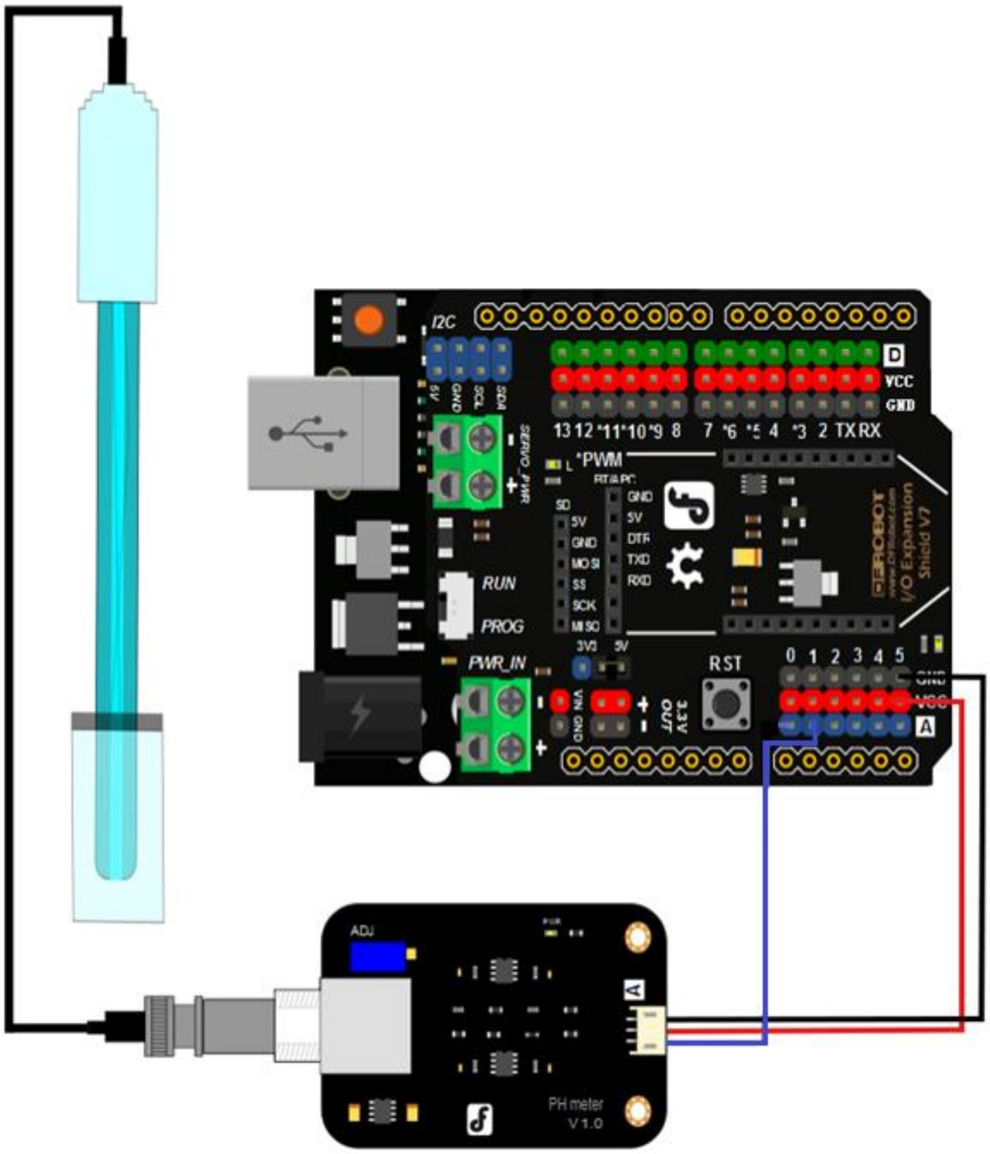

*Figure 10: pH sensor circuit diagram (taken from the user manual)*

In the proof of concept project Analog pH Meter v1.0 is used. The sensor is connected to the analog pin A1 of the Arduino board using a BNC connector as shown in the figure 10 and Figure 11. The Arduino board reads the sensor values from the analog pin A1. It then converts the analog reading (which goes from 0 - 1023) to a voltage (0 – 5V) using the following formula:

$$resultVoltage = \ sensorValue * \left(\frac{5.0}{1024.0}\right)$$

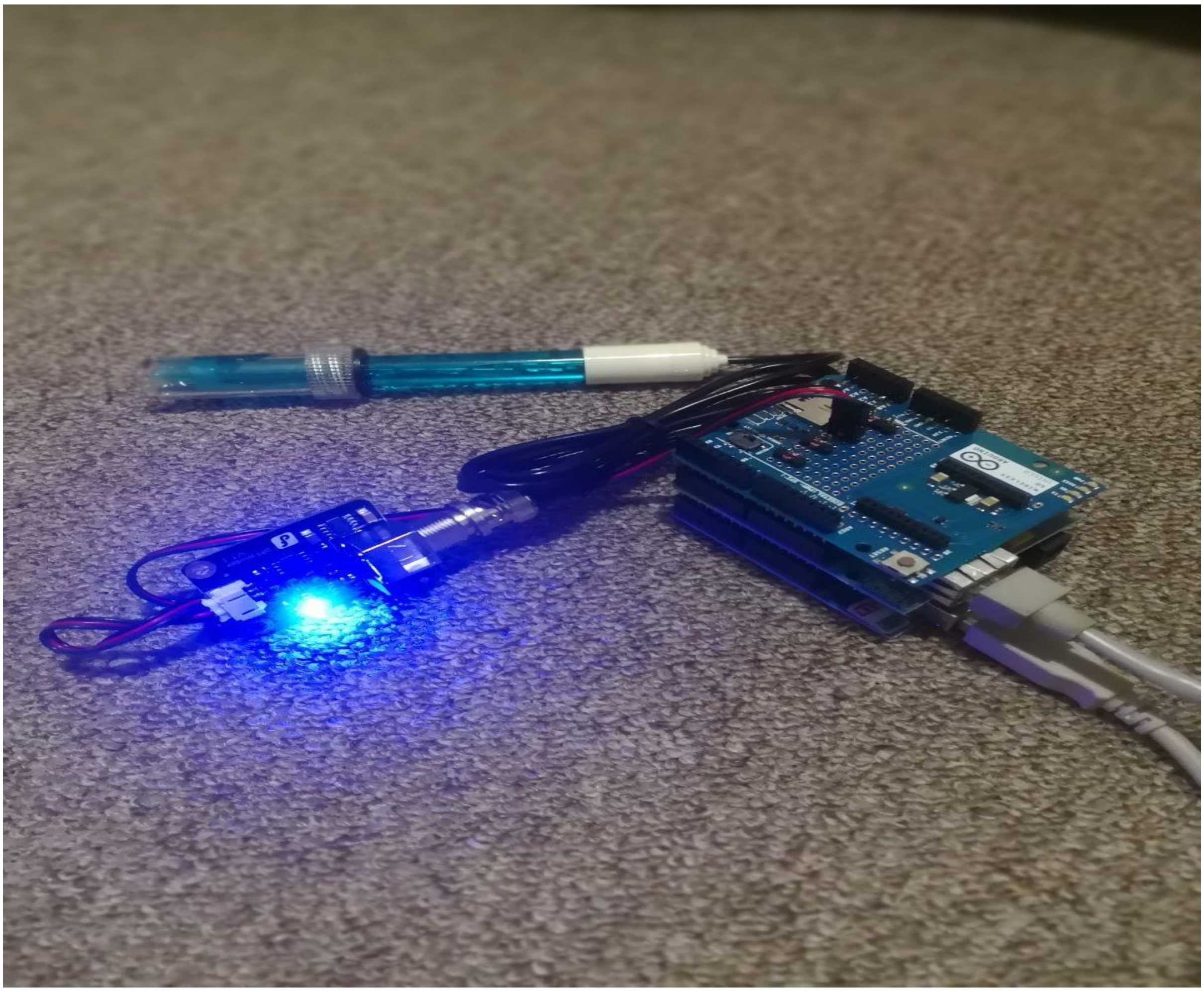

*Figure 11: Proposed pH sensor*

#### 5.2.1.4 Network interface

Network interface connects Smart water monitoring node to local area network inside a house. For the proof of concept purpose a simple Ethernet shield for Arduino is used to achieve the connectivity of smart water monitoring node with the network. This Ethernet is a cabled connection that has its own pros and cons. For wireless connectivity a ZigBee, Bluetooth, or Wi-Fi connection can also be used with the Arduino setup.

### 5.2.2 Water quality monitoring system

The water quality monitoring system runs on a server machine in the Internet cloud. It is the central repository where all the drinking water quality monitoring information from a node is stored. The server-side monitoring system is further divided into four components as shown in figure 4.

#### 5.2.2.1 Water quality standards

Water quality standards is a repository that holds the standard values for the different parameters monitored in the water sample. For example in an ideal water sample the value of pH varies between 6 and 8. The water source that has pH values lower than 6 is called acidic water, whereas the water that has values more than 8 is called alkaline. Similarly, this repository holds the standard values and their ranges for other parameters monitored in the system. Once the values are received from the Smart water monitoring node, they can be compared with the ranges specified in this component to determine the potential problems if exist.

#### 5.2.2.2 Database management system

Database management component manages all the requests queried from the physical database. For the proof of concept MySQL as a database management system has been used. MySQL is a powerful, open source object-relational database system with a proven reputation for reliability, data integrity, and correctness.

**Database**

The database serves as the core data repository for all data storage. All drinking water quality information coming from a consumer is kept in the database. For the proof of concept, this database is kept very simple.

#### 5.2.2.3 Authentication management

Authentication management component on the server side system validates and authenticates each request to access the information from the database. These requests include query the data about drinking water quality information, or issuing commands to alert relevant authorities in case of abnormality. The authentication also applies constraints on every user to view the data related to him/her. This function is not implemented in the system and recommended for the future work

#### 5.2.2.4 Web service interface

Web service interface is a simple PHP based service running on the server side and performs following actions:

1. The smart water monitoring node communicates with the web service using HTTP protocol. It sends data using the HTTP POST method and the PHP services receives that data. Once received, the services validates the received data and then stores it into the database.

a. There was an option to use MQTT protocol to implement the same thing. However for the proof of concept purposes the current implementation is still suitable for this application. MQTT is a lightweight messaging protocol used for IOT based applications. It keeps a connection to the service open for quick response to feed changes. This is suitable in the applications where bi directional communication is needed. In this proof of concept the smart water monitoring node acquires data from the connected sensors and posts that data to the server every 15 mins. Considering these simple needs a simple HTTP based REST API is best suitable.

2. It compares the received data with the water quality standards. If the data is in the danger ranges the services sends out an email to the predefined email addresses for alert purposes.

### 5.2.3 Water quality access system

Water quality access system logically is the end user application package. It is a web application package as indicated in the logical system architecture shown in figure 5. The users can open this in their web browser to view the data received from the smart water monitoring node in real-time.

# 6 Chapter 6 Experimentation

## 6.1 Introduction

This research is conducted based on the principles of design, development and testing the effectiveness of the proposed concept. As identified in Section 4, the third part of the research is to determine the effectiveness of the parameters monitored using the proof of concept system with the detailed laboratory analysis on the same water samples. In order to achieve this, an experimental set has been designed. Water samples were collected from the water sources used for domestic water supply. Those samples were tested using the proof of concept system explained in Section 6.2 and 6.2.1. The system monitored few parameters and concluded if the water was safe for drinking or indicated potential problems if identified. The same samples were then sent to the laboratory for advance testing. At the end of this chapter both the results are compared and effectiveness of the system has been discussed.

## 6.2 Collection of samples

The results of any water sample testing depends on collection of samples. It is important to follow some procedures for collecting the water samples to get accurate results. One of the important objectives for sample collection is quantity of water that can be transferred and handed easily in the laboratory. Furthermore, the size of the bottle is important to ensure that a person has enough sample quantity to run analysis because large samples obtain lower detection level. The other precautions for sample collection are bottle type, preservation technique, holding time, sampling point and documentation of samples. For the experimentation purposes sterilized bottles are used to collect water samples.

### 6.2.1 Guidelines for collecting samples for testing

World Health Organization (WHO), Waterwise, and the Department of Water Affairs and Forestry [86, 87] recommends the following precautions in collection the water samples for testing.

1. Before collecting the samples wash your hands with soap and warm water
2. Use separate samples for chemical, bacteriological and microscopic examinations
3. Collect the samples in a sterilized or approved sampling bottle and rinse the bottle two or three times with the water being collected
4. The samples need to be as fresh as possible because it takes time from drop off location to the laboratory

5. Collect the samples just before leaving for drop off location
6. Always take the samples from cold tap (if possible). Before collecting run the water constantly at least 2 to 5 minutes
7. Put the cap on the bottle and make sure you don't over tighten the cap
8. Fill the requisition form (name, daytime, collection site etc) and mark each sample bottle clearly for identification purposes. Put the sample and requisition form in a bag that came with sampling bottle.
9. Put the sample in ice cooler and bring it to drop off location. The laboratory restores the water back to the temperature at which it was collected before doing actual testing.

In addition to above, if possible, collect a sample from tube-well after sufficient pumping to ensure that the sample represents the ground water source. It has also been noticed when collecting samples from a river or stream, analytical result may vary with depth, flow, distance from the shore. Sample should be collected from the middle of the stream and at mid depth.

### 6.2.2 Collections of samples from sources of drinking water

The research is focused on monitoring and identifying the problems in the quality of drinking water. For the experimentation purposes the water samples are collected from five different sources of drinking water in an urban area. For each source, three samples are collected and tested individually. Collecting more than one sample from a source is to make sure any irregularities in collecting the samples are catered for. This also ensures that the average results of three samples for every source are considered at the end to determine the effectiveness of the hypothesis.

The details of each sample and their source are mentioned in Table 12.

*Table 12: Collection of samples from drinking water sources*

| Drinking water samples | | | |
|---|---|---|---|
| **Sample No.** | **Bottle colour** | **Source of water** | **Date and time of collection** |
| Sample 1A | Red | Surface water plant | 14 Dec 2017 14:00 |
| Sample 1B | Red | Surface water plant | 14 Dec 2017 14:04 |
| Sample 1C | Red | Surface water plant | 14 Dec 2017 14:07 |
| | | | |
| Sample 2A | Brown | Hand pump near canal | 14 Dec 2017 14:25 |
| Sample 2B | Brown | Hand pump near canal | 14 Dec 2017 14:28 |
| Sample 2C | Brown | Hand pump near canal | 14 Dec 2017 14:31 |
| | | | |
| Sample 3A | Yellow | Household shallow bore (approximately 100feet) | 15 Dec 2017 11:15 |
| Sample 3B | Yellow | Household shallow bore (approximately 100feet) | 15 Dec 2017 11:18 |
| Sample 3C | Yellow | Household shallow bore (approximately 100feet) | 15 Dec 2017 11:22 |
| | | | |
| Sample 4A | Orange | Household shallow bore (300feet to 400feet) | 15 Dec 2017 12:42 |
| Sample 4B | Orange | Household shallow bore (300feet to 400feet) | 15 Dec 2017 12:46 |
| Sample 4C | Orange | Household shallow bore (300feet to 400feet) | 15 Dec 2017 12:49 |
| | | | |
| Sample 5A | Green | Household shallow bore (500feet to 600feet) | 15 Dec 2017 13:33 |
| Sample 5B | Green | Household shallow bore (500feet to 600feet) | 15 Dec 2017 13:36 |
| Sample 5C | Green | Household shallow bore (500feet to 600feet) | 15 Dec 2017 13:40 |

### 6.2.3 Collections of samples from waste water sources

For the completeness of the experimentation samples from three different sources of waste water are also collected and tested. Similar to the drinking water samples three samples from each source are collected for the accuracy of the results purposes. Table 13 shows the list of samples collected from different sources of waste water.

*Table 13: Collection of samples for wastewater*

| Waste water samples | | | |
|---|---|---|---|
| **Sample No.** | **Bottle colour** | **Source of water** | **Date and time of collection** |
| Sample 6A | Blue | Chemical factory wastage | 16 Dec 2017 12:05 |
| Sample 6B | Blue | Chemical factory wastage | 16 Dec 2017 12:08 |
| Sample 6C | Blue | Chemical factory wastage | 16 Dec 2017 12:010 |
| | | | |
| Sample 7A | Black | Yard wastage | 16 Dec 2017 12:40 |
| Sample 7B | Black | Yard wastage | 16 Dec 2017 12:44 |
| Sample 7C | Black | Yard wastage | 16 Dec 2017 12:47 |
| | | | |
| Sample 8A | Purple | Kitchen wastage | 16 Dec 2017 13:15 |
| Sample 8B | Purple | Kitchen wastage | 16 Dec 2017 13:17 |
| Sample 8C | Purple | Kitchen wastage | 16 Dec 2017 13:19 |

## 6.3 Testing of water samples

The second step in the experiment is testing the collected samples of water. The testing is done in two phases. In the first phase, the water samples were tested with the proof of concept system presented in chapter 5. Second phase of the testing was done in the laboratory. The details about the laboratory and the testing done in the laboratory are presented in Section 6.3.2.

Each of the collected samples is divided into two portions. One of these portions is used to conduct tests using proof of concept system. The second portion of the sample is analysed in the laboratory for detailed analysis.

### 6.3.1 Results of testing using proof of concept system

In order to measure the water quality parameters using the proof of concept system, each probe and sensor was thoroughly rinsed, cleaned and dried before running every set of tests for all the samples. The detailed measurement of those parameters tested with the proof of concept system are attached in Appendix IA. The summary of the results and problems (if found) are presented in the table 14 below.

*Table 14: Testing using POC*

| Sample No. | Problems identified | Recommendations |
|---|---|---|
| | | |
| Sample 1A | • Temperature is higher than the optimum water temperature for drinking | Water is too hot for drinking. Because of the temperature water may contain some forms of bacteria and other germs. Get it tested in a laboratory for detailed problem identification. |
| Sample 1B | • Temperature is higher than the optimum water temperature for drinking | Water is too hot for drinking. Because of the temperature water may contain some forms of bacteria and other germs. Get it tested in a laboratory for detailed problem identification. |
| Sample 1C | • Temperature is higher than the optimum water temperature for drinking | Water is too hot for drinking. Because of the temperature water may contain some forms of bacteria and other germs. Get it tested in a laboratory for detailed problem identification. |
| | | |
| Sample 2A | • No problems are found | Fit for drinking |
| Sample 2B | • No problems are found | Fit for drinking |
| Sample 2C | • No problems are found | Fit for drinking |
| | | |
| Sample 3A | • No problems are found. | Fit for drinking |
| Sample 3B | • Value of pH is higher | Water is potentially hard. The disturbance in the value of pH can be because of dissolved solids in the source. Get it tested in a laboratory for detailed problem identification |
| Sample 3C | • Value of pH is higher | Water is potentially hard. The disturbance in the value of pH can be because of dissolved solids in the source. Get it tested in a laboratory for detailed problem identification |
| | | |
| Sample 4A | • No problems are found | Fit for drinking |
| Sample 4B | • No problems are found | Fit for drinking |
| Sample 4C | • No problems are found | Fit for drinking |
| | | |
| Sample 5A | • No problems are found | Fit for drinking |

| | | |
|---|---|---|
| Sample 5A | • No problems are found | Fit for drinking |
| Sample 5A | • No problems are found | Fit for drinking |
| | | |
| Sample 6A | • Value of pH is higher<br>• Water colour is Light Green<br>• Higher values of Turbidity<br>• Higher values of Conductivity<br>• Temperature is high | Strongly hard water, Murky and too hot to drink. Predicted to have bacteria and other solvents and recommended for testing in the laboratory testing. |
| Sample 6B | • Value of pH is higher<br>• Water colour is Light Green<br>• Higher values of Turbidity<br>• Higher values of Conductivity<br>• Temperature is high | Strongly hard water, Murky and too hot to drink. Predicted to have bacteria and other solvents and recommended for testing in the laboratory testing. |
| Sample 6C | • Value of pH is higher<br>• Water colour is Light Green<br>• Higher values of Turbidity<br>• Higher values of Conductivity<br>• Temperature is high | Strongly hard water, Murky and too hot to drink. Predicted to have bacteria and other solvents and recommended for testing in the laboratory testing. |
| | | |
| Sample 7A | • Temperature is high<br>• Water colour is Green and Yellow<br>• Higher values of Turbidity<br>• Higher values of Conductivity | Water is dirty and too hot to drink. Predicted to have bacteria and other solvents and recommended for testing in the laboratory testing. |
| Sample 7B | • Temperature is high<br>• Water colour is Green and Yellow<br>• Higher values of Turbidity<br>• Higher values of Conductivity | Water is dirty and too hot to drink. Predicted to have bacteria and other solvents and recommended for testing in the laboratory testing. |
| Sample 7C | • Temperature is high<br>• Water colour is Green and Yellow<br>• Higher values of Turbidity<br>• Higher values of Conductivity | Water is dirty and too hot to drink. Predicted to have bacteria and other solvents and recommended for testing in the laboratory testing. |
| | | |
| Sample 8A | • Value of pH is higher<br>• Temperature is high<br>• Water colour is Green<br>• Higher values of Turbidity<br>• Higher values of Conductivity | Strongly hard water, Murky and marginally hot to drink. Predicted to have bacteria and other solvents and recommended for testing in the laboratory testing. |
| Sample 8B | • Value of pH is higher<br>• Temperature is high<br>• Water colour is Green<br>• Higher values of Turbidity | Strongly hard water, Murky and marginally hot to drink. Predicted to have bacteria and other solvents and recommended for testing in the laboratory testing. |

| | | |
|---|---|---|
| | • Higher values of Conductivity | |
| Sample 8C | • Value of pH is higher<br>• Temperature is high<br>• Water colour is Green<br>• Higher values of Turbidity<br>• Higher values of Conductivity | Strongly hard water, Murky and marginally hot to drink. Predicted to have bacteria and other solvents and recommended for testing in the laboratory testing. |

### 6.3.2 Results of testing in the laboratory

In Section 6.3, the results of the water samples (collected in Section 6.2.2 and Section 6.2.3) are discussed. These results are obtained using the proof of concept system proposed in Chapter 5. The same samples are then sent to the laboratory for the detailed analysis and testing of the quality of water. This Section discusses the summary of the results in laboratory testing for each sample. Complete laboratory reports and the detailed analysis for the quality of the water tested in the laboratory are attached in Appendix IB.

The tests were conducted at the laboratory working under the control and supervision of Water and Sanitation Authority Gujranwala (WASA), which is an agency of Gujranwala Development Authority (GDA). WASA was created in November 1997 for the execution of water supply and sewerage projects. Further details about the laboratory and how they conducted tests in the laboratory are presented in Appendix 2.

*Table 15: Laboratory results*

| Sample No. | Problems identified | Recommendations |
|---|---|---|
| Sample 1A | • Total Coliform, Fecal Coliform, and Escherichia Coli (E.coli) bacteria found the water. | Chemically Fit and microbiologically Unfit on the basis of parameters tested |
| Sample 1B | • Total Coliform, Fecal Coliform, and Escherichia Coli (E.coli) bacteria found the water | Chemically Fit and microbiologically Unfit on the basis of parameters tested |
| Sample 1C | • Total Coliform, Fecal Coliform, and Escherichia Coli (E.coli) bacteria found the water | Chemically Fit and microbiologically Unfit on the basis of parameters tested |
| | | |
| Sample 2A | • No problems are found | Chemically Fit and microbiologically Fit on the basis of parameters tested |
| Sample 2B | • No problems are found | Chemically Fit and microbiologically Fit on the basis of parameters tested |
| Sample 2C | • No problems are found | Chemically Fit and microbiologically Fit on the basis of parameters tested |
| | | |
| Sample 3A | • Total Coliform, Fecal Coliform, and Escherichia Coli (E.coli) bacteria found the water | Chemically Fit and microbiologically Unfit on the basis of parameters tested |
| Sample 3B | • Value of pH is slightly higher<br>• Total Coliform, Fecal Coliform, and Escherichia Coli (E.coli) bacteria found the water | Chemically Fit and microbiologically Unfit on the basis of parameters tested |
| Sample 3C | • Value of pH is higher<br>• Total Coliform, Fecal Coliform, and Escherichia Coli (E.coli) bacteria found the water | Chemically Fit and microbiologically Unfit on the basis of parameters tested |
| | | |
| Sample 4A | • No problems are found | Chemically Fit and microbiologically Fit on the basis of parameters tested |
| Sample 4B | • No problems are found | Chemically Fit and microbiologically Fit on the basis of parameters tested |
| Sample 4C | • No problems are found | Chemically Fit and microbiologically Fit on the basis of parameters tested |
| | | |

| | | |
|---|---|---|
| Sample 5A | • No problems are found | Chemically Fit and microbiologically Fit on the basis of parameters tested |
| Sample 5A | • No problems are found | Chemically Fit and microbiologically Fit on the basis of parameters tested |
| Sample 5A | • No problems are found | Chemically Fit and microbiologically Fit on the basis of parameters tested |
| | | |
| Sample 6A | • Value of pH is higher<br>• Water colour is Light Green<br>• Higher values of Turbidity<br>• Higher values of total dissolved solids<br>• Higher values of Total Hardness mg/l as $CaCO_3$<br>• Higher values of Bi Carbonates<br>• Slightly higher values of Chloride<br>• Higher values of Conductivity<br>• Total Coliform, Fecal Coliform, and Escherichia Coli (E.coli) bacteria found the water | Chemically Unfit and microbiologically Unfit on the basis of parameters tested. |
| Sample 6B | • Value of pH is higher<br>• Water colour is Light Green<br>• Higher values of Turbidity<br>• Higher values of total dissolved solids<br>• Higher values of Total Hardness mg/l as $CaCO_3$<br>• Higher values of Bi Carbonates<br>• Higher values of Conductivity<br>• Total Coliform, Fecal Coliform, and Escherichia Coli (E.coli) bacteria found the water | Chemically Unfit and microbiologically Unfit on the basis of parameters tested. |
| Sample 6C | • Value of pH is higher<br>• Water colour is Light Green<br>• Higher values of Turbidity<br>• Higher values of total dissolved solids<br>• Higher values of Total Hardness mg/l as $CaCO_3$<br>• Higher values of Bi Carbonates<br>• Slightly higher values of Chloride<br>• Higher values of Conductivity<br>• Total Coliform, Fecal Coliform, and Escherichia Coli (E.coli) bacteria found the water | Chemically Unfit and microbiologically Unfit on the basis of parameters tested. |
| | | |

| | | |
|---|---|---|
| Sample 7A | • Water colour is Green and Yellow<br>• Higher values of Turbidity<br>• Slightly higher values of total dissolved solids<br>• Higher values of Calcium<br>• Higher values of Total Hardness mg/l as CaCO3<br>• Higher values of Bi Carbonates<br>• Higher values of Conductivity<br>• Total Coliform, Fecal Coliform, and Escherichia Coli (E.coli) bacteria found the water | Chemically Unfit and microbiologically Unfit on the basis of parameters tested. |
| Sample 7B | • Water colour is Green and Yellow<br>• Higher values of Turbidity<br>• Slightly higher values of total dissolved solids<br>• Higher values of Calcium<br>• Higher values of Total Hardness mg/l as CaCO3<br>• Higher values of Bi Carbonates<br>• Higher values of Conductivity<br>• Total Coliform, Fecal Coliform, and Escherichia Coli (E.coli) bacteria found the water | Chemically Unfit and microbiologically Unfit on the basis of parameters tested. |
| Sample 7C | • Water colour is Green and Yellow<br>• Higher values of Turbidity<br>• Slightly higher values of total dissolved solids<br>• Higher values of Calcium<br>• Higher values of Total Hardness mg/l as CaCO3<br>• Higher values of Bi Carbonates<br>• Higher values of Conductivity<br>• Total Coliform, Fecal Coliform, and Escherichia Coli (E.coli) bacteria found the water | Chemically Unfit and microbiologically Unfit on the basis of parameters tested. |
| | | |
| Sample 8A | • Value of pH is higher<br>• Water colour is Green<br>• Higher values of Turbidity<br>• Higher values of Bi Carbonates<br>• Higher values of Conductivity<br>• Total Coliform, Fecal Coliform, and Escherichia Coli (E.coli) bacteria found the water | Chemically Unfit and microbiologically Unfit on the basis of parameters tested. |

| | | |
|---|---|---|
| Sample 8B | • Value of pH is higher<br>• Water colour is Green<br>• Higher values of Turbidity<br>• Higher values of Bi Carbonates<br>• Higher values of Conductivity<br>• Total Coliform, Fecal Coliform, and Escherichia Coli (E.coli) bacteria found the water | Chemically Unfit and microbiologically Unfit on the basis of parameters tested. |
| Sample 8C | • Value of pH is higher<br>• Water colour is Green<br>• Higher values of Turbidity<br>• Higher values of Bi Carbonates<br>• Higher values of Conductivity<br>• Total Coliform, Fecal Coliform, and Escherichia Coli (E.coli) bacteria found the water | Chemically Unfit and microbiologically Unfit on the basis of parameters tested. |

## 6.4 Comparison of results and discussion

In Section 6.3.1 and Section 6.3.2 the results of the water testing using the proof of concept system and laboratory are presented. This section compares and discusses the results from both of those sets. The effectiveness of this research has also been discussed in this section.

### 6.4.1 Sample 1

Sample 1 is collected from a surface water plant. It is tested with the proof of concept system and found its temperature too high to drink. Based on the considerations of the temperature (as discussed in Section 4.3.1) the proof of concept system indicated the potential presence of the bacteria in the water sample. In the laboratory tests bacteria growth is indeed identified. This proves our initial hypothesis that the variation of temperature can indicate the presence of bacteria in the source of water.

*Table 16: Result comparison for sample 1*

| Results comparison (Sample 1) | | | |
|---|---|---|---|
| **Sample No.** | **Proof of Concept Recommendations** | **Laboratory Outcome** | **Matching Status** |
| Sample 1A | Water is too hot for drinking. Because of the temperature water may contain some forms of bacteria and other germs. Get it tested in a laboratory for detailed problem identification. | Chemically Fit and microbiologically Unfit on the basis of parameters tested | Result matched |
| Sample 1B | Water is too hot for drinking. Because of the temperature water may contain some forms of bacteria and other germs. Get it tested in a laboratory for detailed problem identification. | Chemically Fit and microbiologically Unfit on the basis of parameters tested | Result matched |
| Sample 1C | Water is too hot for drinking. Because of the temperature water may contain some forms of bacteria and other germs. Get it tested in a laboratory for detailed problem identification. | Chemically Fit and microbiologically Unfit on the basis of parameters tested | Result matched |

### 6.4.2 Sample 2

Sample 2 is collected from a hand pump near canal. The proof of concept system monitored the values of temperature, pH, turbidity, and electric conductivity. All these parameters are found in the range suitable for drinking water. The same samples are then tested in the laboratory and no problems are identified in all three samples collected from this source. This approves our hypothesis that the water is suitable for domestic consumption if the values of temperature, pH, turbidity, and electric conductivity are in the given range for drinking water.

*Table 17: Result comparison for sample 2*

| Results comparison (Sample 2) | | | |
|---|---|---|---|
| **Sample No.** | **Proof of Concept Recommendations** | **Laboratory Outcome** | **Matching Status** |
| Sample 2A | Fit for drinking | Chemically Fit and microbiologically Fit on the basis of parameters tested | Result matched |
| Sample 2B | Fit for drinking | Chemically Fit and microbiologically Fit on the basis of parameters tested | Result matched |
| Sample 2C | Fit for drinking | Chemically Fit and microbiologically Fit on the basis of parameters tested | Result matched |

### 6.4.3 Sample 3

Sample 3 is collected from the household shallow bore that is approximately 100 feet deep. Three samples from the same source are collected and tested.

In Sample 3A the proof of concept system found that the values of temperature, pH, turbidity, and electric conductivity are in the acceptable range. Based on the parameters tested the proof of concept system declared the water suitable for drinking. However, in the laboratory the Sample 3A was declared chemically fit and microbiologically unfit for drinking. Laboratory testing for Sample 3A indicated the presences of Bactria. In this case the proof of concept system was not able to identify and predict the potential problem.

*Table 18: Result comparison for sample 3*

| **Results comparison (Sample 3)** | | | |
|---|---|---|---|
| **Sample No.** | **Proof of Concept Recommendations** | **Laboratory Outcome** | **Matching Status** |
| Sample 3A | Fit for drinking | Chemically Fit and microbiologically Unfit on the basis of parameters tested | Result did not matched |
| Sample 3B | Water is potentially hard. The disturbance in the value of pH can be because of dissolved solids in the source. Get it tested in a laboratory for detailed problem identification | Chemically Fit and microbiologically Unfit on the basis of parameters tested | Result matched |
| Sample 3C | Water is potentially hard. The disturbance in the value of pH can be because of dissolved solids in the source. Get it tested in a laboratory for detailed problem identification | Chemically Fit and microbiologically Unfit on the basis of parameters tested | Result matched |

However, for Sample 3B and Sample 3C the results between the proof of concept system and laboratory testing matched. The proof of concept system found that the water samples have higher values of pH. This indicates that the water is potentially hard as discussed in the impacts of higher pH values in Section 4.3.2. In addition to that, the disturbance in the value of pH can be because of higher number of dissolved solids in the source of water. This can also encourage the existence and growth of different types of bacteria. Considering this, the proof of concept system indicated potential problems with the water and a possibility of presence of bacteria. The laboratory testing reported that the Sample 3B and 3C are chemically fit but microbiologically unfit because of the presence of bacteria in the water sample. The laboratory results proved that the prediction of the proof of concept system about the potential presence of bacteria is right.

A difference to note here is that the laboratory considers the ranges for WHO's maximum permissible levels for the pH values whereas, the proof of concept system considers WHO's desirable levels. This is one of the differences why the proof of concept system labelled Sample 3B and 3C chemically unfit and the laboratory considered these samples fit.

Furthermore, using the proof of concept system, the values of pH in Sample 3A, 3B, and 3C are slightly different from the laboratory results. This is possibly because of the sensor used in the proof of concept system is a low cost sensor and has an accuracy to ± 0.1pH at 25 ℃. The sensor also needs to be calibrated before conducting the test. The irregularities in the calibration can cause result to vary. To avoid such differences it is advised to use more accurate and advanced sensors for more accurate readings.

### 6.4.4 Sample 4

Sample 4 has been collected from a household shallow borehole that is 300 feet to 400 feet deep. The proof of concept system monitored the values of temperature, pH, turbidity, and electric conductivity. All these parameters are found in the range suitable for drinking water. The samples are then tested in the laboratory and no problems are identified in all three samples collected from this source. This endorses our hypothesis that the water is suitable for domestic consumption if the values of temperature, pH, turbidity, and electric conductivity are in the given range for drinking water.

*Table 19: Result comparison for sample 4*

| Results comparison (Sample 4) | | | |
|---|---|---|---|
| **Sample No.** | **Proof of Concept Recommendations** | **Laboratory Outcome** | **Matching Status** |
| Sample 4A | Fit for drinking | Chemically Fit and microbiologically Fit on the basis of parameters tested | Result matched |
| Sample 4B | Fit for drinking | Chemically Fit and microbiologically Fit on the basis of parameters tested | Result matched |
| Sample 4C | Fit for drinking | Chemically Fit and microbiologically Fit on the basis of parameters tested | Result matched |

### 6.4.5 Sample 5

Sample 5 is collected from a household shallow borehole that is 500 feet to 600 feet deep. The proof of concept system monitored the values of temperature, pH, turbidity, and electric conductivity. All these parameters are found in the range suitable for drinking water. The samples are then tested in the laboratory and no problems are identified in all three samples collected from this source. This approves our hypothesis that the water is suitable for domestic consumption if the values of temperature, pH, turbidity, and electric conductivity are in the given range for drinking water.

*Table 20: Result comparison for sample 5*

| **Results comparison (Sample 5)** | | | |
|---|---|---|---|
| **Sample No.** | **Proof of Concept Recommendations** | **Laboratory Outcome** | **Matching Status** |
| Sample 5A | Fit for drinking | Chemically Fit and microbiologically Fit on the basis of parameters tested | Result matched |
| Sample 5B | Fit for drinking | Chemically Fit and microbiologically Fit on the basis of parameters tested | Result matched |
| Sample 5C | Fit for drinking | Chemically Fit and microbiologically Fit on the basis of parameters tested | Result matched |

### 6.4.6 Sample 6

Sample 6 is collected from the stream where the chemical wastage of a factory is also drained. The parameters tested using the proof of concept system found that the temperature of the water is very high for drinking and also is ideal for the growth of bacteria. Furthermore, water is strongly alkaline. As discussed in Section 4.3.2.2, if the values of pH are higher than 7, the water is considered as hard water. The value of total dissolved solids can also change the pH values of water, resulting in the change of the taste of water. The turbidity of the water is above the range for the water suitable for drinking. Electric conductivity is detected abnormal and indicates that there are higher range of dissolved solids in the sample. The proof of concept system recommended that the water is not suitable for drinking and must be tested in laboratory for detailed problem identification.

*Table 21: Result comparison for sample 6*

| Results comparison (Sample 6) | | | |
|---|---|---|---|
| **Sample No.** | **Proof of Concept Recommendations** | **Laboratory Outcome** | **Matching Status** |
| Sample 6A | Strongly hard water, Murky and too hot to drink. Predicted to have bacteria and other solvents and recommended for testing in the laboratory testing. | Chemically Unfit and microbiologically Unfit on the basis of parameters tested. | Result matched |
| Sample 6B | Strongly hard water, Murky and too hot to drink. Predicted to have bacteria and other solvents and recommended for testing in the laboratory testing. | Chemically Unfit and microbiologically Unfit on the basis of parameters tested. | Result matched |
| Sample 6C | Strongly hard water, Murky and too hot to drink. Predicted to have bacteria and other solvents and recommended for testing in the laboratory testing. | Chemically Unfit and microbiologically Unfit on the basis of parameters tested. | Result matched |

In the laboratory testing, it is identified that the water samples are chemically and microbiologically unfit for domestic consumption. The laboratory also found water strongly alkaline and light green in colour. The samples are very murky and their turbidity level is higher than the desired values. The water samples had higher values for total dissolved solids including Bi carbonates, chloride and total hardness mg/l as $CaCO_3$. The laboratory also found the presence of bacteria in the water samples.

As discussed in Section 6.4.3 the values of pH between proof of concept system and laboratory results are slightly different. This is possibly because of the sensor used in the proof of concept system is a low cost sensor and has an accuracy to ± 0.1pH at 25 ℃. The sensor also needs to be calibrated before conducting the test. The irregularities in the calibration can cause result to vary. To avoid such differences it is advised to use more accurate and advanced sensors for more accurate readings.

### 6.4.7 Sample 7

Sample 7 is collected from the yard wastage. The parameters tested using the proof of concept system found that the temperature of the water is higher than the suitable temperature for drinking and also is ideal for the growth of bacteria. The water looked murky and it is shown by the abnormal values of turbidity. The higher values of electric conductivity indicates that the water may have high value of solvents. The proof of concept system recommends that the water is not suitable for drinking and must be tested for detailed problem identification.

*Table 22: Result comparison for sample 7*

| **Results comparison (Sample 7)** | | | |
|---|---|---|---|
| **Sample No.** | **Proof of Concept Recommendations** | **Laboratory Outcome** | **Matching Status** |
| Sample 7A | Water is dirty and too hot to drink. Predicted to have bacteria and other solvents and recommended to be tested in the laboratory. | Chemically Unfit and microbiologically Unfit on the basis of parameters tested. | Result matched |
| Sample 7B | Water is dirty and too hot to drink. Predicted to have bacteria and other solvents and recommended to be tested in the laboratory. | Chemically Unfit and microbiologically Unfit on the basis of parameters tested. | Result matched |
| Sample 7C | Water is dirty and too hot to drink. Predicted to have bacteria and other solvents and recommended to be tested in the laboratory. | Chemically Unfit and microbiologically Unfit on the basis of parameters tested. | Result matched |

In the laboratory testing, it is identified that the water samples are chemically and microbiologically unfit for domestic consumption. The water samples are green and yellowish in colour. The samples are very murky and their turbidity level is higher than the desired values. The laboratory also found the presence of bacteria in the water samples.

The matching of results between proof of concept system and laboratory testing approves our hypothesis that the values of temperature, pH, turbidity, and electric conductivity can indicate the suitability of water for drinking.

### 6.4.8 Sample 8

Sample 8 is collected from sink wastage from a household. The proof of concept system identified the abnormal values of pH. This probably because of the usage of different detergents for washing kitchen utensils. . Furthermore, the water was foggy which is indicated by the value of turbidity shown in the testing. Based on the higher values of electric conductivity the proof of concept system predicts the higher ratio of solvents in the water samples. Based on the parameters monitored the proof of concept system does not recommend the water to be used for drinking purposes.

*Table 23: Result comparison for sample 8*

| **Results comparison (Sample 8)** | | | |
|---|---|---|---|
| **Sample No.** | **Proof of Concept Recommendations** | **Laboratory Outcome** | **Matching Status** |
| Sample 8A | Strongly hard water, Murky and marginally hot to drink. Predicted to have bacteria and other solvents and recommended for testing in the laboratory testing. | Chemically Unfit and microbiologically Unfit on the basis of parameters tested. | Result matched |
| Sample 8B | Strongly hard water, Murky and marginally hot to drink. Predicted to have bacteria and other solvents and recommended for testing in the laboratory testing. | Chemically Unfit and microbiologically Unfit on the basis of parameters tested. | Result matched |
| Sample 8C | Strongly hard water, Murky and marginally hot to drink. Predicted to have bacteria and other solvents and recommended for testing in the laboratory testing. | Chemically Unfit and microbiologically Unfit on the basis of parameters tested. | Result matched |

In the laboratory testing the water was found strongly alkaline and green in colour. Based on the parameters tested, the laboratory declared water unfit for drinking both chemically and microbiologically. The result between the proof of concept system and laboratory testing matched. This also approves our initial hypothesis that use of temperature, pH, turbidity, and electric conductivity can enable us to qualify the quality of water for drinking.

# 7 Chapter 7 Conclusion and Future works

## 7.1 Conclusion

Water is the basic necessity for all the living organisms. 67% of the Earth's is covered by water. The quality of water is one of the most critical problems in the world today. In rural areas of South Africa, quality of water is a major public health concern.

Several researchers had showed that the quality of the water can be tested effectively in the field as well as the samples can be brought to the laboratory for testing. Many researchers agree that the laboratory testing is more detailed but costly and require a long time to get results.

In the field, it is also possible to test the water quality accurately with handheld instruments but it requires expensive instrumentation and significant manual work to monitor the quality of potable water. Alternatively, remote monitoring system on water supply systems to monitor all or few water quality parameters and transmit the results to the base station for record and action if there is any indication of deterioration of water quality.

The proposed system adapted the similar technique. Few vital parameters related to water quality were being chosen for real time monitoring.

As indicated in the problem statement and research question sections that this research was about determining the list of minimum parameters that can generate enough information about the quality of drinking water.

Many systems had been developed to monitor the physiochemical properties of the water by using direct and indirect ways. Temperature, pH, turbidity, dissolved nitrates, dissolved oxygen, water hardness, total dissolved solids, electric conductivity and oxidation reduction potential (ORP) were some of the most important parameters. Different combinations of these parameters were used in existing monitoring systems. However, in all of these cases the researchers did not describe the scientific evidence behind their choice. Technically it was possible to use all the available parameters to monitor the quality of water. However, the parameters were inter-dependent and fewer parameters can provide a full picture of water quality if selected carefully.

Considering all these challenges, it was identified that there was a need for research that could found a list of least number of parameters in a water sample to determine the quality of water that was safe for drinking in a domestic environment.

This work recommended to measure fewer significant parameters that affect the quality of drinking water. The action can be taken if the measured parameter values go out of the range. The possible action could be a detailed investigation (in laboratory) of the quality of water if the measured parameters stay out of range for an appreciable length of time.

The parameters mentioned below are used for this work.

1. pH
2. Temperature
3. Turbidity
4. Electric Conductivity

These parameters are good candidates due to the robustness of the sensors as well as the low cost. The proposed method is cost effective, efficient and provide enough information about the water quality in a given sample or a running water source. The measured data transmitted to the base station with existing wireless technologies and used for decision making and record keeping.

## 7.2 Future work recommendations

1. Because of the limited funding available, the development of the circuitry for measuring the electric conductivity was not designed. To measure the electric conductivity an instrument was borrowed from the laboratory. However the selection of the suitable technology has been discussed in Section 4.4.1.4. It is recommended to develop the circuit for measuring the electric conductive for future research.
2. For future developments it is recommended that the Ethernet shield must be replaced with WiFi or 3G shields for Arduino. This is to achieve the ease of installation in the domestic water usage environment.
3. Currently the system is targeted as a single node system. However there is a possibility to design a multi node system. As discussed in Section 4.5, designing and modelling such a system is not the scope of this report however a brief proposed multimode system has been shown in Figure 3. In future work a multi node system is recommended. A multimode system can enable the water supply utilities to get the data from multiple remote sites, accumulate it to a central hub, and that hub can then post that data to the main data centre. The future research can study about the technologies that can be used to

communicate between the different nodes. It can also study about the impact between the different time intervals for posting data to the data centre.

# References

[1] Milwaukee, 1993: The Largest Documented Waterborne diseases outbreak in US history available at (http://www.waterandhealth.org/milwaukee-1993-largest-documented-waterborne-disease-outbreak-history/) last visited on 18 May 2017

[2]Article "Water for Life "by Kaye Sehm, 2011 available at (https://steps.org.au/Health/Water-for-Life.html) last visited on 15 March 2017

[3] Kleiner SM. 1999. Water: an essential but overlooked nutrient. Nutritional Sciences Program, University of Washington. Journal of the American Water Works Association. 99(4), p.411.

[4] Managing legionella in hot and cold water systems available at

(http://www.hse.gov.uk/healthservices/legionella.htm)last visited on 13 September 2016

[5] WHO (World Health Organization). 2008. Guidelines for Drinking Water Quality.3rd edn. Incooperating the first and second addenda. Volume 1, Recommendations. World Health Organization, Geneva.

[6] SANS (South African National Standards) 241. (2011). Drinking Water Standards. Standards South Africa (a division of SABS), Pretoria.

[7] Definition of water available at

(http://www.merriam-webster.com/dictionary/water), last visited on 25th March 2016,

[8] MNB Momba, Z Tyafa, N Makala, BM Brouckaert and CL Obi Safe drinking water still a dream in rural areas of South Africa, Case Study: The Eastern Cape Province, ISSN 0378-4738 = Water SA Vol. 32 No. 5 (Special edn. WISA 2006), ISSN 1816-7950 = Water SA (on-line).

[9] The world water volume 8 by Peter H.Cleick, ISBN: 978-1-61091-482-6.

[10] UN-Water 2009 World Water Day brochure. Available at (http://www.unwater.org/worldwaterday/downloads/wwd09brochureenLOW.pdf.) last visited on 20 May 2016

[11] WHO and UNICEF (World Health Organization and United Nations Children's Fund). 2006. Meeting the MDG Drinking Water and Sanitation target. The urban and rural challenge of the decade.

[12] F. X. R Van Leeuwen; Food and Chemical Toxicology, 38(2000)51-58.

[13] G. Holgate; Environmental and Waste Management, 3(2000)105-112.

[14] GOAL 6 TARGETS available at (http://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-6-clean-water-and-sanitation/targets/) visited on 08th March 2017.

[15] G. H. Huang and J. Xia; Journal of Environmental Management, 61(2001)1-23.

[16] The Water Crisis in Kenya: Causes, Effects and Solutions by Samantha Marshall, Global Majority E-Journal, Vol. 2, No. 1 (June 2011), pp. 31-45

[17] Water situation in South Africa (water wise rand water) available at

(http://www.waterwise.co.za/site/water/environment/situation.html), last visited on 15th April 2016.

[18] Clean water for developing countries by Hilary wighton in December 2009. The Faculty of the Social Sciences Department CALIFORNIA POLYTECHNIC STATE UNIVERSITY, San Luis Obispo

[19] Water and environment available at

(https://www.ec.gc.ca/eau-water/default.asp?lang=En&n=F2F43FC7-1) , last visited on 4th April 2016.

[20] WHO (World Health Organization). 1993. Guidelines for Drinking Water Quality. 2 nd edn. Volume 1, Recommendations, World Health Organization, Geneva.

[21] Water scarcity and importance of water available at

(https://thewaterproject.org/water_scarcity), last visited on 15h April 2016.

[22] WHO (World Health Organization). 2001. Water Quality Guidelines, Standards and Health: Assessment of risk and risk management for water-related infectious disease. Fewtrell L, ed. WHO. Geneva.

[23] Vega M, Pardo R, Barrado E and Debaâ L. 1998. Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis. Water Research. 32(12), pp.3581-3592.

[24] WRI (World Resources Institute). 1992. World resources 1992-1993. Oxford University Press, New York.

[25] Nash L. 1993. Water Quality and Health. In: Gleik P (ed). Water in Crisis: New York. Oxford University Press.

[26] USEPA (US Environmental Protection Agency). 1999a. Guidance manual on turbidity provisions: Importance of turbidity. United States Environmental Protection Agency. Washington, DC. Available at (http://www.epa.gov/ogwdw/mdbp/pdf/turbidity/chap_07.pdf), last visited on 28th March 2017.

[27] Aydemir S, Sönmez O and Sakin E. 2005. The effects of commonly used chemical substances on water quality in Geliş, Tarihi. Soil Science. 9(2), pp.1-10.

[28] SEN0161 and SEN0169 datasheet available at

(https://media.digikey.com/pdf/Data%20Sheets/DFRobot%20PDFs/SEN0161_SEN0169_Web.pdf) last visited on 22 August 2017

[29] Sensors datasheets available at

(https://www.phidgets.com) last visited on 22 August 2017

[30] Zamxaka M, Pironcheva G and Muyima NYO. 2004. Microbiological and Physico-chemical assessment of the quality of domestic water sources in selected rural communities of the Eastern Cape Province, South Africa. Water South Africa. 30(3), pp.333-334.

[31] Mackintosh G and Colvin C. 2003. Failure of rural schemes in SA to provide potable water. Environmental Geology. 44(1), p.101.

[32] DWAF (Department of Water Affairs and Forestry, South Africa). 2005a. A drinking water quality framework for South Africa. Department of Water Affairs and Forestry, Pretoria.

[33] The Water Crisis in Kenya: Causes, Effects and Solutions by Samantha Marshall, Global Majority E-Journal, Vol. 2, No. 1 (June 2011), pp. 31-45

[34] Africa Bio. 2002. Biotechnology in South Africa, a report submitted to the 2002 World summit on sustainable development. Pretoria.

[35] Wright J. 2006. The impact of Katse dam water on water quality in the Ash, Liebenbergsvlei and Wilge rivers and the Vaal dam. Master of Science Dissertation. University of Johannesburg.

[36] Water in crisis- South Africa (The Water Project) available at

(https://thewaterproject.org/water-in-crisis-south-africa), last visited on 03 May 2016.

[37] USEPA (United States Environmental Protection Agency). 1999b. 25 years of the safe drinking water act: History and trends. USEPA Report 816-R-99-007. Available at (http://yosemite.epa.gov/water/owrccatalog.nsf/0/b126b7616c71450285256d83004fda48?OpenDocument), last visited on 15h August 2016.

[38] Cohen B. 2006. Urbanization in developing countries: current trends, future projections, and key challenges for sustainability. Technology in Society. 28, pp.63-80.

[39] Kiera Cavalleri and Bethany Brinkman "Water Treatment in Context Resources and African Religion" IEEE Systems and Information Engineering Design Symposium 2015.

[40] UNFP (United Nations Population Fund). 2007. State of world population 2007: Unleashing the potential of urban growth.104, New York. Available at (http://www.unfpa.org/upload/lib_pub_file/695_filename_sowp2007_eng.pdf last), visited on 20th June 2016.

[41] Winter CT, Hudson WJ, Franke OL and Alley WM. 2002. Groundwater and surface water, a single resource. US Geology Survey.

[42] Wright J, Gundry S and Conroy R. 2004. Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use. Tropical Medicine International Health. 9, pp.106-117

[43] Jagals P, Grabow WOK and Williams E. 1997. The effects of supplied water quality on human health in an urban development with limited basic subsistence facilities. Water South Africa. 23, pp.373-378.

[44] Adams S, Titus R, Piertesen K, Tredeoux G and Harris C. 2001. Hydro chemical characteristics of aquifers near Sutherland in the Western Karoo, South Africa. Journal of Hydrology. 241(1-2), p.91.

[45] Definition of water available at

(http://www.merriam-webster.com/dictionary/water), last visited on 25th March 2016.

[46] Sombo Yamamura, World Health Organization, Geneva, Switzerland. Chapter # 5, Drinking Water Guidelines and Standards. Available at

(http://www.who.int/water_sanitation_health/dwq/arsenicun5.pdf) last visited on 8 January 2017

[47] Joshua Nizel Halder, M. Nazrul Islam 2015. Water Pollution and its Impact on the Human Health. JOURNAL OF ENVIRONMENT AND HUMAN: ISSN (Online): 2373-8332

[48] Deborah Chapman 1992-1996. Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring-Second Edition.

[49] Ulrike Rivett, Michael Champanis and Toni Wilson-Jones 2012.

Monitoring drinking water quality in South Africa: Designing information systems for local needs, presented in Water Institute of Southern Africa (WISA) Biennial Conference, Cape Town,

[50] UN WWAP. 2009. United Nations World Water Assessment Programme. The World Water Development Report 3: Water in a Changing World. UNESCO: Paris, France.

[51] WHO (World Health Organization) 2003. United Nations Environment Programme, WHO. Geneva.

[52] Sensors datasheets available at

(https://www.dfrobot.com) last visited on 25th March 2017.

[53] Sensors datasheets available at

[54] (https://www.atlas-scientific.com) last visited on 25th March 2017.

[55]Sustainable development goals fact sheet of the united nation available at

(http://www.un.org/sustainabledevelopment/wpcontent/uploads/2015/08/Factsheet_Summit.pdf) last visited on 23 May 2016

[56] Charrois P and Jeffrey W. 2010. Private drinking water supplies: challenges for public health. Canadian Medical Association Journal. 182(10), pp.1061-1064.

[57] Zhe SY, Shi ZN, Zhang DP, Huang JQ and Yu GP. 1991. Investigation of the effect of drinking water polluted by petroleum chemical industrial waste water on village residents [in Chinese]. Huanjing Yu Jiankang Zazhi .Journal of Environment and Health. 8(5), pp.193-195.

[58] Rufener S, Mäusezahl D, Mosler H and Weingartner R. 2010. Quality of drinking water at source and point of consumption: Drinking cup as a high potential recontamination risk: A field study in Bolivia. Journal of Health, Population and Nutrition. 28(1), pp.34-41.

[59] Makoni FSN. 2001. Assessment of water and sanitation facilities and related diseases among poor urban communities in Zimbabwe. Master of Science Thesis (unpublished), University of Zimbabwe.

[60] Ulrike Rivett*, Michael Champanis, and Toni Wilson-Jones 2012.

Monitoring drinking water quality in South Africa: Designing information systems for local needs: iCOMMS, Department of Civil Engineering, University of Cape Town, South Africa, presented in Water Institute of Southern Africa (WISA) Biennial Conference, Cape Town

[61] Mariana Jurian, and Cristian Panait, Visan Daniel, Cioc Bogdan 2010. Monitoring Drinking Water Quality and Wireless Transmission of Parameters, presented in IEEE, 33rd Int. Spring Seminar on Electronics Technology.

[62] Aravinda S. Rao, Stephen Marshall, Jayavardhana Gubbi and Marimuthu Palaniswami 2013. International Conference on Advances in Computing, Communications and Informatics (ICACCI). Presented in IEEE.

[63] Pradeepkumar M, Monisha J, Pravenisha R, Praiselin V, Suganya Devi K 2016. The Real Time Monitoring of Water Quality in IoT Environment. International Journal of Innovative Research in Science, Engineering and Technology, Vol. 5, Issue.

[64] Pandian D R & Dr. Mala K 2015. Smart Device to monitor water quality to avoid pollution in IoT environment. International Journal of Emerging Technology in Computer Science & Electronics (IJETCSE) ISSN: 0976-1353 Volume 12 Issue.

[65] Mompoloki Pule, Abid Yahya and Joseph Chuma 2016. A Wireless Sensor Network Solution for Monitoring Water Quality in Botswana. IEEE 3rd National Foundation for Science and Technology Development Conference on Information and Computer Science.

[66] Chilton PJ and Foster SSD. 1995. Hydrogeological characterization and water supply potential of basement aquifers in tropical Africa. Hydrogeology Journal. 3(1), pp.36-49.

[67] Pedley S and Howard G. 1997. Effects of water on health: The public health implications of microbiological contamination of groundwater. Journal of Engineering Geology and Hydrogeology. 30, pp.179-188.

[68] Ashbolt NJ. 2004. Microbial contamination of drinking water and disease outcomes in developing regions. Toxicology. 198, pp.229-238.

[69] Marco Zennaro, Athanasios Floros, Gokhan Dogan, Tao Sun, Zhichao Cao, Chen Huang, Manzoor Bahader, Herve' Ntareme 2009. On the design of aWater QualityWireless Sensor Network (WQWSN): an Application toWater Quality Monitoring in Malawi International Conference on Parallel Processing Workshops

[70] Basavaraja Simpi, S.M. Hiremath, KNS Murthy, K.N.Chandrashekarappa, Anil N Patel, and E.T.Puttiah 2012. Analysis of Water Quality Using Physico-Chemical Parameters Hosahalli Tank in Shimoga District, Karnataka, India. Global Journal of Science Frontier Research, Vol 9 Issue.

[71] DWAF (Department of Water Affairs and Forestry, South Africa). (1996). South African Water Quality Guidelines. Volume 1: Domestic Water Use Second Edition. Department of Water Affairs and Forestry, Pretoria.

[72] Haron, N. S., Mahamad, M. K., Aziz, I. A. & Mehat, M., 2009. Remote Water Quality Monitoring System using Wireless Sensors.

[73] World Meteorological Organization, 2013, Technical Report Series No. 3: PLANNING OF WATER-QUALITY MONITORING SYSTEMS, ISBN 978-92-63-11113-5.

[74] Raspberry Pi or Arduino Uno available at

(https://makezine.com/2015/12/04/admittedly-simplistic-guide-raspberry-pi-vs-arduino/), last visited on 23th October 2017.

[75] Nanode available at

(www.nanode.eu/what-is-nanode/), last visited on 21th October 2017.

[76] Arduino available at

(https://www.arduino.cc/en/Guide/Introduction), last visited on 21th October 2017.

[77] Raspberry Pi available at

(https://www.raspberrypi.org/help/what-%20is-a-raspberry-pi/), last visited on 21th October 2017.

[78] Ethernet cable available at

(https://www.lifewire.com/what-is-an-ethernet-cable-817548), last visited on 21th October 2017.

[79] zigbee vs wifi available at

(https://www.link-labs.com/blog/zigbee-vs-wifi-802-11ah), last visited on 22th October 2017.

[80] Bluetooth and zigbee available at

(http://www.differencebetween.info/difference-between-zigbee-and-bluetooth), last visited on 22th October 2017.

[81] 3G,4G and LTE available at

(http://www.ianswerguy.com/what-is-3g-4g-lte/), last visited on 22th October 2017.

[82] Asymmetric digital subscriber line available at

(searchnetworking.techtarget.com › Network Design › Telecom), last visited on 23th October 2017.

[83] MQTT vs HTTP available at

(www.rfwireless-world.com/Terminology/MQTT-vs-HTTP.html), last visited on 23th October 2017.

[84] XMPP definition available at

(https://xmpp.org/about/), last visited on 23th October 2017.

[85] MangoDB vd RDBMS available at

(https://www.tutorialsjar.com/mongodb-vs-rdbms-difference), last visited on 23th October 2017.

[86] Water sampling and analysis by WHO available at

(http://www.who.int/water_sanitation_health/dwq/2edvol3d.pdf), last visited on 05 September 2017

[87] Water collection practices by water technology solution for industry management available at

(https://www.watertechonline.com/best-practices-for-collecting-water-samples/), last visited on 26 December 2016

[88] Electric conductivity manual

(https://www.dfrobot.com/wiki/index.php/Analog_EC_Meter_SKU:DFR0300), last visited on 18 October 2017