REAL TIME AUTOMATED WATER QUALITY MONITORING SYSTEM

A case study of Thiririka River, Kiambu County

By

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Project report submitted to the department of Geomatic Engineering and geospatial Information Systems degree of Bachelor of Science in Geomatic Engineering and Geospatial Information Systems.

Department of Geomatic Engineering and Geospatial Information Systems (GEGIS)

DECLARATION

I declare that this project is my own work and has not been submitted by anybody else in any other university for the award of any degree to the best of my knowledge.

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CERTIFICATION

This project has been submitted for examination with my approval as the candidate's supervisor.

Sign……………………………. Date ………………………………………………

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Table of Contents

List of figures

Abstract

Water is a crucial commodity for humanity. We cannot live without it, we use it for domestic, industrial, recreational and for power production through hydro-electric power generation. It is paramount to conserve and protect our water resources if we are to use it in the first place.

Water pollution is the contamination of the water caused by human action leading to reduction in the water quality and increased toxicity. Watersheds and systems have been polluted over the years by human and animal waste, soil erosion, effluent discharge from industries, organic waste or agricultural chemicals, metals among others. This results in loss of the various applications of water discharge such as water for domestic and industrial use, irrigation, recreation and many more.

Globally, many countries in the world experience water pollution; be it contamination of rivers, streams, lakes and even the ocean and seas. According to the United Nations, about 30% of fresh water that is accessible is used for industries and agriculture yet water pollution reduces the available usable water for drinking and other domestic purposes.

In Sub-Saharan Africa, only 40% of residents have access to clean and safe water. Unsafe drinking water, poor sanitation and poor hygiene cause high rate of infection of cholera in region. 42% of the population lack an improved water source within 500m, 16% lack proper sanitation, and 36% cannot access soap for hand washing.

In Kenya, water pollution is a major environmental problem. According to the Kenya Water Pollution 2019 statistics, 42% of the population are unable to use clean and safe water while 59% of the population does not practice safe sanitation.

Furthermore, the spread of water-borne diseases such as cholera, dysentery, typhoid among others has become more rampant in the city - “Nairobi County issues a warning on the cholera outbreak”, according to The Star Newspaper March 2019. River remediation should be an imperative venture not only locally but also globally. Demographic pressures produce acute water shortages which make the provision of future environmental flows highly unlikely. (Wal, Abdul, Muhammad et al in Environmental Pollution, 2019).

Research done on water pollution was done on emphasis on water turbidity in rivers. Turbidity is a measure of light passing through water and the clarity of the water. Most methods of monitoring pollution is done by sampling and testing method; whereby samples are collected and analysed in the laboratory.

With increasing levels of pollution in our water systems, there is a necessity to monitor and assess the levels in real time to prevent further pollution. There are point and non-point sources of pollution. Using modern sensor technology, we can track the pollution and determine the source or extent. State-of-the-art water turbidity meters are being installed in rivers and other water resources to provide an instantaneous turbidity reading. A long device is lowered into the water and at the end is a turbidity sensor that reads turbidity in the river by measuring the amount of light penetration in the water and reading how much light is reflected back to the sensor. These devices can house multiple water-quality sensors, such as a conductivity sensor to measure electrical conductance of the water, which is strongly influenced by dissolved solids, pH sensors among others.

The results achieved are in form of graphs and maps showing the level of pollution and the extent. These results aid in monitoring and assessing pollution of a given watershed. Therefore this will inform the public and relevant authorities on how to mitigate and manage the situation. The research gap to be filled include coming up with more sophisticated equipment that is robust and measures various kinds of pollutants in the water in real time such as a combination of turbidity, pH, temperature, dissolved oxygen, suspended solids, dissolved solids among others.

1 Chapter One

Introduction

• 1.1 Background

Water pollution is the contamination of the water caused by human action leading to reduction in the water quality and increased toxicity. Water sheds and systems have been polluted over the years by human and animal waste, soil erosion, effluent discharge from industries, organic waste or agricultural chemicals, metals among others. This results in loss of the various applications of water discharge such as water for domestic and industrial use, irrigation, recreation and many more.

Water contamination is a worldwide problem. Water pollution is becoming rampant throughout the world especially in Africa, Latin America and Asia according to the United Nations. The pollution is mainly caused by human activities such as agriculture, industrialization, domestic activities, waste disposal among many others. People living near rivers or water resources dump their waste organic and inorganic into the water. Industries dispose of their waste into the rivers without regard for the rule of law and care for the environment. Agricultural activities happening near the water sources lead to run off of soil with chemicals such as fertilizers, pesticides and herbicides finding its way into the water systems. Soil erosion is a major contributor to reduced turbidity in rivers. Siltation and sedimentation increase in the rivers and can be seen in the brown colour of many of our rivers. Water makes 70% of the globe and only 2.5% is fresh water yet we can only access 1% of it while the other sources are remote glaciers and snow fields thus river remediation should be an imperative venture not only locally but also globally.

A report by the United Nations Environmental Programme (UNEP), shows that 80% of waste water goes untreated globally. This means that a lot of it finds its way back to the various application that we use water for like drinking, domestic use, agricultural use, industrial and even recreational. A 2016 report by the same agency showed that a third of the rivers in Africa, Asia and Latin America are heavily polluted by various pathogens while a seventh have severe to moderate salinity. There is a great and urgent need to reduce this pollution of our water resources before it is too late. Approximately 783 million people globally lack access to clean and safe water and 80% of the diseases and infections worldwide are as a result of poor sanitation and contaminated water (United Nations Report on Water, 2019). About 90% of sewage waste in developing countries is dumped in water bodies. Poor sanitation is the main cause of water pollution (United Nations Educational, Scientific and Cultural Organization, 2019). Two billin people in the world are at risk of contracting water-borne diseases (World Health Organization, 2017).

Water Pollution Crisis report of 2019 shows that around 319 million people in Sub-Sahara Africa cannot access safe reliable water yet the region has one of the highest demands in the world. Moreover, 1 in 3 people living in the region use proper toilet and practice proper sanitation.

According to Water.org 2019 report, a water credit organization in Kenya, approximately 24 million people lack access to sanitation or clean water. This is almost half the county's population and it is a very worrying and disturbing trend because the numbers continue to increase day by day. Furthermore, municipal waste management is a major problem in developing countries like Kenya. More people moving to urban areas accommodating 60% of the population within 5% of the urban land (RK Henry, Z Yongsheng, D Jun - Waste management, 2006). Therefore, everyone including the government and relevant agencies ought to begin remediation and rehabilitation efforts to curb this menace. Water pollution of the River Athi has been studied in terms of salinity levels whereby streamflow measurements were done to show how fresh the water is (JM Munyao, 2018).

The Thiririka river is situated in Kiambu County and joins Ruiru river as a left tributary of the Athi River. It flows about 30km south of Nairobi. The upperstream starts in the Aberdare Ranges and flows into densely populated areas as it moves downstream. The coordinates are -1.08762, 36.90040 -0.97304, 37.03663; minimum elevation: 4,832 ft; maximum elevation: 6,018 ft and average elevation: 5,226 ft. The river flows into a basin of around 120 km^2 that is tubular and on average only 2 km wide.

Figure 1 below represents a section of the Thiririka River. Some sections of the water look clearer than others but there's a need to actually take turbidity readings for certainty.

Figure 1: Thiririka River

The river flows through areas of high agricultural productivity owing to people practicing agroforestry along the river course. The area receives approximately 700-1800mm of rainfall throughout the year and people carry out mixed and cash crop farming. Moreover, there is a lot of charcoal burning hence deforestation. This can raise the turbidity levels through soil erosion, siltation and sedimentation causing the clarity of the water to reduce.

Furthermore, the spread of water-borne diseases such as cholera, dysentery, typhoid among others has become more rampant in the city and neighbouring counties such as Kiambu - "Nairobi County and its environs issues a warning on the cholera outbreak", according to The Star Newspaper March 2019. Water makes 70% of the globe and only 2.5% is fresh water yet we can only access 1% of it while the other sources are remote glaciers and snow fields thus river remediation should be an imperative venture not only locally but also globally.

The main contaminants and pollutants in our rivers and water sources include: heavy metals such as Zinc, Lead, Manganese, Calcium and others that are toxic when in high levels of concentration. Other pollutants are bacteria and organisms such as *Vibrio cholera, Salmonela typhi, Burkholderia pseudomallei, Cryptosporidium parvum, V.parahaemolyticus, V.mimicus, V.alginolytic* among other disease causing organisms. They led to serious health problems when found in high concentrations in water used by people for various applications especially domestic. High level of such pathogens is common in areas with inadequate sewer and sewerage systems such as informal settlements. Surface run-off mixes with sewerage discharge or discharge from pit latrines and septic tanks. The result is disastrous to the residents and can be propagated to other areas within the water system. Other pollutants are chemicals containing nitrates, phosphorus and others mainly from agricultural activities in the riverine area that sip into the water especially during the rainy season with surface run-off.

Restoring water to its natural clean state would involve a lot of activities and investments. Waste water treatment ought to be improved and aid in cleaning water; carrying out green agriculture or that is eco-friendly by not using toxic chemicals for fertilizers, pesticides, fungicides and herbicides. Improving stormwater management to reduce effects of surface run-off thus also improving general drainage. Setting up laws and procedures of waste disposal for industries and individuals.

River remediation is still possible, and involves restoring water systems to their former clean state before pollution and degradation occurred. It is an expensive venture but definitely worthwhile with the increased demand for water. Clean up of the riverine area and riparian land is part of the exercise in addition to cleaning the river. Before river rehabilitation, the level and extent of pollution must be known.

This research has a goal of using sensor and communication technology to assess water quality in real time and determine relative positions of polluted water in the river.

• 1.2 **Motivation and problem statement**

Water turbidity is a very crucial water quality parameter that measures the clarity of water. It is a measure of the amount of light that can pass through the liquid and dispersed by the particles inside. The more the particles, the more turbid the water is. This thus shows heavy presence of organic matter, sedimentation, dissolved organic compounds among others that contribute towards higher turbidity.

Water turbidity is measured using turbidity sensors mounted into the water by a platform and gives out the readings. Water turbidity is seen in the colour of the water. Clear water is less turbid than brown colour water. It is a relative measure of how light can penetrate water and scattered by the particles inside. Turbidity is measured in Nephelometric turbidity units (NTU). Highly turbid water is impossible to drink just from the aesthetics to the fact that microbes and pathogens can be sheltered within the water (United States Geological Survey, 2010). Thus, there is necessity in being able to measure the level of turbidity that can be coupled with other water quality parameters such as pH, temperature, dissolved oxygen, electrical conductance, dissolved solids, presence of metal ions and many more. This would create a robust system of real time water quality monitoring with a range of parameters to validate.

Real time monitoring of water quality has been done in other countries for rivers and water ways using various techniques such as use of a mobile sensor accompanied by sensors and chemical analysers. It is costly but yields results useful in river remediation. In Spain, a method of collecting samples from a water resource and analyzing them in a lab was employed. The samples underwent Microtox analysis to check the toxicity levels and use of a multisensory system to carry out sensiometric measurements (Water pollution monitoring by an artificial sensory system, 2015). DNA technologies have also been used in water pollution monitoring. Increased demography causes increase in pollution through anthropogenic activities, reducing quality of aquatic life and water quality. DNA extraction of bacteria strains and culture conditions was done together with DNA microarray and harvesting of bacterial cells from sea water. This enables representation of pathogens in the water such as *Vibrio cholera* and *Salmonela typhi*. This advanced technique was used in Japan using advanced genetics. (DNA Technologies for monitoring water-borne pathogens: A revolution in water quality monitoring, 2009)

In Kenya, dissolved oxygen modelling was done using artificial neural networks in River Nzoia, Lake Victoria basin. Sample points were established and modelled using root mean square error (RMSE) and R^2. Resulting into generation of regression models and Pearson Correlation Coefficients. (Dissolved Oxygen Modelling using Artificial Neural Networks: A Case Study of River Nzioa, Lake Victoria Basin, 2016). There are many other methods some expounded in the literature review. Water quality degradation trends in Kenya show that pollution has rapidly increased over the past decades. This is especially common in urban areas such as Nairobi with high demographic pressures. Nairobi river is one of the most polluted rivers in the continent with toxicity levels way above the standard and required levels. The pollution is so high that it can be assessed by the natural senses of sight and smell. Piles of trash debris and pollutants can be seen for kilometers within the river channel and course. The river used to be clean a few decades ago with people swimming in it and fishing activities. Now, the river has lost all its previous applications and purposes.

Population increase in Thiririka sub-catchment is causing high demand of water against limited supply. Currently, only 12,000 households out of 250,000 in the catchment have access to pipe water. Therefore, most residents result to use water from boreholes or the Thiririka river. The water in the river is already polluted and thus poses health risks to the residents. In Kiambu County in Kenya, 25% of residents use unimproved water sources such as ponds, direct from the rivers, unprotected springs and from water vendors (KNBS and SID, 2013).

According to the United Nations Environment Programme (UNEP) 2015 report, once the water is contaminated it is very costly or even almost impossible to remove the pollutants. With this knowledge, we should do all we can to protect our water systems from any kind of pollution. Demographic pressures produce acute water shortages which make the provision of future environmental flows highly unlikely. (Wal, Abdul, Muhammad et al in Environmental Pollution, 2019). According to the study, human population pressure hinders river rehabilitation efforts. Water contamination leads to the spread of water-borne diseases such as cholera, typhoid, dysentry among others. River basin management in the DRC Congo has led to improved drinking water for the people (UN Environment, 2017). A 2016 report on the state of Nairobi River found that agricultural activities, domestic effluent discharge, refuse dump runoff and runoff from car wash and garage were the main anthropogenic sources of pollution in the river. The report concluded that the water was unsafe for domestic purposes, including drinking— especially due to the concentration of lead, found to be unsafe for both the World Health Organisation and Kenya Bureau of Standards' specifications.

There is need to restore our water sources and improve accessibility to clean and safe water. A right to access clean water is for all citizens irregardless of social class, race, tribe, area of residence. There should be no exceptions. This research aims at spatially monitoring and assessing the extents of pollution in the water by use of sensor technology that gives real time and locational data. This helps in the safeguarding this precious commodity.

• 1.3 Justification

Smart and digital ways of solving water pollution problems for water quality monitoring are gaining importance with advancement in communication technology. The system provides an alert to a remote user, when there is a deviation of water quality parameters from the pre-defined set of standard values. These standard values are set by the relevant organizations such as the United Nations Environmental Programme (UNEP) and the National Environmental Management Authority (NEMA).

Water pollution is very dynamic with regard to space and time thus requiring a real time monitoring system that provides an avenue for early detection and mitigation of pollution. According to the United Nations Environment Programme (UNEP), once water is contaminated it is very costly or even almost impossible to remove the pollutants. With this knowledge, we should do all we can to protect our water systems from any kind of pollution.

Water is life, making 75% of the world (Water Quality Degradation Trends in Kenya over the Last Decade, 2012). High population pressures is reducing the amount of water available for the population. As time goes, water shortages are the order of the day even in Kenya's capital city of Nairobi. The Nairobi City Water & Sewerage Company (NCWSC) reported that there is a 25% shortfall in water supply to the city and its environs. Furthermore, the increase in population over the years has affected the supply of water due to insufficient planning and excess pollution of the water resources. This causes the frequent water shortages and water rationing as seen over the decade in many parts of the city yet only about 50% of the city residents have direct access to piped clean water.

This justifies the prompt undertaking of river restoration and rehabilitation through assessing and monitoring the existing levels of pollution. After which remediation efforts can be mapped and laid out before it is too late.

• 1.4 Research identification

Research identification and objectives

General Objectives.

The main aim of this study is to develop a real time automated water quality monitoring system.

The specific objectives are:

1) To develop an automated water turbidity sensor.
2) To test the turbidity sensor on the Thiririka River.
3) To develop an automated water turbidity platform.

• 1.5 Study outline

This study is divided into 6 chapters whereby the first chapter includes the introduction, motivation and problem statement, objectives and research questions; Chapter 2 contains the reviewed literature and the gap that the research addressed. Moreover, Chapter 3 shows the data and methods used in the studies with Chapter 4 highlighting the results for the findings. Chapter 5 contains the discussion of the findings and finally, Chapter 6 demonstrates detailed conclusion and recommendation for future research.

Chapter Two

Literature review

Water quality is a paramount aspect of everyday life and general water and environmental studies. A downgrade in the quality leads to reduced or no usefulness of the resource. In this regard, legislations have been passed through the relevant government and non-governmental agencies for example the National Environmental Management Authority (NEMA), World Health Organisation (WHO) to set standards in water quality parameters. These parameters include pH (6.5-8.5), Suspended solids (30 mg/L), Pathogens and bacteria (Nil/100ml), Fluoride (1.5mg/L), Total dissolved solids (1200mg/L), Ammonia (0.5 mg/L), Nitrates (10mg/L), room temperature and many other water quality parameters. The Water Service and Regulatory Board set guidelines for drinking water and effluent monitoring through sampling and testing exercises and checking if the parameter concentrations coincide with the set values. Following the regulations, one can know whether certain water is suitable for human consumption or for domestic use at home such as cooking, cleaning, recreational purposes.

Research done on the State of Water Quality in Nairobi and its environs (Nairobi Metropolitan Area) 2016 showed the quality has significantly deteriorated over the decades. The study was conducted to assess the physical chemical characteristics and heavy metal presence in a section of Nairobi river. River Thiririka is a tributary of River Athi that connects with the Nairobi river. Samples were taken during the wet and dry season and measured in situ. Determination of the heavy metal was done using spectroscopic techniques, incubation, gravimetric and titration methods. The levels of biochemical oxygen demand and total suspended solids in addition to nitrates and phosphate levels were all represented in tables and graphs. The general results showed dangerous toxic levels of the water in the city.

Water quality monitoring is defined as the collection of information at set locations and at regular intervals in order to provide data which may be used to define current conditions, establish trends, etc. (Niel et al., 2016; Muinul et al., 2014; Jianhua et al., 2015). Main objectives of online water quality monitoring include measurement of critical water quality parameters such as microbial, physical and chemical properties, to identify deviations in parameters and provide early warning identification of hazards. Also, the monitoring system provides real time analysis of data collected and suggest suitable remedial measures.

Smart solutions for water quality monitoring are gaining importance with advancement in communication technology. This paper presents a detailed overview of recent works carried out in the field of smart water quality monitoring. Also, a power efficient, simpler solution for in-pipe water quality monitoring based on Internet of Things technology is presented. The model developed is used for testing water samples and the data uploaded over the Internet are analyzed. The system also provides an alert to a remote user, when there is a deviation of water quality parameters from the pre-defined set of standard values.

Increased turbidity leads to pollution of a water body. This is because there are more particles in the water therefore causing sedimentation and siltation. As a result, less light passes through affecting the ecological activities in the water. Furthermore, the biodiversity is disturbed with aquatic life at the receiving end© United States Geological Survey (USGS) Water Science School.

Integration of various methodologies such as the RQ approach done in Malaysia; using the Risk Quotient Approach to show colour coded hazards and each hazard level for each parameter assessed at each location eg. turbidity at a given point of the river and mapped using Geographical Information Systems (Wal, Abdul, Muhammad et al, 2019). Increased turbidity can promote regrowth of pathogens in the water, leading to waterborne disease outbreaks, which have caused significant cases of intestinal sickness throughout the United States and the world. Although turbidity is not a direct indicator of health risk, numerous studies show a strong relationship between removal of turbidity and removal of protozoa. The particles of turbidity provide "shelter" for microbes by reducing their exposure to attack by disinfectants. Microbial attachment to particulate material has been considered to aid in microbe survival. Fortunately, traditional water treatment processes have the ability to effectively remove turbidity when operated properly. (Source: U.S. Environmental Protection Agency)

The Demographic pressures produce acute water shortages which make the provision of future environmental flows highly unlikely. (Wal, Abdul, Muhammad et al in Environmental Pollution, 2019). Increased population in the city and its environs has greatly contributed to the increased pollution. The need for real time monitoring of water quality is increasingly becoming a necessity for many countries. Water pollution is very dynamic with regard to space and time; therefore a real time monitoring system provides an avenue for early detection and mitigation of pollution. High turbidity causes siltation leading to flooding during the wet season since there is a lot of blockage and sediments in the river and river basin. Flooding leads to loss of life, destruction of property, spread of waterborne diseases including other adverse effects.

Turbidity can be used in operational monitoring of treatment processes and performance of clarification chemicals used in household and small drinking-water supplies (Elliott et al., 2008; Preston et al., 2008; Koltarz et al., 2009; WHO, 2011; Mwabi et al., 2012; WHO/ UNICEF, 2012). Turbidity can also be used to measure the performance of some treatment processes in reducing chlorine demand or the performance of barriers designed to remove pathogens and microbial indicators (Elliott et al., 2008; Mwabi et al., 2012). Low turbidities in drinking-water is a proven indicator of pathogen removal and hence of drinking-water safety in relation, incidents of elevated turbidity have been associated with several outbreaks of disease (Hrudey and Hrudey, 2004; Mann et al., 2007). This shows the importance of turbidity as a water quality parameter.

Turbidity is measured in Nephelometric method which means its units are in Nephelometric Turbidity Units (NTU). Other units include formazin nephelometric units, formazin attenuation units, Jackson turbidity units and turbidity units. The various turbidity units are related, and often similar, but not always equivalent. This is particularly true for Jackson turbidity units and turbidity units which are based on visual assessments while the other units are meter readings. Standardized methods – including guidance on sample collection and calibration standards – have been established for various types of turbidity meters (APHA/AWWA/WEF, 2012; Health Canada, 2012; ISO, 2016).

Geomatics based approach in assessing lake and water resource pollution has been done in Egypt. Sample points were established using field survey, lab analyses and geospatial techniques to monitor the various water quality parameters. The results were tables, graphs and maps showing the concentrations of the parameters.

Ecological modelling of nitrate pollution has been carried out in the Czech Republic. It entailed modelling the river basin characteristics by land cover attributes and representing the different concentrations of the water quality parameters. They used Remote Sensing to classify the land covers and land use in the area (LANDSAT 7). Using Geographical Information Systems (GIS) the spatial distribution of the pollution was achieved.

A GIS-based emergency response system for sudden water pollution was developed in China. (Ma, Xu, and Wang 2014; Zhang 2014). It uses GIS technology and a hydraulic water quality model to represent the levels and extents of pollution. Maps showing the spatial distribution of the sample points are generated. Simulation is done to help in prediction of further pollution hence mitigate it. In Zimbabwe, a near real time water quality monitoring system was used in Chivero and Manyame lakes using a set of water quality parameters in order to help in decision making with regard to pollution of the water (Kibena et al, 2013).

According to the United Nations Environment Programme (UNEP), once water is contaminated it is very costly or even almost impossible to remove the pollutants. With this knowledge, we should do all we can to protect our water systems from any kind of pollution.

2.1 Gaps in Research

There is great potential in research and innovation in the development of real time water quality monitoring systems. This would greatly improve the activities of water and environmental conservation and management. More such systems that enable tracking and tracing of water pollution.

Chapter Three

Methodology

3.1 Materials

a) Turbidity Sensor

The sensor is used to measure water turbidity. It is made up of tiny light sensors within it that detect the amount of total suspended solids and scattered particles in the water by measuring the extent of light penetration. As the TTS increases, the liquid turbidity level increases. The turbidity sensor has a digital converter that converts its analogue data to digital. Some of its specifications include: Operating Voltage: 5V DC, Operating Current: 40mA (MAX), Response Time: <500ms, Output Method: Analog output: 0-4.5V, Operating Temperature: 5℃~90℃, Storage Temperature: -10℃~90℃, Weight: 30g

These are the general functionalities of any typical turbidity sensor. These sensors cost roughly Kshs. 1600/=. They connect with other components in a circuit with an analog and digital switch output together with a threshold potentiometer that regulates the signal mode. The device is the main component of the system giving turbidity values of the case study river.

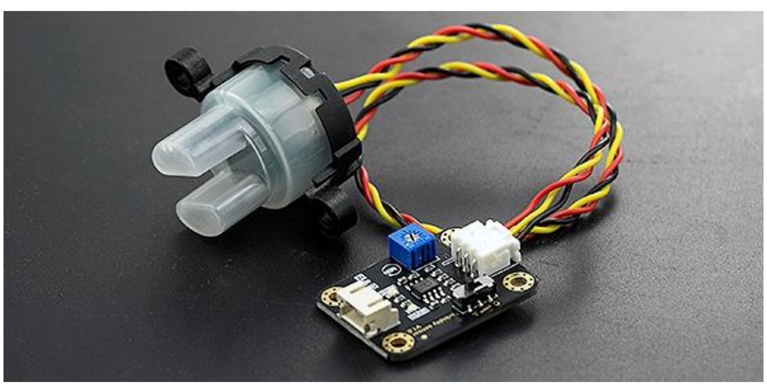

Figure 2: Turbidity Sensor

b) GSM Module

The GSM Module is used for communication. It stands for Global System for Mobile Communication and was developed by the European Telecommunications Standards Institute (ETSI). Uses protocols for second generation (2G) digital cellular networks for cell phones used globally. It requires a power supply and an interface with a user and a mobile network. Some of its functions include sending SMS messages, monitoring the signal strength, they use AT commands (ATtention) to carry out SMS commands. The GSM Module also has an antenna that communicates to nearby cell phone towers by transmitting and receiving signals. The module costs about Kshs. 800/= and connects with other components since it cannot work without a power supply. It is necessary in this study because it allows a user to receive real time turbidity values on your mobile phone as an SMS message.

Figure 3: GSM & GPS Modules

c) GPS Module

The GPS module (Global Positioning Systems) is used to determine the location. It uses the technology of satellites whereby there is a transmitter and a receiver. The GPS module is activated and locks onto a satellite. It requires a minimum of 4 satellites in order to give the position and time (fix). GPS uses a control segment, user segment and space segment. GPS was developed by the United States military and is now available for civilian applications. The raw GPS data gives the latitude, longitude, altitude, time with reference to the Greenwich Meridian Time and number of satellites locked onto. The module comes with an antenna that acts as the receiver. The choice of antenna influences the position fix. The GPS module costs about Kshs. 800/=. It uses a lot of power and thus has its own power supply unlike the other components. Without this module, one cannot know the exact location of the point turbidity readings were taken which is necessary to assess the level of pollution.

d) Arduino sensor

The choice of which Arduino to use was influenced by price and efficiency in this project. I decided to use the Arduino Nano as my micro-controller because it is also relatively small and less complex suitable for this study. It is bread-board friendly and is based on the ATmega328P released in 2008 and is similar to other Arduino models like the Arduino Uno. Some of its technical specifications include: Operating Voltage: 5 Volts, Input Voltage: 6 to 20 Volts, Digital I/O Pins: 14 plus 6 can PWM output pins, Flash Memory: 32 KB of which 0.5 KB used by bootloader, Clock Speed: 16 MHz, Length: 45 mm, Width: 18 mm, Weight: 7g. Arduino Nano has been used in various projects to program the components to achieve the user's desires. The Arduino Nano costs Kshs. 2500/=. The micro-controller uses C-programming language to communicate commands with other components. The micro-controller is crucial to the functioning of the whole system, it acts as the brain of the system. It comes with a USB cable that is used to connect to a computer.

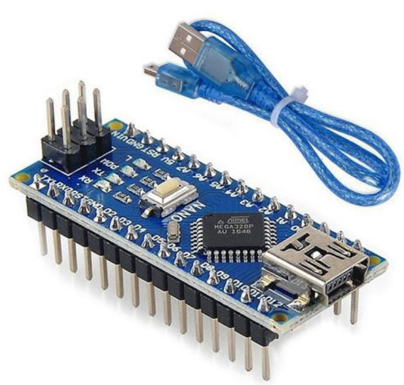

Figure 4: Arduino Nano

3.2 Prototype Process

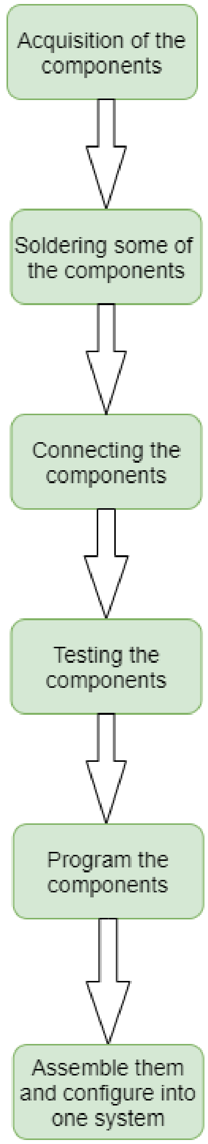

Figure 5: Prototype Process

The above process is what it took to develop the system of hardware and software. The components are first acquired and they will need to be soldered using a wire and soldering gun so as to stick the pins into them. These pins as can be seen in figure 4 are inserted into the bread-board and stuck there as it acts as a circuit board for the system.

Figure 6: Soldering iron

The soldering iron is connected to a socket and heats up. It is used to melt a copper wire that liquefies onto the holes meant to hold the pins. The pins are then glued into the holes and are permanently part of the components; now they can be fixed into the bread-board. The components are fixed and connected using connecting wires as shown below.

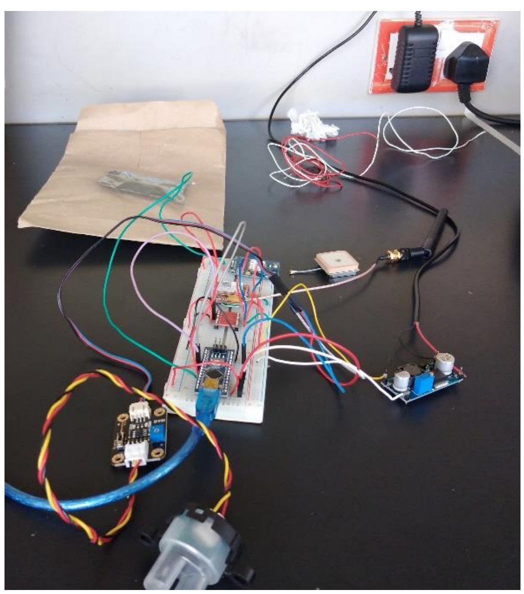

Figure 7: Sensor System

Some of the minor components that are shown above include the logic level convertor, the bread-board and a power supply that is connected to a power socket. All the components work together as a unit to form a real time automated water quality system. The main programming language used is Arduino C. The main function is to initialize the whole process and a serial function of taking readings after a given time that is called the baud rate.

3.3 Data Flow

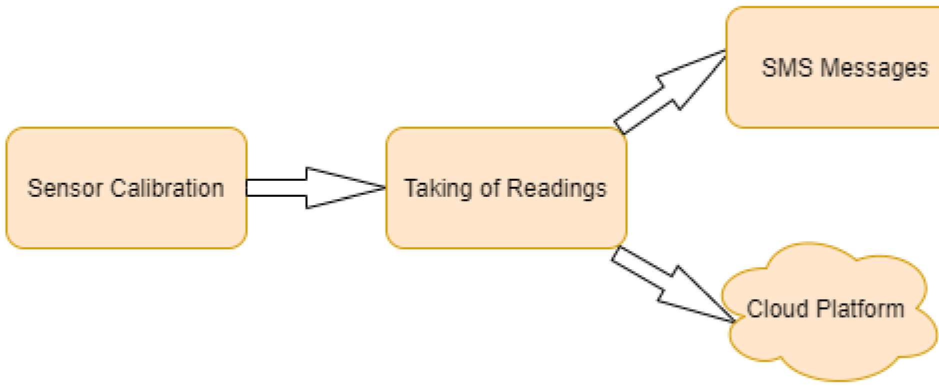

Figure 8: Data Flow

The data is the turbidity values in form of voltage. The turbidity sensor is placed inside a water sample and starts giving readings. The initial readings are shown on the serial monitor of the Arduino software as shown below.

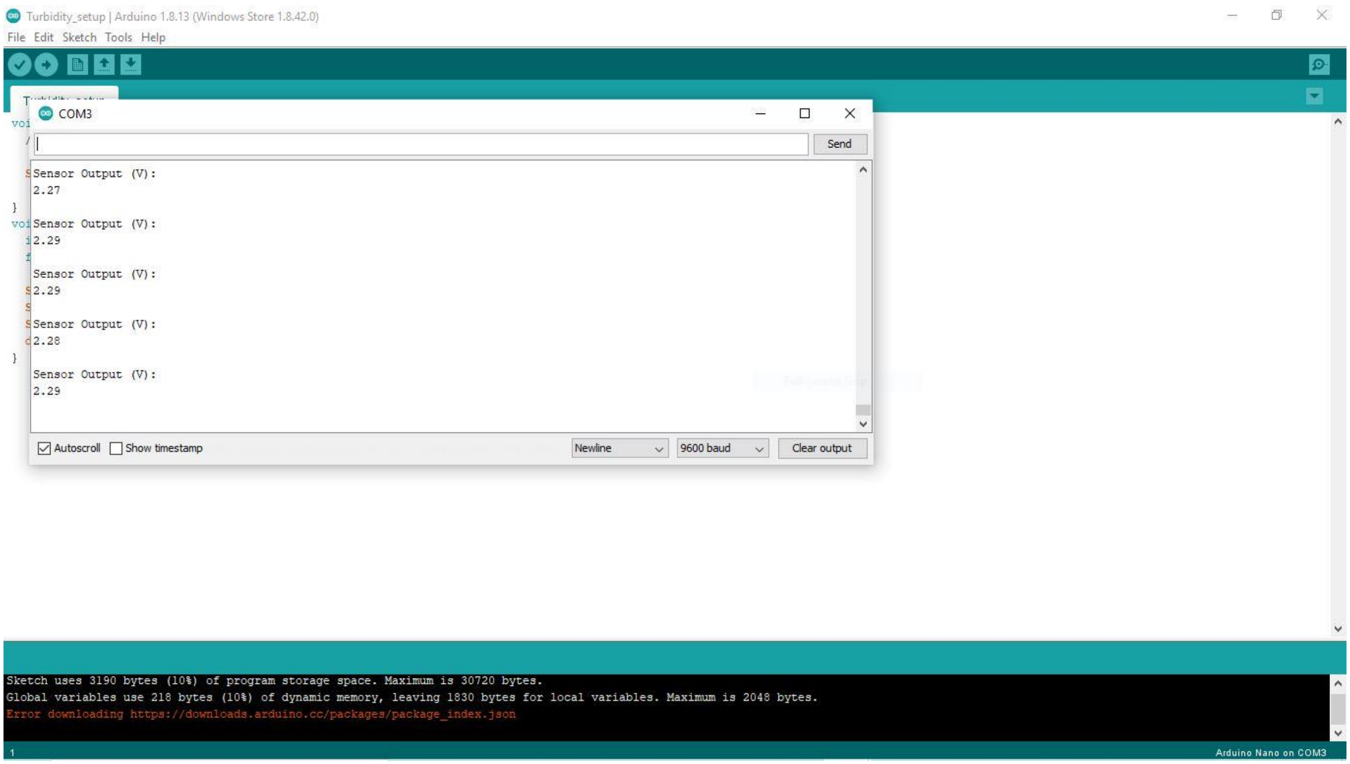

Figure 9: Turbidity values

The Arduino Nano is connected to the computer via the USB cable and displays the values in the software. The tools dialogue box is selected and one has to ensure the Arduino Nano option is selected together with the USB port that is connected to the Arduino. After using the code for connecting the turbidity sensor with the GSM module, one can receive the readings via text messages as shown below

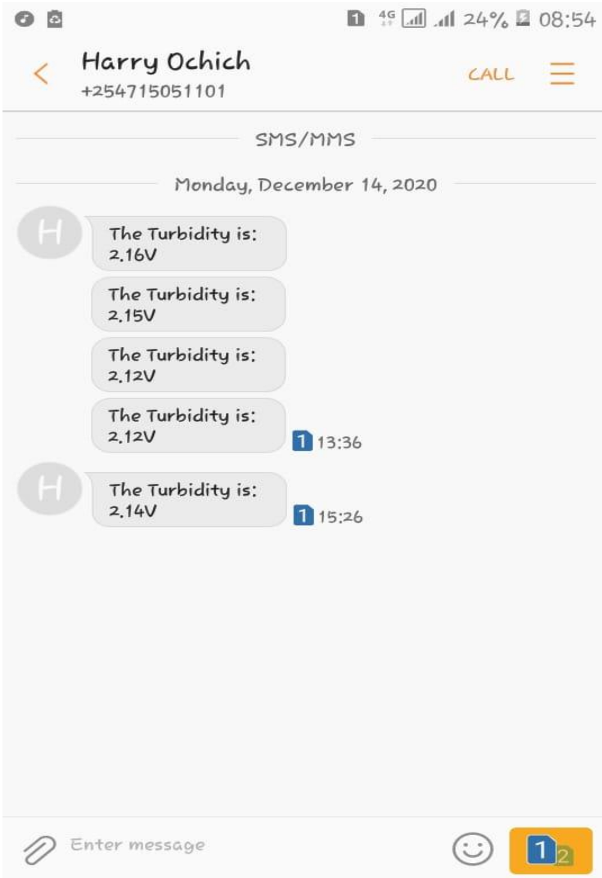

Figure 10: SMS Messages

The GPS module is then included into the set up and now gives the locational information in form of latitude, longitude, altitude and time. The text message includes all of them and a cloud platform is used to analyse and represent the data graphically.

3.4 Study Area

River Thiririka is a left tributary of the River Athi and flows into Ruiru River. Its source is in the Southern slopes of the Aberdare Ranges in the Kikuyu Escarpment Forest and flows in a South by East direction to emerge from the forest near to the East of the Karatu Rural Market and joins Ruiru River at Juja farm, which later joins Nairobi river downstream. Geographically, the Thiririka Sub-catchment is bounded by the following coordinates, longitudes 36° 34.6' 0", 37° 9' 0" and latitudes 0° 51' 0" and 1° 13.7' 0

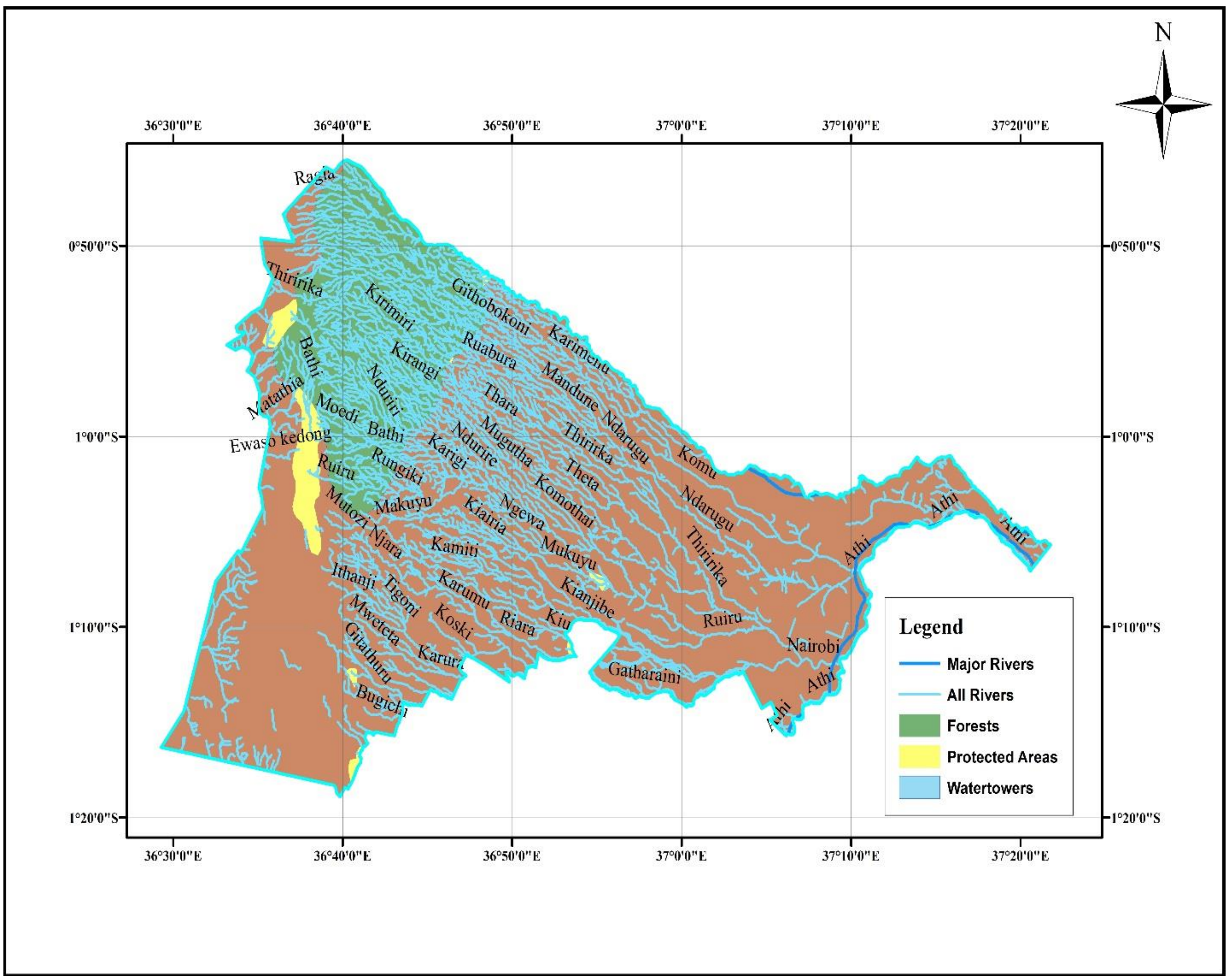

Figure 11: Study Area Map

The map shows the general hydrology for Kiambu County which includes the case study, Thiririka River, that flows from the North West that is of higher altitude to the South East of lower altitude. The study involved using samples from the river and comparing at different points and locations.

Figure 12: A Section of the River

3.5 Methodology Flowchart

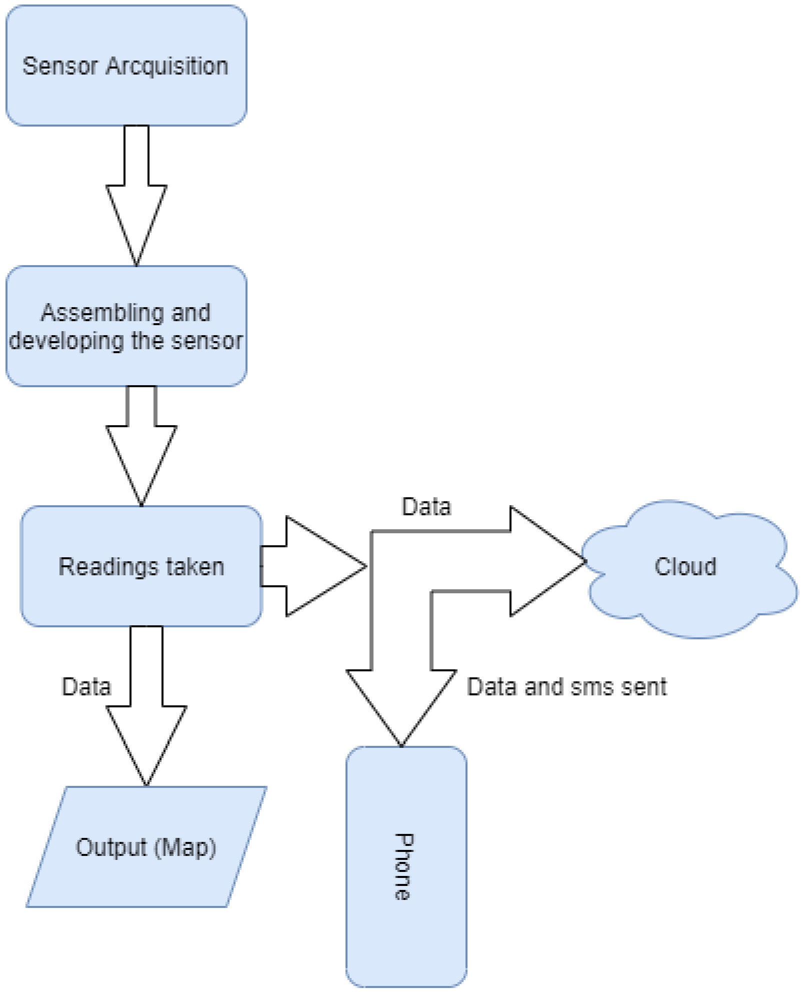

Figure 13: Methodology Flowchart

The sensor is already acquired together with its components as mentioned in the materials section. The turbidity sensor is tested first before developing the whole unit as a single fabrication. This fabrication is the prototype that is used in carrying out turbidity readings in the Thiririka river. The results are transmitted to a cloud platform and also through the Short Message Service (SMS) to a phone. The results are represented finally in a map showing the levels of turbidity in the Thirirka river for a given section at particular times and intervals

The turbidity sensor is tested by programming it using the arduino nano and the code stored in its memory. It is then tested with water to give preliminary results.

Figure 14: Project Sensor

The turbidity sensor is configured with the arduino nano using arduino C programming language. The code has a serial function to initiate the process and a loop function that is repeated and enables the blinking of the red light and takes readings. Connect the Voltage Common Collector (the 3 wires) of the Turbidity Sensor with Arduino 5V(blue), GND to GND (black) & Analog Output to Arduino A0 (red)pin as shown in the image below.

Arduino Nano: This is a type of Arduino technology that is small, complete and bread-board friendly. It uses the ATmega328 (Arduino Nano 3.x.) technology and works with a mini-USB cable rather than a standard one. Some of its technical aspects include:

Microcontroller	ATmega328

Architecture	AVR
Operating Voltage	5 V
Flash Memory	32 KB of which 2 KB used by bootloader
SRAM	2 KB
Clock Speed	16 MHz
Analog I/O Pins	8
EEPROM	1 KB
DC Current per I/O Pins	40 mA (I/O Pins)
Input Voltage	7-12 V
Digital I/O Pins	22
PWM Output	6
Power Consumption	19 mA
PCB Size	18 x 45 mm
Weight	7 g
Product Code	A000005

Arduino Nano is an open source hardware thus one can build upon it as desired depending on the project. It has 8 analog pins each of which provide 10 bits of resolution; they measure from ground to 5 volts and the 6 and 7 pins cannot be used as digital pins. The Arduino communicates using the digital pins as transmitters and receivers. Moreover, it communicates with the computer using the USB cable connected to the computer. The programming is done using the Arduino Software that allows uploading of the codes together with manipulation as long as the Tools menu is checked if the Arduino Nano is connected to the right port and the Arduino Nano option is selected.

The programming language used by the components is Arduino C programming language. This language is divided into three main parts: functions, values (variables and constants) and structure. The Function part is used to control the Arduino Nano board and carry out computations. Examples: Time delay() that enables the sensor take a specific time after every reading; analogRead() that allows reading of analog values.

Values read the data types and constants such as int() and float() for reading integers and decimal numbers in the code. The structure shows the elements of Arduino C++ code such as the loop() and setup() parts that allow continuous measurements and initiate the sensor reading process respectively.

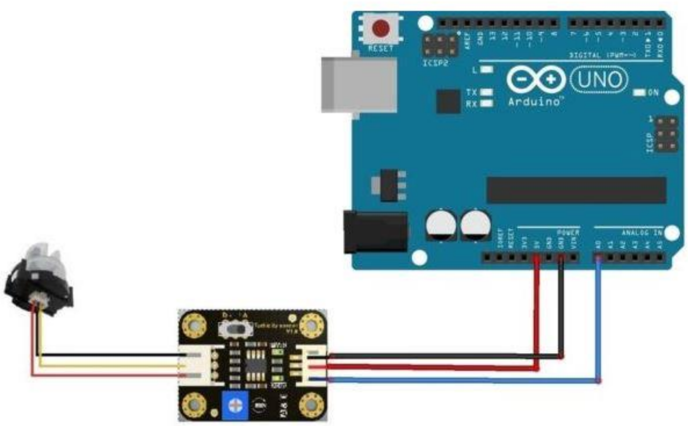

Figure 15: Sensor connected to the Arduino

The program starts by communicating the Arduino with the computer. The program uses C-programming language. It has two main functions of initializing the sensor working and a serial function that aids in the display of the turbidity values. The baud rate is 9600; it is the rate of transferring data with the Arduino Nano. The sensor reads values in form of voltage and later converted to NTU values.

$y = -1120.4x^2 + 5742.3x - 4352.9$ The sensor understands the values in voltage form having its own microchip or minicomputer. The above formula is used to convert to NTU values.

Turbidity readings are 4.2V for clear water and decrease with increase in turbidity. Turbidity is measured in from of Nephelometric Turbidity Units (NTU) and according to the World Health Organization, the NTU values should not surpass 5 NTU**.** The code enables communication between the components and results to sending the sensor values to a given phone number as a text message. The text shows the turbidity values together with the location information in form of latitude, longitude and altitude.

Chapter Four

Results

4.1 Introduction

The problem in which this study has been trying to deal with is the increasing levels of turbidity in rivers especially the Thiririka River. Increase in turbidity values is caused by soil erosion within the river banks or the riparian land owing to human activities taking place therein. Agricultural activities are known to lead to this problem. In Kiambu County, many residents practise farming along riparian lands of streams and rivers as is the case in Thiririka river. This is a major contributor of siltation and sedimentation leading to higher turbidity in the river.

Over time, further siltation and sedimentation leads to blockages and results to flooding of the riparian land area especially when the river bursts its banks during the wet season. The study aims at measuring the level of turbidity in River Thiririka and give insights on the level of pollution with regard to that parameter and thus aid in decision making and prospects of river remediation.

4.2 Turbidity Measurements

Turbidity readings were taken from samples from the river and compared to that of tap water. Values were measured in voltage form and clear water ranges from 4.2V and values go down with increase in turbidity. The water from the river was giving values less than 2V, and this is the result of the turbidity communicating with the GSM module thus allowing text messages to be sent to a phone number.

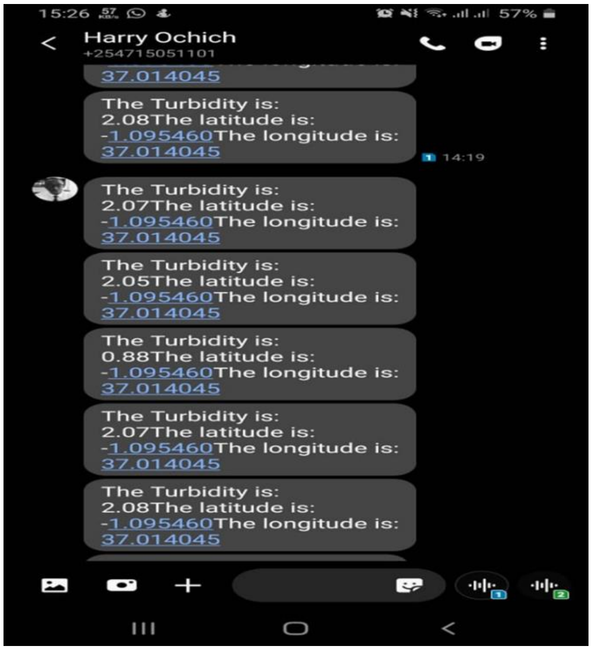

Figure 16: Text Messages

The GPS module is configured and now the SMS messages show the coordinates of the sample location in latitude and longitude. After the text messages are able to be sent, the GPS is configured and gives raw data as shown below

$GPRMC,160048.00,A,0105.72859,S,03700.84394,E,0.425,,151220,,,A*63

$GPVTG,,T,,M,0.425,N,0.786,K,A*29

$GPGGA,160048.00,0105.72859,S,03700.84394,E,1,08,0.94,1530.8,M,-22.0,M,,*5E

$GPGSA,A,3,13,19,02,06,15,05,12,17,,,,,2.08,0.94,1.86*00

$GPGSV,3,1,12,02,42,164,22,05,27,203,11,06,38,106,20,07,03,119,*7B

$GPGSV,3,2,12,12,18,288,26,13,79,302,27,15,39,304,23,17,25,027,23*72

$GPGSV,3,3,12,19,48,025,17,24,08,331,11,28,02,039,,30,23,096,*7F

$GPGLL,0105.72859,S,03700.84394,E,160048.00,A,A*7C

$GPRMC,160049.00,A,0105.72851,S,03700.84394,E,0.259,,151220,,,A*67

$GPVTG,,T,,M,0.259,N,0.480,K,A*21

$GPGGA,160049.00,0105.72851,S,03700.84394,E,1,08,0.94,1531.1,M,-22.0,M,,

The data you are getting over a serial interface are actually NMEA sentences. NMEA is an acronym for the National Marine Electronics Association. This is a standard message format for Nearly all GPS receivers. The NMEA standard is formatted in lines of data called sentences. Each sentence is comma separated to make it easier to parse by computers and microcontrollers. (©Last minute engineers). The table below explains the meaning of the GPS signals.

$	Every NMEA sentence starts with $ character.
GPRMC	Global Positioning Recommended Minimum Coordinates
123519	Current time in UTC – 12:35:19
A	Status A=active or V=Void.
4807.038,N	Latitude 48 deg 07.038′ N
01131.000,E	Longitude 11 deg 31.000′ E
022.4	Speed over the ground in knots
084.4	Track angle in degrees True
220318	Current Date – 22rd of March 2018
003.1,W	Magnetic Variation

*6A	The checksum data, always begins with *

$	Starting of NMEA sentence.
GPGGA	Global Positioning System Fix Data
123519	Current time in UTC – 12:35:19
4807.038,N	Latitude 48 deg 07.038′ N
01131.000,E	Longitude 11 deg 31.000′ E
1	GPS fix
08	Number of satellites being tracked
0.9	Horizontal dilution of position
545.4,M	Altitude in Meters (above mean sea level)
46.9,M	Height of geoid (mean sea level)
(empty field)	Time in seconds since last DGPS update
(empty field)	DGPS station ID number
*47	The checksum data, always begins with *

The raw data is encoded and gives results as shown

Latitude: -1.095507

Longitude: 37.013988 Altitude: 1416.00

Date: 12/13/2020

Time: 16:06:12.00

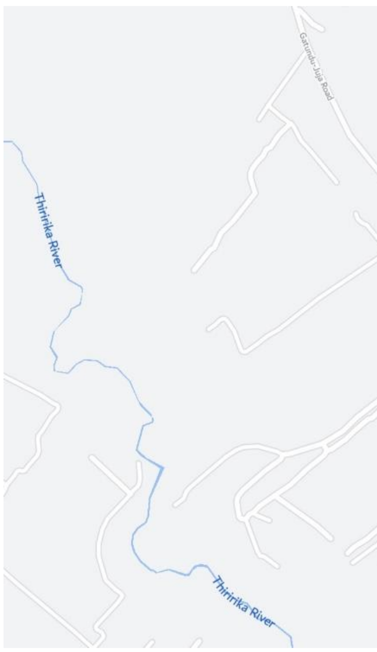

Figure 17: Overview Map

4.3 Platform

The sensor is now connected to the GSM and GPS module, giving results in form of the sensor output and coordinates in latitude and longitude. The results are transmitted to a cloud platform called ThingSpeak. This is an open source Internet of Things platform with MATLAB analytics. I created an account in order to access it and use it for results analysis. The figure below shows a graph of sensor output for a duration of time for the period of a couple of hours in 15th December from 6:00pm to the following day.

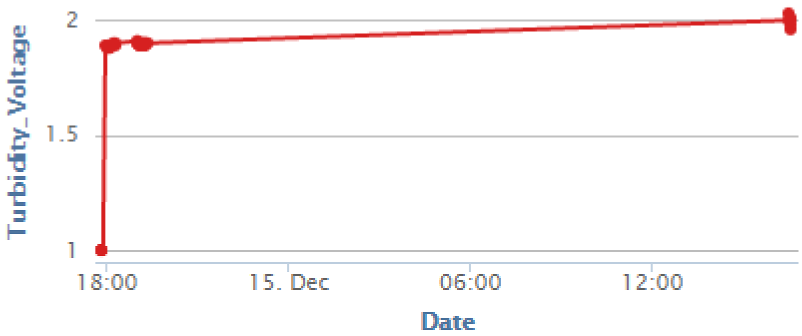

Figure 18: Graph 1

The portal is able to represent the results in form of graphs and maps. This helps in data analysis of the level of pollution in the river in form of turbidity. The platform shows real time results with regard to time and space as shown above. This leads to formation of a continuous graph as long as measurements and readings are taken. The variations are expected because the river is in constant motion. River Thiririka is a flowing river that is used by the local residents as a water supply. Figure 18 shows the continuous measurements taken between 16th and 17th December together with the time in hours.

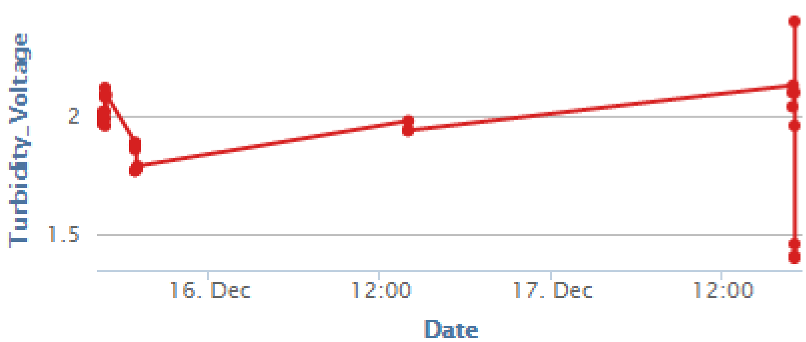

Figure 19: Graph 2

The graphs are of turbidity value against time and uses Internet of Things technology that is quickly gaining popularity in the world. It enables connection of almost all spheres and sectors of life to improve work efficiency in education (for learners and teachers), air quality monitoring, precise agriculture, energy monitoring, engineering among others.

The web portal shows the pin location of the sample point alongside the statistics of the turbidity values in form of a continuous graph with respect to the time and date. This provides a system for real time monitoring that can also be done remotely. The sensor takes the readings and they are sent to the web platform for analysis and representation. The graphical representation of the turbidity sensor values together with the locations in the portal allows locational representation of the sample points. The use of a pin drop like google maps shows the exact position of the point the sensor was used to take readings. This is important in assessing the sources of pollution in a water resource. They can be point or non-point sources such as spillages, dumping by an industry or by residents living near the water resource.

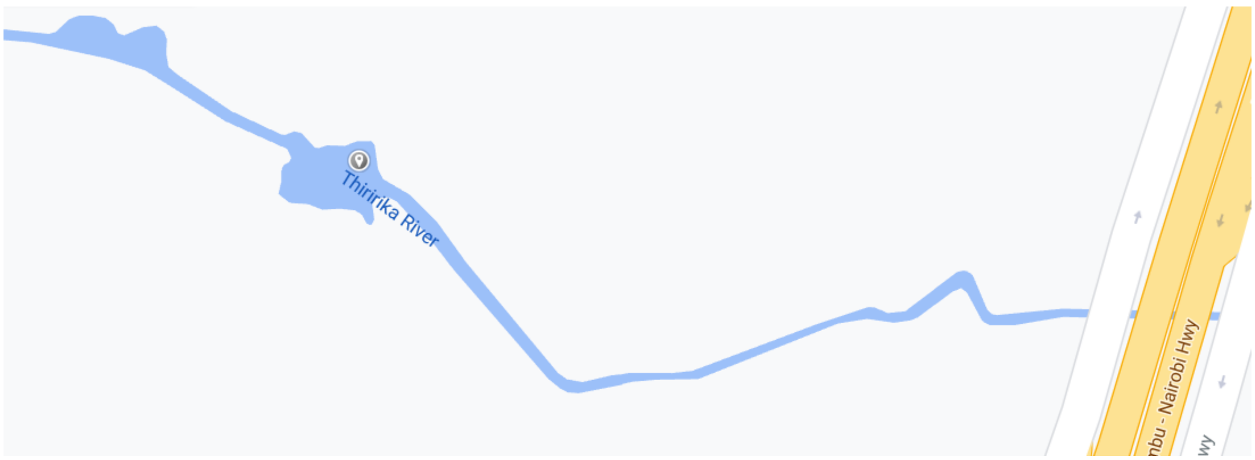

Figure 20: Sample Point

Figure 21: Lab Demonstration Point

Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community

Chapter Five

Discussion

The sensor as a whole is made up of various components namely the water turbidity sensor, GSM and GPS modules with their antennae, Arduino Nano, breadboard that acts as the circuit board, power supply and a logic level convertor. The sensor is made up of hardware and software and measures water turbidity in real time giving the location in form of latitude, longitude, altitude, time according to Greenwich Meridian Time (GMT) and the number of locked satellites.

The turbidity of River Thiririka is below 4V for the samples taken and this shows high levels of sedimentation and siltation owing to increase in soil erosion. Agricultural activities happening near the river banks is a major contributor of this together with deforestation. Therefore, this system can help in tracing sources of pollutants in the river. The results show that such a system can be used in water quality monitoring. Turbidity values are read and transmitted to a phone number and an online cloud platform ThingSpeak. The platform allows for analysis in form of graphs and charts as shown. The results are also shown in a map output owing to the collection of coordinates by the GPS module. Internet of Things enabled water quality monitoring shows how water quality monitoring can be in real time and in an automated way.

The system of hardware and software has improved water quality monitoring and assessment enabling it to be in real time and give the spatial attribute of location. Such a system helps in faster pollution tracing, tracking and general assessment of the extent of water pollution. Sources of water pollution are point source and non-point source. Such a system is useful in finding these sources and hence reduce river pollution from the onset.

Areas of improvement are on the matters of fabrication and acquiring a permanent power supply. This will allow the sensor to be covered properly in a water proof casing that allows for buoyancy and water navigation. An inertial navigation system can be implemented in order for the sensor to be autonomous and move alone avoiding obstacles such as debris, rocks and cataracts. Therefore the fabrication should also be tough and be able to withstand the river currents and nature of flow. Furthermore, including other water quality parameters such as water pH, total dissolved solids, total suspended solids, biochemical oxygen demand, electric conductivity among others. This would ensure the robustness and wide range of water quality monitoring capabilities by such a sensor.

Chapter Six

Recommendations and outlook

This sensor can be used in rivers, streams, springs, dams and even lakes to assess the level of turbidity. It can be used to monitor a given water body and thus help in decision making in matters of environmental conservation and management in water studies.

With more funding and expertise, such a project can be better modified. A fabrication put up that is water proof, allows for buoyancy and water navigation. The sensor would be able to navigate in the water. Adding artificial intelligence and an inertial navigation system can allow the sensor to move and avoid obstacles such as the trash debris, rocks and cataracts and also detect nearby waterfalls or deviations in the path of motion.

Moreover, addition of several such sensors floating in the river channel placed at strategic positions picking the sensor values and locations can help in generating a representation of the level of pollution in the water for a given stretch. Furthermore, a device that has its own motor system can move and operate on its own as the expert/ engineer views its functionality remotely. In addition to that, there should be use of more water quality parameters such as pH, electrical conductance, temperature, total dissolved solids, total suspended solids, presence of nitrates, phosphates, metal ions among many others. Such a system would be more robust and efficient in showing the level of pollution and determining the pollutants involved. This entails creation of real time (web) maps and graphs showing the water quality parameters being monitored.

Such an invention would revolutionise water quality monitoring in any water body or resource. This innovation would to be useful to organizations such as the National Environmental Management Authority (NEMA), Ministry of Water and Sanitation, Ministry of Environment and Natural Resources, United Nations Environmental Programme (UNEP) among other relevant agencies and organizations.

More research needs to be done on the use of sensors in water quality monitoring. The need to have the sensors staying in the water and taking readings remotely while in motion and sending the results to a secure portal. A robust system measuring many other water quality parameters as mentioned earlier and the recruitment of skilled personnel in the fields of engineering, IT, environmentalists and others to fully implement such innovations.

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Appendix

```
void setup() {
  Serial.begin(9600);
}
void loop() {
  int sensorValue = analogRead(A0);
  float voltage = sensorValue * (5.0 / 1024.0);
  Serial.println ("Sensor Output (V):");
  Serial.println (voltage);
  Serial.println();
  delay(1000);
}
#include <SoftwareSerial.h>

//Create software serial object to communicate with SIM800L
SoftwareSerial mySerial(3, 2); //SIM800L Tx & Rx is connected to Arduino #3 & #2
void setup()
{
  //Begin serial communication with Arduino and Arduino IDE (Serial Monitor)
  Serial.begin(9600);
```

```
  //Begin serial communication with Arduino and SIM800L
  mySerial.begin(9600);
  Serial.println("Initializing...");
  delay(1000);
  mySerial.println("AT"); //Once the handshake test is successful, it will back to OK
  updateSerial();
}
void loop()
{
  int sensorValue = analogRead(A0);
  float voltage = sensorValue * (5.0 / 1024.0);
  Serial.println ("Sensor Output (V):");
  Serial.println (voltage);
  mySerial.println("AT"); //Once the handshake test is successful, it will back to OK
  updateSerial();
  mySerial.println("AT+CMGF=1"); // Configuring TEXT mode
  updateSerial();
  mySerial.println("AT+CMGS=\"+254717266700\"");//change ZZ with country code and xxxxxxxxxxx with phone number to sms
  updateSerial();
  mySerial.print("The Turbidity is: \r");
```

```
  mySerial.print(voltage); //text content

  mySerial.print("V");

  updateSerial();

  mySerial.write(26);

  delay(10000);

}

void updateSerial()

{

  delay(500);

  while (Serial.available())

  {

    mySerial.write(Serial.read());//Forward what Serial received to Software Serial Port

  }

  while(mySerial.available())

  {

    Serial.write(mySerial.read());//Forward what Software Serial received to Serial Port

  }

}
```