An Early Warning System for flash floods in Mauritius

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PROJECT DECLARATION

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b. I have submitted a soft copy of my dissertation through the Turnitin Platform.

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ABSTRACT

Flash floods are one of the most destructive natural hazards around the world including Mauritius resulting in casualties, loss of lives and properties. This project aims at designing and implementing an Early Warning System for flash floods in Mauritius which would help to alert the residents about the catastrophe beforehand and lessen the loss of lives and property.The main requirements of the system are low cost, effectiveness and reliability. The project entails both monitoring the different parameters concerning flash flood and warning locals in the event of a flash flood. Different sensors are chosen to monitor the parameters related to flash floods such as temperature, moisture, water level and flow rate and data is transmitted through the Reyax Module. The parameters are then displayed on Cayenne dashboards and the Blynk application. The data is collected using an Arduino Uno and sent to the receiver consisting of a NodeMCU. When a flash flood event is detected a trigger is sent to the user via SMS or email to warn them about the imminent flooding. The Gumbel distribution is used to forecast flooding based on historical rainfall data.

LIST OF ABBREVIATIONS

MQTT- Message Queuing Telemetry Transport
SMS- Short Message Service
EMAIL- Electronic Mail
MCU- Microcontroller Unit
GSM- Global System for Mobile Communications
SIM- Subscriber Identity Module
LoRaWan- Long Range Wide Area Network
LPWAN- Low Power Wide Area Network
GPRS- General Packet Radio Service
LCD- Liquid Crystal Display
CNN- Convolutional Neural Network
YOLO- You Only Look Once
WiFi- Wireless Fidelity
BLE- Bluetooth Low Energy
IoT- Internet of Things
IFTTT- If This Then That
PWM- Pulse Width Modulation
o/p- output
i/p- input
GPIO- General Purpose Input Output
RSSI- Received Signal Strength Indication
PVC- Polyvinyl Chloride
HTML- HyperText Markup LLanguage

CHAPTER 1: INTRODUCTION

1.1 Problem Statement

Flooding is one of the threatening natural calamities to mankind and the economy in the world. It is usually caused due to significant precipitation in areas such as rivers and lakes and occurs very rapidly (in about less than twelve hours). Overflowing rivers are caused by flash floods, which can have serious consequences for the economy, the environment, and the people who reside nearby. As seen in many areas, flash floods can damage homes, infrastructures such as hospitals, offices, and roads, harm vegetation, and cause major accidents and casualties. The government's task of restoring everything back to normal becomes laborious. Some of the factors that lead to flash floods are as follows (What factors contribute to floods?, 2018).

1) Heavy rainfall

   Flash floods are prone to occur when torrential rain forces a lot of water to accumulate in a particular region. Water from higher ground levels rushes downstream, flooding water bodies. As a result, the water level rises, causing it to overflow from the riverbanks and inundate the surroundings.

2) Levee Breach

   A levee breach is when the embankment to prevent overflowing of a river unexpectedly fails. This results in the water to flow through the breach to the land.

3) Debris Flow

   Debris flows are fast-moving landslides that pose a considerable risk to life and property due to their speed, ability to kill objects in their course and unpredictability. They carry large objects and trees into water bodies and move downstream causing flooding.

Factors that influence flash floods are:

1) Intensity of the rain

   A highly intense rainfall on a steep slope may result in flash floods.

2) Topography

   A small catchment area may cause the water to overflow from the river banks. Steeper the terrain, higher is the rate of surface runoff.

3) Vegetation

   Rain overflows instead of being soaked into the ground due to a lack of vegetation.

4) Type of soil

   Soil with high permeability allows the water to infiltrate into the ground rather than overflow.

5) Water content of the soil

   Saturated soil prevents water from infiltrating the ground therefore the rain water may overflow during intense rainfall.

Some of the human factors that contribute to flash floods are:

1) Urbanisation

   Since the surfaces of towns and cities are more impermeable, the rain water is not absorbed. The impermeable surfaces are not able to soak up the water and therefore the water will flow downstream into rivers resulting in flash floods.

2) Deforestation

   Since trees avoid sediment runoff and forests retain more water than fields or grasslands, deforestation plays a significant role in flooding. If a river can't accommodate the amount of water it is required to carry, it will overflow its banks.

In Mauritius flash floods occur mainly due to heavy precipitation. Flash floods are inevitable events. Nonetheless, an Early Warning System is facilitative in notifying residents of impending flash floods. As a result, they can take the required safeguards to prevent potential loss of life and property.

1.2 Flash Flood History

Due to their fast speed and unpredictability, flash floods are one of the most menacing types of floods throughout several parts of the world , including Mauritius. Two flash flood events are described below.

1. Machchhu Dam Failure

The Machchhu Dam Failure occurred on 11 August 1979 in Gujarat, India. The Machchu dam located in the Machchhu River burst, flooding the town of Morbi. The dam failure was principally due to an excess of precipitation which resulted in an observed flow of 16307 m/s. The dam was not designed for such a flow and it collapsed. It resulted in between 1800-25000 fatalities and is considered the worst flash flood witnessed in history (1979 Machchhu dam failure - Wikipedia, n.d).

2. Flash Flood in Port Louis City

Mauritius encountered a devastating flash flood on 30th March 2013 in the capital due to massive torrential rainfall hitting Port-Louis. The speed of the water torrents resulted in the death of ten people. Many people were left homeless, the roads were blocked and there were sewage problems. A national mourning day was declared the next day in Mauritius. 150 mm of rain was recorded in less than two hours which is extreme compared to the average rainfall for the entire month of March being around 220mm (SAPA, 2013).

1.3 Aims and Objectives

1.3.1 Aims

The principal motive of this project is to design and implement an Early Warning System for flash floods in Mauritius.

1.3.2 Objectives

The objectives are as follows:

i. Monitoring and storage of sensors' data related to flash floods.
ii. Implementation of communication technology between transmitter and receiver.
iii. Flash flood prediction and notification.
iv. Use of Meteorological data to predict flash floods

1.4 Project Scope

The main features of the Early Warning System are:

1. Transmitter: The transmitter collects the real-time sensors' data from the river and sends it to the receiver for processing.
2. Receiver: The receiver processes the data and monitors it on dashboards.
3. Communication Technology: A proper communication link is established between the transmitter and receiver to allow sending and receiving of data.
4. Data monitoring: The data collected from the receiver are monitored on dashboards.
5. Alarm: An alarm is sent to the residents in case of a flash flood warning.

Using past Meteorological data, flash flood events can be predicted using probability distributions as described in Chapter 3.

1.5 Project Outline

The report is divided into eight chapters and various aspects are analysed and discussed in each chapter.

Chapter one entails the general background of the project. The problem identification, brief history of flash flood, the aims and objectives are discussed in the first chapter.

Chapter two critically analyses different existing early warning systems for flash floods.

The theoretical backgrounds are discussed in the third chapter. Different parameters and probability distribution for flash floods are identified and discussed.

Chapter four discusses the conceptual design process. The general architecture of the system is developed and different components are analysed.

The detailed design is discussed in the fifth chapter. The circuit for the early warning system is designed and the different sensors are explored.

The implementation and testing of the system are discussed in the sixth chapter. The different sensors are tested and the overall system is implemented and tested.

The different data collected are analysed in the seventh chapter. Probability distributions are used for prediction of flash floods using past data from Mauritius Meteorological services.

The eighth chapter sums up the project and looks ahead to future work.

1.6 Project timeline

The Gaant chart below shows the planned and actual time taken for the project completion.

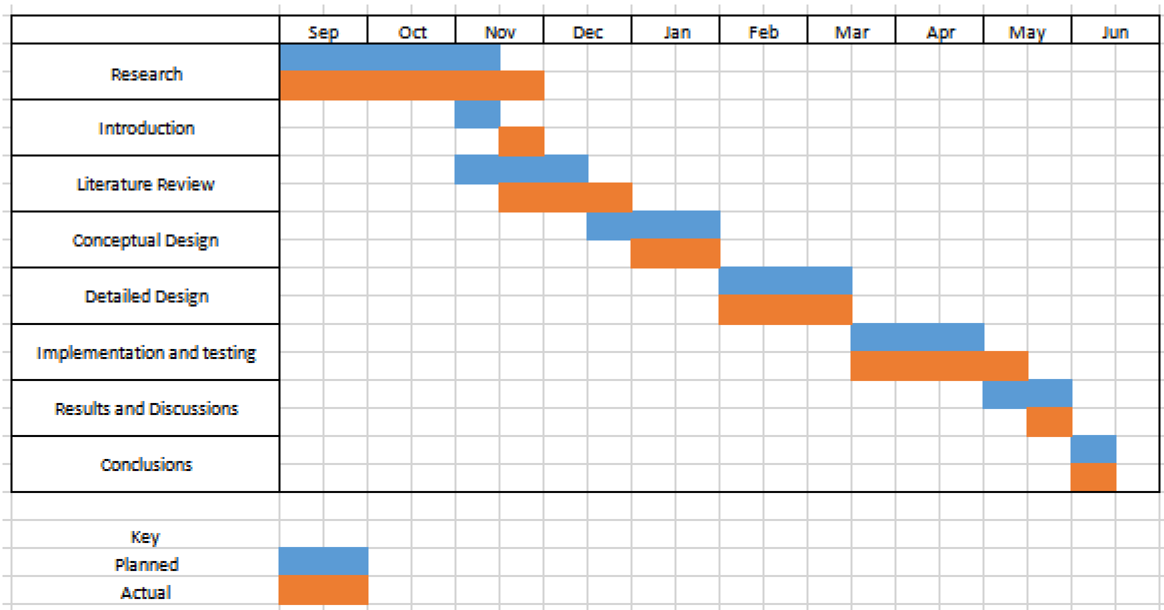


Figure 1-1: Project Plan

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter critically analyses the different existing flash flood warning systems. The operating principles of each existing system are described briefly identifying both positive and negative aspects.

2.2.1 Existing system 1

Abdullah et Al implemented an early warning system for flash floods using the Blynk application. An ultrasonic sensor for water level measurement together with a rainfall sensor was interfaced with the nodeMCU. A buzzer and three leds were used to alarm the user. Critical, warning, and safe were represented by red, yellow and green leds respectively. The sensors' values were displayed on Blynk gauge widgets. Additionally the users were notified through emails when a certain threshold value set for the water level was exceeded (Abdullah, Faruq and Mohd Sabre, 2019). The system could be easily implemented at low cost. Nonetheless, as illustrated in the figure below the system lacked features such as monitoring of soil conditions and flow of water. These features would have further aided in predicting any potential flash flood. The system required a WiFi connection to operate which might have been difficult to find in the midst of a river due to its short range.

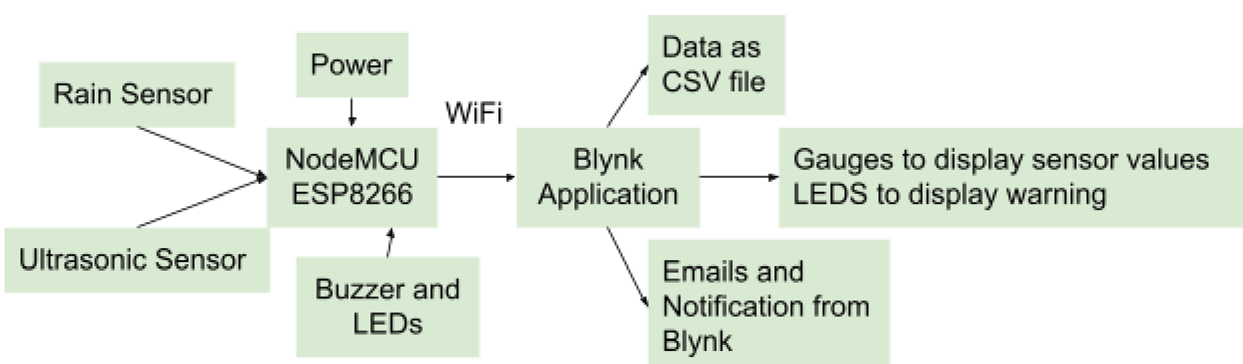


Figure 2-1: Existing System 1 Block Diagram

2.2.2 Existing system 2

Fahad implemented a Flood Monitoring System with SMS alerts using a microcontroller and GSM module. He designed his own microcontroller board using the Atmega328 which is cheaper than the Arduino UNO. For the water level measurement, he designed his own sensor consisting of multiple rods. The rods were connected to the input of the Atmega328 and each rod indicated a certain level. The rods had greater accuracy and were less prone to errors than using the ultrasonic sensor. The monitoring stations could communicate with the main station using the GSM module. The flood monitoring system application was designed using visual basics. The water level was classified as low, medium, high or critical depending on the threshold values chosen. An SMS was sent to the main station when the threshold values were exceeded (Fahad, 2019). The GSM module, on the other hand, was costly and demanded a SIM card. The SIM had to be refilled on a frequent basis. The sensor could only monitor the level of river water, as indicated in the diagram below, but could not collect information such as flow rate, soil moisture, or rain.

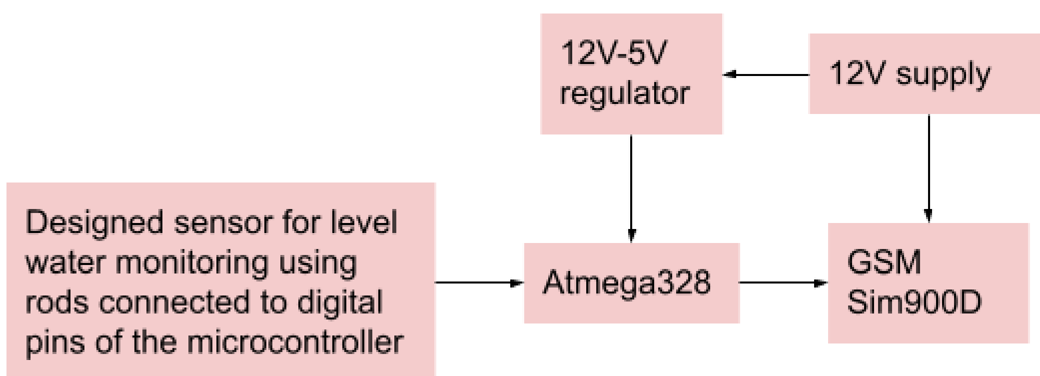


Figure 2-2: Existing System 2 Block Diagram

2.2.3 Existing system 3

Reaney and Perks designed an early warning system for flash floods.The system consisted of a weather station (ATMOS41) which could measure air temperature, relative humidity, vapour pressure, barometric pressure, wind speed and direction, solar radiation, precipitation and lightning. Rainfall was measured using the rain gauge and the river discharge was also measured. The data collected could then be transmitted through the LoRaWan network. To prevent false alarms, a catchment hydrological simulation model was implemented. The system was calibrated accordingly using rainfall and discharge data. The river discharge could then be found, taking rainfall data as input, using machine learning methods (Reaney and Perks, n.d). The system could monitor all parameters related to flash flood and allowed long distance communication through the LoraWan network. Nevertheless, the implementation was time consuming since data needed to be collected for years to create the hydrological model and use machine learning techniques. The system was also costly to implement.

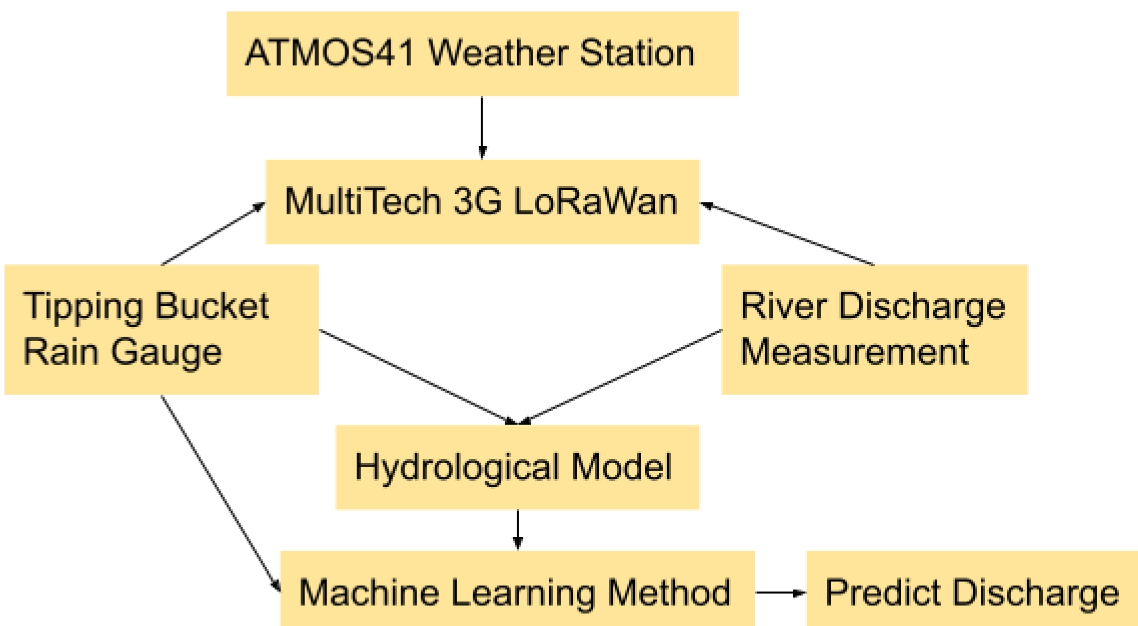


Figure 2-3: Existing System 3 Block Diagram

2.2.4 Existing system 4

Sunkphoo and Ootamakorn implemented a real time flood monitoring and warning system in Thailand. The parameters monitored were the water level, water velocity and rainfall. The Starflow sensor was used to measure the water level and velocity and the precipitation sensor to measure rainfall. The starflow sensor consisted of a data logger to collect real time data and was sent to the General Packet Radio Service Data Unit (GDU) for processing and transmission. The data was then transmitted through the General Packet Radio Service (GPRS) tunnel to the control unit. The user could access the real time data collected through the web browser (Sunkpho and Ootamakorn, 2011). The system could be used to monitor the main flood parameters and the data could be transmitted at long distances using GPRS. However the system was costly to implement. The user could only monitor the data and there was no warning message provided to the users.

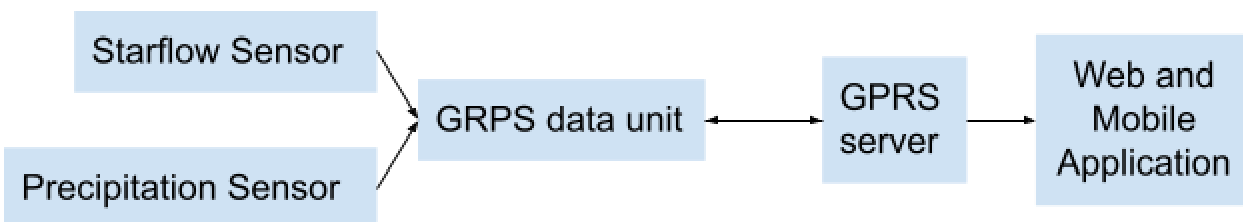


Figure 2-4: Existing System 4 Block Diagram

2.2.5 Existing System 5

Keerthan and Al implemented a flood monitoring and detection system using Internet of Things with image processing capability to identify trapped victims. The sensors used were the rainfall sensor, ultrasonic sensor and flow sensor to monitor precipitation, water level and flow rate of the river respectively. The different sensors were interfaced with the Arduino Uno connected to an ESP8266 module. When the threshold values of the sensors were exceeded, a message or email was sent. The sensors' data were displayed on an LCD. CNN was used to train the images and YOLO was used as the image processing platform to identify trapped victims in the flood (Keerthan et al., 2020). The system was cheap to implement and the people could be easily warned. However the sensors' data were not monitored on an appropriate platform.

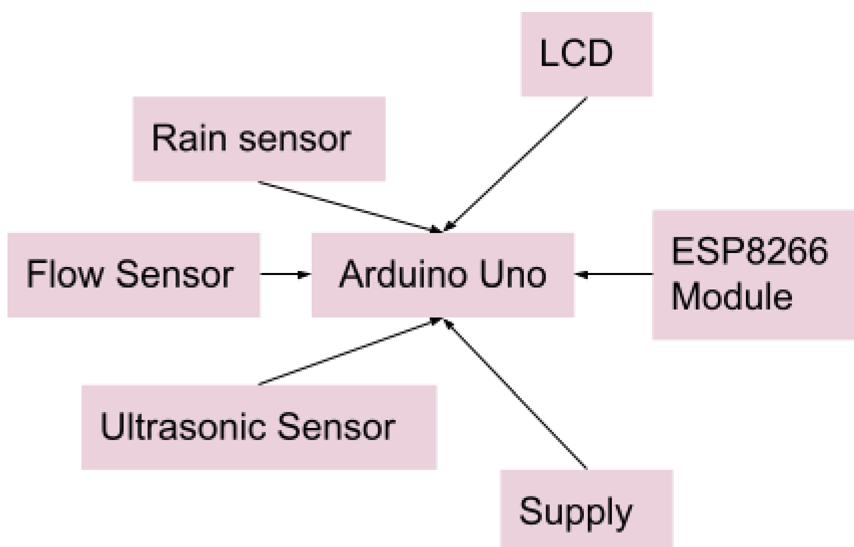


Figure 2-5: Existing System 5 block diagram

CHAPTER 3: THEORETICAL BACKGROUND

3.1 Introduction

In this chapter several flash flood parameters are analysed. The Gumbel probability distribution is introduced which can be used to predict flash floods on a long term basis.

3.2 Parameters variations during flash flood

1. Soil Quality

During rainy conditions or flash flood events, the soil moisture tends to increase with rise in water level across the river banks.

The soil permeability acts as an indicator to determine whether the run off water could be absorbed within the ground or not. A permeable soil would help to soak the water into the ground thereby reducing the flood effect.

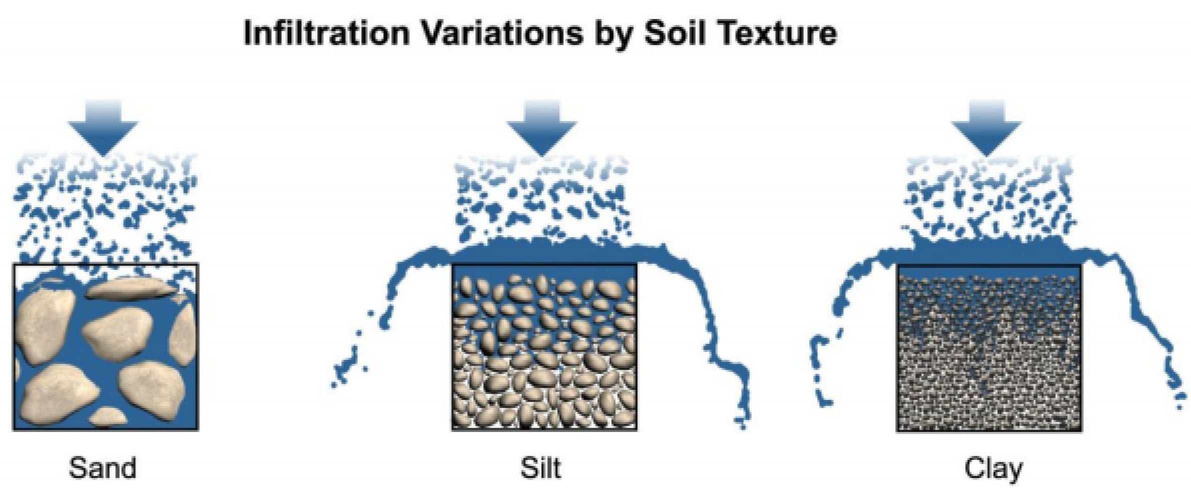


Figure 3-1: Infiltration Variation by Soil Texture (Tesař, Fiedler and Dvořák, n.d.)

From the soil texture we can determine the permeability of the ground. From the figure sand has got the highest permeability whereas clay the largest, that is sand is more porous than clay.

2. Rain Intensity

The amount of rain that occurs over time is determined by rainfall intensity. Rain intensity is determined by the height of the water layer that covers the ground over time. High intensity rain may lead to flash floods on steep slopes and may lead to urban floods on flat surfaces if the drainage system is not well established. The figure below shows how the rain intensity varied during a flash flood event which occurred in Spain. We can see that the rain reached a maximum intensity of 120 mm/h at 15.00.

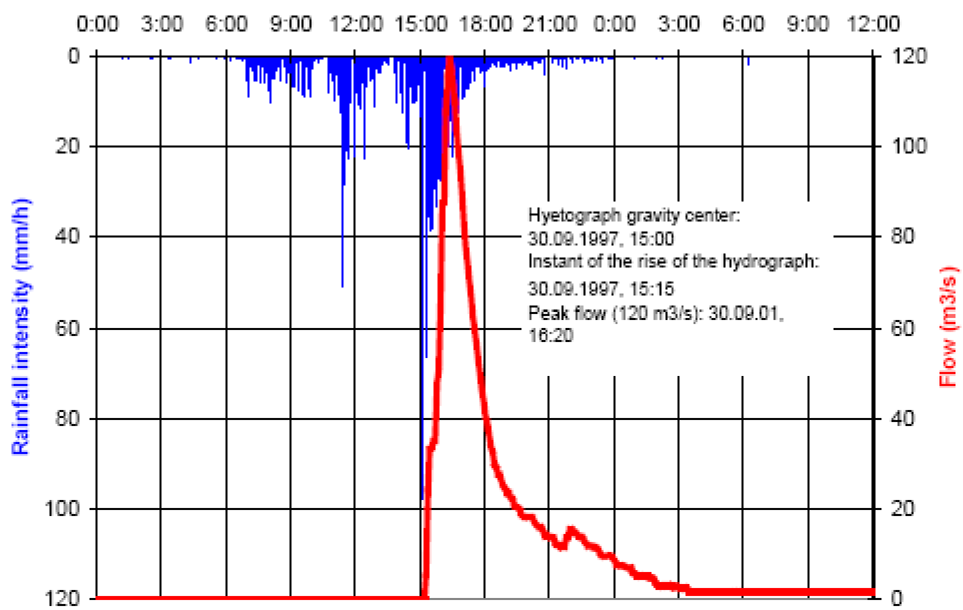


Figure 3-2: flash flooding in the Jucár basin in Spain (Sancho, 2008)

3. Flow Rate

During flash flood events the flow rate of the river may increase significantly. In a narrow canyon the flow rate increased from 1.4 to 42 m^3/s in only one second killing eight people (Hjalmarson, Hjalmar, 1984).

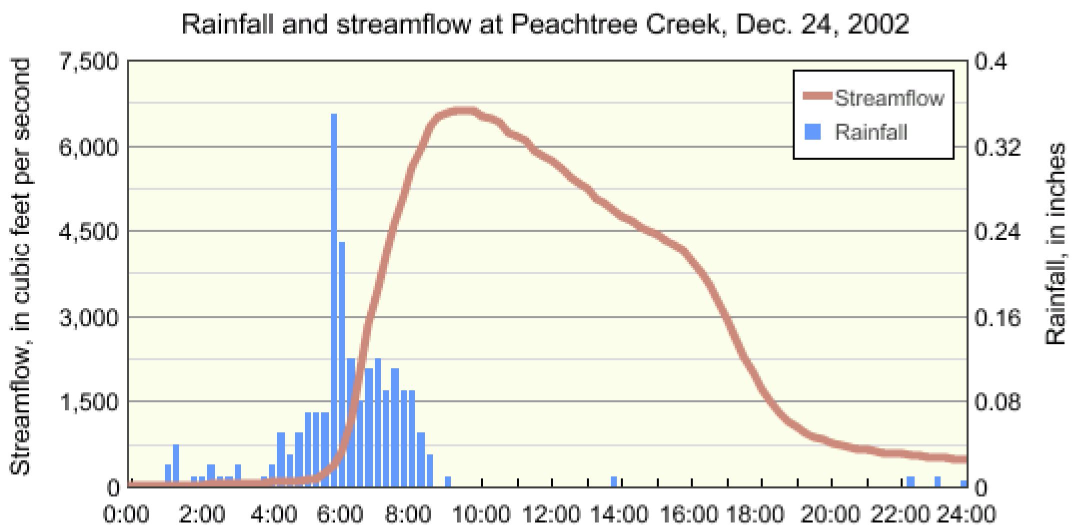


Figure 3-3: Streamflow and Rainfall Variation over time(Usgs.gov, 2021)

From the graph we can deduce that as the amount of rain increased, the flow rate also increased implying a positive correlation between rainfall amount and flow rate.

4. Temperature and Humidity

The probability of flash floods during cooler months are higher than in hotter months.

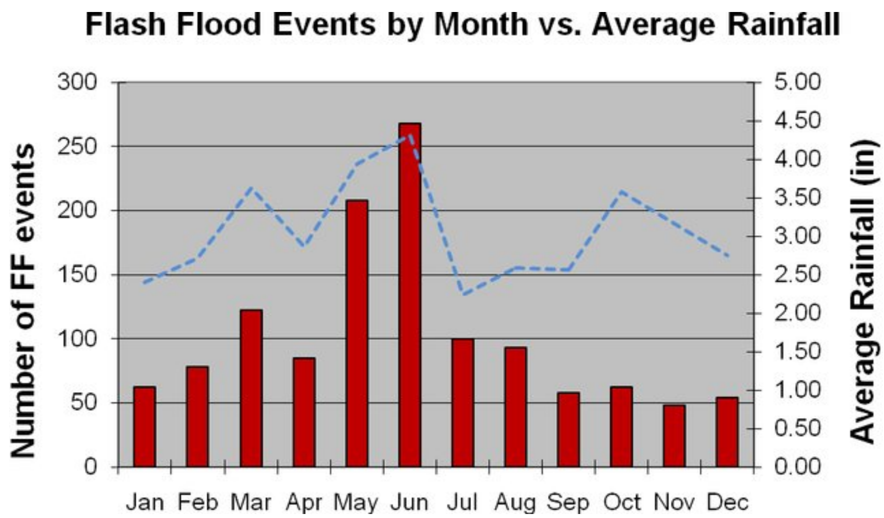


Figure 3-4: Annual Rainfall and flash flood events(Hanes, 2007)

During winter months, the temperature is lower and wetter, there is less evaporation of rainwater due to lower temperature and therefore flash flood events are more likely to occur.

3.3 Gumbel Probability distribution

Rainfall frequency analysis allows engineers and others to detect the possibility of any flash floods, allowing them to devise risk management strategies to minimize significant damage. In hydrological models, the Gumbel distribution is one of the most commonly used probability distribution functions in hydrological models for predicting floods, rainfall, wind speed, discharge, etc (Chikabvumbwa and Dessalegn Worku, n.d.). The rainfall frequency can be analysed using the Gumbel distribution.

The Gumbel distribution is given as follows:

$$F_x(x) = p = exp[-\ exp\{-\ 1 \times (\frac{x-u}{\alpha})\}] \qquad \text{equation (3.1)}$$

Let the annual data *x* for *n* years be given where x can be rainfall, wind speed, discharge, etc. The mean and standard deviation for the n years can be computed as shown below.

$$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n}$$ equation (3.2)

$\bar{x}$-mean data calculated for n years

S_x^2-variance of data for n years

x_i-data for the i^th year

The constants u and ***α*** can be computed as follows.

$$u = \bar{x} - 0.5772\alpha$$ equation (3.3)

$$\alpha = \frac{\sqrt{6}S_x^2}{\pi}$$ equation (3.4)

Then the gumbel probability p is calculated for each value of x. The return period T for x is given by:

$$T = \frac{1}{1-p}$$ equation (3.5)

If x is chosen to be the annual rainfall, T will be the return time in years for the rainfall to reach that particular amount.

3.4 River Topography

The chosen location for the project implementation is at Riviere Seche situated at Bel-Air. The width of the river is 5 metres and the elevation is 230 feet above sea level.

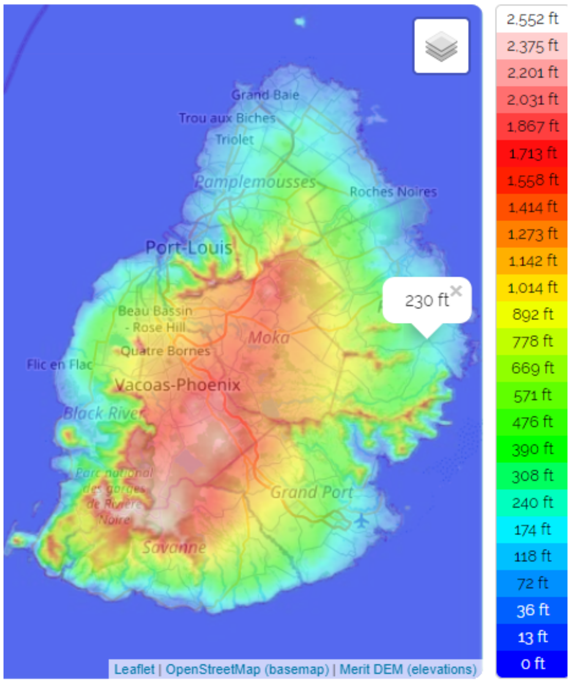


Figure 3-5: Site Location

The catchment area has a width of 5 metres and length of around 25 metres. The figure shows a model of the catchment area.

Figure 3-6: River Bank Height

CHAPTER 4: CONCEPTUAL DESIGN

4.1 Introduction

This chapter discusses the conceptual design process, which identifies the project's core requirements. Different sensors used for data collection are analysed. Afterwards, various data monitoring, communication, and alarm system concepts are presented, and the best design is chosen.

4.2 System Architecture

The diagram below shows an overview of the system.

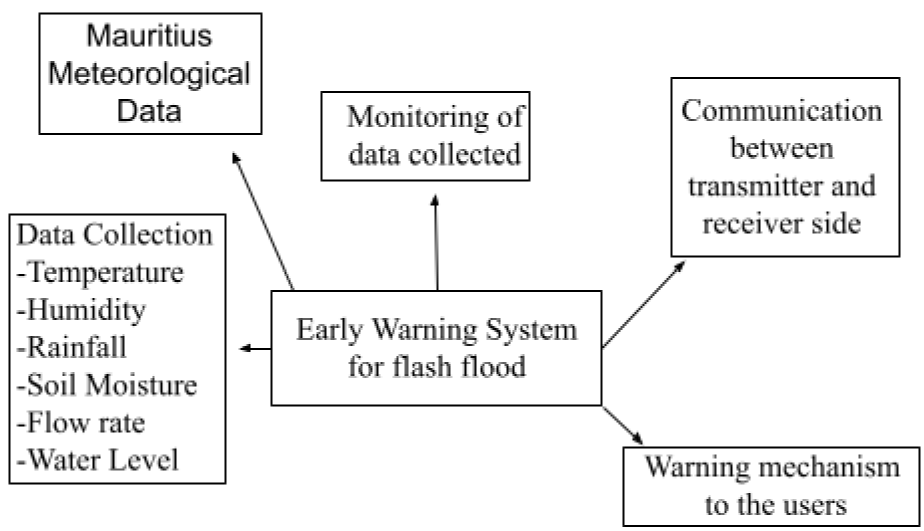


Figure 4-1: System Architecture

- Flash flood parameters are collected using appropriate sensors.
- The values are then monitored on cloud.
- The data collected are then communicated with the gateway.
- When an alarm is triggered, a warning message is sent to the users.
- Meteorological data can be used to predict flooding.

4.3 Project Requirements

To design the early warning system it is imperative to identify and assess all the key requirements. The table below identifies some of the principle requirements.

Table 4-1: Key Requirements of the system

Function	● The system should be able to store and monitor parameters related to flash flood (temperature, water level, flow rate, soil moisture, rainfall). ● The system should allow long distance communication (from river site to home location) . ● The system should be able to notify the residents in case of flash flood warning.
Cost	● The system should be cost effective to implement. ● The device should be cheap to maintain. ● The device should be easily accessible to the public with an affordable price.
Reliability	● The data collected should be reliable. ● The system should not be producing any false alarms. ● The system should be accurate.
Safety	● The system should be properly enclosed. ● Proper insulation should be used to prevent any short circuits or shock to the users.
Material	● The material used should be water resistant to prevent damage to the sensors. ● The material used should be resistant to weather changes, heat, rust, insect attacks. ● The base material should be stiff to prevent toppling during strong water flows.
Aesthetics and Ergonomics	● The system should not be a sore to the eyes. ● The user interface should be friendly.
Scalability	● The system should be able to support additional sensors. With future advances in technology, the system should allow further expansion.
Environmental Aspects	● The designed system should be environmentally friendly with minimum carbon footprint.

	• The system should not be causing any harm to wildlife (birds, aquatic animals).
Power Consumption	• The system should consume minimum power and operate efficiently.
Size	• The system should be made of minimum size to prevent destruction of the habitats of the aquatic animals.
Programming Software	• The software used should be able to be practically implemented. • The software used should be compatible with the different sensors. • The software used should be able to communicate with the IoT platform. • The memory should be able to store the sensor data. • The software should be reliable.

4.4 Data Collection

Flash floods are unanticipated natural disasters that vary in complexity according to topography. The topography of Mauritius varies from region to region, challenging flash flood analysis. However, some flood parameters have been chosen that can be used to detect and predict flash floods in rivers, such as:

1. Water Level
2. Flow Rate
3. Rainfall
4. Soil Moisture
5. Temperature
6. Humidity

Different sensors are available for measuring the different parameters which will be explored and the best sensors are chosen to meet the required specifications.

4.4.1 Water Level

The water level in rivers rises during flash flood events, making it a crucial parameter to monitor. Some of the sensors that can be used to measure the water level in rivers are included in the table underneath.

Table 4-2: Water Level Sensors

Sensors	Benefits	Drawbacks
Ultrasonic Sensor	● Unaffected by object colour, texture and type. ● Low power consumption ● Inexpensive ($ 9.99) ● Easily paired with microcontrollers ● Great accuracy	● Limited range of detection (2cm-200cm) ● Requires calibration
Optical Liquid Level Sensor	● Compact size and has no moving parts ● Low cost ($ 9.99)	● Reduced accuracy with changing environmental conditions. ● Decrease in accuracy when top mounted due to moisture condensation
Capacitive Probe	● High precision ● Compact	● Requires calibration ● Reduced accuracy with changing environmental conditions.
Microwave	● High accuracy ● No required calibration	● Expensive ● Affected by environmental conditions

The ultrasonic sensor is chosen to monitor the water level because of its low cost and great accuracy. The ultrasonic sensor is simple to program with a microcontroller and is widely available.

4.4.2 Flow Rate

Another important parameter in predicting flash floods is the water flow rate. In Mauritius, several people's properties were destroyed and several people were killed as a result of heavy water flows during flash floods in Port-Louis in 2013 . Some of the flow sensors that can be utilized are listed in the table below.

Table 4-3: Flow Sensors

Sensors	Characteristics
FL-308T Water Flow Sensor	• Range: 0.3- 10L/min • Cost: $ 7.99 (Amazon) • Water Pressure < 0.8MPa • Lightweight, small size, easy to use • Uses the hall effect to measure flow rate
YF-S201 Water Flow Sensor	• Range: 1-30L/min • Cost: $9.90 (Amazon) • Water Pressure< 2MPa • Light weight, small size, easy to install. • Uses hall effect to measure flow rate
FL-908 Water Flow Sensor	• Range: 1-60L/min • Cost: $10.99 (Amazon) • Water Pressure<1.75MPa • Small size, waterproof, easy to install • Uses hall effect to measure flow rate

The YF-S201 Water flow sensor is chosen due to its affordable price and acceptable range of flow. The sensor uses the hall effect to measure the flow rate which will be further described in chapter 5.

4.4.3 Temperature and Humidity

Other key elements utilized as flash flood parameters are temperature and humidity. The majority of flash floods occur in summer during thunderstorms and with heavy rainfall in winter. The temperature and humidity sensors that can be utilized are listed in the table below.

Table 4-4: Temperature and Humidity Sensors

Sensors	Benefits	Drawbacks
DHT11	• Cheap • Reading can be obtained after each second.	• Low temperature range (0ºC-50ºC) • Low Humidity range (10%-90%) • Low accuracy ((+/- 2ºC for temperature)
DHT22	• Large temperature and humidity range (-40ºC-80ºC) (0-100%) • Great accuracy (+/- 0.5 ºC for temperature)	• Less cheap than DHT11 • Reading obtained after each two seconds
BME280	• Can measure temperature, humidity and pressure • Large temperature range(-40ºC-85ºC) • Great temperature accuracy (+/- 0.5 ºC)	• Self heating causing temperature to increase slightly above actual temperature • Expensive

Because of its high accuracy and wide temperature and humidity range, the DHT22 sensor is chosen. The DHT22 sensor, unlike the BME280, does not self-heat.

4.4.3 Rainfall Detection

Flash floods are most probable during rainy seasons therefore the precipitation should also be monitored to predict flash flood events. Some of the rain sensors that can be used to measure precipitation are discussed in the table below.

Table 4-5: Rainfall Measurement

Sensors	Benefits	Drawbacks	Comments
Tipping Bucket Rain Gauge	• High accuracy	• Requires calibration • Expensive • Requires interrupt	Measures rainfall in mm (amount)
Rain Sensor	• No calibration required • Very cheap	• Decrease in lifespan when exposed to environmental changes • Requires sensor board	Measures rainfall in percentage (rate)

The chosen sensor is the rain sensor which is cheap and easily available in markets. It can be easily used to detect rainfall and requires no complex programming.

4.4.5 Soil Moisture

During flash flood season the soil can no longer absorb any water and this leads the river water to flow downstream resulting in damage of properties or casualties. Therefore, a soil moisture sensor will aid in the monitoring of riverbank moisture content. Some of the soil moisture sensors that can be employed are listed in Table 4-6.

Table 4-6: Soil Moisture sensors

Sensors	Characteristics
Capacitive soil moisture sensor	● Expensive and accurate ● No sensor board required ● Corrosion resistant material
Soil Hygrometer (Resistive)	● Cheaper and accurate ● Requires additional sensor board ● Corrosion of sensor probes due to DC current flowing resulting in electrolysis of probes

The chosen sensor is the soil hygrometer due to its low cost and good accuracy.

4.5 Communication technology between receiver and transmitter

The transmitter side is located in the river and receiver side at my residence. An appropriate wireless long range communication technology needs to be established to send the sensors' data to the receiver. The horizontal distance between the transmitter and receiver side from google maps is 128.4 m.

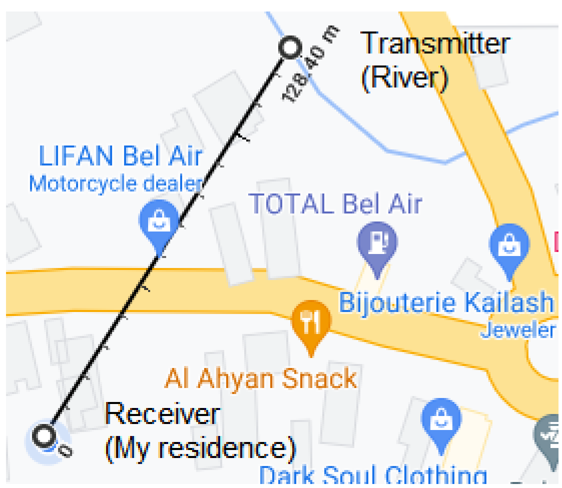


Figure 4-2: Transmitter and Receiver Location

The table below shows different wireless communication systems available.

Table 4-7: Communication Technology between transmitter and receiver

Wireless Communication Technology	Benefits	Drawbacks	Comments
Wifi (ESP)	• Available at a cheap cost. • Easy to set up	• Lower range • Multiple esp required for long distance communication	
LoRa	• Wide Range (in kms) • Consume low power • Immune to interference • Easy to deploy	• Low bandwidth • Communication is asymmetric. • Costly	• Uses radio frequency signals to communicate. • Asymmetric communication occurs when the the speed and quantity of data that can be transmitted changes with direction
BLE	• Very Low Power Consumption • 2 years lifetime with single cell • cheap	• Low Range (100metres)	• Communication via bluetooth
Zig-Bee	• High bandwidth • Symmetric communication	• Limited range of communication • Unreliable • Difficult to set up	• Symmetric communication occurs when the speed and quantity of data

			transmitted is the same in both directions.
NRF	• Cheap • Low Power consumption	• Low Range (100m)	• Uses radio frequency to communicate

The chosen communication technology is LoRa due to its long range communication capacity and immunity to interference. It can be easily implemented with microcontrollers.

The Reyax RYLR890 Lora module is a transceiver module which is selected for data communication.It can communicate up to 4.5 kilometres and can be easily interfaced with microcontrollers like Arduino, NodeMCU or raspberry pi using AT commands.

4.6 Data Monitoring

The sensors' data collected need to be monitored in an appropriate IoT platform. The table below shows different IoT platforms available.

Table 4-8: IoT platforms to monitor sensors' data

IoT Platform	Characteristics
Thingspeak	● User friendly ● Functions is limited
Thingsboard	● Alarms available ● Multiple widgets available ● Multiple functionalities ● Difficult to understand for newbies
Cayenne	● User Friendly ● Multiple functionalities ● Multiple widgets available ● Free of cost ● Additional trigger alarms available ● (emails and SMS) ● Mobile application available
Ubidot	● User friendly ● Easy to add widget ● Free of cost ● Multiple functionalities
Blynk	● User friendly ● Mobile Application ● Easy to add widget ● Limited free energy to add widgets ● No complex programming required

The two IoT platforms are chosen for monitoring the sensors' data are:

1. Cayenne
2. Blynk

4.7 Alarm

As soon as a probable flash flood warning is issued, the persons affected should be notified. The methods of alarm systems are examined in the following table.

Table 4-9: Alarm Notification

Alarm Method	Characteristics
Trigger from Cayenne	● Free of cost ● User friendly ● Emails and SMS available ● Unlimited amount of triggers ● No programming required to add triggers ● Very small delay in receiving alarm ● Need to be logged in with cayenne to receive notification
IFTTT	● Allows remote notification ● Easy to set up ● Notification service is free ● Limited number of notifications are available
GSM	● Requires SIM card ● Each SMS sent is payable ● GSM module is costly ● Easy to set up
Buzzer	● Cheap ● Easy to implement ● No internet connection required ● No remote notification ● Disruptive

The chosen method for monitoring the sensors' data was cayenne. The cayenne trigger is chosen for notifying concerned people about any flash flood warning through emails and SMS since of its free cost and has unlimited amount of notifications available.

4.8 Choice of microcontrollers

For the transmitter and receiver sides, appropriate microcontrollers must be chosen. Some of the microcontrollers that can be utilized, as well as their properties, are included in the table below.

Table 4-10: Microcontrollers

Microcontroller	Pros	Cons
Arduino UNO	• Cheap • Contains 6 analog pins • Contains both 3.3V and 5V outputs • No operating system is required	• Requires additional shields or modules for wireless connectivity (WiFi or bluetooth) • Low processing speed • Large size
NodeMCU (ESP8266)	• Cheap • On Board WiFi • High processing speed • Small size • No operating system required	• Contains only 1 analog pin • Contains no PWM pins • Contains only 3.3V outputs
Raspberry Pi	• Built in bluetooth and wifi • High processing speed	• Costly • Requires operating system (Linux) • Requires knowledge of linux • Consume more power

For the transmitter side the chosen microcontroller is Arduino Uno due to its lower price and no required operating softwares. The Arduino will be sending sensors' data via the reyax module therefore there is no need for WiFi or Bluetooth.For the receiver side the chosen microcontroller is the NodeMCU due to its low cost and on board WiFi. It can communicate with the MQTT server Cayenne and requires no additional operating system. The Arduino and NodeMCU will be communicating through the Reyax Module.

CHAPTER 5: DETAILED DESIGN

5.1 Introduction

This chapter deals with the overall system design. The circuit is designed on Fritzing and the system is implemented on Tinkercad. The different hardware used are analysed thoroughly and flowcharts are developed to facilitate writing of the sketch.

5.2 System Block Diagram

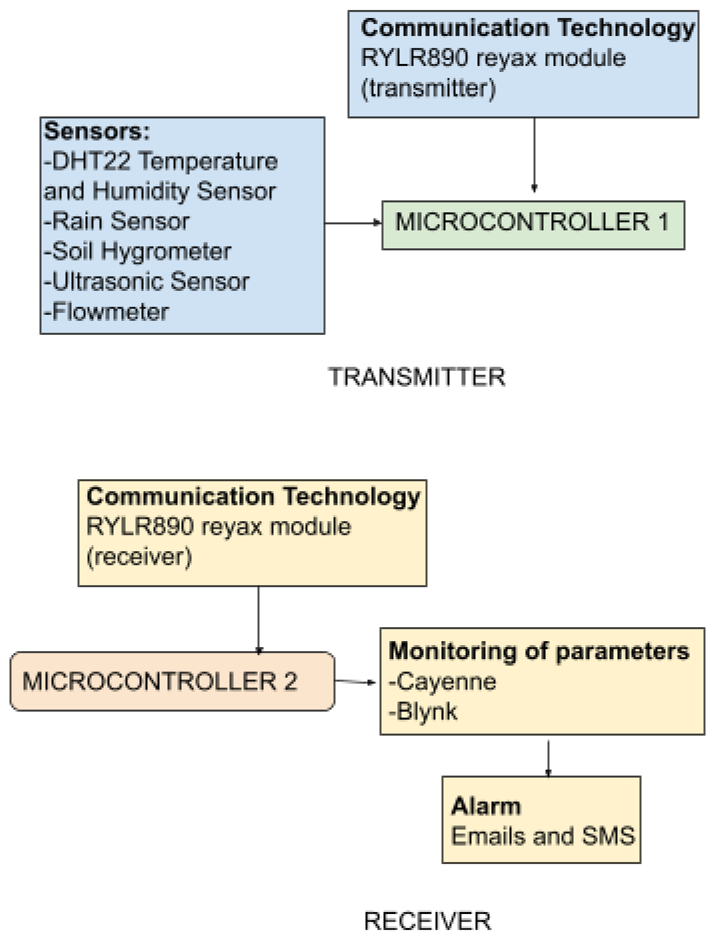


Figure 5-1: Transmitter and Receiver Block diagram

The Arduino Uno (microcontroller 1) collects the data from the sensors and converts it to a string message. The gateway receives the string message through LoRa communication technology. The string message received at the Node MCU (microcontroller 2) is then broken down into individual variables to store the sensors' data. The sensors' data are then sent to the Cayenne and Blynk dashboard. The data are displayed on gauges and graphs. The gauges are calibrated on the dashboard to allow the user to identify the critical level of the measured parameters from the sensors (red for critical, green for safe, yellow for warning). When the threshold values chosen are exceeded, a message and an email are sent to the residents.

5.3 Circuit Design

The transmitter and receiver circuits are implemented on Fritzing. The table below shows the connection of the transmitter with the different sensors and LoRa Module.

Table 5-1: Arduino and Sensors Pin Connections

Arduino Pins / Sensor Pins	5V	GND	Digital Pin	Analog Pin
Ultrasonic	VCC	GND	Echo Pin Trig Pin	-
Flowmeter	VCC	GND	o/p signal	-
Soil Moisture	VCC	GND	-	A0
Rain Sensor	VCC	GND	D0	A0
DHT22	VCC	GND	Data	-

For the reyax Module, the connection is as follows: VCC-3V3, GND-GND

The TX pin of the arduino is connected to the RX pin through a potential divider since the TX pin of the arduino is at 5V and the divider is used to drop the potential to about 3.4V. The resistors chosen are 4.7k and 10k so that the voltage at the RX pin is:

$$V_{TX} = \frac{10}{4.7+10} \times 5V = 3.4 \qquad \text{equation (5.1)}$$

The receiver side circuit consists of the reyax module connected to the NodeMCU. The connection of the Reyax with the NodeMCU is as follows.

Table 5-2: Receiver connections

NodeMCU Pin	Reyax Pin
3V3	VDD
GND	GND
RX	TX

5.3 Flowchart for Transmitter and Receiver side

Transmitter

The figure below describes the flowchart for the transmitting side circuit.

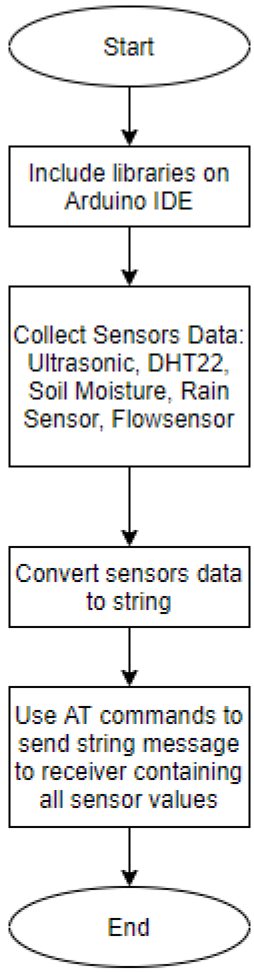


Figure 5-2: Transmitter Flow Chart

Receiver

The figure below describes the flow chart for the receiver side circuit

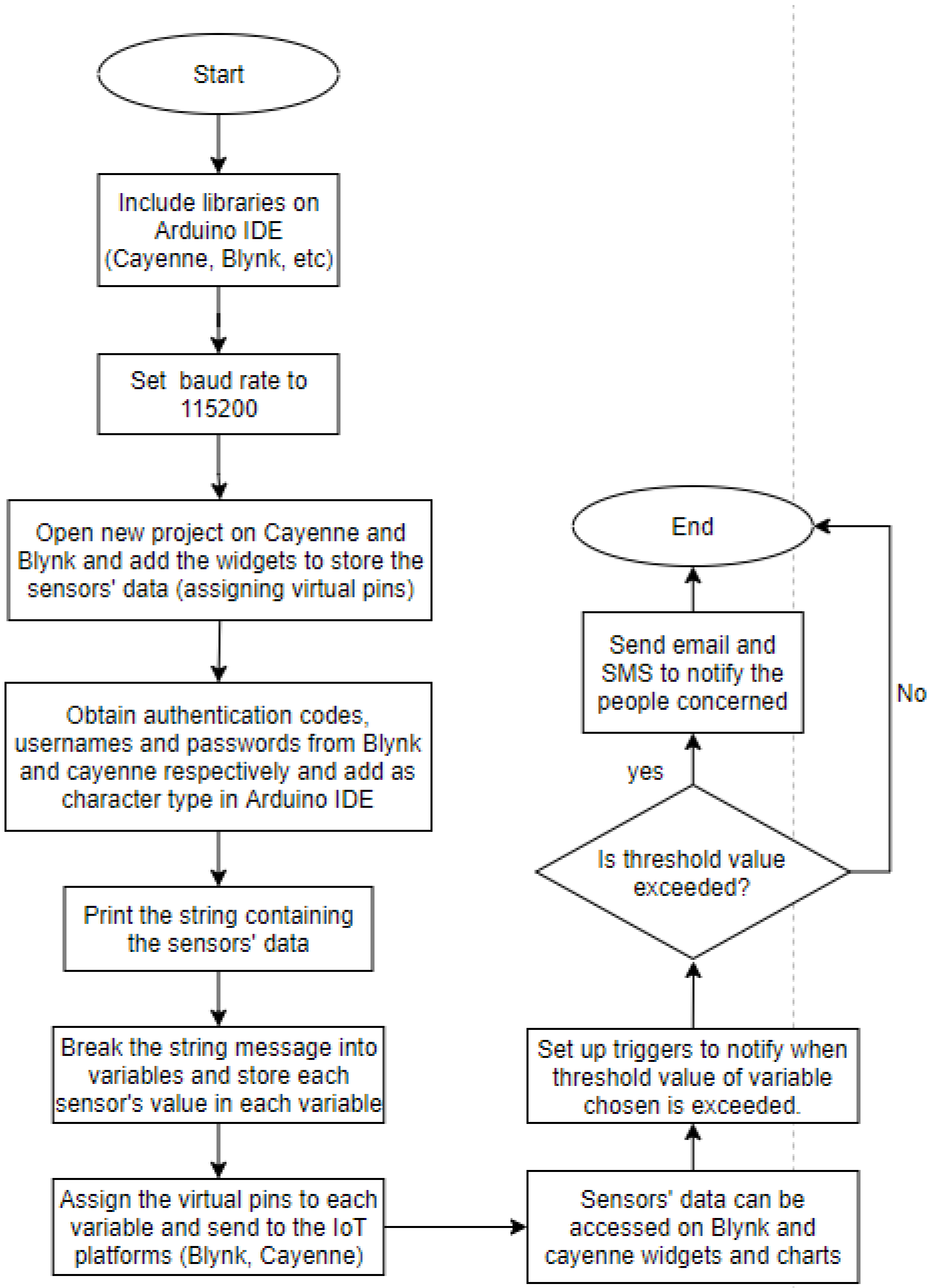


Figure 5-3: Receiver Flow Chart

5.4 System Design on TinkerCad

The figure below shows the system designed on tinkercad.

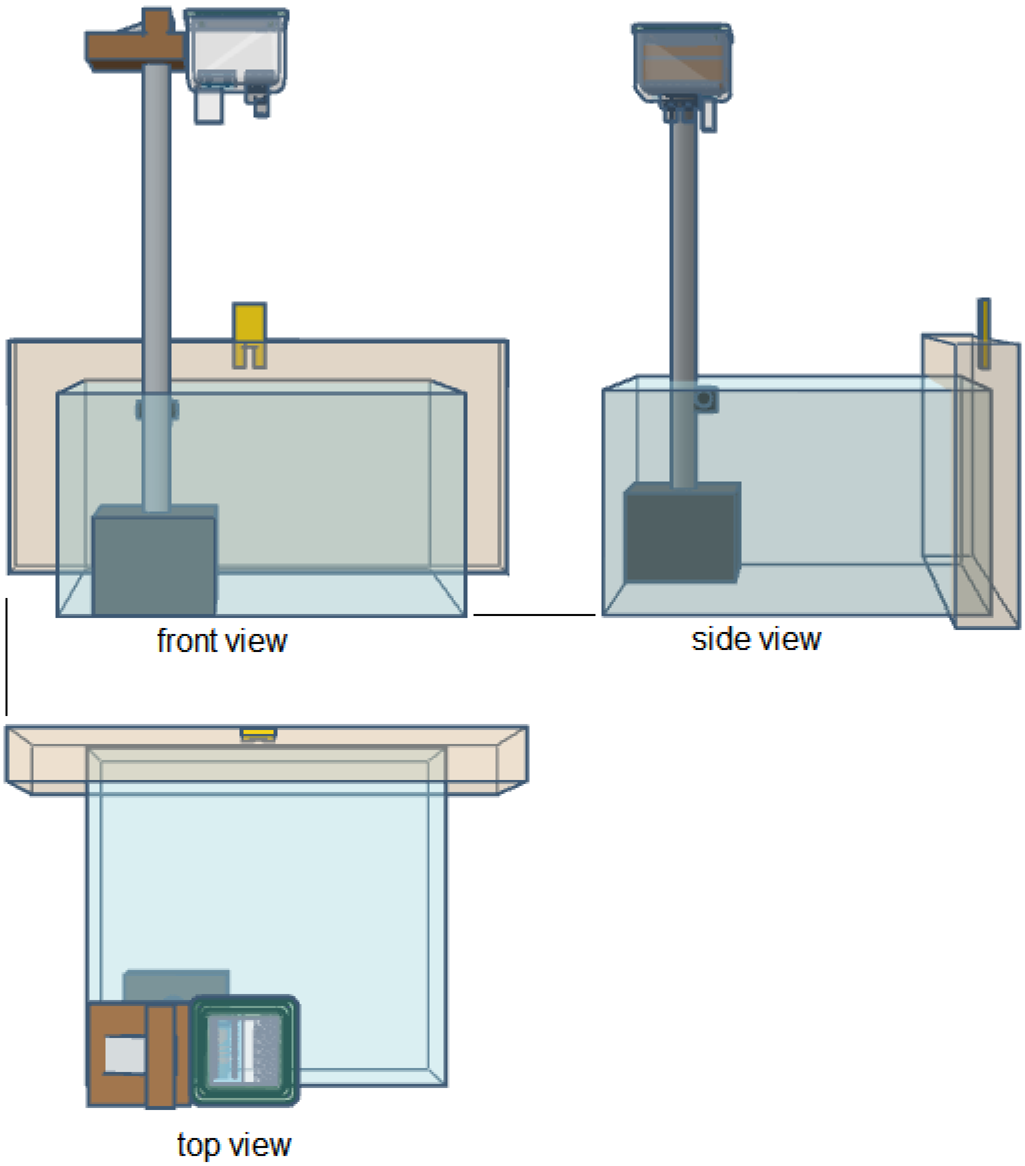


Figure 5-4: Orthographic view

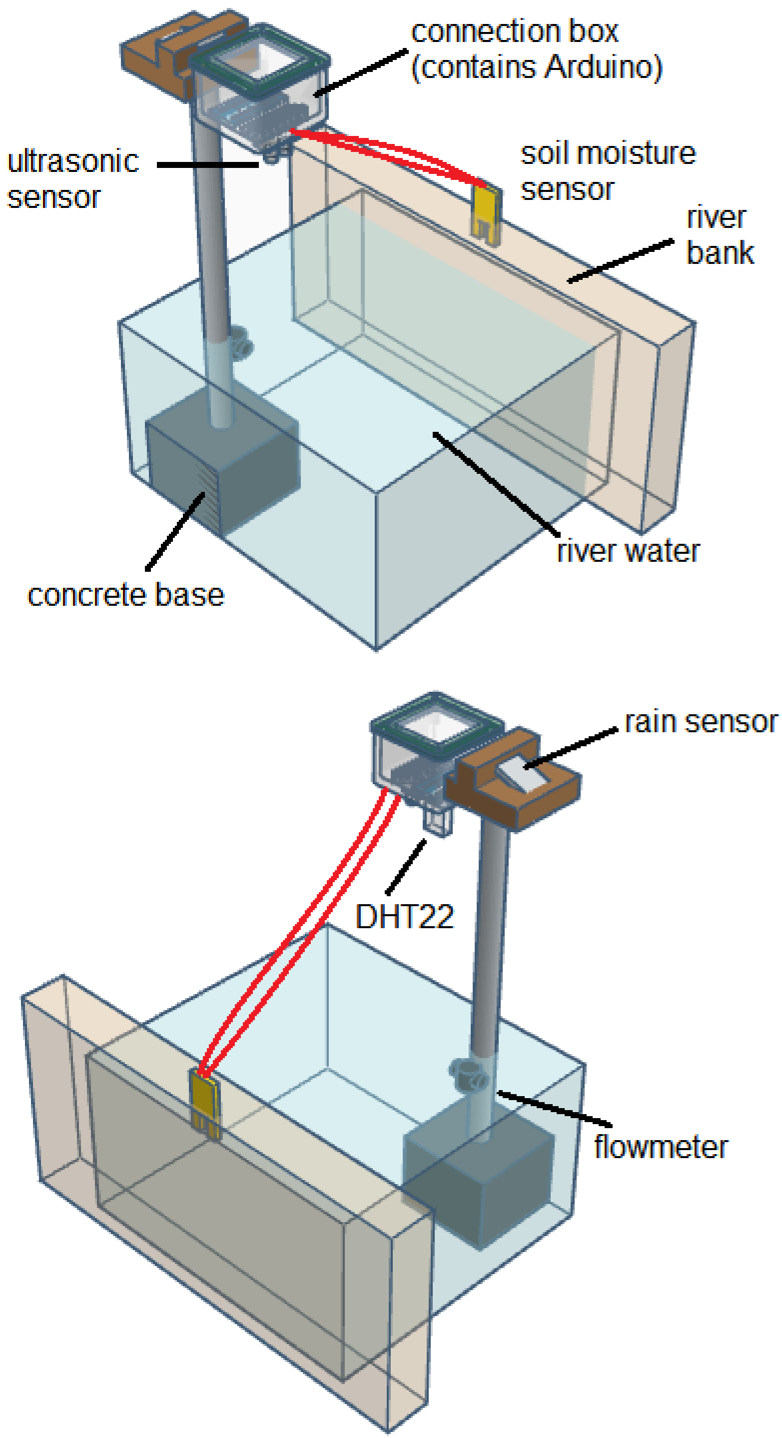


Figure 5-5: Tinkercad design

5.5 Components Design

The specifications of the different components present in the system are analysed and flowcharts are made to understand the operations of the components used. The table below shows the different components used in the project.

Table 5-3: Components Design

Microcontrollers	Sensors	Monitoring of sensors' data	Communication Technology	Alarm
Arduino Uno (Transmitter Side)	Ultrasonic Sensor (HC-SR04)	Cayenne	Lora (Reyax RYLR 890)	Cayenne SMS
NodeMCU (Receiver Side)	Flowmeter (YF-S401)	Blynk		Cayenne Email
	Soil Moisture Sensor (YL-69)			
	Rain Sensor (YL-83)			
	Temperature and Humidity Sensor (DHT22)			

5.5.1 Microcontroller

The microcontrollers used are:

1. Arduino Uno for the transmitter side
2. NodeMCU for the receiver side

5.5.1.1 Arduino Uno

The Arduino Uno is a micro-controller board based 8-bit ATmega328P microcontroller. It has 14 digital pins (input and output) among which 6 can be used as PWM outputs and 6 analog input pins. Each pin operates at 5V and can provide or receive a maximum current of 40mA. The different sensors (ultrasonic, DHT, rain sensor, flow-meter) are connected to the Arduino board and the data can be sent through the Lora module to the node MCU.

5.5.1.2 NodeMCU (ESP8266)

The Node MCU is an open source IoT platform consisting of an inbuilt WiFi module. It consists of 4 MB of storage and 128 kB of memory. It can be easily programmed using the Arduino IDE. It operates at 3.3V and has 13 GPIO (General Purpose Input Output) pins. The node MCU is a gateway which is connected to the Blynk application and MQTT application (CAYENNE) and it displays the sensors' values in an appropriate format. It also serves to alert the concerned people about any potential flash flood through messages and emails.

5.5.2 Sensors

5.5.2.1 Ultrasonic Sensor (HC-SR04)

Figure 5-6: Ultrasonic Sensor (Negi, 2019)

Ultrasonic sensor emits high frequency signals (40kHz) from the transmitter and the signal is reflected back to the receiver as shown in the figure.

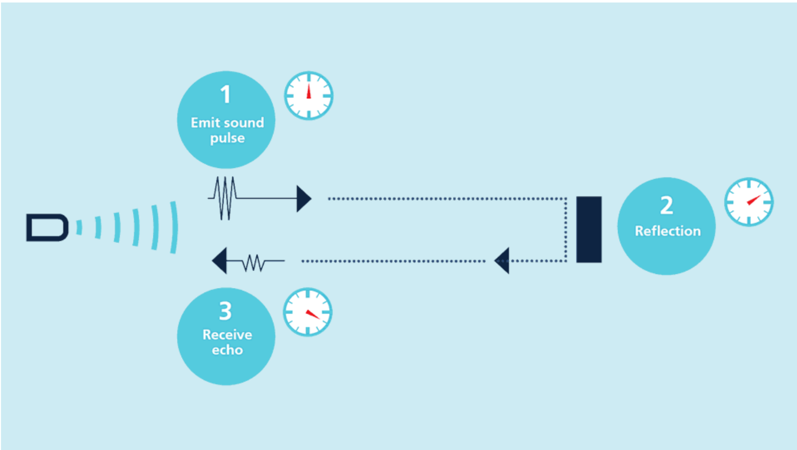


Figure 5-7: Working principle of ultrasonic sensor (microsonic, n.d.)

The waves propagate from the transmitter at the same speed of sound therefore the distance travelled by the sound wave is given by:

$$s = vt \qquad \text{equation (5.2)}$$

where v is the speed of sound (330m/s), s is the distance travelled by the sound wave and t is the time taken for the wave to travel between the transmitter and receiver.

The distance, d between an object and the ultrasonic sensor is given by:

$$d = 0.5s \qquad \text{equation (5.3)}$$

The distance, dw of the water level in the river can be found as follows.

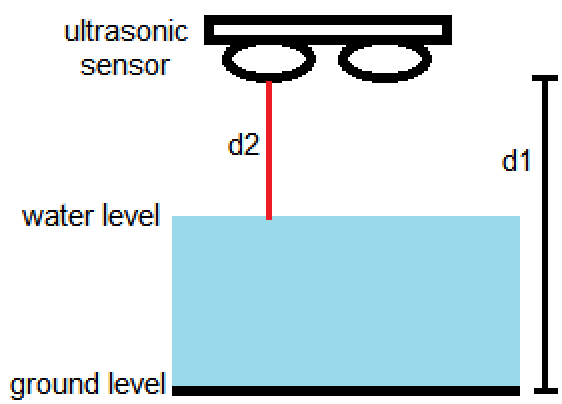


Figure 5-8: Water level calculation with ultrasonic sensor

$$dw = d1 - d2 \qquad \text{equation (5.4)}$$

Where d1 is the distance between the ultrasonic sensor and ground level (measured using measuring tape), d2 is the distance between the ultrasonic sensor and water level (measured using ultrasonic sensor) and dw is the water level calculated.

The table below shows the specifications of the ultrasonic sensor.

Table 5-4: Ultrasonic sensor specifications

Operating Voltage	VCC- 5V
Distance Range	2cm-400cm
Accuracy	3mm
Operating frequency	40kHz
Trigger Pin	● Connected to Arduino I/O pin ● Input pin which is kept high for 10 microseconds initially to begin measurement by transmitting ultrasonic wave
Echo Pin	● Connected to Arduino I/O pin ● Output pin which receives the transmitted signal from the Trigger pin ● Initially kept high for 10 microseconds

The pin connections of the ultrasonic sensor with Arduino Uno are shown below.

Table 5-5: Ultrasonic sensor and Arduino connections

Ultrasonic Sensor	Arduino Uno pins
VCC	5V
GND	GND
TRIG	Digital I/O pin
ECHO	Digital I/O pin

Working Principle of Ultrasonic sensor

The figure below shows the flow chart to demonstrate the operating principle of the ultrasonic sensor for water level measurement.

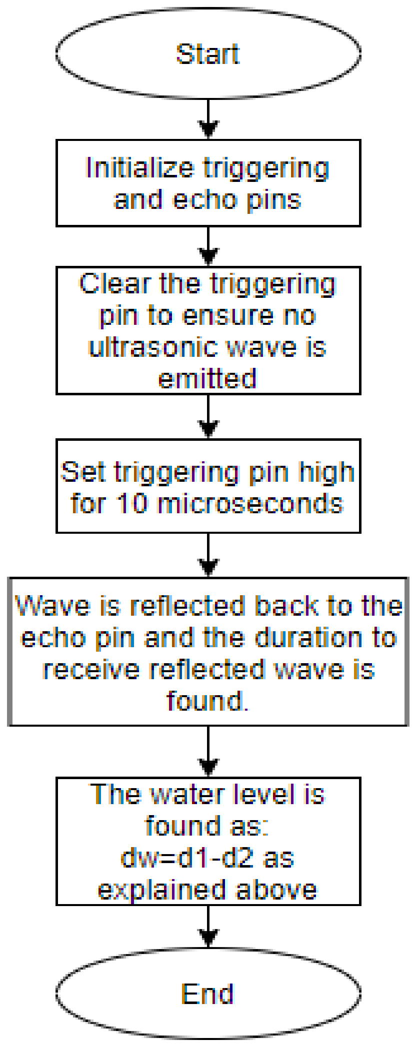


Figure 5-9: Flowchart to demonstrate working principle of ultrasonic sensor

5.5.2.2 Flowmeter (YF-S201)

Figure 5-10: Flowmeter YF-S201 (Sanjeev, 2018)

The flow meter is used to measure the flow rate of the river in litres/hour or litres/minute. The flow meter works on the principle of hall effect. The main components are the hall effect sensor, a rotating wheel and a magnet. As the water moves in the sensor, the wheel rotates causing the magnet fixed to the wheel to rotate also. This rotation of the magnetic field triggers the hall effect sensor generating square pulses. The flow of water can be found by counting the number of pulses.

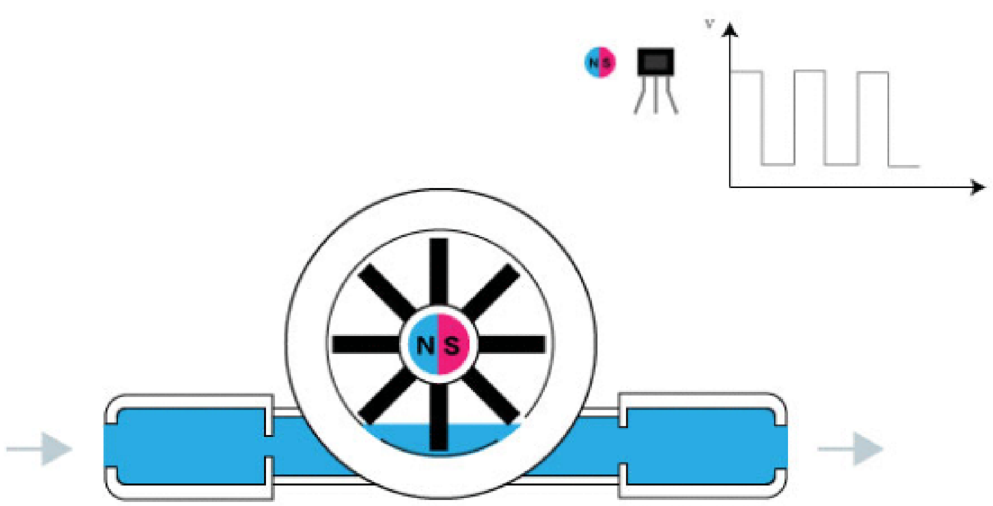


Figure 5-11: Hall effect in flow meter (Ains, 2021)

For YF-S201, 450 pulses are produced for each litre produced.

For 1 pulse, the volume of water flowing is 1/450 litres.

For N pulses, the total volume of water flowing is N/450 litres.

The total volume flowing is also given by Q(L/s) * t(s) where Q is the water flow rate in L/s and t is the time is seconds. Hence

$$\frac{N}{450} = Qt \qquad \text{equation (5.5)}$$

N/t is the frequency f

$$f = 450Q \qquad \text{equation (5.6)}$$

$$Q(L/s) = \frac{f}{450} \qquad \text{equation (5.7)}$$

$$Q(L/h) = \frac{f}{450}(3600) = 8f \qquad \text{equation (5.8)}$$

where f is the pulse frequency.

The table below shows the pin connection for the flowmeter.

Table 5-6: Flowmeter pin connections

Flowmeter pins	Arduino Pins
Black (GND)	GND
Red (5V)	5V
Yellow (Signal)	I/O pins

Note that the signal pin needs to be connected to an interrupt pin in order to catch the required pulses to measure the flow rate. Arduino has got only two interrupt pins:

Digital pin 2: interrupt pin 0

Digital pin 3: interrupt pin 1

Working Principle of flowmeter

The following flowchart shows the working principle of the flowmeter with Arduino.

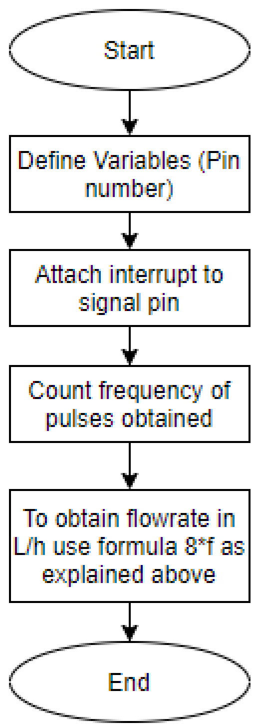


Figure 5-12: Flowchart to demonstrate working principle of flowmeter

The following table shows the specifications for the flow meter YF-S201.

Table 5-7: Flowmeter specifications

Operating voltage	5V-24V
Current Max	15mA (5V)
Pressure Range	<2MPa
Working Temperature Range	0ºC- 80ºC
Flow Rate range	1- 30 litres/minute

5.5.2.3 Soil Moisture Sensor (YL-69)

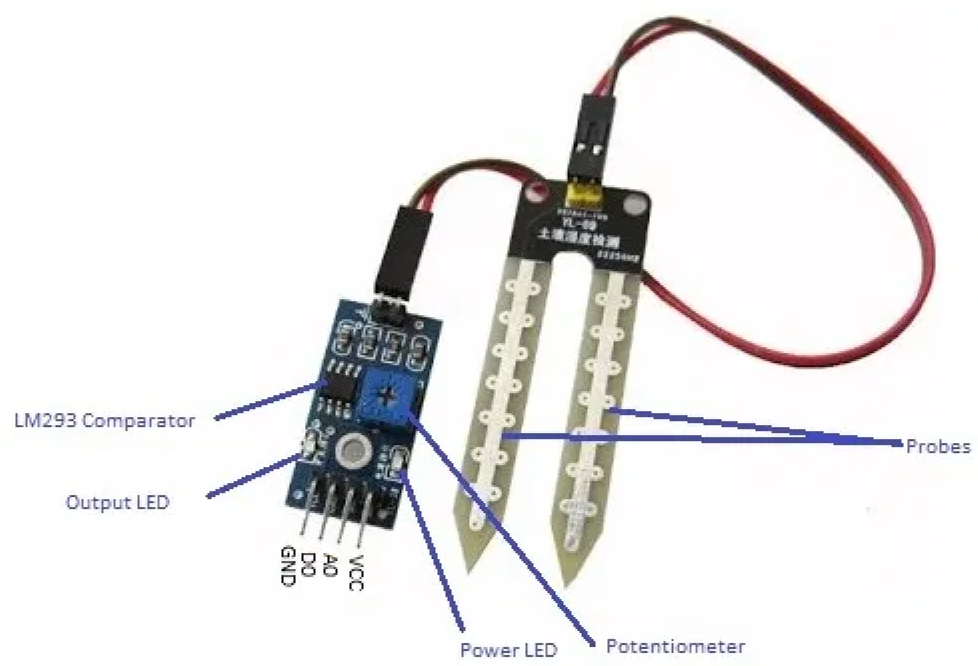


Figure 5-13: Soil Moisture Sensor (Arduino&Soil Moisture Sensor-Interfacing Tutorial-Circuit Diagram,Applications, 2020)

The soil moisture sensor is used to detect the water content in the river. They are attached at the river banks. During flash floods, the water content of the soil rises and the soil moisture parameter can be used for flash flood prediction.

The soil moisture sensor contains two probes which measure the moisture of the soil. When the soil is moist, the resistance of the probes decreases and allows a larger current to flow. This output is high (1023). When the soil is dry, the resistance is higher. This allows smaller current to flow and results in a minimum low value (0). To find the moisture content of the soil in percentage the following formula is used.

$$Percentage\ of\ moisture\ content = \left[\frac{1023-a}{1023}\right]\times 100\% \qquad \text{equation (5.8)}$$

where a is the analog value obtained from the sensor.

An analog value of 0 represents moisture content of 100% whereas an analog value of 1023 represents a moisture content of 0%.

In Arduino the analog value obtained can be easily mapped to percentage using the mapping syntax:

```
soil_moisture_percentage=map(soil_moisture_analog_value,1023,0,0,100)
;
```

To measure the moisture content with the soil moisture sensor YL-69, a soil moisture module as well as Dupont wires are required.

The sensitivity of the digital output DO the soil moisture sensor can be easily adjusted by rotating the blue potentiometer on the soil moisture module. When the analog value exceeds a predefined threshold value, D0 is low and when the analog value is below the predefined value, DO is high. The threshold value can be easily adjusted using the potentiometer. The comparator compares the analog value with the threshold value to give the output D0 (1 or 0).

The specifications of the soil moisture sensor are given below.

Table 5-8: Soil Moisture Sensor Specifications

Input Voltage	3.3V-5V
Output voltage	0-4.2V
Output Current	35 mA
Output	Digital and analog

The table below shows the pin connections of the soil moisture sensor with Arduino

Table 5-9: Pin connections of soil moisture sensor

Arduino	Soil Moisture
Analog Pins (A0-A7)	A0
Analog or Digital Pins	D0
5V	VCC
GND	GND

The flowchart below shows the working principle of the soil moisture sensor.

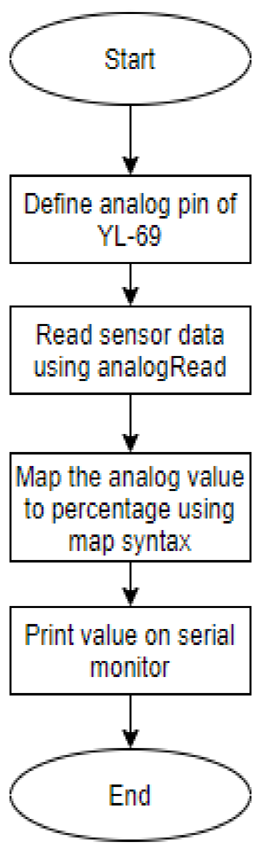


Figure 5-14: Flowchart to demonstrate working principle of soil moisture sensor

5.5.2.4 Rain Sensor (YL-83)

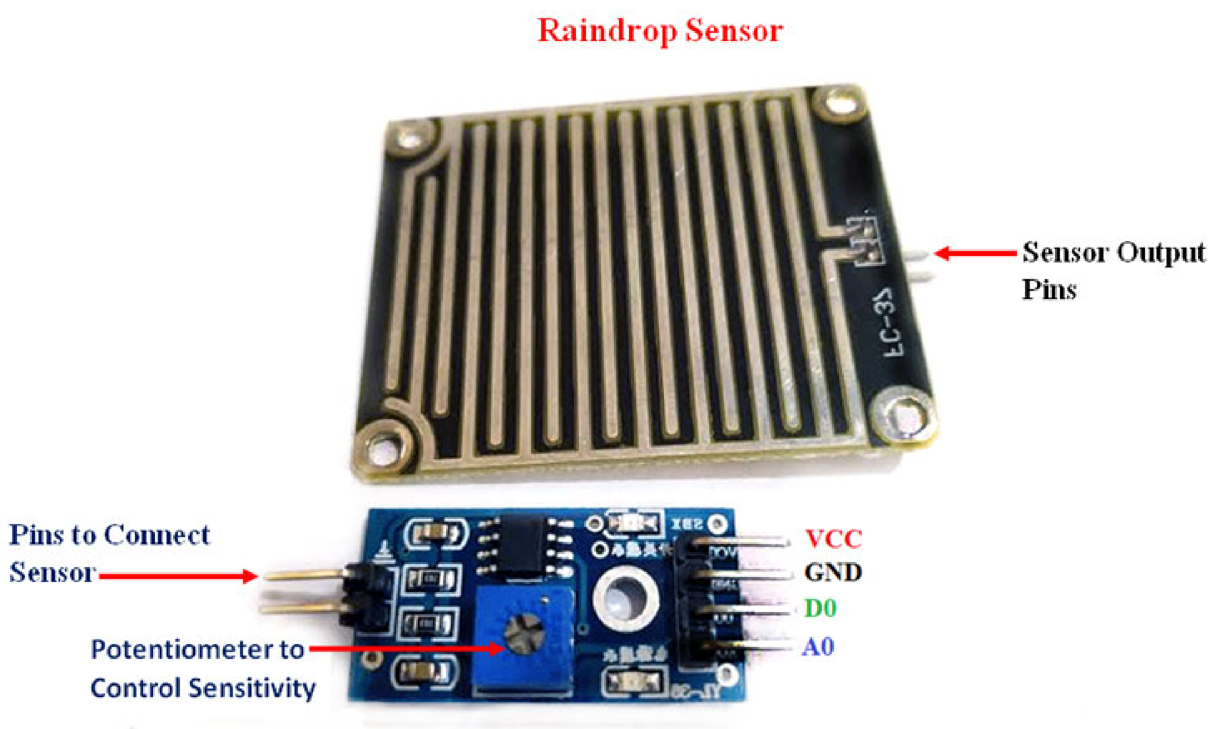


Figure 5-15: Rain sensor (Raindrop Sensor Pinout | Sensor, Analog to digital converter, Rain drops, n.d.)

The rain sensor is made up of two modules namely:

1. The rain board
2. The control module

The rain sensor works with a similar concept as the soil moisture sensor. During the rainy season, the sensor outputs a low voltage (minimum analog value=0) and during the dry season the rain sensor outputs a high voltage (maximum analog value=1024). The rain percentage can be calculated as follows:

$$Percentage\ of\ rain = \left[\frac{1023-a}{1023}\right] \times 100\% \qquad \text{equation (5.9)}$$

where a is the analog value recorded from the sensor.

The analog value of rain can be mapped to rain percentage on Arduino using the following syntax.

```
rain_percentage=map(rain_analog_value,1023,0,0,100);
```

The table below shows the specifications of the rain sensor.

Table 5-10: Rain Sensor Specifications

Input Voltage	5V
Output voltage	0-4.2V
Output Current	35 mA
Output	Digital and analog

The pins connection with Arduino is shown below.

Table 5-11: Soil Moisture Sensor Pins Connections

Arduino	Soil Moisture
Analog Pins (A0-A7)	A0
Analog or Digital Pins	D0
5V	VCC
GND	GND

Working principle of rain sensor

The flowchart below shows the working principle of the rain sensor.

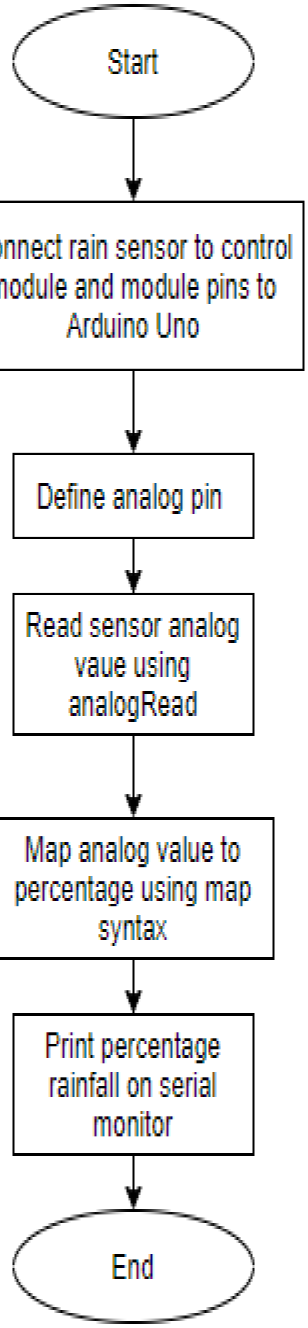


Figure 5-16: Flowchart to demonstrate working principle of rain sensor

5.5.2.5 Temperature and Humidity Sensor (DHT22)

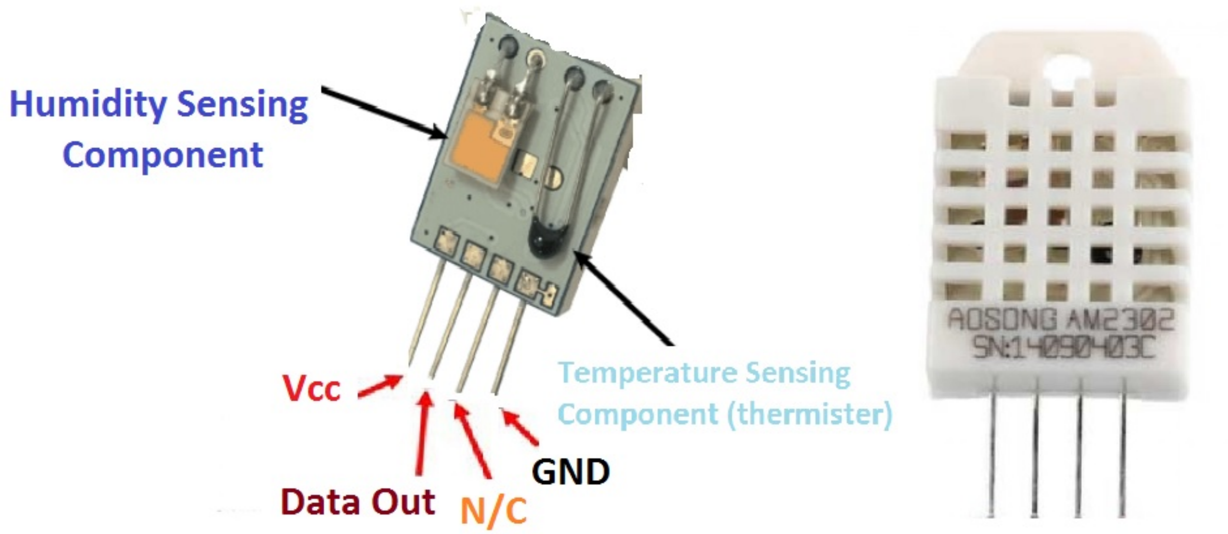


Figure 5-17: DHT22 sensor (Ali, 2019)

The DHT22 sensor is a low cost device used to measure temperature and humidity. It has a high level of accuracy and can be used to measure a large range of temperature and humidity.

Humidity Measurement

For humidity measurement, the DHT22 sensor contains two electrodes consisting of a moisture holding substrate within. As the humidity changes, the resistance of the electrodes also changes and is processed by the Arduino to express the humidity in percentage.

Temperature Measurement

A negative temperature coefficient thermistor is used to measure the temperature. As the temperature increases, the resistance of the thermistor decreases and as the temperature decreases the resistance increases. This resistance value is processed by the microcontroller to display the temperature.

The table below shows the specifications of the DHT22 sensor.

Table 5-12: DHT22 Specifications

Operating Voltage	3.5V-5.5V
Temperature range	-40ºC-80ºC
Humidity Range	0%-100%
Temperature accuracy	±0.5°C
Humidity accuracy	±1%
Humidity Sensing Element	Polymer humidity capacitor
Temperature sensing element	DS18B20

Connections between Arduino and DHT22 sensor are as follows.

Table 5-13: DHT22 Pins Connections

DHT22 pins	Arduino pins
VCC	5V
GND	GND
Data Out	Digital Pins
NC	Not Connected

The diagram below shows the working principle of the DHT22 sensor.

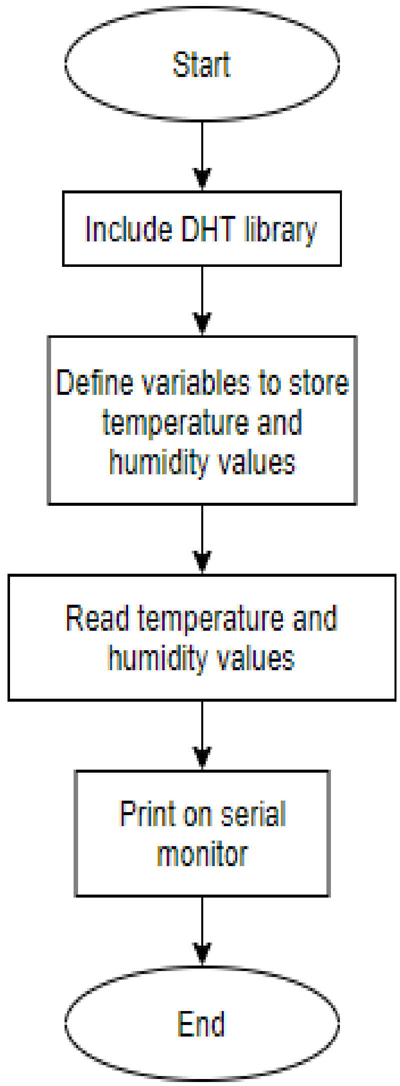


Figure 5-18: Flowchart to demonstrate working principle of DHT22 sensor

5.5.3 Communication Technology

The reyax module is a transceiver module based on lora technology. Lora is a wireless type of communication technology to create low power wide area networks (LPWAN) for long distance communication.

The figure below shows the reyax module.

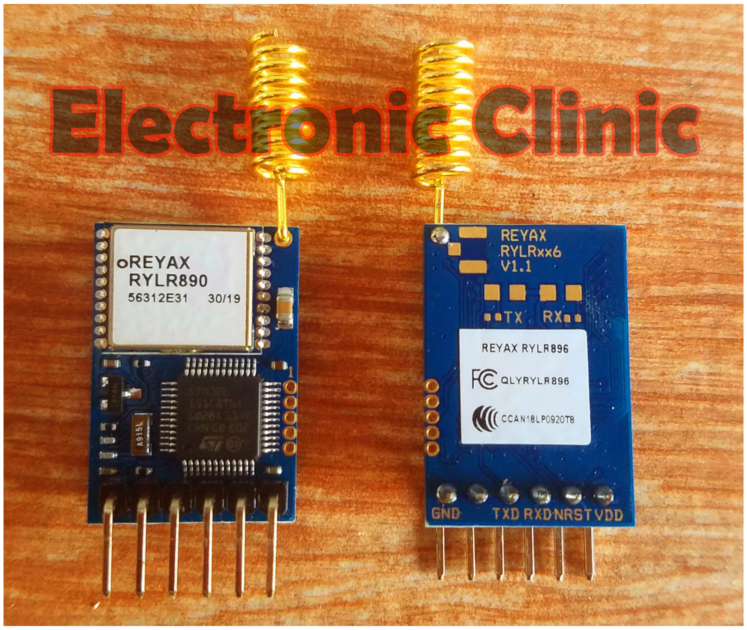


Figure 5-19: Reyax RYLR890 Module (Fahad, 2020)

The reyax transceiver module contains a processor which communicates with the microcontrollers using serial communication in full duplex mode so that both sender and receiver can communicate with each other. The data is sent bitwise unlike parallel communication where multiple bits can be sent at one time therefore fewer input and output lines are required for serial communication.

The typical range for communication is 0- 4.5km. The maximum communication distance can be up to 15km.

The specifications for the reyax transceiver module are shown below.

Table 5-14: Reyax RYLR890 Specifications

Minimum Voltage	2.8V
Rated Voltage	3.3V
Maximum Voltage	3.8V
Minimum frequency	820 MHz
Maximum frequency	1020 MHz
Rated frequency	868 MHz- 915 MHz
Transmitter Current	43 mA
Receiver Current	16.5 mA

The transmitter consists of the Arduino Uno with different sensors attached together with the Reyax module. The receiver side consists of the NodeMCU together with the transreceiver (Reyax) Module.Two transceiver modules are required.

Transmitter

The transmitter consists of the Arduino UNO connected with the different sensors namely ultrasonic, DHT22, flowmeter, soil moisture and rain sensor. The reyax module is connected to the transmitter and with the use of AT commands the data is sent to the receiver.

Receiver

The receiver consists of the NodeMCU and the Reyax transreceiver module. The data are sent to the receiver through the AT commands. Then the data collected are shown on the Cayenne dashboard using the MQTT protocol and on the Blynk application. Whenever a warning is detected, a trigger is activated on the dashboard which then notifies the concerned people about the current warning such as water level or flow rate has exceeded the threshold value.

The table below shows the connection of the transceiver module with the transmitter and receiver.

Table 5-15: Transceiver module connection with Arduino (Transmitter)

Reyax pin	Arduino pin
VDD	3V
RX through potential divider	TX
GND	GND

Table 5-16: Transceiver module connection with NodeMCU (Receiver)

Reyax pin	NodeMCU pin
VDD	3V
TX	RX
GND	GND

The other pins of the Reyax module are left unconnected. The RX and TX pins should be connected to Arduino TX and NodeMCU RX only after uploading the sketch.

5.5.4 Monitoring of sensors' data

The data obtained from the receiver need to be monitored on appropriate and user-friendly IoT platforms. The chosen Iot platforms are

1. Cayenne
2. Blynk

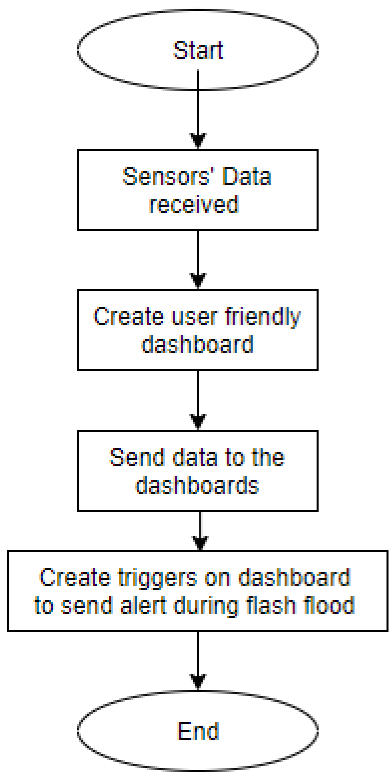


Figure 5-20: Flowchart to demonstrate working principle of IoT platforms

CHAPTER 6: IMPLEMENTATION AND TESTING

6.1 Introduction

The chapter deals with the implementation of each subsystem and the subsystems are combined to build the overall system. The components are individually tested before implementing the whole system. Then data is collected from the river for one month.

6.1.1 Ultrasonic Sensor Testing

The ultrasonic sensor is fixed at a certain height and the distance is measured between the ultrasonic sensor and the bottom of the bucket (d1). As water is poured in the bucket the ultrasonic sensor measures the distance between the sensor and the water level (d2). Then the water level can be found as d1-d2.

The ultrasonic sensor records d2 and finds the water level after each five seconds. The results are then sent to the serial monitor.

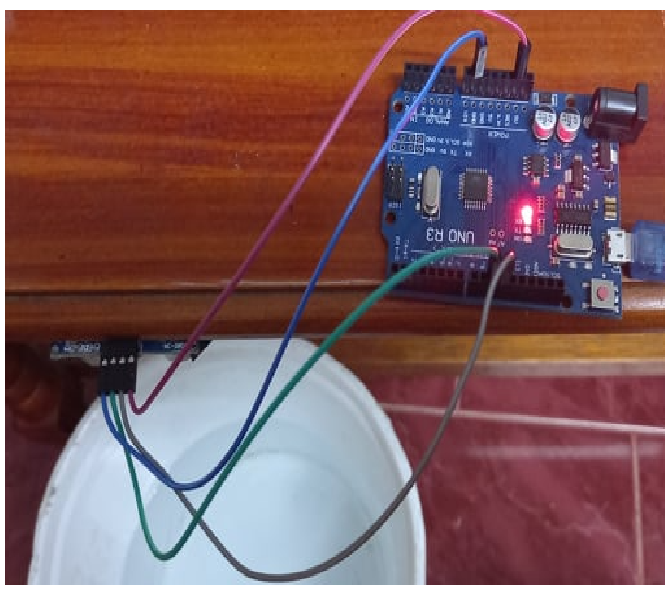


Figure 6-1: Ultrasonic Sensor Testing

The results obtained from the serial monitor are as follows. Note that distance implies the level of water.

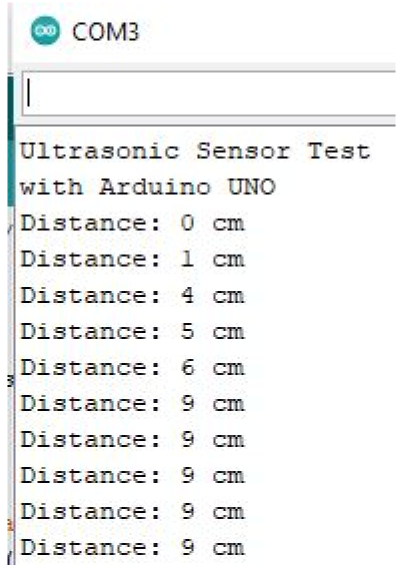


Figure 6-2: Water Level readings on Serial Monitor

6.1.2 Flow Meter Testing

The flowmeter measures the flow of water in litres per hour..

Figure 6-3: Flowmeter Testing

When water is poured through the inlet of the flowmeter the flowrate is recorded on the serial monitor after each five seconds as shown below.

```
Flow meter TestingFlow rate in litres/hr:0 L/hr
Flow rate in litres/hr:0 L/hr
Flow rate in litres/hr:0 L/hr
Flow rate in litres/hr:0 L/hr
Flow rate in litres/hr:0 L/hr
Flow rate in litres/hr:24 L/hr
Flow rate in litres/hr:24 L/hr
Flow rate in litres/hr:72 L/hr
Flow rate in litres/hr:64 L/hr
Flow rate in litres/hr:112 L/hr
Flow rate in litres/hr:144 L/hr
Flow rate in litres/hr:32 L/hr
Flow rate in litres/hr:56 L/hr
Flow rate in litres/hr:120 L/hr
Flow rate in litres/hr:120 L/hr
```

Figure 6-4: Flow rate readings on serial monitor

6.1.3 Soil Moisture Sensor Testing

The soil moisture sensor is used to determine the percentage of water content in the soil. The analog values are mapped into a percentage where 0% is dry soil and 100% is completely wet soil.

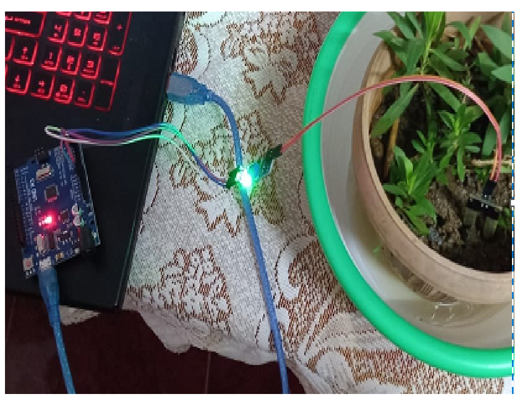


Figure 6-5: Soil Moisture Testing

For testing purposes, the probes of the soil moisture sensor were placed in a flower pot and water was added to the soil. The results were then displayed on the serial monitor as shown.

```
Soil Moisture Sensor Testing
Analog Value : 359     Percentage of soil moisture:65%
Analog Value : 361     Percentage of soil moisture:65%
Analog Value : 224     Percentage of soil moisture:79%
Analog Value : 221     Percentage of soil moisture:79%
Analog Value : 218     Percentage of soil moisture:79%
Analog Value : 211     Percentage of soil moisture:80%
Analog Value : 209     Percentage of soil moisture:80%
Analog Value : 208     Percentage of soil moisture:80%
Analog Value : 245     Percentage of soil moisture:77%
Analog Value : 230     Percentage of soil moisture:78%
```

Figure 6-6: Soil Moisture percentage Readings on serial monitor

As water was added to the soil, the analog value decreased and the percentage of soil moisture increased as expected.

6.1.4 Rain Sensor Testing

The rain sensor gives a high analog value when dry and a low analog value when wet. The analog value is then mapped into percentage rainfall.

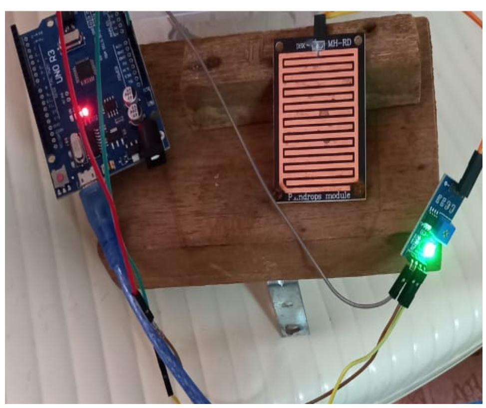


Figure 6-7: Rain Sensor Testing

When the rain sensor receives water,the analog value decreases and the percentage increases as expected. The results are displayed on the serial monitor.

```
Rain Sensor Testing
Analog Value : 1023      Percentage of rain:0%
Analog Value : 1014      Percentage of rain:1%
Analog Value : 764      Percentage of rain:26%
Analog Value : 739      Percentage of rain:28%
Analog Value : 779      Percentage of rain:24%
Analog Value : 712      Percentage of rain:31%
Analog Value : 769      Percentage of rain:25%
Analog Value : 773      Percentage of rain:25%
Analog Value : 757      Percentage of rain:27%
Analog Value : 747      Percentage of rain:27%
Analog Value : 741      Percentage of rain:28%
Analog Value : 736      Percentage of rain:29%
```

Figure 6-8: Rain sensor readings on serial monitor

6.1.5 Temperature and Humidity Sensor Testing

The DHT22 sensor measures the temperature and humidity of the atmosphere.

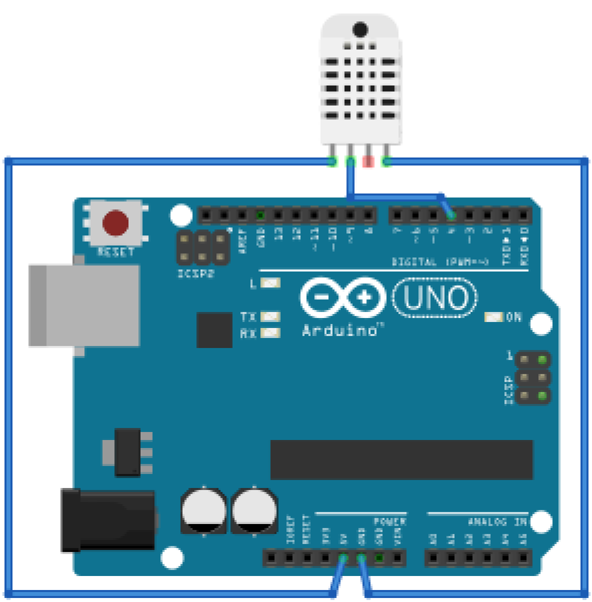


Figure 6-9: DHT22 sensor testing

The obtained results were then displayed on the serial monitor as shown below.

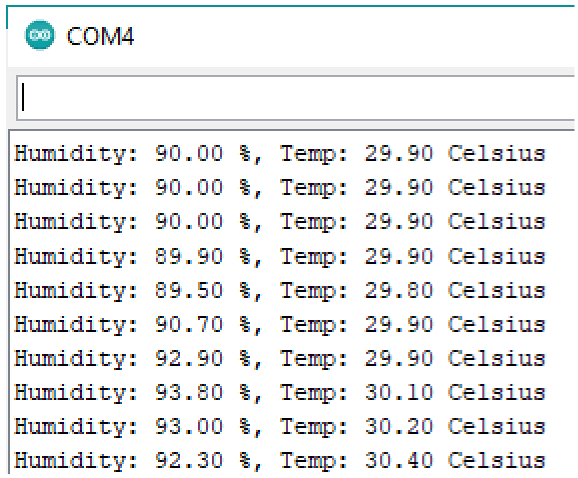


Figure 6-10: Rain sensor readings on serial monitor

6.1.6 Reyax RYLR890

The transceiver module can be configured using AT commands on the serial monitor on Arduino IDE. The pins connections of the reyax module with the NodeMCU are shown below.

Table 6-1: RYLR890 pin configuration with NodeMCU

Reyax RYLR890	NodeMCU
VDD	3V
GND	GND
TX	TX
RX	RX

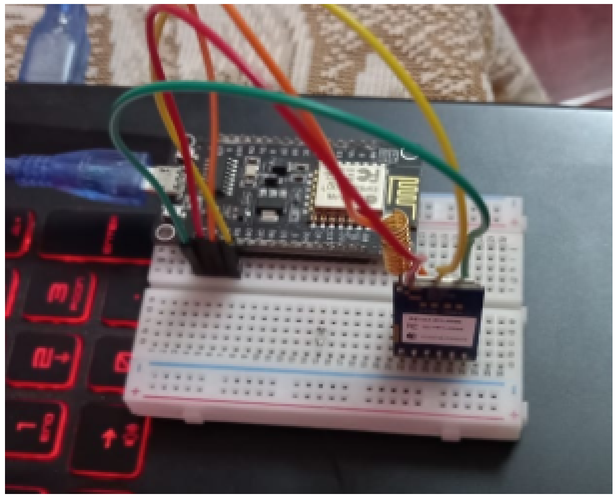


Figure 6-11: Testing of Reyax module

The results are displayed on the serial monitor for the different parameter configurations.

```
+OK
+IPR=115200
+BAND=915000000
+PARAMETER=12,7,1,4
+ADDRESS=0
+OK
+SEND=50,5,HELLO
```

Figure 6-12: Using AT commands on serial monitor

AT+SEND

This command is used to send data from the transmitter to the receiver.

AT+ADDRESS

This command is used to set the address of the transceiver module. The address allows identification of the transmitter and the receiver.

+RCV

The received data can be displayed using this command

AT+IPR

The baud rate can be set by the user accordingly. Both the transmitter and receiver should be set at similar baud rates to allow serial communication between them. The default baud rate is 115200.

AT+PARAMETER

This command sets the radio frequency parameters described below.

1) Spreading Factor

A large spreading factor will increase sensitivity but transmission time also increases.

2) Bandwidth

A smaller bandwidth increases the sensitivity. However the transmission time also increases.

3) Coding Rate

Coding rate is fastest if set to 1.

4) Programmed Preamble

Programmed preamble is set to prevent the loss of data while transmitting. A higher value decreases the chance of losing data.

Other AT commands are attached in the appendix.

Testing of Reyax RYLR890 with ultrasonic sensor and Blynk

The Reyax module is tested with the ultrasonic sensor. The data is sent to the blynk application and cayenne. The transmitter circuit is implemented on the Arduino UNO and receiver circuit is implemented on the nodeMCU. The transceiver modules are left at default settings.

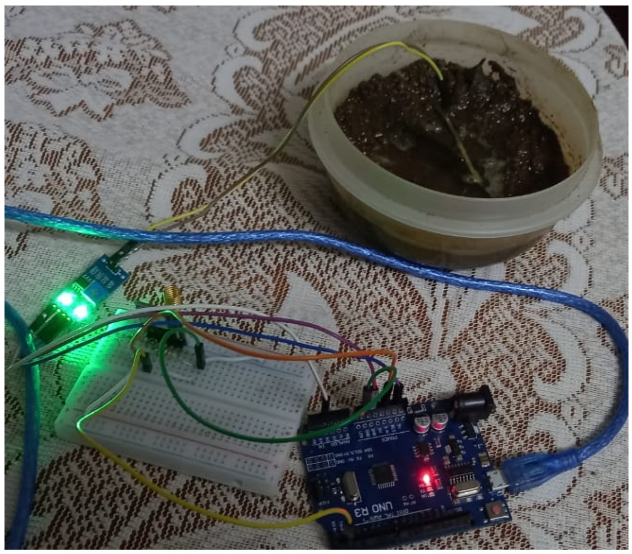


Figure 6-13: Soil Moisture sensor data transmission using the transceiver module

The transmitter sends data using AT commands. The result displayed on the serial monitor of the transmitter is as follows.

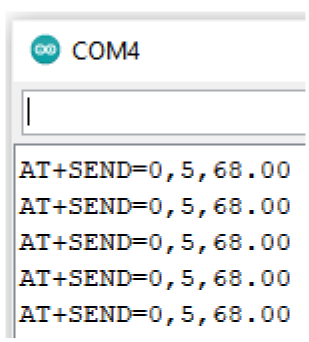


Figure 6-14: Transmitter serial monitor

The receiver receives the data in the form of a string message +RCV as shown below. The string message is broken down to pick the soil moisture value.

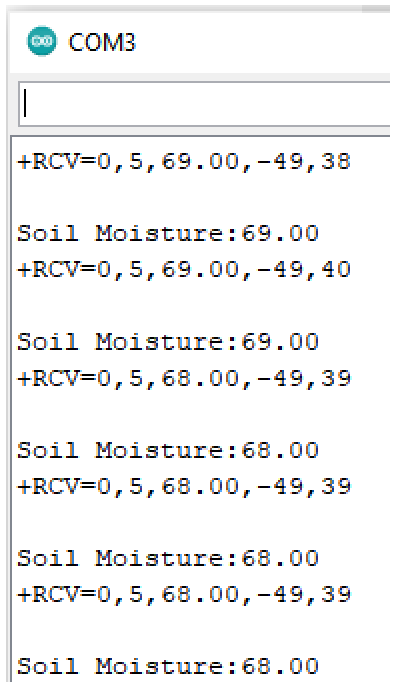


Figure 6-15: Receiver Serial Monitor

The received data is in the format +RCV=<Address>,<Length>,<Data>,<RSSI>,<SNR>

The address of the transmitter, length of data received, data sent from transmitter, received signal strength indicator and signal-to-noise ratio are shown in the string message.

The RSSI value indicates how well the signal is received from the transmitter. As the distance between transmitter and receiver is increased, the RSSI value decreases.

A high value of the SNR implies lesser disturbances to the signal received.

The soil moisture value can be displayed on the Blynk application and cayenne as shown below.

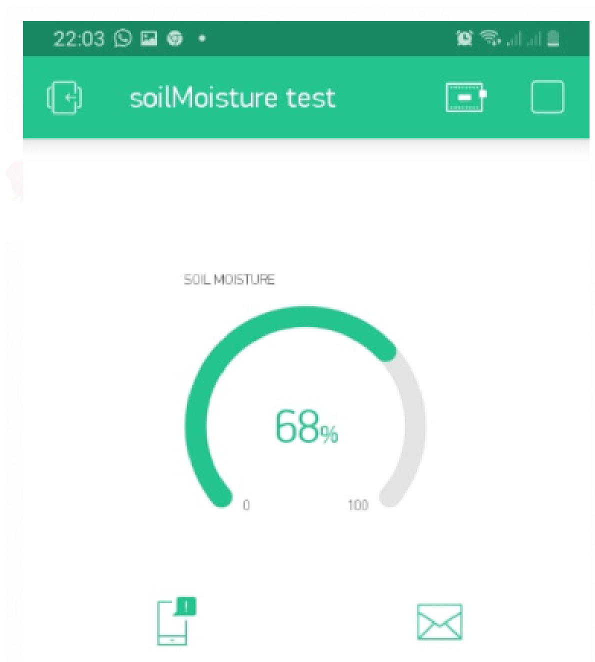


Figure 6-16: Soil Moisture Sensor data on Blynk

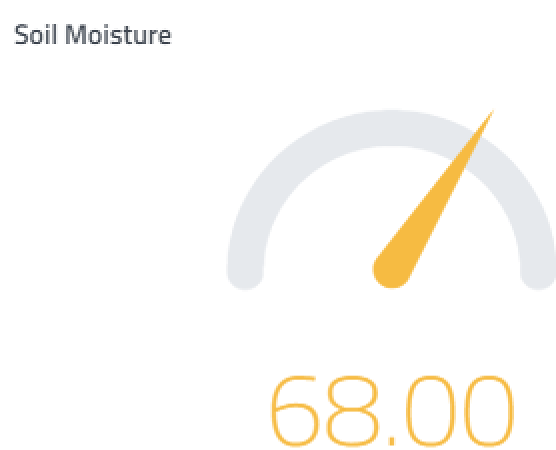


Figure 6-17: Soil Moisture Sensor data on Cayenne

For testing purposes, the threshold value for the soil moisture sensor chosen was 70.

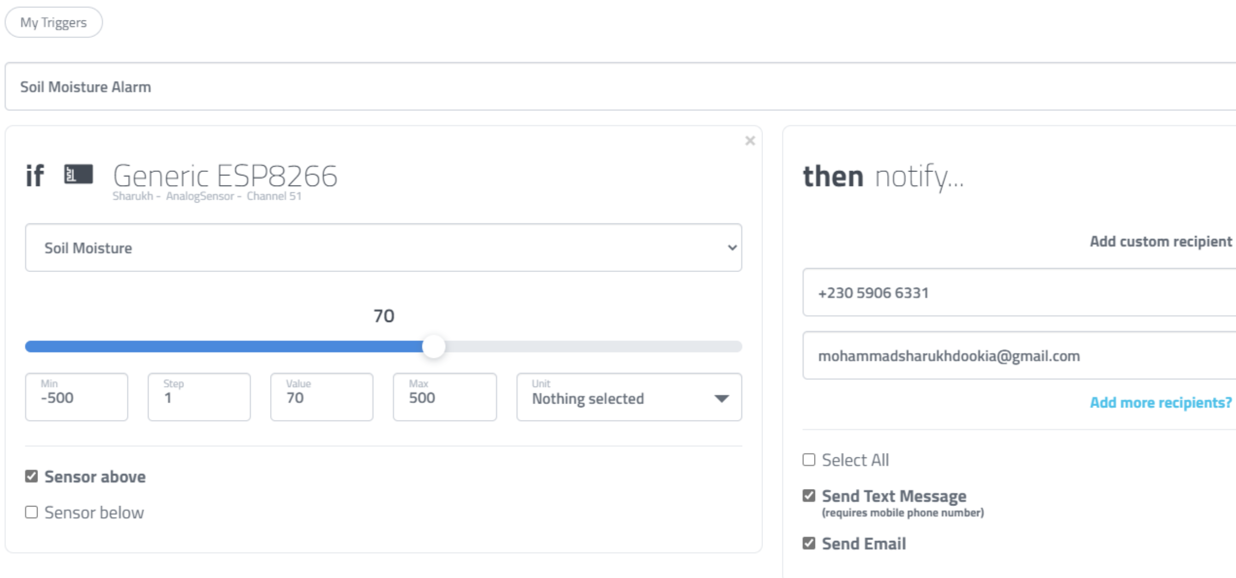


Figure 6-18: Choosing threshold value on Cayenne to send email and SMS

When the threshold value was exceeded an email and an SMS was received. The soil moisture sensor was connected to channel 51 on Cayenne.

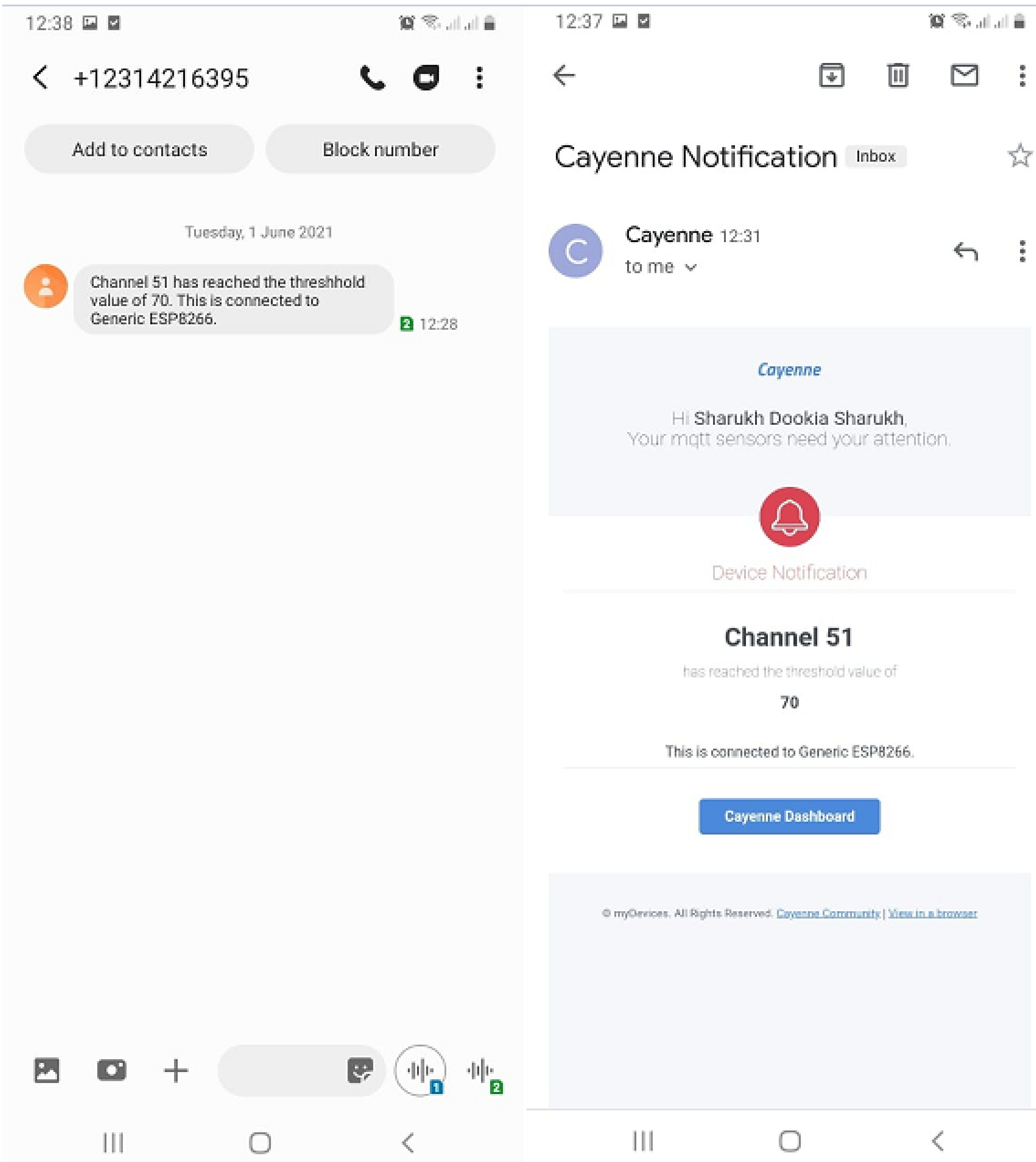


Figure 6-19: Cayenne Notification when threshold value is exceeded

6.2 Overall System Implementation and Testing

After completion of the components' testing, the overall system is mounted step by step. The whole system consists of four parts namely:

1. Transmitter side
2. Receiver Side
3. Monitoring
4. Alarm

6.2.1 Transmitter

The sensors' data are collected on Arduino Uno and transmitted through the Lora module using AT commands. The data collected on the microcontroller are printed on the serial monitor..

The base is made of concrete and the support is made of polyvinyl chloride. The mounting process is shown below.

Figure 6-20: Mounting of base structure

The fully implemented transmitter is shown below.

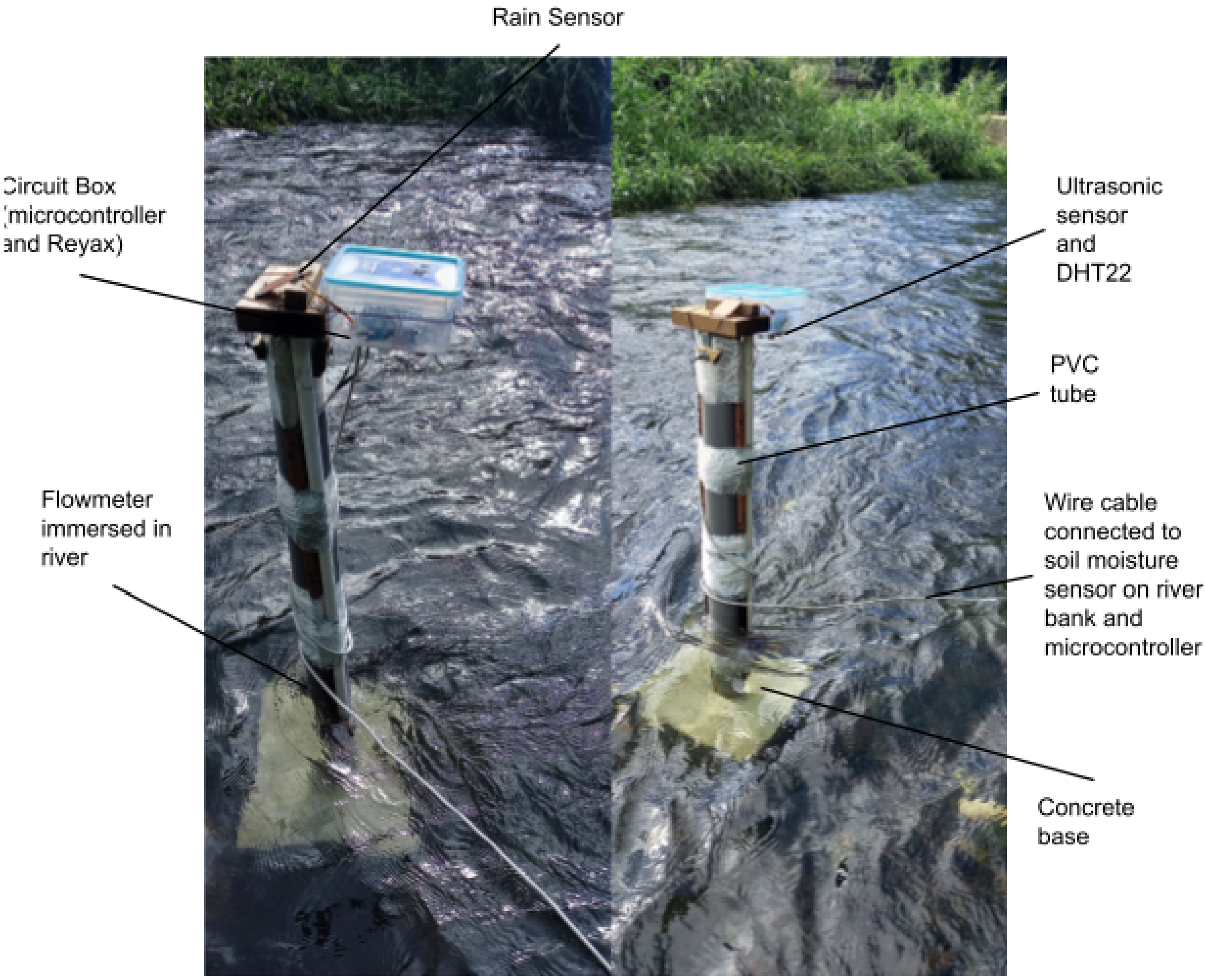


Figure 6-21: Transmitter

The different sensors used are namely:

1. Ultrasonic
2. Flowmeter
3. Temperature and Humidity
4. Rain
5. Soil Moisture

The sensors' data are collected from the Arduino and sent to the receiver side using the LoRa module as a string message.

6.2.2 Receiver

The receiver receives the data in the form of a string. The string is then broken down into individual variables to store each sensor data. The receiver side is shown below.

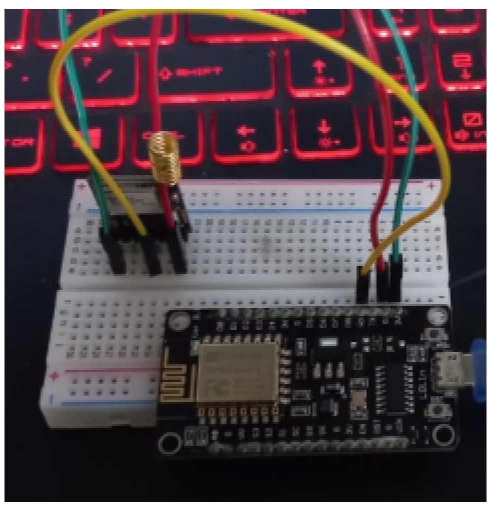


Figure 6-22: Receiver

The received data printed on the serial monitor is as follows.

```
+RCV=0,35,90.60%23.20%52.82%128.00%55.00%2%0%,-121,-35

Humidity:
90.60
Temperature:
23.20
Water Level:
52.82
Flowrate:
128.00
Soil Moisture:
55.00
Rain percentage:
2
Rain yes no:
0%
```

Figure 6-23: Receiver data on serial monitor

6.2.3 Monitoring on Blynk and Cayenne

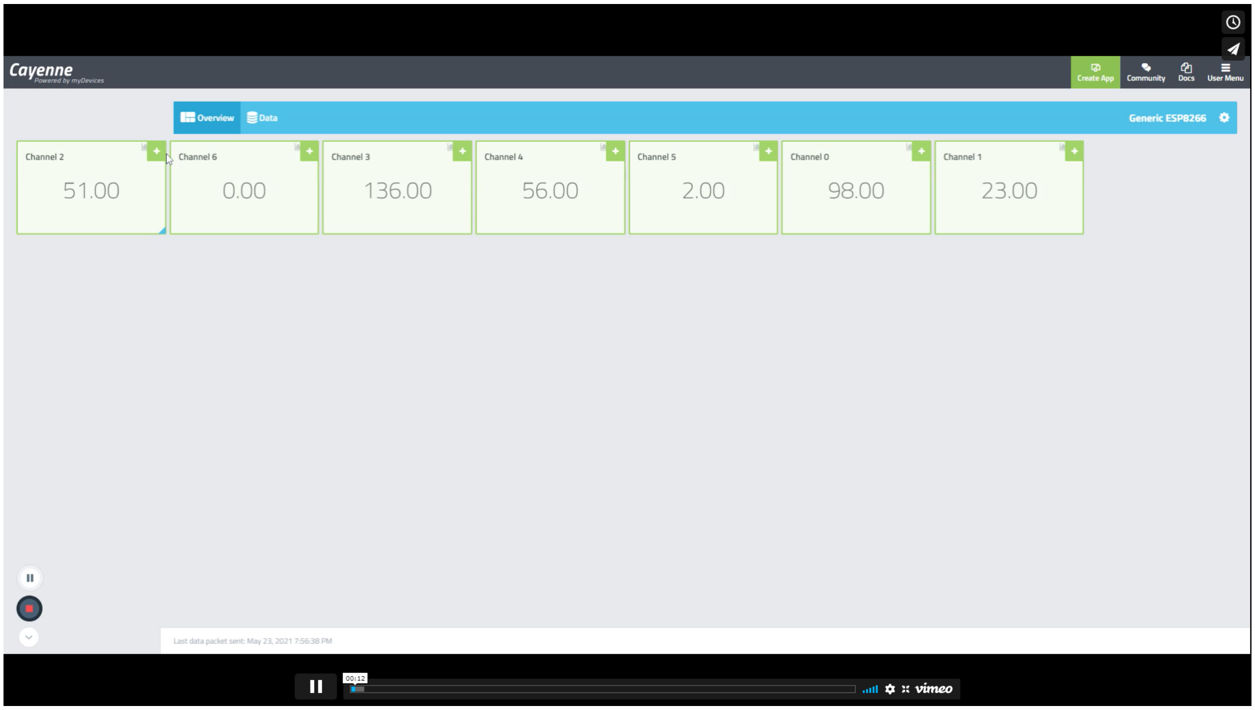
The received data is monitored on two IoT platforms namely:

(i) Cayenne

An html server is created to allow easy access to the user. He simply has to click on the link to access his/her dashboard.

Figure 6-24: html server to access cayenne dashboard

The data can be accessed through the Cayenne dashboard once the link has been clicked.



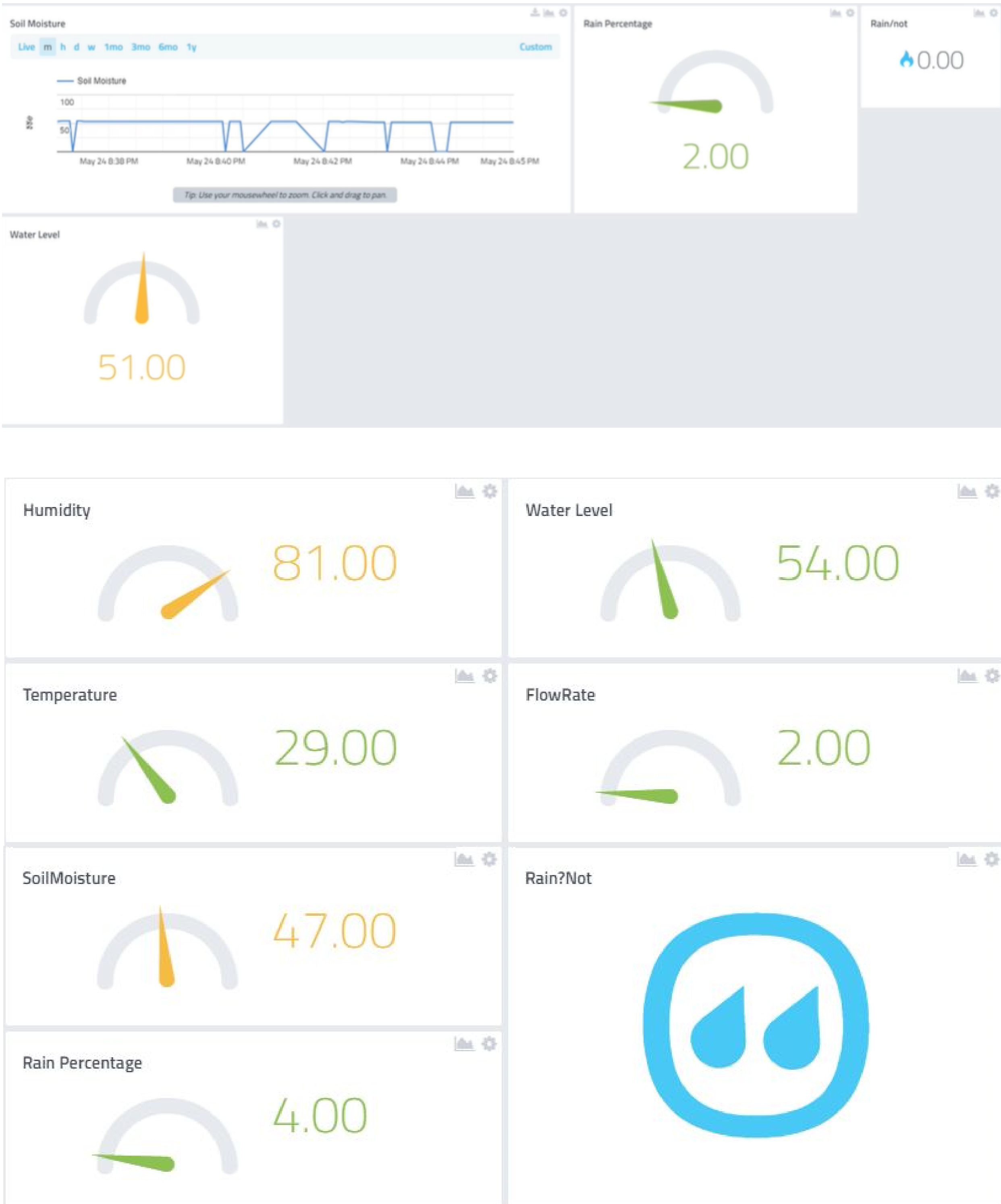


Figure 6-25: Sensors' data on Cayenne dashboard

(ii) Blynk

The data collected is displayed on the Blynk application as shown below.

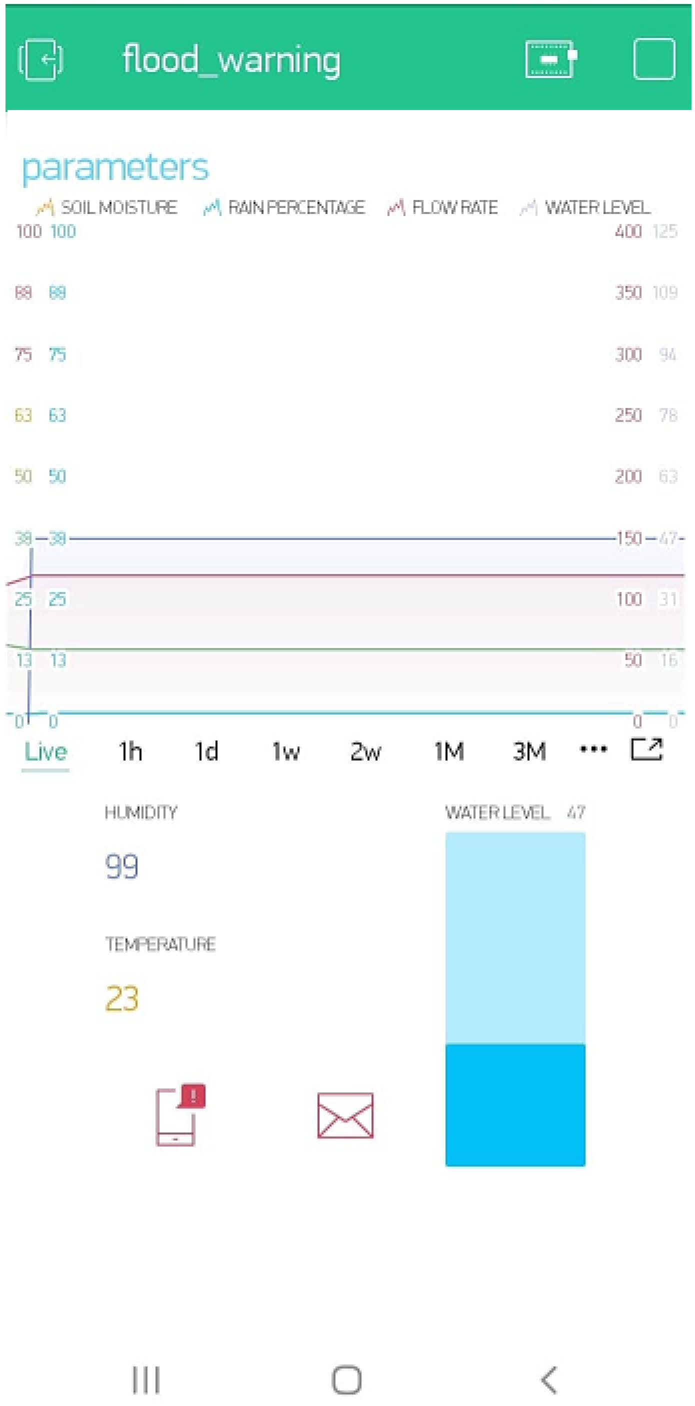


Figure 6-26: Sensors, Data on Blynk application

6.2.4 Alarm System

Three methods are chosen for predicting flash floods.

(i) Choosing a threshold value for the water level

(ii) Choosing a threshold value for the flow rate

(iii) Choosing a threshold value for the soil moisture

When the threshold values are exceeded, an SMS is sent from cayenne.The threshold value chosen during testing was 52 cm. When the water level exceeded this predefined value an SMS was sent as shown below.

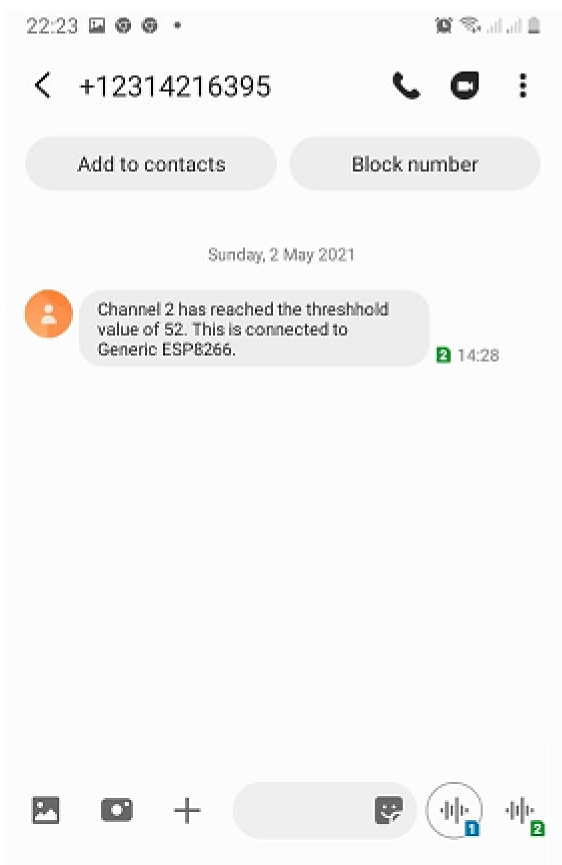


Figure 6-27: SMS alarm when threshold value was exceeded

6.3 Cost Evaluation of the system.

The overall cost for implementing the prototype is tabulated below.

Table 6-2: Cost evaluation

Item	Quantity	Price in dollars ($)
Arduino Uno	1	10.69
NodeMCU	1	11.99
Reyax RYLR890	2	39.00
DHT22	1	6.99
Soil Moisture Sensor	1	1.62
Rain Sensor	1	1.99
Flow meter	1	8.99
Ultrasonic Sensor	1	5.95
Wires and batteries		5.00
Shipping cost		40.59
Total cost		132.81

The total cost of the project is $132.81, making it feasible to implement. Therefore, the requirement of implementing a low-cost project has been fulfilled.

CHAPTER 7: RESULTS AND DISCUSSIONS

7.1 Data collection for the Month of May

The average data collected for the month of may are shown below.

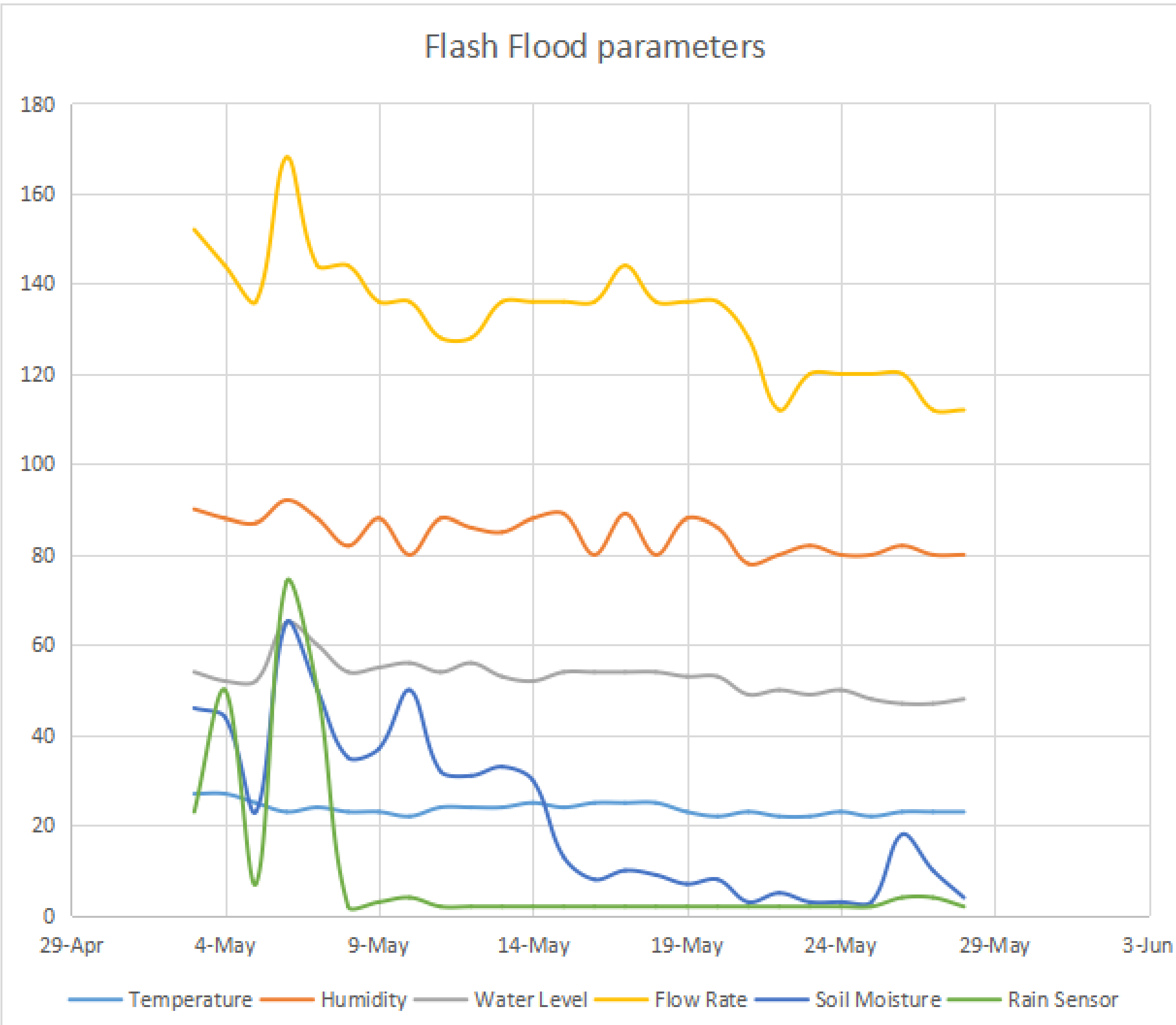


Figure 7-1: Data collected for the month of May

On the 6th of May there was heavy rainfall at Bel-Air and flash floods at several places in Mauritius which resulted in the water level rising as shown from the diagram. This heavy rainfall resulted in noticeable changes in the water level, soil moisture and flow rate. However there was no noticeable change in temperature and humidity.

The sensors used in the project are certified and accurate. For example the ultrasonic sensors data were tested by actually measuring the level using a measuring tape and the results obtained were almost similar.

The threshold value of the water level was already chosen. Therefore threshold values of soil moisture and flow rate could be identified using an interpolation method.

The graph of water level against flow rate and water level against soil moisture was plotted on matlab and the results are depicted below.

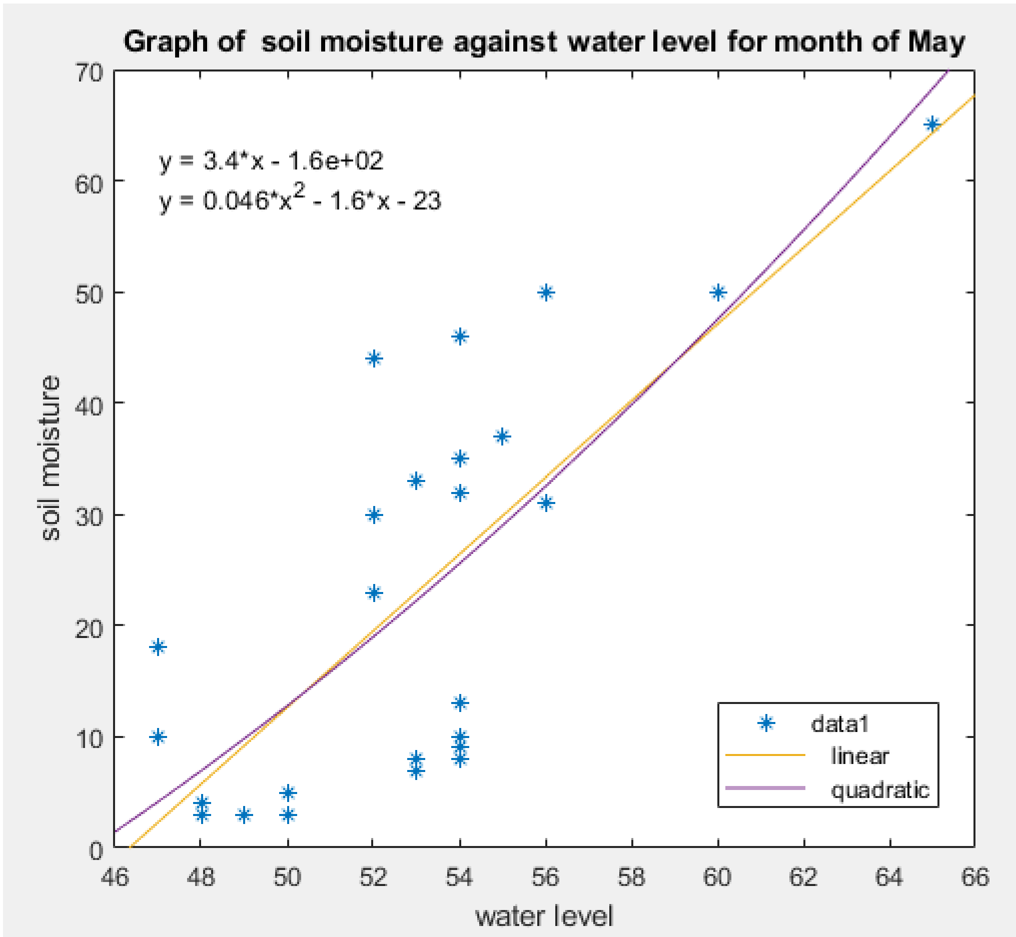


Figure 7-2: Graph of soil moisture versus water level for month of May

Chosen threshold value for water level is 70cm. Using the linear interpolation,

$y = 3.4(70) - 1.6(100)$=78

Therefore the threshold value chosen for the soil moisture is 75%.

The graph of water level against flow rate is shown below.

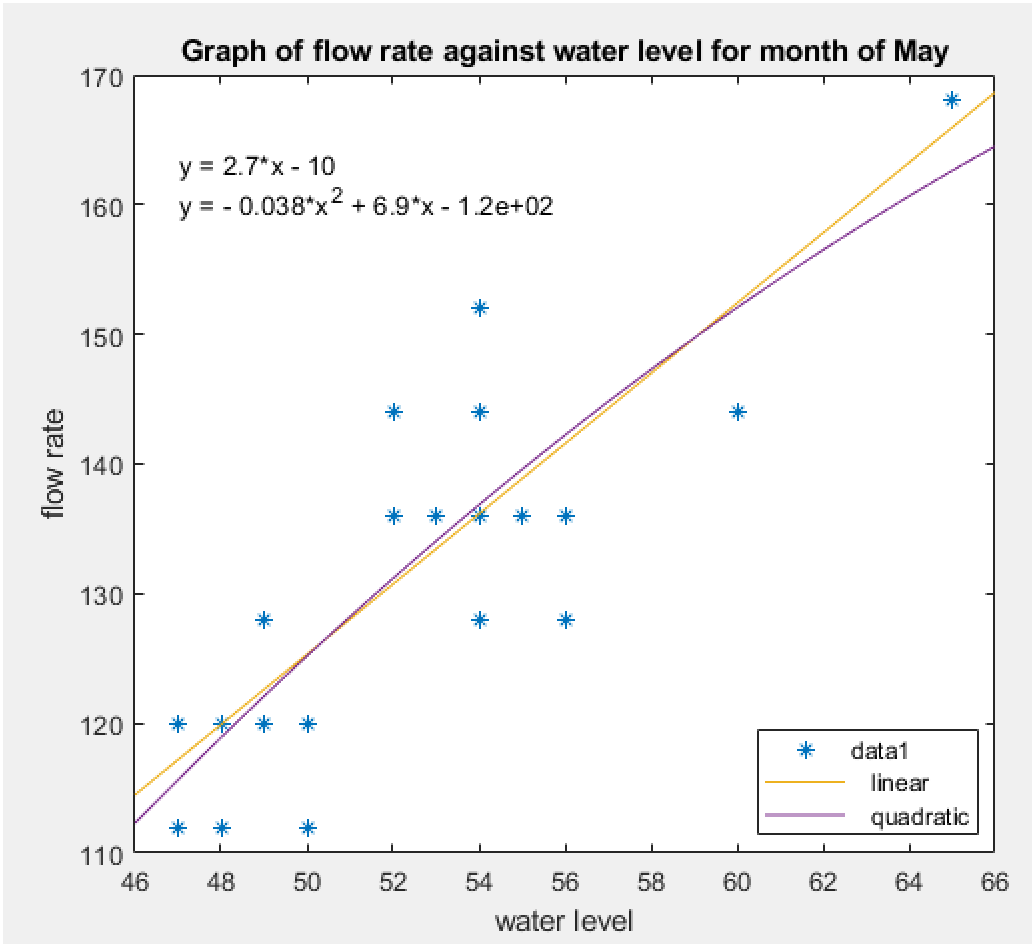


Figure 7-3: Graph of flow rate versus water level for month of May

Chosen threshold value for water level is 70cm.

Using the linear interpolation,

$y = 2.7(70) - 10$=179

Therefore the threshold value chosen for the flow rate is 170 litres/hr.

7.2 Flood Prediction using rainfall data Available from meteomauritius

Rainfall data (in millimetres) from 2013 to 2020 are tabulated below. The data are available on the website meteomauritius (meteomauritius.com, n.d.). T represents the annual rainfall for each year in mm.

Table 7-1: Monthly rainfall data from meteomauritius

Year	2013	2014	2015	2016	2017	2018	2019	2020
Jan	113.2	185.8	268.6	81.6	69.0	475.4	203.2	295.6
Feb	279.8	101.2	116.0	291.0	149.4	180.6	119.8	180.2
Mar	109.2	109.8	303.2	110.4	123.4	209.0	193.0	302.8
Apr	67.4	144.4	82.6	118.6	188.2	180.6	248.0	100.2
May	39.8	98.0	73.0	29.0	253.4	23.2	53.8	34.4
Jun	30.2	12.6	128.0	57.6	133.0	26.6	103.6	67.8
Jul	13.0	22.6	85.4	73.0	89.4	101.0	56.0	34.4
Aug	39.2	37.4	54.8	51.4	84.8	40.0	48.6	39.6
Sep	8.2	33.4	30.0	33.8	14.4	46.6	29.6	43.0
Oct	59.6	25.6	73.6	29.6	30.2	21.8	58.0	35.8
Nov	54.0	36.6	55.0	40.2	107.4	87.66	27.2	32.8
Dec	24.8	169.4	128.4	0.0	0.0	86.6	179.8	122.0
Annual Total	838.4	976.8	1398.6	916.2	1242.6	1479.0	1320.6	1288.6

The graph below shows the variation of monthly rainfall for the year 2013-2020. Series 1 corresponds to the year 2013 and series 8 to 2020.

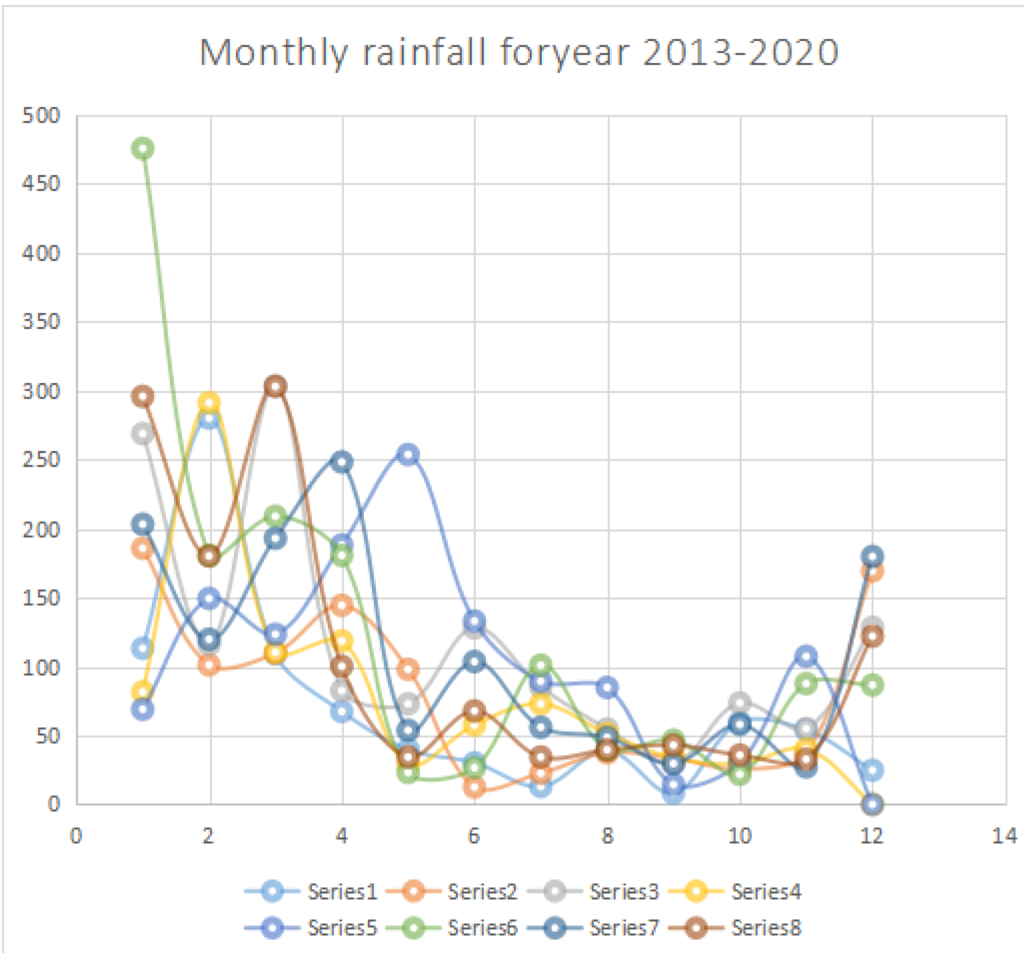


Figure 7-4: Variation of monthly rainfall over 8 years.

7.3 Rainfall frequency Analysis using Gumbel Distribution

The total annual rainfall for the year 2013-2020 is depicted in the graph below.

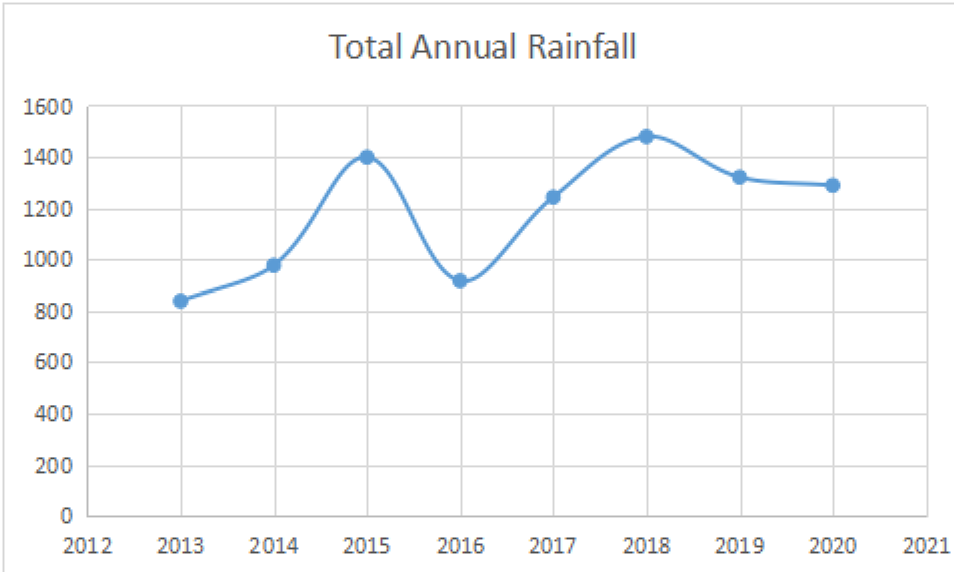


Figure 7-5: Variation of annual rainfall over 8 years.

Given the following formulas.

$$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n} \qquad \text{equation (7.1)}$$

$$S_x^2 = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2 \qquad \text{equation (7.2)}$$

$$u = \bar{x} - 0.5772\alpha \qquad \text{equation (7.3)}$$

$$\alpha = \frac{\sqrt{6}S_x^2}{\pi} \qquad \text{equation (7.4)}$$

$$p = exp\left[-\ exp\left\{-\ 1(\frac{x-u}{\alpha})\right\}\right] \qquad \text{equation (7.5)}$$

Where n is the number of years for which the data has been collected,

$\overline{x}$ is the mean rainfall calculated for n years,

S is the standard deviation,

P is the gumbel probability.

The mean annual rainfall for the 8 years is:

$$\overline{x} = \frac{\Sigma x}{n} = \frac{9460.8}{8} = 1182.6 \qquad \text{equation (7.6)}$$

The variance for the 8 years is:

$$S_x^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2 = \frac{400185.2}{7} = 57169.3 \qquad \text{equation (7.7)}$$

The mean and variance values are used to compute the constants u and α.

$$\alpha = \frac{\sqrt{6}S_x^2}{\pi} = \frac{\sqrt{6}(57169.3)}{\pi} = 44574.7 \qquad \text{equation (7.8)}$$

$$u = \overline{x} - 0.5772\alpha = 1182.6 - 0.5772(44574.7) =- 23654. \quad \text{equation (7.9)}$$

Probability p is found and the results are tabulated as shown according to its rank (starting from smallest annual rainfall to largest annual rainfall).

$$p = exp\left[- exp\left\{- 1\left(\frac{x-u}{\alpha}\right)\right\}\right] \quad \text{equation (7.10)}$$

The return time is calculated using the formula:

$$T = \frac{1}{1-p} \quad \text{equation (7.11)}$$

Table 7-2: Gumbel probability and return time

Year	x	p	T
2013	838.4	0.5614	2.280
2016	916.2	0.5620	2.283
2014	976.8	0.5624	2.285
2017	1242.6	0.5644	2.296
2020	1288.6	0.5647	2.297
2019	1320.6	0.5649	2.298
2015	1398.6	0.5655	2.301
2018	1479.0	0.5661	2.305

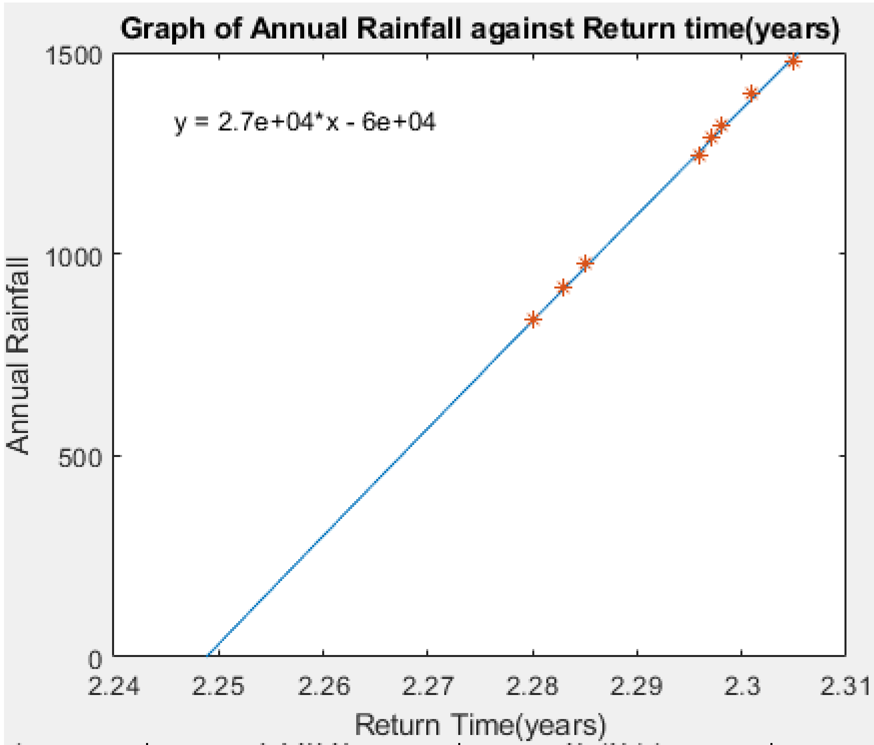


Figure 7-6: Graph of annual rainfall against return time

The Gumbel distribution method can be used to predict long term floods and can be used to create flood risk mapping. Annual Rainfall data obtained from the meteomauritius was used to find the return period of rain occurring during a current year. Flash floods in Mauritius are usually associated with heavy rainfall. This rainfall data can be used to predict the year in which similar rainfall might occur. For example a certain flash flood which occurred during a certain year x brought a high level of rainfall and the return period was found as r years. There is a high possibility of such flood to occur in year x+r.

CHAPTER 8: CONCLUSION

Flood Prediction using real-time data from sensors

Flash floods can be predicted using different flood parameters. During flash floods, the river banks overflow and the water flows into the residences of many locals and damages their property. This project successfully monitors the water level and associated parameters that vary with flash floods such as soil moisture and flow rate on Cayenne and Blynk and sets thresholds values for the changing parameters. Once the parameter is exceeded, Cayenne sends an email and an SMS to the concerned people.

The reyax module allows communication of sensors' data collected from the river to the dashboards. The dashboards are user friendly and threshold values are set on the gauges to allow the users to identify a potential flash flood. When the gauge value exceeds the predefined value, the gauge reading turns red.

The results obtained for the month of May can be compared with past results. When there is an increase in rainfall, the water level also increases. From usgs.gov, the variation of flow rate and rainfall were reviewed. As the rainfall increased, the flowrate also increased. Therefore, an increase in water level also results in an increase in flow rate during rainy conditions. The variation of water level against flow rate from the results adhered to past literature and we were able to derive a linear relationship between them. Tesař, Fiedler and Dvořák discussed the variation of soil permeability versus soil texture. Soil whether in the sand, clay, or silt form always absorbs water. The water absorbed causes the soil to become moist. As water level rises, more water is absorbed on the river banks and from the results a linear relationship was derived to show the soil moisture variation with water level.

Flood prediction using meteomauritius data

Rainfall is another parameter that is associated with flash floods. The Gumbel probability distribution can be used to predict the return time of a certain flood. This is certainly useful to make risk assessments and planning decisions to reduce flood risk. Data for eight years are analysed and the return time is calculated.

Future Works

Nonetheless there are further improvements that can be done as listed below.

(i) Machine learning method can be employed to the datasets collected from the sensors to predict potential flash floods. This will require data collection of several years to improve the accuracy of the system.

(ii) Analysing rainfall data for multiple years will improve the accuracy of predicting the return time of rainfall using the Gumbel distribution.

(iii) Placing multiple systems at rivers where there is a potential risk of flash floods. As mentioned earlier, the topography of the rivers vary differently. Therefore multiple systems need to be placed at locations where there is high risk of potential flash floods.

(iv)The system was powered using batteries. However batteries cannot be used for a long period of time. We can use an off grid photovoltaic system consisting of PV arrays, battery charger, charge controller to power the system.

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APPENDIX

1. LORA AT COMMAND GUIDE

REYAX
TECHNOLOGY CORPORATION, LTD

03-JULY-2020 56322E32

Lora AT COMMAND GUIDE

APPLY FOR：

1. RYLR405
2. RYLR406
3. RYLR895
4. RYLR896

THE SEQUENCE OF USING AT COMMAND

1. Use "AT+ADDRESS" to set ADDRESS. The ADDRESS is regard as the identification of transmitter or specified receiver.
2. Use "AT+NETWORKID" to set the ID of Lora network. This is a Group function. Only by setting the same NETWORKID can the modules communicate with each other. If the ADDRESS of specified receiver is belong to different group, it is not able to communicate with each other.
   The recommend value: 1~15
3. Use" AT+BAND" to set the center frequency of wireless band. The transmitter and the receiver are required to use the same frequency to communicate with each other.
4. Use" AT+PARAMETER" to set the RF wireless parameters. The transmitter and the receiver are required to set the same parameters to communicate with each other. The parameters of which as follows:

   [1] <Spreading Factor>: The larger the SF is, the better the sensitivity is. But the transmission time will take longer.

   [2] <Bandwidth>: The smaller the bandwidth is, the better the sensitivity is. But the transmission time will take longer.

[3] <Coding Rate>: The coding rate will be the fastest if setting it as 1.

[4] <Programmed Preamble>: Preamble code. If the preamble code is bigger, it will result in the less opportunity of losing data. Generally preamble code can be set above 10 if under the permission of the transmission time.
Communication within 3 km: Recommend to set "AT + PARAMETER = 10,7,1,7"
More than 3 km: Recommend to set " AT + PARAMETER = 12,4,1,7"

5. Use "AT+SEND" to send data to the specified ADDRESS. Please use "Lora Modem Calculator Tool" to calculate the transmission time. Due to the program used by the module, the payload part will increase more 8 bytes than the actual data length.

AT Command Set

It is required to key in "enter" or "\r\n" in the end of all AT Commands.
Add" ? "in the end of the commands to ask the current setting value.
It is required to wait until the module replies +OK so that you can execute the next AT command.

1. **AT** Test if the module can respond to Commands.

Syntax	Response
AT	+OK

2. **Software RESET**

Syntax	Response
AT+RESET	+RESET +READY

3. **AT+MODE** Set the work mode

Syntax	Response
AT+MODE=<parameter> <parameter>range from 0 to 1 0 : Transmit and Receive mode (default). 1 : Sleep mode. Example : Set the sleep mode, AT+MODE=1	+OK
AT+MODE? Any text	+MODE=0 'Transmit and Receive mode +READY 'Sleep mode.

4. **AT+IPR** Set the UART baud rate

Syntax	Response
AT+IPR=<rate> <rate> is the UART baud rate : 300 1200 4800 9600 19200 28800 38400 57600 115200(default). Example: Set the baud rate as 9600, **The settings will be memorized in EEPROM.* AT+IPR=9600	+OK
AT+IPR?	+IPR=9600

5. **AT+PARAMETER** Set the RF parameters

Syntax	Response
AT+PARAMETER=<Spreading Factor>, <Bandwidth>,<Coding Rate>, <Programmed Preamble> <Spreading Factor>7~12, (default 12) <Bandwidth>0~9 list as below 0 : 7.8KHz (not recommended, over spec.) 1 : 10.4KHz (not recommended, over spec.) 2 : 15.6KHz 3 : 20.8 KHz 4 : 31.25 KHz 5 : 41.7 KHz 6 : 62.5 KHz 7 : 125 KHz (default). 8 : 250 KHz 9 : 500 KHz <Coding Rat>1~4, (default 1) <Programmed Preamble> 4~7(default 4) Example : Set the parameters as below: <Spreading Factor> 7,<Bandwidth> 20.8KHz, <Coding Rate> 4,<Programmed Preamble>5, AT+PARAMETER=7,3,4,5	+OK
AT+PARAMETER?	+PARAMETER=7,3,4,5

6. **AT+BAND** Set RF Frequency

Syntax	Response
AT+BAND=<parameter> <parameter>is the RF Frequency, Unit is Hz 470000000: 470000000Hz(default: RYLR40x) 915000000: 915000000Hz(default: RYLY89x) Example : Set the frequency as 868500000Hz, AT+BAND=868500000	+OK
AT+BAND?	+BAND=868500000

7. **AT+ADDRESS** Set the ADDRESS of module

Syntax	Response
AT+ADDRESS=<Address> <Address>=0~65535(default 0) Example : Set the address of module as 120, **The settings will be memorized in EEPROM.* AT+ADDRESS=120	+OK
AT+ADDRESS?	+ADDRESS=120

8. **AT+NETWORKID** Set the network ID

Syntax	Response
AT+NETWORKID=<Network ID> <Network ID>0~16(default 0) Example : Set the network ID as 6, **The settings will be memorized in EEPROM.* **The" 0" is the public ID of Lora. It is not recommend to set 0 to make the distinction of NETWORK.* AT+NETWORKID=6	+OK
AT+NETWORKID?	+NETWORK=6

9. **AT+CPIN** Set the AES128 password of the network.

Syntax	Response
AT+CPIN=<Password> <Password>: An 32 character long AES password From 00000000000000000000000000000001 to FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF Only by using same password can the data be recognized. After resetting, the previously password will disappear. Example : Set the password as below: FABC0002EEDCAA90FABC0002EEDCAA90 AT+CPIN=FABC0002EEDCAA90FABC0002EEDCAA90	+OK
AT+CPIN?	+CPIN=FABC0002EEDCAA90FABC0002EEDCAA90 +CPIN=No Password! 'Default value

10. **AT+CRFOP** Set the RF output power

Syntax	Response
AT+CRFOP=<power> <power>0~15 15 : 15dBm(default) 14 : 14dBm ...... 01 : 1dBm 00 : 0dBm Example: Set the output power as 10dBm, AT+CRFOP=10	+OK
AT+CRFOP?	+CRFOP=10

11. **AT+SEND** Send data to the appointment Address

Syntax	Response
AT+SEND=<Address>,<Payload Length>,<Data> <Address>0~65535, When the <Address> is 0, it will send data to all address (From 0 to 65535.) <Payload Length>Maximum 240bytes <Data>ASCII Format Example : Send HELLO string to the Address 50, AT+SEND=50,5,HELLO	+OK
AT+SEND?	+SEND=50,5,HELLO

12. **+RCV** Show the received data

Syntax	Response
+RCV=<Address>,<Length>,<Data>,<RSSI>,<SNR>, <Address>Transmitter Address ID <Length>Data Length <Data>Data <RSSI> Received Signal Strength Indicator <SNR> Signal-to-noise ratio	
Example: Module received the ID Address 50 send 5 bytes data, Content is HELLO string ,RSSI is -99dBm, SNR is 40, It will show as below: +RCV=50,5,HELLO,-99,40	

13. **AT+VER?** to inquire the firmware version

Syntax	Response
AT+VER?	+VER=RYLR406_Vx.x.x(RYLR40x) +VER=RYLR89C_Vx.x.x(RYLR89x)

14. **AT+UID?** to inquire the unique ID number of the module

Syntax	Response
AT+UID? 12 Bytes Unique ID	+UID=164738323135383200100025

15. **AT+FACTORY** Set all current parameters to manufacturer defaults

Syntax	Response
AT+FACTORY Manufacturer defaults : BAND : 915MHz UART : 115200 Spreading Factor : 12 Bandwidth : 125kHz Coding Rate : 1 Preamble Length : 4 Address : 0 Network ID : 0 CRFOP : 15	+FACTORY

16. **Other messages**

Syntax	Response
After RESET	+READY

17. Error result codes

Syntax	Response
There is not "enter" or 0x0D 0x0A in the end of the AT Command.	+ERR=1
The head of AT command is not "AT" string.	+ERR=2
There is not "=" symbol in the AT command.	+ERR=3
Unknow command.	+ERR=4
TX is over times.	+ERR=10
RX is over times.	+ERR=11
CRC error.	+ERR=12
TX data more than 240bytes.	+ERR=13
Unknow error.	+ERR=15

2. ULTRASONIC SENSOR

Ultrasonic Ranging Module HC - SR04

Product features:

Ultrasonic ranging module HC - SR04 provides 2cm - 400cm non-contact measurement function, the ranging accuracy can reach to 3mm. The modules includes ultrasonic transmitters, receiver and control circuit. The basic principle of work:

(1) Using IO trigger for at least 10us high level signal,

(2) The Module automatically sends eight 40 kHz and detect whether there is a pulse signal back.

(3) IF the signal back, through high level , time of high output IO duration is the time from sending ultrasonic to returning.

Test distance = (high level time×velocity of sound (340M/S) / 2,

Wire connecting direct as following:

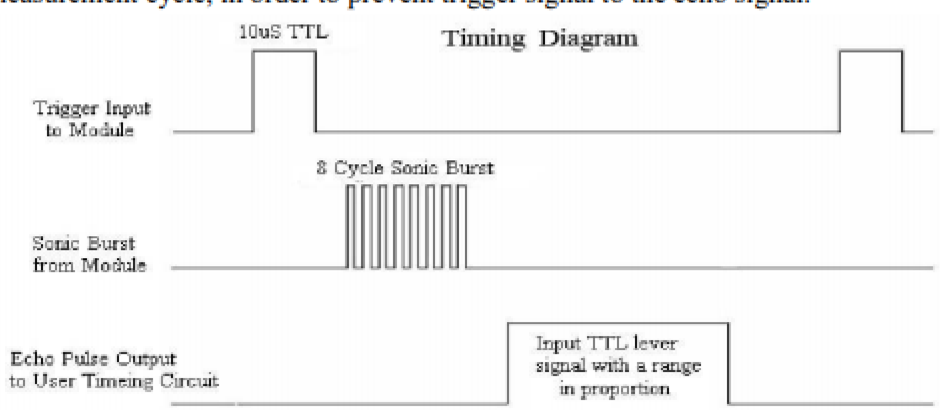
- 5V Supply
- Trigger Pulse Input
- Echo Pulse Output
- 0V Ground

Electric Parameter

Working Voltage	**DC 5 V**
Working Current	**15mA**
Working Frequency	**40Hz**
Max Range	**4m**
Min Range	**2cm**
MeasuringAngle	**15 degree**
Trigger Input Signal	**10uS TTL pulse**
Echo Output Signal	**Input TTL lever signal and the range in proportion**
Dimension	**45*20*15mm**

Timing diagram

The Timing diagram is shown below. You only need to supply a short 10uS pulse to the trigger input to start the ranging, and then the module will send out an 8 cycle burst of ultrasound at 40 kHz and raise its echo. The Echo is a distance object that is pulse width and the range in proportion .You can calculate the range through the time interval between sending trigger signal and receiving echo signal. Formula: uS / 58 = centimeters or uS / 148 =inch; or: the range = high level time * velocity (340M/S) / 2; we suggest to use over 60ms measurement cycle, in order to prevent trigger signal to the echo signal.



3. WATER FLOW SENSOR

Sensors & Sensor Modules : YF-S201 Water Flow Sensor

Measure liquid/water flow for your solar, water conservation systems, storage tanks, water recycling home applications, irrigation systems and much more. The sensors are solidly constructed and provide a digital pulse each time an amount of water passes through the pipe. The output can easily be connected to a microcontroller for monitoring water usage and calculating the amount of water remaining in a tank etc.

Features:

- Model: YF-S201
- Working Voltage: 5 to 18V DC (min tested working voltage 4.5V)
- Max current draw: 15mA @ 5V
- Output Type: 5V TTL
- Working Flow Rate: 1 to 30 Liters/Minute
- Working Temperature range: -25 to +80?
- Working Humidity Range: 35%-80% RH
- Accuracy: ±10%
- Maximum water pressure: 2.0 MPa
- Output duty cycle: 50% +-10%
- Output rise time: 0.04us
- Output fall time: 0.18us
- Flow rate pulse characteristics: Frequency (Hz) = 7.5 * Flow rate (L/min)
- Pulses per Liter: 450
- Durability: minimum 300,000 cycles
- Cable length: 15cm
- 1/2" nominal pipe connections, 0.78" outer diameter, 1/2" of thread
- Size: 2.5" x 1.4" x 1.4"

ITEM INCLUDED:

1 x YF-S201 Water Flow Sensor

4. RAIN SENSOR AND SOIL MOISTURE CONTROL BOARD

Specifications

- Adopts high quality of RF-04 double sided material.
- Area: 5cm x 4cm nickel plate on side,
- Anti-oxidation, anti-conductivity, with long use time;
- Comparator output signal clean waveform is good, driving ability, over 15mA;
- Potentiometer adjust the sensitivity;
- Working voltage 5V;
- Output format: Digital switching output (0 and 1) and analog voltage output AO;
- With bolt holes for easy installation;
- Small board PCB size: 3.2cm x 1.4cm;
- Uses a wide voltage LM393 comparator

Pin Configuration

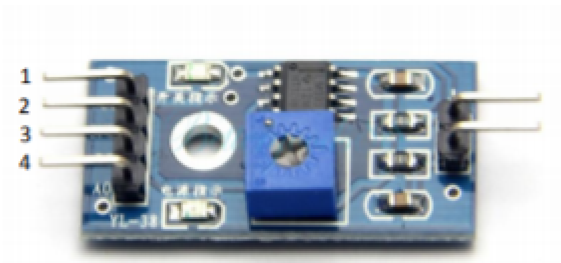


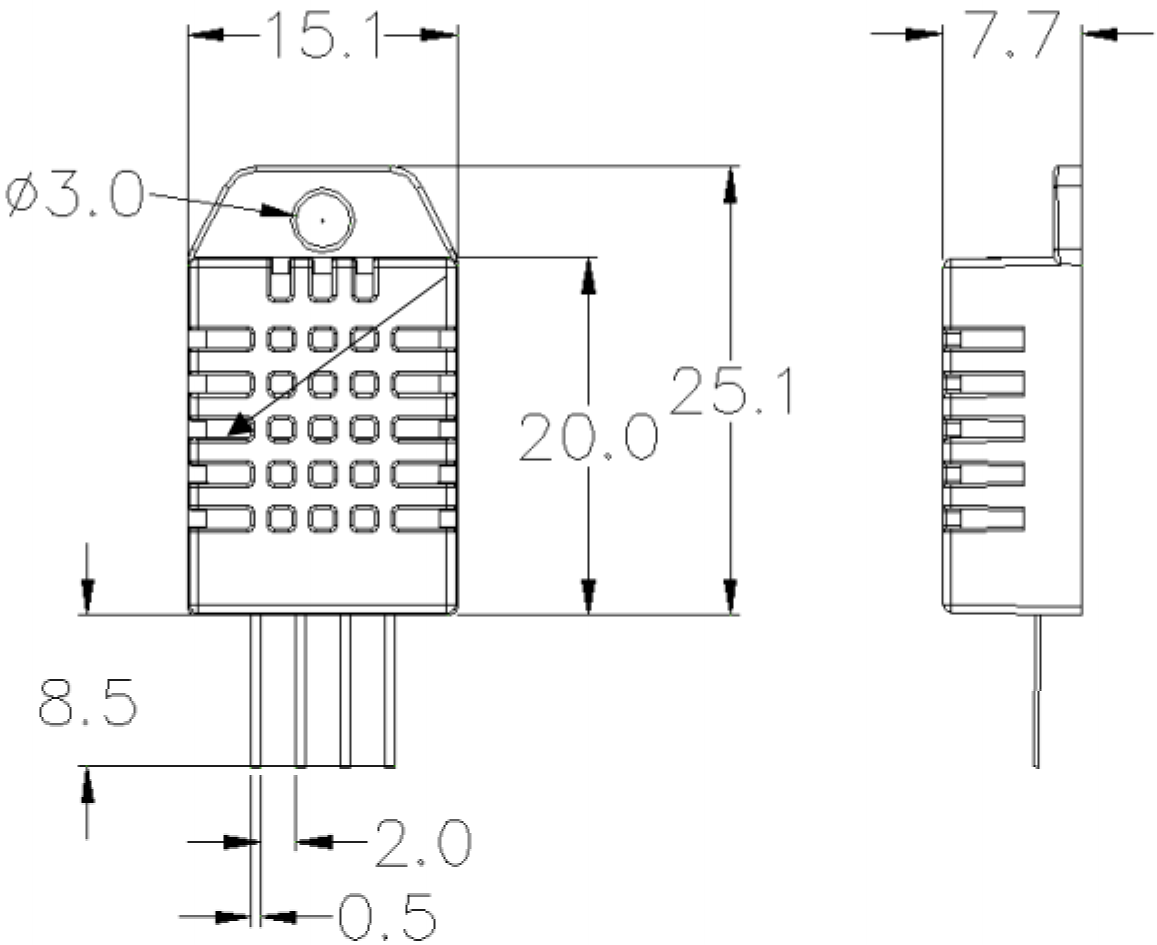
Figure (i) Control board

1. VCC: 5V DC
2. GND: ground
3. DO: high/low output
4. AO: analog output

5. DHT22 SENSOR

Technical Specification:

Model	DHT22
Power supply	3.3-6V DC
Output signal	digital signal via single-bus
Sensing element	Polymer capacitor
Operating range	humidity 0-100%RH; temperature -40~80Celsius
Accuracy	humidity +-2%RH(Max +-5%RH); temperature <+-0.5Celsius
Resolution or sensitivity	humidity 0.1%RH; temperature 0.1Celsius
Repeatability	humidity +-1%RH; temperature +-0.2Celsius
Humidity hysteresis	+-0.3%RH
Long-term Stability	+-0.5%RH/year
Sensing period	Average: 2s
Interchangeability	fully interchangeable
Dimensions	small size 14*18*5.5mm; big size 22*28*5mm



Pin sequence number: 1 2 3 4 (from left to right direction).

Pin	Function
1	VDD----power supply
2	DATA--signal
3	NULL
4	GND

6. MICROCONTROLLERS PINOUT

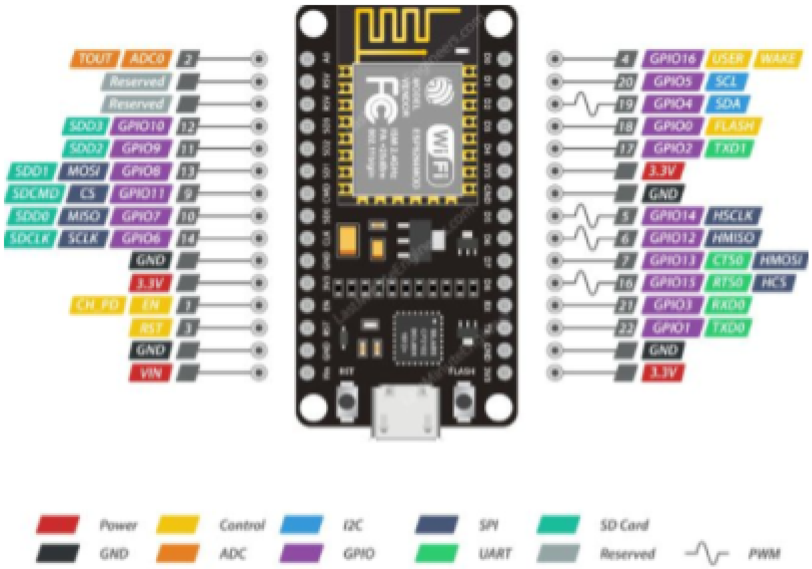


Figure (ii): NodeMCU pinout

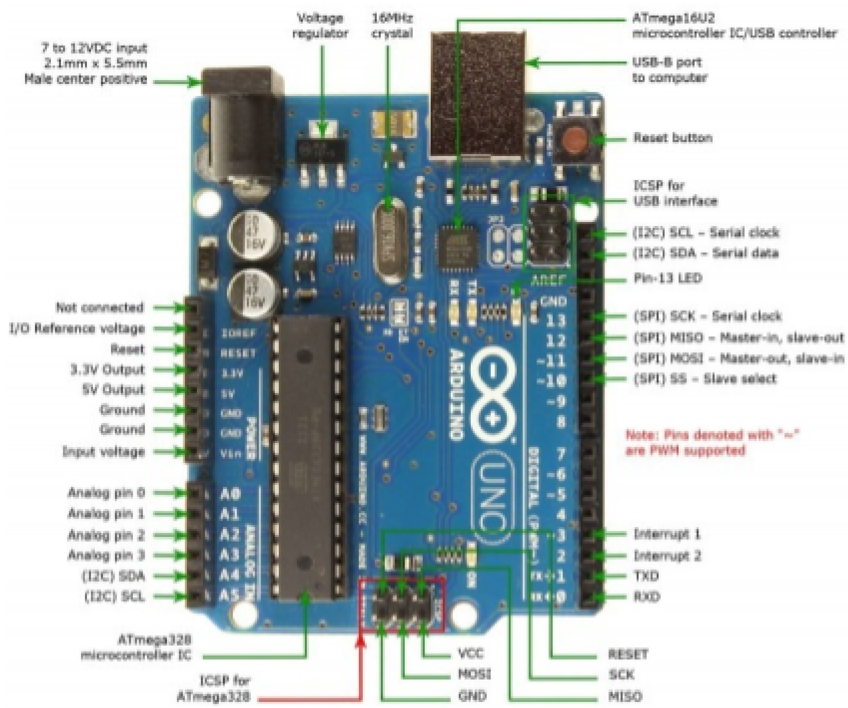


Figure (iii): Arduino Uno pinout