DESIGN AND IMPLEMENTATION OF A WEATHER STATION FOR FLOOD-PRONE AGRICULTURAL LANDS

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Declaration

It is hereby declared that

1. The Final Year Design Project (FYDP) submitted is my/our own original work while completing degree at Brac University.

2. The Final Year Design Project (FYDP) does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.

3. The Final Year Design Project (FYDP) does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.

4. I/We have acknowledged all main sources of help.

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Ethics Statement

We hereby declare that the following was observed throughout the preparation of this work:

1. The material is solely the original work of the named authors prepared under the supervision of the mentioned Academic Technical Committee panel members; no material from external sources has been included.

2. All sources used as reference have been appropriately credited and cited.

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4. The reported similarity index of this work is **[20%]**

Abstract

One of the frequent natural hazards in Bangladesh is flooding which has a devastating impact on the agricultural productivity especially in the low-lying and rural areas. The absence of localized, real-time weather surveillance and the early notification of floods frequently causes a lot of crop loss, economic setbacks, and a decrease in livelihood of the agricultural people. This project will constitute the design and deployment of a low-cost, IoT based weather station that will be specifically designed to work on flood prone agricultural land. The system, proposed, incorporates the various environmental sensors to measure the significant parameters of rainfall, temperature, humidity, soil moisture, wind speed, atmospheric pressure, and water level in real-time. To process, store, and analyze data, data is sent via long-range and low-power LoRa communication network to a cloud-based platform. The prediction model application is based on machine learning to analyze real-time and historical data and estimate flood risks to provide early warnings. The system runs off a solar-powered energy management unit which has battery backup thus making it operate continuously in off-grid and remote regions. The system sends real-time alerts via SMS and a user-friendly web dashboard to the farmers. Experimental analysis proves to have credible data transmission, reasonable sensor accuracy, power-saving, and useful flood risk forecasting. The proposed solution provides a cost-effective, energy-efficient, and scalable solution to enhance flood preparedness, loss of crops, and sustainable agricultural practices in flood prone areas of Bangladesh.

Keywords

IoT-based Weather Station, Flood Prediction, LoRa Communication, Smart Agriculture, Machine Learning, Flood-Prone Areas, Real-Time Monitoring, Sustainable Farming

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Chapter 1: Introduction- [CO1, CO2, CO10]

1.1 Introduction

Bangladesh is a low-lying country boasting of numerous rivers thus very vulnerable to flooding particularly during the monsoon season. Floods cover a huge portion of agricultural land every year and result in severe losses to crop, soil fertility, irrigation systems, and the general productivity of farming in general. The Bangladesh Water Development Board states that an average of 20-25% of the country is flooded annually and during the most extreme event, the 1998 flood, a greater part of the country was flooded by over two-thirds [6]. These recurrent floods cause significant issues on food security, livelihoods of farmers, and the economy of the nation.

Flood prone areas are very sensitive to environmental forces like rainfall, temperature, humidity, speed of wind, and water level, in agricultural activities. The sudden alterations in these conditions may disrupt the growth of crops resulting in excessive losses of crops. Though there are other weather stations and forecast systems, they do not always have the ability to give real time and local information that farmers require and particularly in remote and low lying areas [5]. Moreover, most of the systems that are in place rely on centralized infrastructure and mobile networks that can fail when there is harsh weather.

The recent advancement in the Internet of Things (IoT) technology, low-power sensors, and long-range wireless communication allowed creating affordable and reliable weather monitoring systems. LoRa (Long Range) communication technology enables the transmission of data over considerable distances at minimal power consumption and that is why it is applicable in the rural and flood vulnerable farming regions [3]. The gathered environmental data can be processed, together with machine learning techniques, to forecast the risk of floods and issue early warning.

The current project aims at designing and deploying an IoT based weather monitoring solution that is designed specifically to monitor flood-based agricultural land in Bangladesh. The system monitors the real-time environmental conditions with various sensors, transmits the information over the LoRa network, predicts floods with the help of machine learning models, and displays the results on an easy and convenient dashboard. The overall objective of the project would be to offer a low-cost, reliable and scalable solution that would aid in enhancing flood preparedness, lessening crop destruction and facilitating sustainable agricultural methods.

1.1.1 Problem Statement

Agriculture in Bangladesh is experiencing a severe issue of flooding particularly in the rural areas of the country which is under the low-lying area. Sudden and prolonged floods are frequent and are due to heavy monsoon rain, overflowing rivers and poor drainage. The effects of these floods include destruction of crops, low soil quality, disruption of farming activities and huge financial losses by the farmers. Among the key issues, the fact that farmers fail to get timely and

local information that would assist them to be ready to face floods and minimize the harm is one of them [1].
Flood warning and weather monitoring in Bangladesh is mostly centralized with regional data. This information is not always consistent with the real-life situations in certain fields of farming. Power outages and communication issues occur frequently in case of severe weather, and it is even more difficult to provide farmers with real-time information and early action [4].
Though there are some commercial weather stations, most of them are too costly, consume a lot of power, and cannot be used in flood prone farmlands. Moreover, the majority of the traditional systems are not providing intelligent flood prediction and farmer decisions support as they are only collecting data [10].
Consequently, there is a great demand for a low cost, energy saving as well as effective system of weather monitoring in flood-prone cultivable lands. An example of such a system should be able to gather precise real-time weather information, operate on a long-range basis and provide early warnings on floods. This would assist farmers to minimize losses of crops and enhance flood preparedness in Bangladesh.

1.1.2 Background Study

Flooding is highly vulnerable in Bangladesh since it is a low-lying country that has numerous rivers and high levels of monsoon rain. Floods destroy agricultural land that covers a large area every year, killing crops, lowering the quality of soil, and destroying irrigation systems. Such floods interfere with the normal farming activity and present long term economic and social impacts on the farmer. The experience of previous floods has demonstrated that the absence of early warnings and timely information can make the losses of agriculture even more serious [4].
Rainfall, temperature, humidity, the speed of wind and water level are some weather conditions that are crucial to the growth and production of crops. Alteration of these factors suddenly may disrupt the planting, flowering and harvesting. Water and floods also lead to soil erosion and increase attacks of pest infestations which further lower the yield of crops. Extreme, unpredictable weather conditions are increasingly becoming frequent in the world and this has made farming harder in flood-prone regions due to climatic change [12].
Even though there are weather monitoring systems, locally, many of them cannot be used in agriculture. The traditional weather stations are costly, high-energy consuming and rely on centralized infrastructures. They tend to be unable to deliver real time field level information particularly where the communication networks go dead due to floods. Nevertheless, new changes in the IoT, low-power sensors, and long-range wireless communication have introduced new possibilities of rural weather monitoring. LoRa has a high power efficiency and is able to transmit data at very long distances, which is the most suitable technology to be used in remote regions of agriculture [4], [10], [12]. These systems can be made reliable and work even in an extreme environment when they are combined with cloud platforms and data processing.
Further machine learning approaches can strengthen flood prediction with the analysis of the real time and past weather data. Such forecasts enable farmers to make early preparations, minimize

losses on crops and organize agricultural production in a better way [10], [12]. Thus, the creation of a low-priced, IoT-enabled weather station with a long-range communication system and flood forecasting is a key to the enhancement of flood preparedness and sustainable farming in the flood-prone areas.

1.1.3 Literature Gap

The current literature on the subject of weather surveillance and prediction of floods focuses on the role of quantifying the parameters of the environment that include rain, temperature, humidity, wind speed, and levels of water. Scientific literature has demonstrated that machine learning can effectively forecast the occurrence of floods with both past and real weather information. Such solutions show good prospects of enhancing earlier warning mechanisms and minimizing the damages caused by floods.

Nonetheless, there are still a number of limitations to using these solutions in practice in the context of agriculture. The current weather monitoring systems are mostly regional or urban in nature and do not offer field-level data on a real-time basis that is needed by the farmer [7]. Also, most IoT-based monitoring systems are based on short-range wireless or cellular networks, making them unreliable or unreachable when there is a flood, particularly in rural locations [8] .

The other significant constraint is that current implementations do not have the long-range, low-power communication technologies. Very little research has concentrated on the application of the LoRa communication in making data transmission in flood-afflicted agricultural environments stable and energy efficient [4] [10]. In addition, most of the available systems consider data collection, flood prediction, and user interaction as three distinct entities, which lead to unorganized solutions. Also, little attention is paid to the creation of low-cost and energy-saving and locally adaptable systems for Bangladesh. Affordability, ease of use and long term deployment in rural farming communities are not adequately taken into account by most of the proposed solutions [9].

Thus, there is an apparent research gap in the form of the development of an integrated and affordable system of IoT-based weather monitoring providing a localized real-time data feed, high-quality long-range communication, machine-based flood prediction, and easy-to-use interface by a farmer. The project will help fill such gaps by proposing a specially developed system applicable to occupation of flood-prone agricultural land in Bangladesh to facilitate better flood preparedness and sustainable agricultural farming practices.

1.1.4 Relevance to current and future Industry

The proposed smart IoT-based weather station of agricultural areas that are prone to floods is highly correlated with the existing and future trends of industries in smart farming, environmental surveillance, and disaster control. The use of digital technologies in the modern agricultural production is increasingly associated with the monitoring of environmental parameters such as rainfall, temperature, humidity, wind speed, water level, etc. Such data are used to enhance crop yields, better utilization of resources, and minimization of losses through extreme weather conditions [19].

The system integrates IoT sensors with low-power long-range communication technologies like LoRa which ensures that the system can serve rural and flood-prone regions with only a limited or unreliable traditional communication infrastructure. Remote based access for collecting the information and data-driven decision-making based on the use of cloud-based platforms and user-friendly dashboards focuses on the contemporary standards in the industry in terms of smart farming and environmental monitoring systems [19] [20]. In the future, there will be a higher demand in intelligent and predictive agricultural systems because of the increased rate of climate change and recurrent floods. The integration of machine learning models to predict flooding allows changing reactive reactions to prevent risks. This enables early warning, automatic notifications, and massive implementation of intelligent farming systems [21]. Moreover, Low-cost hardware and energy-efficient design increases the sustainability of the systems, scaling, and long-term reliability of the systems. The mentioned characteristics make the given system particularly appropriate to developing nations. This project will solve both the modern industry needs and the challenges in the future by supporting the use of IoT technology, predictive analytics, and energy-efficient design, to meet the needs of the agriculture industry, environmental monitoring, and reducing the risk of disasters [19].

1.2 Objectives, Requirements, Specification and constant

Having recognized the problem as the frequent flooding of agricultural land in Bangladesh, this project had clear goals on how to solve the problem and curb this problem using a smart weather monitoring and flood prediction system. It aims at gathering real-time environmental measurements, issuing early warnings on floods, and giving information to farmers in an easy and understandable manner. Through such objectives, the system will assist the farmers in minimizing damage inflicted on crops and also make improved decisions in farming.

In order to achieve these goals, the project requirements and specifications were effectively determined. These requirements outline the critical system functions, technical components and anticipated performance levels. The aspects involved in this project include the selection of suitable sensors, effective communication channels, effective power supply alternative, and effective data processing platforms. Besides this, real life limitations like extreme environmental conditions, minimal power supply, reliability of communication when there is a flood, and cost were taken into consideration during the design. By dealing with these limitations, it is possible to guarantee that the offered system will be affordable, reliable, and applicable to the actual use in flood-prone areas of agriculture.

1.2.1. Objectives

This project will enhance the preparedness to floods, safety of agriculture, and decision-making through real-time monitoring of the environment and smart flood prediction. The suggested system will assist farmers and local stakeholders particularly those in the flood prone areas to receive timely warnings and precise weather data. This assists in minimizing crop loss, economic destruction and safety hazard and allows a greater planning and management of agricultural resources.
The key objectives of the proposed system are as follows:

i) To gather real time information on the environment such as rainfall, water level, soil moisture, temperature, humidity and wind conditions of agricultural land.

ii) To develop a low-cost Internet of Things-based weather station with a robust set of sensors and long-range communication technology (LoRa) to easily relay information to distant and wetland locations.

iii) To build a flood prediction model based on machine learning to observe real-time and historical environmental data to predict the risk of floods correctly.

iv) To establish a system of alerting and notification that will give early warnings to farmers and other authorities by way of SMS, dashboards, or visual signals when the floods threat is beyond a predefined level.

v) To create a cloud-based solution of storing, visualizing and analyzing past weather and flood data to assist in long-term agricultural planning and decision making.

1.2.2 Functional and Non-functional Requirements

1.2.2.1 Functional Requirements

Capacity	Data provided by numerous sensors should also be collected and processed by the system at the same time like rain, soil moisture, temperature, humidity, and speed of wind. It should be able to process large data loads in real-time.
Sensor	Some of the sensors that the weather station will have are rainfall, soil water, temperature, wind speed, water level, and the atmospheric pressure.
Cloud Platform	The cloud platform will be linked to a cloud-based IoT platform that will enable farmers to remotely access the weather information through an easy-to-use dashboard.

Data Collection	The sensors will be connected to an onboard microcontroller processing the data obtained and sending it to a cloud-based platform where the data will be analyzed, and real-time decision-making will be performed.
Power Management	The power management system will be solar-powered so that it operates continuously when it is in off-grid rural areas, where it will be supported by a backup battery.
User Interface	User interface will consist of a basic mobile application or a web interface to display data, notifications, and predictions of the floods in a customer-friendly format that will be understandable to farmers who are not highly technical.

Table 1.2.2a: Summary of Functional Requirements

1. System Capacity

The weather station that is proposed should be capable of gathering and processing information of more than one sensor simultaneously, such as rainfall, soil moisture, temperature, humidity, and wind speed. The importance of working with multiple sensors at a time is to prevent delays and provide a smooth working of the system. The system should be in a position to handle continuous and parallel channels of data flow since the aim is to ensure the farmers have real-time data about weather. It also requires real-time processing in large quantities of sensor data to enable precise prediction of a flood before it occurs and early response so that the farmer can act before the flood takes its toll.

2. Sensor Selection

The weather station will have various sensors to measure the main environmental factors which include rainfall, soil moisture, temperature, humidity, wind speed, water level, and atmospheric pressure. The advantages of having many sensors would include providing detailed and accurate information regarding the local weather conditions. This assists farmers to make superior choices in matters concerning irrigation, planting, harvesting and flood preparedness. The sensors should be precise, constant and resilient in that they can perform coherently in the extreme outdoor farm conditions and deliver credible data to make resolutions.

3. Cloud Platform

The system will be linked to an IoT platform which is a cloud based system central hub in data storage, processing and visualization. The internet will enable farmers to have real-time weather data on a simple and user-friendly dashboard. Historical weather data will also be stored in the cloud platform that can be utilized in the trend analysis and future planning. This long storage of data is beneficial in terms of better prediction of weather patterns and it assists in the minimization of risks associated with flooding in agricultural practices.

4. Data gathering and data processing

The data will be read and initial data processing will be done by using an onboard microcontroller and the information will be readied to be transmitted. The processed information will be in turn sent to the cloud platform where further analysis and long term storage will be performed. Data collection has to be real-time to offer immediate feedback to farmers in order to act promptly to the change in weather conditions. The system should also have the integrity of data i.e. sensor readings should be sent to the system and lost or corrupt data must not be sent to the system.

5. Power Management

To maintain its functioning, particularly in rural and flood-prone regions where electricity is not reliable, the weather station will make use of solar power as its primary source of energy. The sensors, microcontroller and communication modules will be powered using solar panels, which will be an effective and affordable solution in order to provide power to these devices. It will have a rechargeable battery as backup in order to operate when it is dark or rainy. Proper management of power is necessary so that there are no gaps in continuous monitoring of the environmental conditions.

6. User Interface

The system will offer an easy and convenient mobile application or web based interface to the farmers. It is possible to view real-time weather, receive alerts, and forecast the risk of floods via this interface. The interface will be user-friendly in a way that would enable the farmers possessing a low level of technical know-how to feel comfortable using it. Timely warnings and flood forecasts will assist farmers to take appropriate steps in time and make decisions as far as their farming business is concerned.

1.2.2.2 Non-functional Requirements

Data Accuracy	All sensor readings (e.g., rainfall, temperature, etc.) are supposed to have an accuracy of 5% in the system.
Data Transmission	Real-time analysis and alerts on the data transmitted to cloud platforms should take less than 5 seconds.

Prediction Model	The model that forecasts the risk of floods will be trained on historical data and reconfigured to the real-time environmental measurements so that it can give correct predictions.
Sensors	The refresh rate of the sensors will be at least 1 minute to real-time monitor and collect the data.
Alerts	The system will alert about floods when the estimated flood threat is beyond a given threshold, and it will send real-time alerts to the farmers via SMS.
Cloud Platform	The data that is transferred should contain the required data logs and the history that is to be accessible at least 30 days.
Power Efficiency	The system must be designed in such a way that it is low in power consumption so that in the long term, it can operate smoothly.
User Training	The system will be user friendly and farmers will have few learning curve.

Table 1.2.2b : Summary of Non-functional Requirements

1. Data Accuracy

The weather station offers highly accurate data to a range of five percent of all sensor measures such as rainfall, temperature, soil moisture, humidity, wind speed and atmospheric pressure. Correct data will be critical in predicting floods and also enabling farmers to make decisions. Such wrong information might result in misleading predictions and end up destroying agriculture and injuring agricultural activities in floodplains.

2. Data Transmission

It takes not more than 5 seconds to send sensor data to the cloud platform. Real-time analysis and flood warnings require fast and reliable transmission of data. Timely flow results in farmers implementing preventative measures to curb the floods like irrigation adjustments, crop protection, or other flood control measures. Late data could decrease the time spent on the preparations and increase the possibility of crop losses.

3. Prediction Model

The flood prediction system will be based on the past weather records as well as current sensor measurements. The model should keep on being updated with the prevailing environmental conditions to give the right prediction. It is timely updated so that the system can alert the farmer depending on the current weather patterns and not on past data only.

4. Sensor Refresh Rate

The minimum refresh rate of all the sensors should be one per minute. The constant changes in the rainfall, temperature, soil moisture or water level are recorded as they occur. With real-time monitoring, the system is able to deliver precise flood warnings and alerts to the farmers and miss out on important environmental changes.

5. Alerts

The automated flood warning will be generated when the forecasted flood risk differs above a set limit. Farmers will receive alerts and other forms of notification through SMS. Messages will be short, realistic, and may have special instructions to ensure that farmers act accordingly in time.

6. Cloud Platform

All sensor data will be stored on cloud-based technology. This will be a platform where real time and past weather data will be available to farmers and other parties so that they can monitor trends, predictions and make better plans in the future. Cloud storage is simple to maintain data integrity, scalability, and reliability in case the local infrastructure is constrained or unavailable in case of extreme weather conditions.

7. Power Efficiency

The weather station should also run on low power so as to facilitate long-term operation. The main source of power will be solar energy, and as a backup power source, the battery will be used during the night or cloudy weather. Power management and energy-efficient components will minimize the maintenance requirements and provide the necessary reliability to operate in rural or off-grid settings.

8. User Training and Interface

It has to be easy to use, and the mobile or web interface needs to be easy to use and does not need much technical expertise. Data should be readable, flood warnings should be comprehensible and farmers should be in a position to act without going through rigorous training. The guidelines will be clear and the design user-friendly so as to be adopted and integrated into the routine farming practice.

1.2.3 Specifications

	Parameters	**Specification**
	Protection System	Polycarbonate/ABS Plastic, UV-Resistant, IP67, 200mm x 200mm x 100mm, 250g, Height: 1.5m - 2m, Post Diameter: 3-4

Mounting and Protection		inches, 15-25kg
	Elevated Mounting Structures	Height: 1.5m - 2.5m, Load Capacity: 20kg, Dimensions: 2.5m pole height

Table 1.2.2c : Summary of specification

	Parameters	**Specification**
Communication	**Data Logger**	Storage: 32GB SD Card, 5V, LoRa, GSM, 4G, Logging Interval: 1 min to 1 hour, 150g
	Telemetry Module	Data Rate: 50kbps (LoRa), , Range: 10-15 km (LoRa), 10-50 km (NB-IoT), 50g
	IoT Gateway	4G/LTE, Wi-Fi, Ethernet, 5V (via Solar Panel or Mains)
	Cloud-Based Monitoring Platform	Features: Real-time Data Display, Historical Data Logs, Alerts Alert Mechanism: SMS, Email, Push Notifications

Table 1.2.2d : Summary of specification

	Parameters	**Specification**
Power Supply Subsystem	**Rechargeable Batteries**	12V, Capacity: 2800mAh, Lithium-ion, 0.185kg per cell

Table 1.2.2e : Summary of specification

	Parameters	**Specification**
Notification	**Automated Warning Systems**	Siren Output: 110dB at 1 meter, LED Display: Red, Yellow, Green for status 12V or Solar-powered
	Communication Platforms	SMS: Sends Real-time Alerts
	Public Address Systems	12V DC or Solar-powered, Sound Output: 100dB at 1 meter, Wireless or Wired, 4-6kg

Table 1.2.2f : Summary of specification

	Parameters	Specification
Weather Input	**Rainfall**	3.3V – 5V,Output: Analog and Digital, 0 mm – 400 mm/hour (approx.), Nickel-plated rain board
	Soil moisture	3.3V – 5V, Output: Analog, 0% – 100% soil moisture, Corrosion-resistant PCB
	Water	5V, 20 cm – 600 cm, Output: Digital (pulse width)
	Temperature	3.3V – 6V, 0°C to +80°C, ±0.5°C (temp),Humidity 0% ,100% RH, ±2% RH
	Pressure	1.8V – 3.6V, 300 – 1100 hPa, ±1 hPa
	Wind Speed & Direction	5V – 24V, Pulse output (speed), analog (direction), 0 – 50 m/s (wind speed), 0°–360° (direction)

Table 1.2.2g : Summary of specification

1. Mounting and Protection

The Mounting and Protection subsystem ensures the stability and safety of the weather station in extreme weather conditions. Key specifications include:

i) **Electrical Range:** 5V – 24V
ii) **Outputs:** Pulse output (speed), analog output (direction)
iii) **Wind Measurement:** 0 – 50 m/s (speed), 0°–360° (direction)
iv) **Enclosure:** High-density Polycarbonate/ABS, waterproof and dustproof (IP67 rated)
v) **Physical Design:** Height 1.5–2.5 m, load-bearing up to 20 kg

The elevated design reduces the disturbance of the surrounding plants and buildings as well as offering practical dependability to sensors and electronics in adverse environmental factors.

2. Communication

The Communication subsystem enables real-time transmission of data from the weather station to cloud platforms and end-users:

i) **Data Logger:** 32 GB SD card for local storage
ii) **Protocols:** LoRa, GSM, GPRS

iii) **Logging Interval:** Programmable from 1 minute to 1 hour
iv) **Telemetry Module:** Long-range data transmission (10–15 km) using LoRa and NB-IoT
v) **IoT Gateway Connectivity:** 4G/LTE, Wi-Fi, Ethernet
vi) **Power Flexibility:** Can operate using solar or mains power for off-grid deployments

3. Power Supply

The Power Supply subsystem supports continuous operation in remote locations:

i) **Battery:** Rechargeable 3.7V – 12V for long-term autonomy
ii) **Solar Power Integration:** Provides sustainable energy and reduces operational costs
iii) **Energy Efficiency:** Designed for low energy consumption, suitable for remote and agricultural areas
This subsystem guarantees uninterrupted monitoring and reduces reliance on conventional power sources.

4. Notification

The Notification subsystem informs users of critical environmental conditions:

i) **Automated Warning System:** Siren (110 dB) and LED indicators (Red, Yellow, Green)

ii) **Alert Delivery:** SMS notifications to farmers and local authorities

iii) **Purpose:** Enables timely flood countermeasures and proactive action based on real-time data

This subsystem ensures that stakeholders are promptly informed of potentially dangerous conditions.

5. Weather Input

The Weather Input subsystem collects environmental parameters required for accurate flood forecasting:

i) Sensors Included: Rainfall, Soil Moisture, Water Level, Temperature, Pressure, Wind Speed, and Wind Direction

ii) Rain Sensor: Measures in mm/hour with a nickel-plated rain board

iii) Soil Moisture: 0% – 100% hydration measurement

iv) Water Level: 0 – 600 cm for flood risk assessment

v) Temperature & Pressure: -40 °C to +80 °C, 300 – 1100 hPa

vi) Wind Sensor: Speed 0 – 50 m/s, direction 0° – 360°

These sensors provide accurate, real-time data essential for flood prediction and monitoring in agricultural fields.

1.2.4 Technical and Non-technical consideration and constraint in design process

The following constraints can be noted regarding the design and development of the proposed weather station system:

1. Technical Constraints

i) The extreme weather conditions can have an impact on sensor accuracy, i.e. heavy rain, high humidity or a substantial shift in temperature.

ii) Reliance on the sun power would restrict the system performance in long spells of cloudy or stormy weather.

iii) There is a possibility of lower reliability of communication in times of floods as signals become blocked or the networks are not stable in distant places.

2. Resource Constraints

i) Limits in the budget do not allow choosing high-precision sensors, communication units, and protective cases.

ii) The accessibility of robust and locally supported parts can have an impact on maintenance, exchangeability and scalability in the long term.

3. Design Constraints

i) The system should possess a strong and small framework that can be used in the fields.

ii) The battery capacity and power efficiency should be maximized to have constant operation in off-grid locations.

iii) The mounting system and the enclosure should be weatherproofed and safe.

4. User Constraints

i) The system should be straightforward and easy to use by farmers having minimal technical skills.

ii) The interface and alerts must be accessible and easy to use using the mobile devices.

iii) The total system price should not be costly to farmers at the small scale level and medium scale in areas characterized by floods.

1.2.5 Applicable compliance, standards, and codes

Subsystem	Standard	Purpose
Low-Rate Wireless Networks	IEEE 802.15.4:2020	Guarantees wireless data interchange, low-power and reliable.
Wireless LAN (Wi-Fi)	IEEE 802.11:2020	Applicable in linking weather stations with cloud services that have Wi-Fi connectivity.
Smart Transducer Interface for Sensors and Actuators	IEEE 1451.0:2007	Ensures the plug-and-play nature of the sensor network based on IoT.
Smart Energy Profile Application Protocol	IEEE 2030.5:2018	Applicable to solar-powered IoT gadgets, with the emphasis placed on the efficient use of power and the management of energy.
Architectural Framework for the Internet of Things (IoT)	IEEE 2413:2019	Offers an architectural framework of the IoT systems that is reliable, secure, and scalable.
Business Continuity Management Systems (BCMS)	ISO 22301:2019	It provides a guideline that assists organizations to plan, react, and recuperate in the occurrence of turbulent events, such as natural calamities such as floods.

Table 1.2.4 : Applicable compliance, standards, and codes

1.3 Systematic Overview/summary of the proposed project

The proposed project is an initiative to design and introduce an IoT-based weather station to agricultural lands that are prone to flood in Bangladesh. The system will aim at enabling the farmers and other local stakeholders to have real-time environmental observations and early flood notification to minimize crop losses, enhance safety, and aid in making better decisions.
The weather station is a combination of several sensors, cloud computing, and machine learning algorithms to allow predicting the risk of floods decently and in time. It gathers important environmental data, which includes the rainfall, soil moisture, temperature, humidity, wind speed, water level, and the atmospheric pressure. The sensor data are initially analyzed on a local level with the help of a microcontroller and sent through the LoRa communication to a cloud platform where they are further analyzed. The prediction model is a machine-learning-based model which examines both past and current measurements to predict the possibility of floods and gives a warning in the form of a SMS, a mobile application, or a visual signal.

To enhance reliability and sustainability, the system runs on solar power under battery back-up and all the components are placed in weatherproof enclosures. An easy to use dashboard will enable farmers to access the latest as well as older data that will help in making informed decisions even without a high level of technical knowledge.
The design is focused on economy, low operation and lifespan, and is suitable in rural and off grid agricultural settings. The proposed weather station will be a practical and reliable tool to enhance agricultural resilience in flood-prone areas in Bangladesh with the help of combining cost-effective IoT technologies, intelligent data analytics, and sustainable energy solutions.

1.4 Conclusion

To sum up, the weather station of the proposed IoT can be considered a feasible and efficient option in addressing the problems of regular flooding in agricultural fields in Bangladesh. The system can monitor floods in real time and send an alert to farmers and local authorities as it incorporates several environmental sensors, long-range communication, the ability to operate with solar power, and the use of machine learning to predict floods. This enables the taking of proactive actions which will secure crops, save economic losses as well as improve safety in flood-prone areas.
The system design has taken into consideration both the technical and non-technical factors, such as the accuracy of data, data informativity, power-efficiency, cost-effectiveness, and accessibility by users. The dashboard and alert systems are also designed in such a way that a user with limited technical knowledge can use the system effectively. Using renewable energy and long-lasting components will guarantee sustainability in the long-run and close to reliable functionality in remote off-grids.
On the whole, this project illustrates that, with the help of the modern IoT technologies, intelligent data analytics, and socially valuable solutions can be offered at a cost-effective, scalable, and socially beneficial level to address the real-life problems of the agricultural industry. The proposed system not only enhances the flood preparedness and the crop management but also leads to sustainable development, economic resilience, and modernization of agricultural practices in Bangladesh.

Chapter 2: Project Design Approach [CO5, CO6]

2.1 Introduction

Various design strategies were also considered during the project design phase in order to make sure that the proposed IoT-based weather station is effective, reliable and feasible in flood prone agricultural regions. Assessment of alternatives helped the project team to consider the technical challenges, the environment, cost constraint and users requirement in meeting the project objectives. Moreover, In every design strategy, the different aspects taken into account included sensor choice, communication technology, power management scheme, data processing scheme, and system architecture. Existing options, strengths, and weaknesses of these options, the optimal design solution was chosen considering the performance, scalability, energy efficiency, cost, and easy deployment in rural and isolated areas. Also, this methodological analysis will ensure that the final design is able to meet both the technical and non-technical specifications leading to a trusted and workable design to real-time environmental surveillance and flood preparedness in Bangladesh.

2.2 Identify multiple design approach

In order to create an effective IoT-based weather monitoring and flood predicting system in the agricultural regions that are at risk of flooding, two alternative designs were identified and discussed. These methods were chosen according to the distance of communication, power consumption, complexity of the system, accuracy and the costs in general. Both of the approaches have certain merits and downsides.

The initial design solution is Localized Broadcaster with a Machine Learning model. Under this method, everything is installed in one place where all the environmental sensors are. These sensors measure the weather parameters which include rain, temperature, humidity, soil moisture, water level and the wind speed. A microcontroller processes the data collected and sends it via the LoRa communication to a server on the cloud. A machine learning model on the server side examines real-time and historical data to make predictions of risks of floods. Depending on the prediction outcomes, there is the alert where the users receive the notification using SMS, email or dashboard alert. This has low power consumption, easy hardware design, and reduced cost of the system. It can also be deployed and maintained with ease, which makes it an appropriate choice when solar power is needed to operate in the rural environment.

The second design technique is Multi-Nodal Edge AI Enabled Broadcaster. In this method, a series of sensor nodes will be used at various points in a region that is prone to floods. Each node polls the environment and transmits the environmental data to an adjacent field gateway. The gateway also processes the initial data with the edge computing techniques and sends early warnings in case of abnormal conditions. The processed information is then sent to a cloud service where complex machine learning models are used to make finer predictions on flood. This method is much more accurate and covers a greater area since multiple locations are studied to obtain data. It demands more sensors, more gateways, more power consumption, and more cost of the system, however. The general complexity in the system is not also that low as it is in the first approach.

The two design methods were compared in terms of the power efficiency, cost, accuracy, coverage, and ease of implementation. Although the second method has a superior spatial coverage and a higher accuracy, the former method is adequate in performance using less power, lower complexity, and less cost. Thus, the two options were regarded as valid solutions as far as design is concerned, and were further examined to come up with the best system in flood prone agricultural lands.

2.3 Describe multiple design approach

2.3.1 Approach 1: Localised Broadcaster incorporating Machine Learning model

● **Phase - 1 (Pre-processing)**

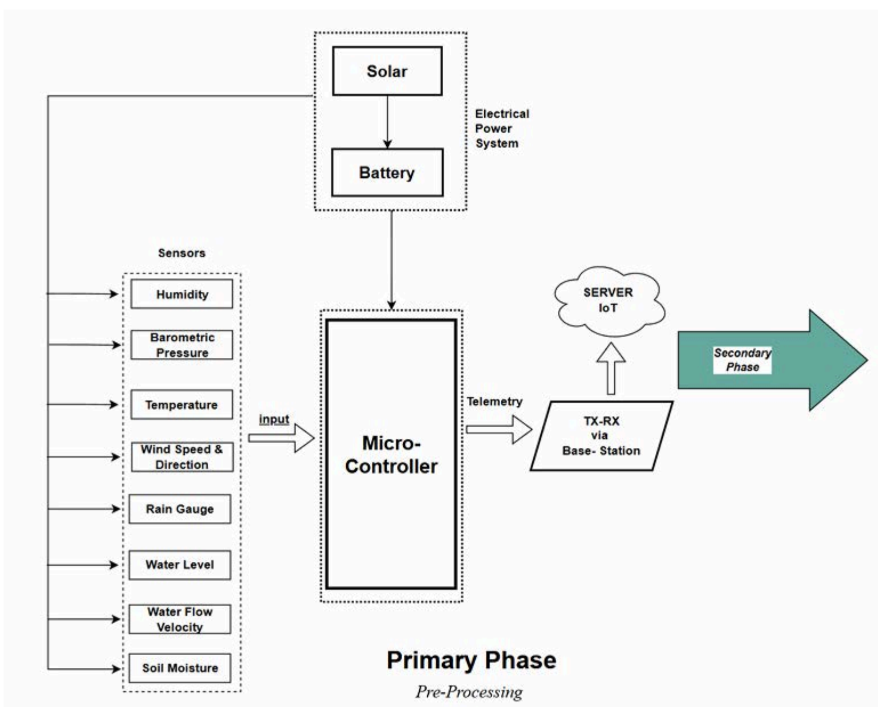


Fig 2.3.1a: Weather Operation Flowchart (Primary Phase)

<u>Primary Phase (Pre-processing):</u> This phase focuses on collecting, processing, and transmitting environmental data from the weather station to a server for further analysis.

1. Data Collection by Sensors:
i) **Humidity Sensor:** Measures relative humidity
ii) **Barometric Pressure Sensor:** Records atmospheric pressure
iii) **Temperature Sensor:** Captures ambient temperature
iv) **Wind Speed & Direction Sensors:** Measures wind speed
v) **Rain Gauge:** Detects rainfall
vi) **Water Level Sensor:** Monitors water levels in nearby water bodies
vii) **Water Flow Velocity Sensor:** Measures the speed of water flow in rivers or channels.
viii) **Soil Moisture Sensor:** Assesses soil moisture levels to evaluate runoff potential.

Each sensor collects data at regular intervals (e.g., every 10 minutes, as per your IoT platform specs).

2. Power Supply and System Stability:
The station has a 10W solar panel which charges a 2800mAh, 12v battery, so that the station will run up to 5 days without sunlight. The power is distributed to the sensors and microcontroller by an electric system that regulates stability of the system even in remote agricultural areas.

3. Microcontroller Processing of Data:
All sensors provide the microcontroller with raw data as inputs.

i) The microcontroller handles Pre-processing functions, including: Noise or erroneous readings (e.g. outlier: a spike to 100C temperature) rejection.
ii) Digitizing raw sensor values (e.g., the amount of rainfall in mm, the speed of the wind in m/s).
iii) Squeezing data into one packet so as to transmit it more efficiently (e.g. a time-stamped record of all parameters).

4. Data Transmission to Server:

i) The data is forwarded and processed information is sent over a transmission module that transmits the data packet either over telemetry to a base station (up to 10 km in rural areas) or directly to a server on an IoT platform based on the cloud..

ii) The relaying is periodic (e.g., every 10 minutes), and this makes the server have real-time updates of data.

<u>Secondary Phase (Post-processing):</u>

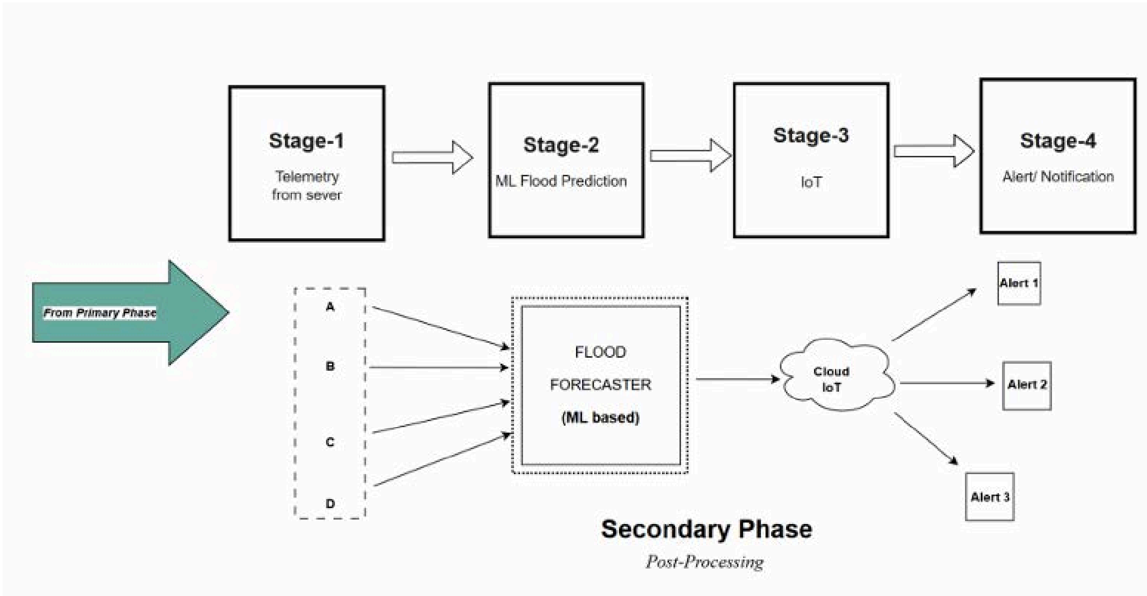


Fig 2.3.1b: Post Processing (Secondary Phase)

i) Train a ML-based flood prediction model using previous due to which the flood occurred.
ii) Measure remote sensors, e.g. - water level rise, temperature, wind, etc and input them into the model.
iii) Lastly, there will be the prediction of the risk of a flood by the model.
iv) Issue the warning through a text message (SMS OR Email) to the citizen/victims.

This phase involves analyzing the transmitted data on the server to predict floods and issue alerts, using machine learning (ML) and IoT technologies.

1. Stage 1: Telemetry from server

The data packet (marked A, B, C, D in the diagram) is sent to the IoT server, the readings of various sensors (rainfall, water level, and so on). The server records this with time stamps and enters the data in a database to be analyzed such that historical data is stored with which the trends are analyzed.

2. Stage 2: ML flood prediction

The server runs a Flood Forecaster (ML-based) module that takes in the incoming data and operates it through a machine learning model, like a deep neural network (DNN), as in the case of . Critical parameters used in the model such as:

i) Intensity of rainfall (e.g. >50 mm/h as mark of heavy rain).
ii) Water level (to identify the increasing flood potential).
iii) Soil moisture (to determine potential runoff).
iv) Barometric pressure, humidity and temperature (to forecast storm occurrence).

Prediction Process:
ML model examines how data trends (e.g. high rainfall with an increase in water level within 24hours). It then measures present data against past flood records in order to forecast the possibility of a flood (e.g. 80 percent chance of flood in the next 6 hours).

Output: The model will produce a forecast of the risk of the flooding (e.g. High Risk, Moderate Risk, or Low Risk) and the model will identify the areas that are at risk depending on the position of the station.

3. Stage 3: IoT Integration and Alert generation

The forecast of flood is forwarded to a Cloud IoT system to be further processed and alarmed. The system compares the risk of a flood to predetermined levels (e.g., there is more than 50 mm/h of rain or water level is above a critical level). In case a threshold is reached, the system sends alert messages:

i) Alert 1: Dispatched through SMS to the local farmers (e.g., "Heavy rainfall anticipated, be prepared of possible floods).

ii) Alert 2: Sent to agricultural officials (e.g., "Flood threat identified in Region X, commence emergency response).
iv) Alert 3: Send an alert to a mobile application so that people can get real-time notifications (e.g. Flood warning: Evacuate low-lying areas).
The alerts are also time stamping and logged to be accountable and analyzed later.

2.3.2 Approach 2: Multi Nodal Edge AI Enabled Broadcaster

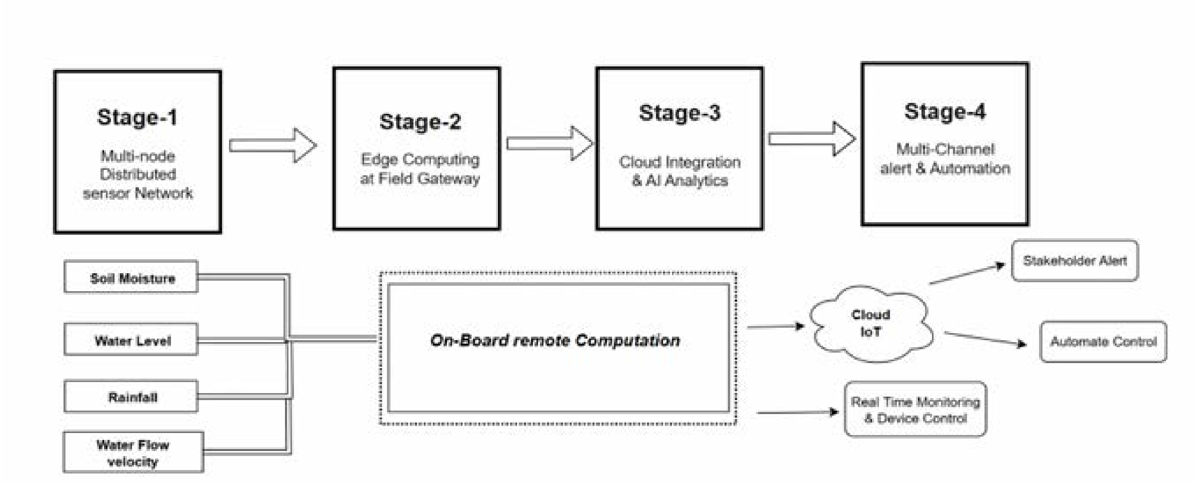


Fig 2.3.2a: Overall flow Operation- Multi Nodal Edge AI Enabled Broadcaster

Multi Nodal Edge AI Enabled Broadcaster

<u>Stage 1: Multi-node Distributed Sensor Network.</u>

Objective: Use a network of sensors to collect real-time environmental data in various sites.

● **Process:**

Install sensors to monitor the major parameters (soil moisture, water level, rainfall, and velocity of water flow) within a flood prone area. Set up the sensors in the form of a multi-node network, which implies each of the nodes to be independent and provide the data to a central system. Make sure that all the nodes provide continuous data collection, which keeps time to record spatial and temporal changes in the environment.

<u>Stage 2: Field Gateway Edge Computing.</u>

● Objective: Conduct preliminary data processing and analysis at the field level to minimize the latency and bandwidth consumption.

● **Process:**

i) Transfer crude data of the distributed sensor network to a field gateway that has edge computing capabilities.

ii) Process data on-board: e.g. remove noise, summarize measurements, detect initial patterns (e.g. rapid increase in water levels).

iii) Transfer the processed information to the next step, optimizing it to integrate effectively into clouds, and storing key information at the edge.

Stage 3: Cloud Integration and AI analytics.

Objective: Use cloud computing and artificial intelligence to process data and forecast floods.

Process:

i) Export the preprocessed data of the field gateway to an IoT cloud based platform.

ii) Use AI analytics (e.g. machine learning models) to process historical and real-time data and identify trends, which could signify possible floods (e.g. continuous heavy rainfall and water level increase).

iii) Produce flood risk forecasts and uncertainty estimates which combine information of more than one node to study the whole region.

iv) Feedback of real time monitoring and device control to modify sensor actions or activate automatic responses.

Stage 4: Multi-Channel Alert and Automation.

Objective : Disseminate the flood warnings and automate the control measures to reduce threats.

Process:

i) According to the AI analytics-generated results, issue multi-channel alerts to stakeholders through channels like SMS, email, or mobile applications.

ii) Introduce automated control measures, e.g. the activation of drainage systems or flood barriers according to the predefined thresholds (e.g. water level higher than some critical point).

iii) Make sure that alerts and automation are configured to meet the requirements of particular stakeholders (e.g. farmers, emergency services) and the area of use.

2.4 Analysis of multiple design approach

Design Aspect	Design 1: Localised Broadcaster with ML	Design 2: Multi-Nodal Edge AI Enabled Broadcaster
Means of Broadcasting Flood Information	Single weather station broadcasts data to cloud server using LoRa communication	Multiple sensor nodes transmit data to a field gateway with edge processing and cloud support
Dependence on Wireless Network Nodes	Independent system operating from a single node	Dependent on multiple sensor nodes and a central gateway
Coverage Area	Suitable for localized agricultural regions	Covers wider geographical areas due to distributed nodes
Communication Technology	LoRa-based long-range, low-power communication	LoRa with additional edge computing and gateway coordination
Component Cost	Lower cost due to fewer sensors and simpler hardware	Higher cost due to multiple sensor nodes, gateways, and edge hardware
Battery Life	Longer battery life due to fewer components and lower power usage	Reduced battery life due to multiple active nodes and edge processing
Power Consumption	Low power consumption, ideal for solar-powered operation	Higher power consumption because of multiple nodes and gateways
System Complexity	Simple system architecture, easy to deploy and maintain	Complex system architecture requiring node synchronization and coordination
Network Protocol Complexity	Simple communication protocol	More complex protocols needed for node coordination and data aggregation
Latency	Lower latency due to direct transmission from station to cloud	Slightly higher latency due to multi-stage processing (node → gateway → cloud)
Reliability	Reliable for localized monitoring with fewer failure points	Higher risk of failure due to dependency on multiple nodes
Accuracy	Good accuracy for localized flood prediction	Higher accuracy due to data collected from multiple locations
Scalability	Limited scalability	Highly scalable by adding more sensor nodes
Maintenance Requirement	Low maintenance due to single deployment unit	High maintenance due to multiple deployed units

Local Availability of Components	Sensors and LoRa modules are easily available locally	Sensors are available, but gateways and edge devices increase procurement effort

Table 2.4: Comparison and Analysis of Both Design Approaches

2.5 Conclusion

The comparison of the various design strategies reveals that care is to be taken to select a system that suits the technical requirements of the project, the environmental factors as well as the user requirements. Though solutions that operate on GSM and Wi-Fi are faster and easy to integrate with cloud, they are more costly and consume more power and cannot be used in remote areas and flood-prone farmlands unless the network is stable.

The most viable and successful solution is the LoRa based system. It presents a range of communication over a long distance, low consumption of energy, and low cost. It can be used with solar power, in combination with cloud storage and machine learning to predict flooding, which allows reliable real-time monitoring and early warning of the flood. This design method is overall balanced on the performance, cost, energy consumption, and scalability, which makes it fit well to be deployed in rural farms.

Chapter 3: Use of Modern Engineering and IT Tool. [CO9]

3.1 Introduction

The intelligent systems of environmental monitoring and disaster management require modern engineering and information technology (IT) tools to develop. They enable real-time data collection, proper analysis and effective communication. This project employs the combination of up-to-date hardware, software, and cloud-based technologies to create a weather monitoring and flood prediction system that is reliable and scalable to be used in agricultural areas in Bangladesh.

In this chapter, the author explains the contemporary engineering and IT tools in the project. These are microcontrollers and embedded systems that can process sensor data in real time, environmental sensors that allow an exact measurement of weather and water level, long range wireless communications like LoRa that can ensure data is reliably transmitted, and cloud computing platforms that provide a centralized location of data storage and visualization. Real-time and historical data are also predicted using machine learning tools to predict the risks of floods. Combined with these tools, it is possible to receive early warnings about floods, make their decision making more efficient, and create a sustainable system that can be effectively used in distant flood prone regions of Bangladesh.

3.2 Select appropriate engineering and IT tools

Engineering is the integration of science, technology and creativity to come up with systems that effectively address real life issues. The engineering design process is usually done through goal setting, identification of possible solutions, performance analysis, prototype development, testing, evaluation of results, and identification of the most appropriate design. This is assisted by information technology (IT) that makes it possible to simulate, analyze data, and compare the various design alternatives based on measurable output.

In the case of this project, the creation of an IoT based weather monitoring and flood prediction system was done using modern engineering and IT tools. The received sensor data was collected and processed in real time with the use of microcontrollers and embedded programming tools. Various approaches to communication such as GSM, Wi-Fi and LoRa were considered in terms of power consumption, reliability and the ability to operate in rural areas. The data were stored, managed, and visualized on cloud computing and data analysis systems and predicted flood risk was estimated using machine learning algorithms with historical and real-time data regarding the environment.

Using these tools, the most reliable, energy-efficient, and low-cost design was selected for flood-prone agricultural areas.

a) Fusion 360
b) Proteus
c) ThingSpeak
d) Arduino IDE
e) Visual Studio Code

3.2.1 Fusion 360

The 3D modeling of enclosure and mounting structures of the weather station was done in Fusion 360. It enabled the development of robust and weatherproof mounts capable of withstanding extreme weather conditions like rain, flooding and extreme winds. It also has the capability of stress and environmental simulation and the test of the design can be carried out in realistic conditions prior to the creation of the physical prototype. Besides that, Fusion 360 offers an easy visualization of the entire system, and it will assist in detecting the design problems early and minimizing errors in the process of fabrication.

3.2.2 Proteus

The sensor integration and circuit simulation of the proposed system were done using proteus. It enables the live monitoring of sensor input changes and confirmation of the related output in virtual screens. It also provides power and fault analysis which allows simulation of subsystems of solar power as well as testing of circuit behavior under fault conditions. Proteus can run a simulation repeatedly without physical hardware, thereby saving a lot of development cost, and allowing any design problems to be detected and corrected before more hardware is even complete.

3.2.3 ThingSpeak

ThingSpeak was employed as the IoT platform for the real-time monitoring and visualization of the data in the cloud. It enables the presentation of sensor information in the form of graphs relative to time, which is easier to comprehend by the stakeholders on environmental trends. Data integration with simulation tools and machine learning models can also be done on the platform and this provides ease in analysis and prediction. Moreover, ThingSpeak has a user-friendly interface that is available on smartphones, and farmers and other users can easily view graphs and receive notifications.

3.2.4 Arduino IDE

In the proposed system, programming of the microcontrollers was done using the Arduino IDE. It offers an easy writing board to write, upload, and execute code of various sensors. Interfacing with sensors is made easier with the availability of built-in libraries, as well as development is made easier. Moreover, it is not only easy to spot and fix the errors in the code as the IDE also provides good debugging with syntax and compilation errors highlighted.

3.2.5 Visual Studio Code

The flood prediction model and related data processing tasks were developed with the help of Visual Studio Code. It offers a clean and user-friendly interface in writing and editing Python scripts, which may include syntax highlighting and auto-completion to help make writing Python scripts faster and error-prone. The built-in terminal enables Python scripts to be run, libraries to be installed and virtual environments to be managed without moving out of the editor. Moreover, the in-built debugging tools allow executing the code step-by-step and examining the variables, which can assist in detecting and resolving problems effectively. The built-in Git version control system facilitates the recent work, manages the changes in code, and maintains orderly and dependable development process.

3.3 Use of modern engineering and IT tools

3.3.1 Usage of Fusion 360

The mechanical structure of the weather station was designed and validated in fusion 360. The given system cannot be used in the field due to the weather conditions, so it needed a durable and high-performing enclosure that is compact and strong.
The system enclosure, sensor mounts, solar panel holder and internal component layout were 3D modeled using Fusion 360. The software enabled dimensions to easily be changed in the course of design. The mechanical visualization guaranteed the correct location of sensor, sufficient air circulation, and safe against rain and floods. The design files could also be used to plan the fabrication and assembly and minimize mechanical failure in deployment.

3.3.2 Usage of Proteus

Proteus, which is a significant engineering tool, was utilized in this project to design and simulate the electric circuits of the weather monitoring system and then construct the actual hardware. The system comprises several parts that include: microcontrollers, environmental sensors (rainfall, temperature, humidity, soil moisture, water level), communication modules and power management circuits. That is why the proper functioning of the circuits had to be checked beforehand. Moreover, proteus enabled simulation of sensor interface circuits and connection with microcontrollers to verify the logic of signal flow, power distribution, and data transmission. Simulation allowed detecting the mistakes (like wrong connections of pins, voltage mismatch and logical errors) on the initial phase. The virtual testing also minimized the chance of damaging hardware and the opportunity to do trial and error when implementing the physical system hence creating a more dependable and stable system design.

3.3.3 Usage of ThingSpeak

ThingSpeak was used as the cloud-based IoT platform where sensor data extracted in the weather station was stored, visualized, and analyzed. The real-time environmental conditions such as rainfall, temperature, humidity and water level were posted to specific channels at ThingSpeak.
The site gave a graphical representation of real-time data as well as historical data in a way that one could easily monitor weather conditions remotely. ThingSpeak stored data was also used to analyse and generate early warnings and flood prediction. Its cloud based quality meant that the key information was accessible by farmers and other stakeholders wherever they are, as this would help them to make their decisions better and also become more prepared to face floods.

3.3.4 Usage of Arduino IDE

The embedded software developed on Arduino IDE that controls sensor collection and communication was run on the microcontroller. It has offered a platform to code, assemble and upload programs to read environmental sensors, process LoRa communication, and manage power-saving operation.
Arduino IDE enabled the serial monitor option that made it possible to monitor sensor values including temperature, humidity, rainfall and water level in real-time during testing. This system was put to test in different conditions such as normal weather conditions, heavy rain conditions and flood-risk areas. Arduino IDE also allowed debugging and quick update of programs and, therefore, was appropriate in creating reliable and real-time embedded systems of the weather station.

3.3.5 Usage of Visual Studio Code

Data processing, backend scripting and machine learning operations were primarily developed using Visual Studio Code (VS Code). It offered a programmed environment to develop Python scripts to analyze sensor data, apply flood prediction code, and coordinate system behavior.
VS Code also assisted in clean code organization and debugging as well as version control which assisted in managing complex scripts effectively. It was also applicable in real-time cloud data feeds and prediction algorithms that were applied in a dynamic and structured fashion to guarantee the stability and maintainability of the system.

3.4 Conclusion

Summing up, the modern engineering and IT tools played a crucial role in developing the system of weather monitoring and flood prediction into the conceptual project into the working and efficient one. All of the tools played an important role: Proteus made it possible to simulate and test electronic circuits, Fusion 360 allowed doing accurate and solid mechanical design, Arduino IDE allowed control over sensors in real-time, Visual Studio Code allowed managing the data processing and machine learning activities, and ThingSpeak allowed storing and managing data in the clouds, visualizing it, and remotely monitoring. The combination of these tools reduced the number of errors, enhanced the performance of the system, and made the development process faster based on the iterative testing process and early fault detection. They also made sure that the system is reliable, energy efficient, scalable as well as cost effective to implement in rural agricultural settings. In general, this project shows how engineering and IT tools can be utilized successfully in contemporary times to come up with intelligent and viable solutions that can be used to assist farmers in flood prone areas of Bangladesh.

Chapter 4: Optimization of Multiple Design and Finding the Optimal Solution. [CO7]

4.1 Introduction

Engineering design is a process that is iterative and optimization-based involving a set of alternative solutions which are analyzed to determine the most efficient, reliable, and feasible solutions. In practice, when dealing with real world systems, particularly with resource limited systems like flood prone agricultural lands in Bangladesh, the choice of design is important to guarantee performance of the system, its sustainability and acceptance by the user.

The present chapter constitutes a methodical optimization of various design solutions that are taken into consideration in the suggested IoT-based weather monitoring and flood prediction system. The analysis will be based on communication technologies, power consumption, scalability, cost, and operational reliability. According to the quantitative and qualitative assessment, the best design methodology is determined and the functionality of the created system is measured to prove its usefulness.

4.2 Optimization of Multiple Design Approaches

4.2.1 Communication and Sensor Deployment Optimization

The system of weather monitoring and flood prediction through the IoT is highly dependable and accurate because of efficient communication and sensor deployment. In the project, the various communication technologies and sensor implementation plans had to be evaluated so as to maximize the performance of the system in rural and flood prone agricultural areas.

Three communication options were taken into consideration, and they were GSM, Wi-Fi, and LoRa. GSM has a large range of coverage, but it is characterized by the high power consumption and the frequent operation cost which is related to the use of SIM cards. Wi-Fi has very high data rate, and lacks range and it demands a stable internet infrastructure, which is lacking in rural regions. LoRa was determined to be the most appropriate communication protocol because it has a long-range ability, low power usage and can fit in solar-powered and off-grid applications. It also promotes scalable network architecture whereby several sensor nodes can effectively send data to a central gateway.

The deployment of the sensors was analyzed in order to provide quality data. A node-based solution offers measurements that are localized, but which are vulnerable to sensor death. It would be more accurate with a multi-node strategy in which sensor inputs are averaged at four geographically separate points, and the effect of individual sensor errors would be minimized. The approach will provide greater spatial coverage, reduce uncertainty, and enhance the strength of flood forecasts, including when sensor data is faulty or noisy.

Proteus-Based Circuit Design and Simulation

Approach-1

Design and validation of the electronic circuitry of the proposed IoT-based weather monitoring system were done using the Proteus simulation, and then actual implementation was done. As the considered system is a combination of several sensors, a microcontroller, communication modules, and power management, it was necessary to simulate the system to make sure that the signals run in the right direction, the voltages do not conflict, and the system is stable. In the Proteus model, the microcontroller was linked to environmental sensors that included temperature, humidity, rainfall, soil moisture and water-level sensors. Both sensor interfaces were emulated to ensure that the data was acquired correctly and the pin setup was correct. The simulation made sure that analog and digital signals were correctly processed without noise distortion as well as voltage difference. The logic of the communication was also tested in the Proteus. The control signals on data transmission were checked such that sensor readings were properly framed and ready to be communicated by LoRa. The behavior of power supply was examined to ensure that it operated stably in the conditions of solar-powered operation with battery backup. The special consideration was paid to keeping the power at low levels during idle and active data transmission states. Using simulation, the various situations of operation were tested such as normal weather conditions, heavy rainy conditions, and abrupt water-level height. Virtual testing aided in detecting errors in the wiring, wrong logic and timing errors earlier in the design process. This enormously lowered the hardware risks, the amount of trial and error in the physical assembly and enhanced the overall system reliability.

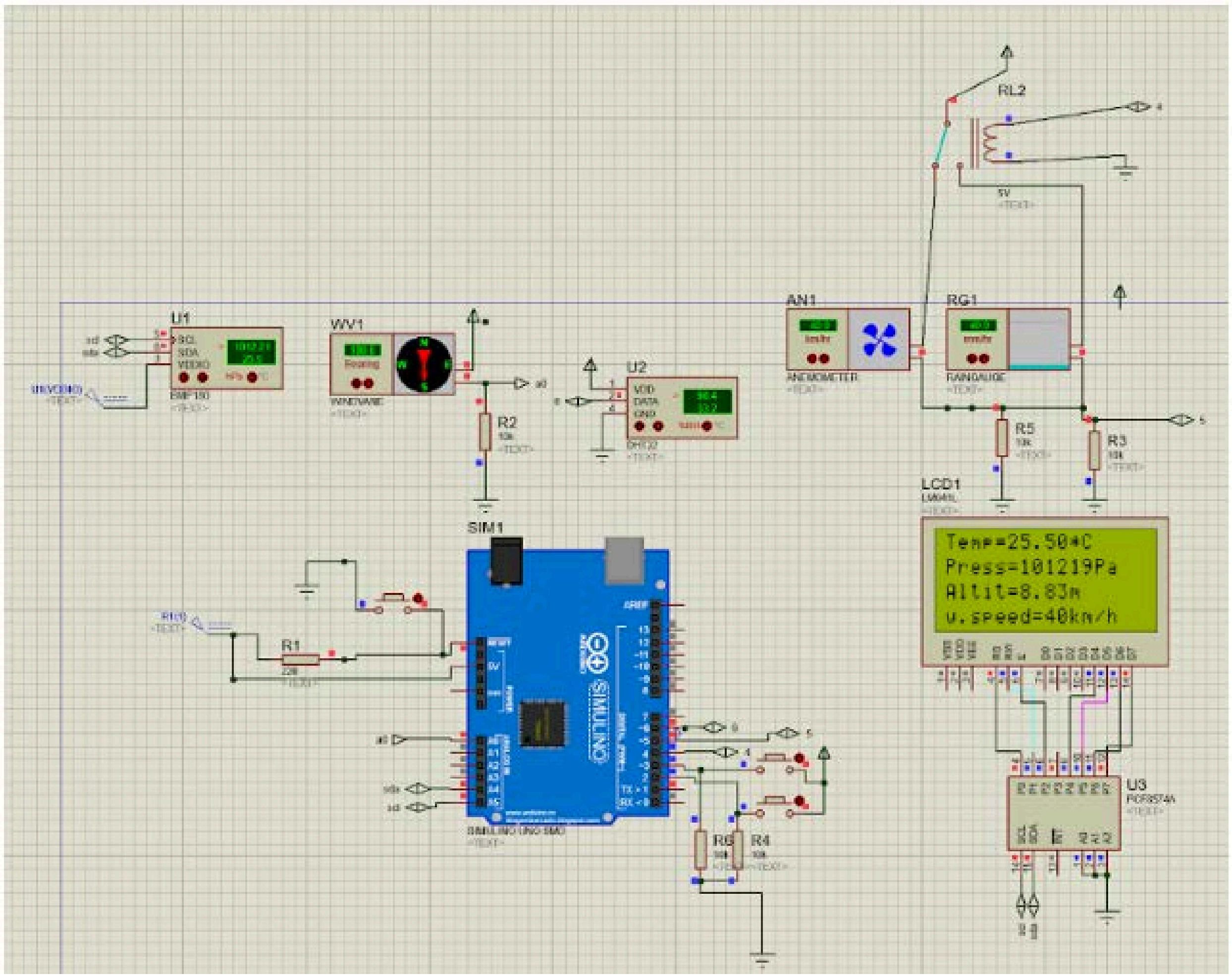


Fig 4.2.1a: Circuit Design for Approach 1

Approach 2

In the second design method, four geographical positions are used to record environmental data by four nodes of sensor distributed sensors. The sensor values at all sites are sent to a centrally located system, and the data is averaged to minimize errors in measurements. The processed information is subsequently presented on an easy-to-use dashboard together with the final outcomes of flood prediction.

A machine learning model trained on past weather data and flood data is used to analyze the sensor data obtained. According to this analysis, the system triggers flood alerts in case there is abnormal weather pattern or high level of flood risk. It also has an alarm system which would alert farmers and stakeholders about any unusual or dangerous weather immediately.

This will enhance the accuracy and reliability of a system since it covers a greater area and reduces the effects of fault sensor reading. The other sensor nodes are useful in ensuring that there is general accuracy in case one sensor is giving out wrong data. Consequently, the design manages to meet the project goals of real time data collection, precise flood forecasting, and straightforward information presentation with an easy to use dashboard.

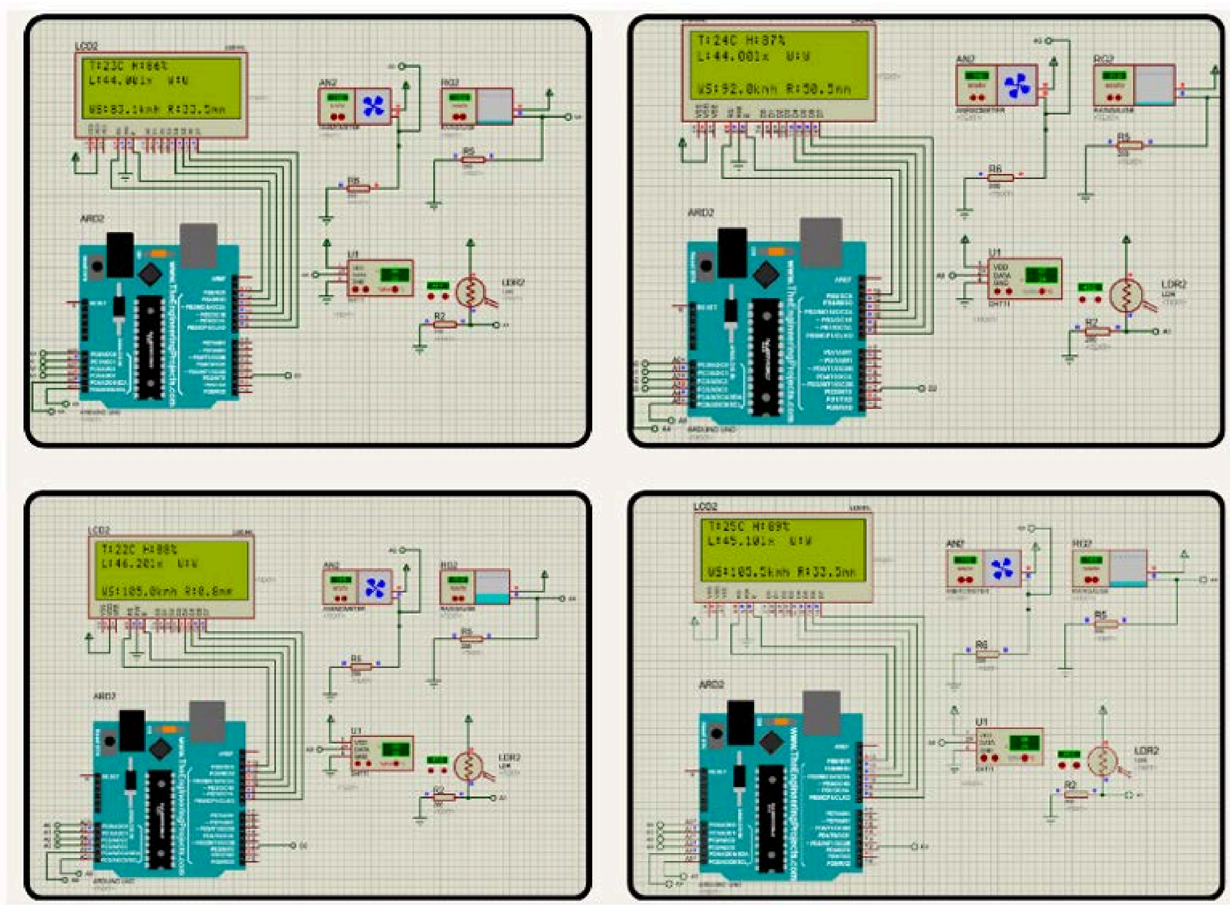


Fig 4.2.1b: Circuit Design for Approach 2

● **Test Cases**

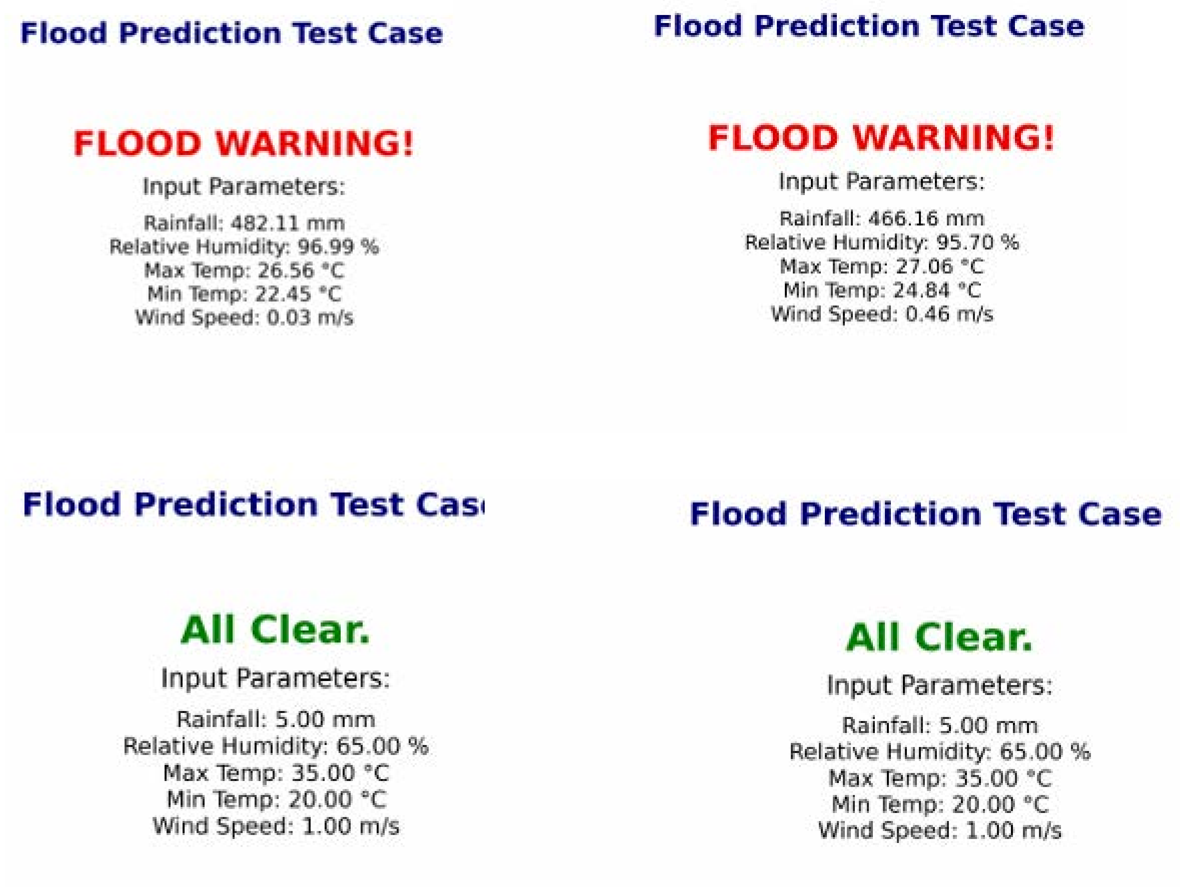


Fig 4.2.1c: Flood Prediction Test Cases

Output

The creation of an easy-to-use dashboard with significant information related to floods is one of the primary aims of this project. The dashboard will show sensor real-time data, trends, and flood warnings in a structured and graphical way.

The interface is designed keeping simplicity and usability as the main key and enabling the users having varied technical skills to easily comprehend the information. The dashboard allows users to make fast and effective decisions in cases of floods by clearly and well-organized data and alert presentations. This will make sure that the essential information is available at all times hence enhancing the overall preparedness, safety and efficiency in response.

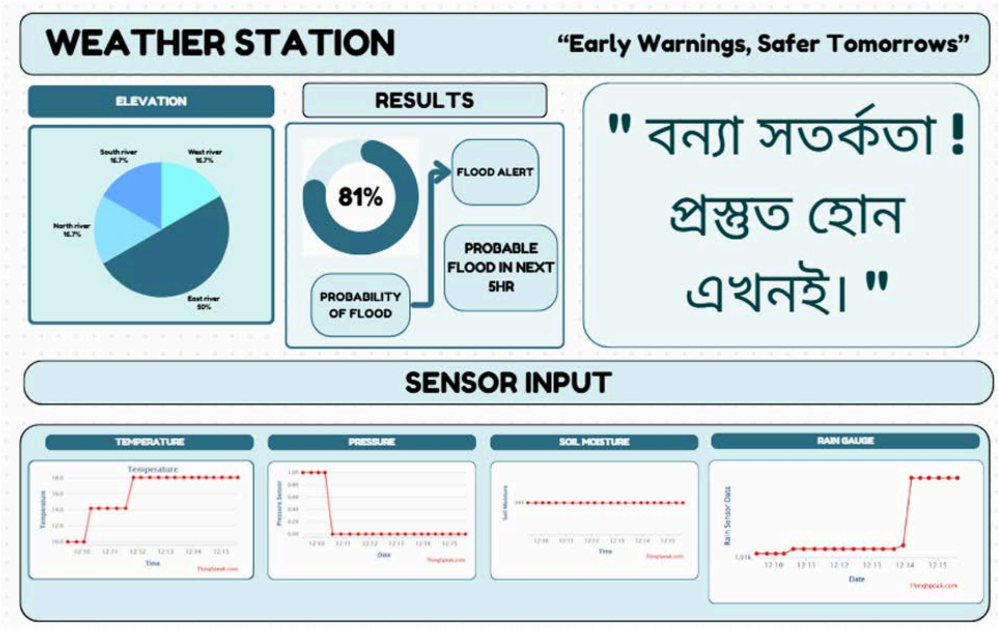


Fig 4.2.1d: Dashboard for both Approach 1 and Approach 2

3D modelling of System:

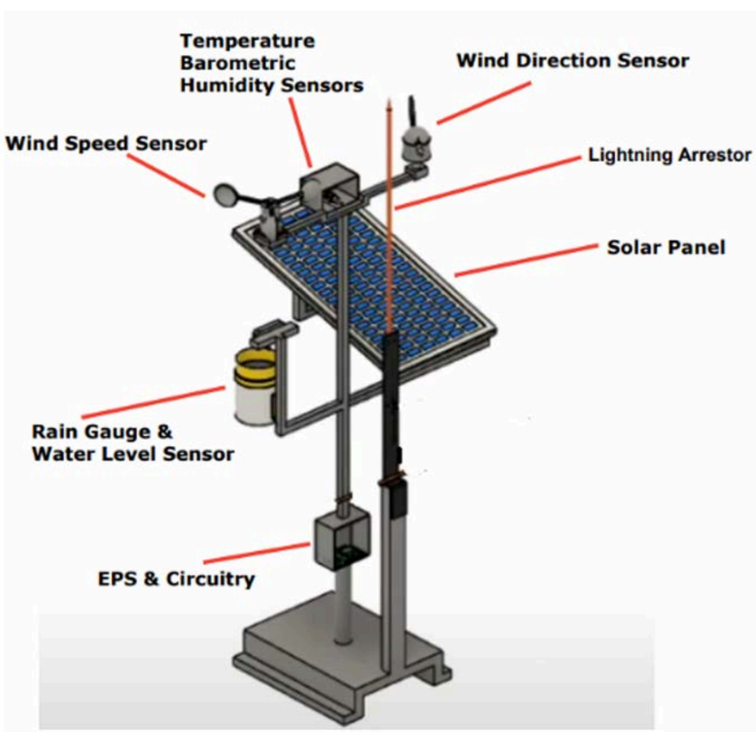


Fig 4.2.1e: 3D Model for the Weather Station

4.2.2 Data Flow and Processing Optimization

Flood predictions require real-time and accurate sensor data, which can only be achieved through efficient sensor data processing and transmission. In this project, data about the environment through multiple sensor nodes is gathered and sent to a central processing unit where it is subjected to a series of steps of preprocessing, cleaning, analysis, and prediction using machine learning models. The optimization of this data flow guarantees that there is minimum latency, accuracy as well as reliability in the generation of alerts to the stakeholders.

● Phase - 1 (Pre-processing)

The first stage of data processing is the primary phase preprocessing when raw sensor data such as temperature, rainfall, humidity, soil moisture, and water level are verified and filtered to eliminate noise or false readings. The stage is demonstrated in the Primary Phase that emphasizes the consecutive process of acquiring data, calibration of the signal, and initial formatting before transmission.

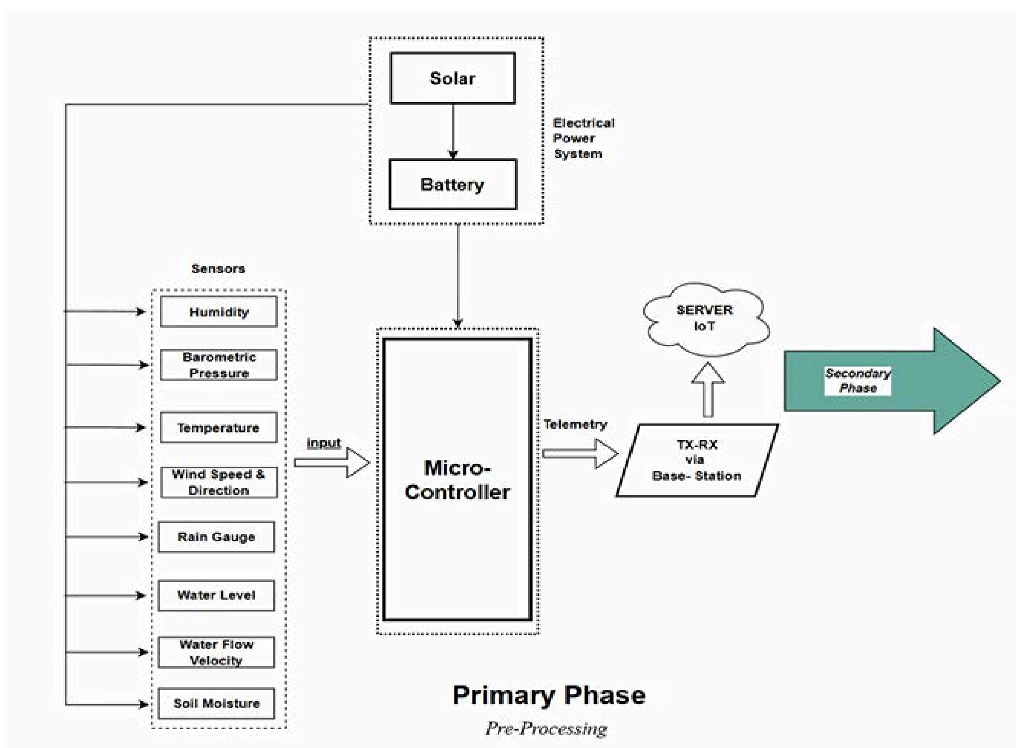


Fig 4.2.2a: Weather Operation Flowchart (Primary Phase)

● **Phase - 2 (Post-processing)**

The data undergoes additional processing at the secondary processing stage where it is analyzed, cleaned and defined in a way to make it ready to be fed into the algorithms of flood prediction. Multi-node sensors present redundant or conflicting data that is reconciled between using averaging and error correction methods. This is illustrated in Post Processing (Secondary Phase) where the data cleaning, normalization, and integration functions with the cloud platform are illustrated.

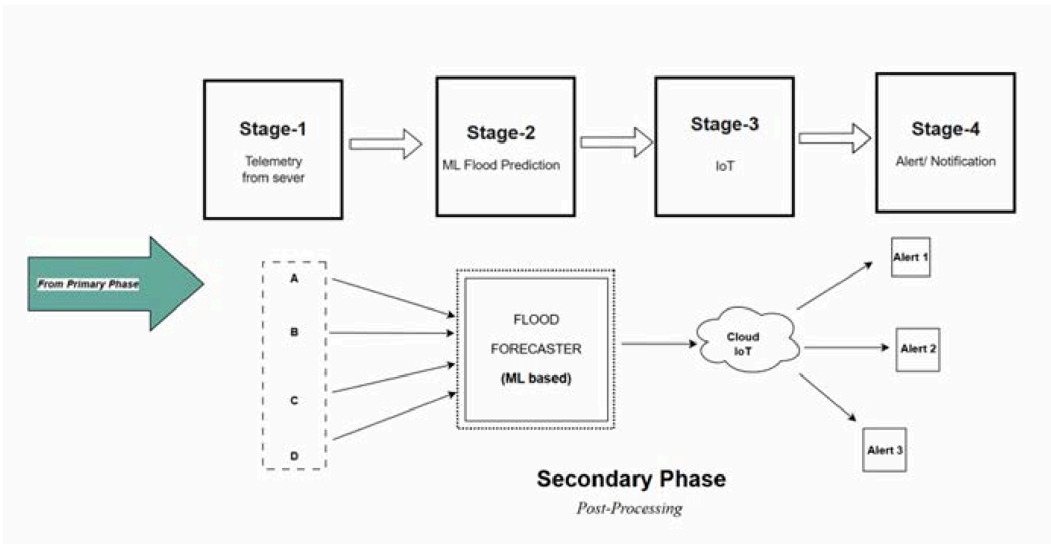


Fig 4.2.2b: Post Processing (Secondary Phase)

Lastly, data flow in general incorporates both multi-node sensor data, edge processing, cloud processing and alert generation. Overall flow Operation Multi Nodal Edge AI Enabled Broadcaster shows the overall architecture of the system, which comprises data aggregation on the sensor nodes of four nodes, edge-level preprocessing, machine learning analysis in the cloud, and real-time alerting. Such architecture will guarantee that the sensor information will be processed efficiently, flood prediction will be provided accurately, and the alerts will be provided to farmers and stakeholders in time.

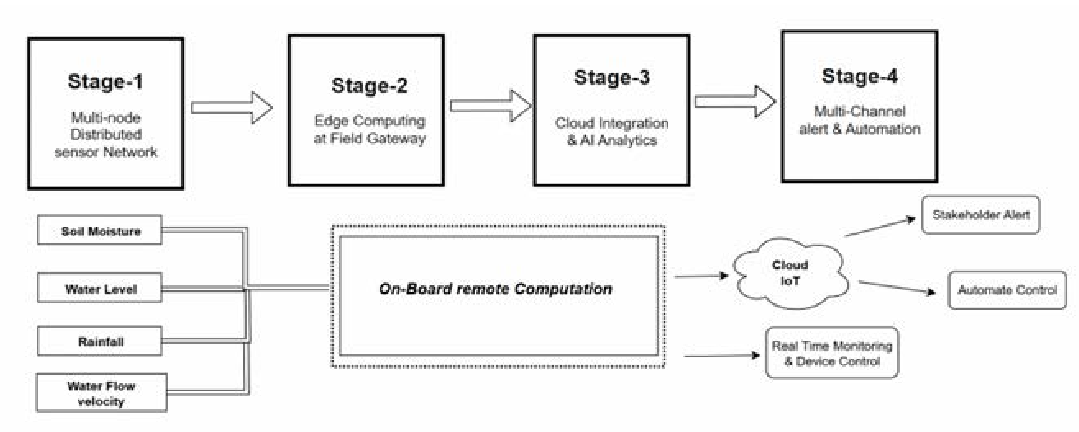


Fig 4.2.2c: Overall flow Operation Multi Nodal Edge AI Enabled Broadcaster

4.2.3 Sustainability and Decision-Making Metrics

The need to make practical decisions and sustainability are important aspects when deciding what design method will be the most efficient to use in the case of the weather monitoring and flood prediction system. The subsection will consider the economic, social, and environmental parameters of the suggested design alternatives so that the chosen solution would be viable, affordable, and applicable to the rural agricultural areas.

Economic analysis takes into account the costs of the development of the system and the cost of operation including maintenance and energy demand. Social sustainability focuses on how accessible it is to users, how simple it is to use by farmers with minimal technical skills and how extensively it can be used. Sustainability is concerned with the energy consumption, use of renewable power and little ecological cost in the deployment and operation.

We have developed a sustainability chart which is given below. Based on the environmental, economic and social parameters, the chart compares both approach 1 and approach 2, and gives an idea of which approach would be the best choice.

Criteria	Weight	Approach 1 (LoRa Based) [Score]	Approach 1 (LoRa Based) [Weighted]	Approach 2 (Edge Ai Based) [Score]	Approach 2 (Edge Ai Based) [Weighted]
Environmental Criteria	**0.4**				
Carbon Footprint	0.05	5	0.25	3	0.15
Energy efficiency	0.05	5	0.25	3	0.15
Material Sourcing	0.05	3	0.15	3	0.15
E-waste Management	0.05	4	0.2	3	0.15
Toxic Substance use	0.05	4	0.2	4	0.2
Renewable energy use	0.05	4	0.2	4	0.2
Water usage	0.05	4	0.2	4	0.2
Biodiversity impact	0.05	4	0.2	4	0.2
Economic Criteria	**0.3**				
Initial Capital Investment	0.05	4	0.2	3	0.15
Operational costs	0.05	4	0.2	3	0.15
Maintenance costs	0.05	4	0.2	3	0.15
Lifespan	0.05	4	0.2	4	0.2
Productivity impact	0.05	4	0.2	5	0.25
Market potential	0.05	4	0.2	4	0.2
Job creation	0.05	2	0.1	4	0.2
Local economic impact	0.05	4	0.2	4	0.2
Social criteria	**0.3**				
Health and Safety	0.05	5	0.25	5	0.25
Community engagement	0.05	4	0.2	4	0.2
Social Equity	0.05	4	0.2	3	0.15
Educational impact	0.05	4	0.2	4	0.2
Quality of life	0.05	4	0.2	4	0.2
Access to services	0.05	4	0.2	3	0.15
Cultural Impact	0.05	4	0.2	4	0.2
Displacement	0.05	4	0.2	4	0.2
Total Score	**1**		**4.8**		**4.45**

Table 4.2.3: Sustainability Chart for Both Approach 1 & Approach 2

The sustainability of our project depends on its impact on certain factors such as social, economic and environmental dimensions. Talking about the social impact, our system promotes community flexibility by providing early flood warnings, making sure the farmers have access to real time data and lowering the reliance on government notifications [4], [10]. Moving on to the economic impact, the proper utilization of low cost technologies like LoRa can reduce the operational costs by a large margin and help the farmers who have low monthly income to afford such a system as a solution to tackle floods [7], [11]. Both of our approaches, approach 1 (LoRa based system) and approach 2 (Edge-AI based system) are energy efficient and can be used as alternatives to the conventional weather monitoring systems. Since, approach 1 has greater range and is more affordable for the farmers, it is a more ideal solution making it an appropriate system for flood prone agricultural lands [12]. Lastly, in terms of environmental impact, our project promotes better planning of crops and also reduces waste of resources that are caused due to flooding. This results in less soil degradation and more sustainable agricultural farming [5], [6]. The use of solar panels (renewable energy) in both of our approaches enhances the environmental viability of our system, reducing the amount of carbon footprint [4], [7].

4.2.4 Risk Analysis / Fault Evaluation

In order to guarantee the validity of the offered weather monitoring and flood prediction system, a fault tree analysis was conducted. This discussion would help to pinpoint possible system failure points, which would be sensors, power supply, communication modules, and alerts. The system can be developed to avoid, identify, and recover errors by mapping the potential faults.

Analysis 1: Fault Tree Diagram

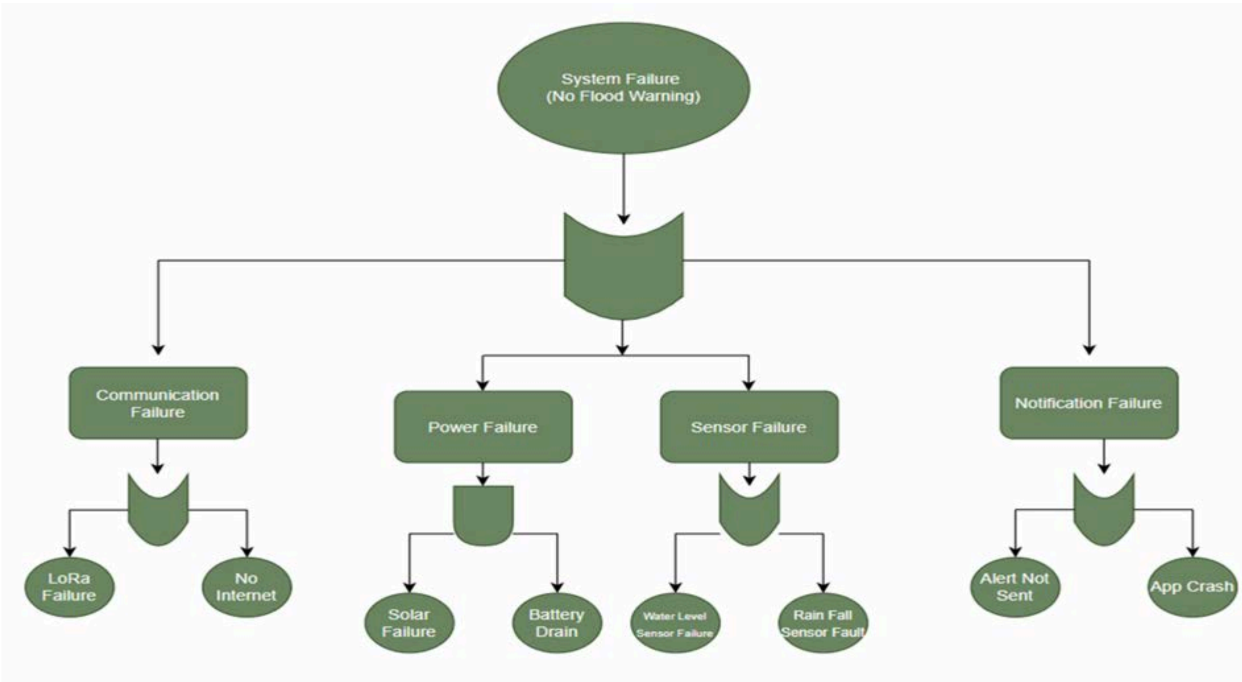
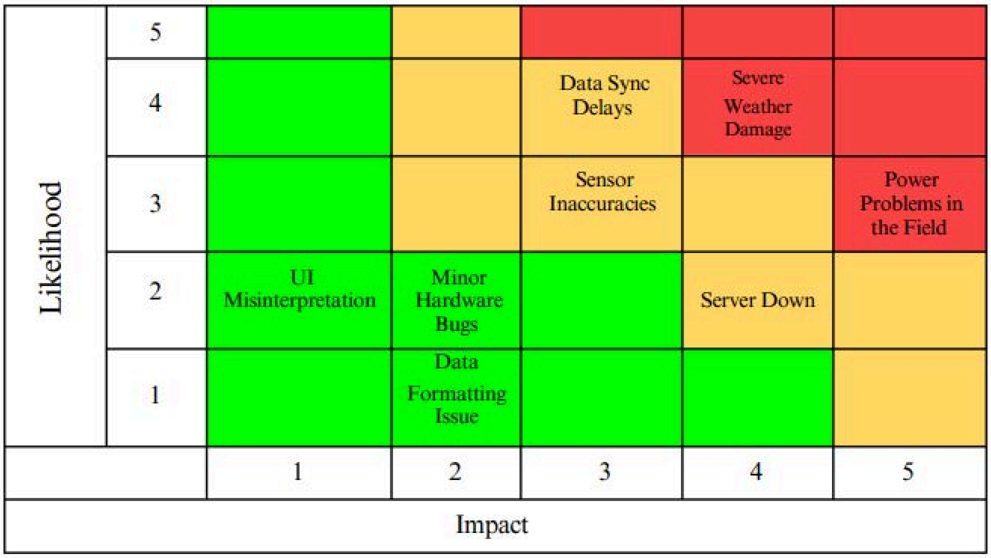


Fig 4.2.4: Fault Tree Analysis

We have developed a fault tree analysis for our project. This will help us to determine the various ways in which our system can fail. In this case, the failure of our system can happen if either of the four issues mentioned occurs: Power, Communication, Sensor and Notification failures. If there is no internet or the LoRa module malfunctions somehow, then communication failure will take place. Power failure can be due to drained batteries and the malfunction of our solar panels. Our sensors can be damaged due to environmental damage or poor calibration. There might be notification errors such as delay in alerts or the app crashing. Each of these problems mentioned in the fault tree analysis contributes to the overall failure, helping us pinpoint weaknesses and improve the system to prevent future breakdowns.

Analysis 2: Fever Chart

Fever Chart :



1	2	3	4	5
very low	*low*	*moderate*	*high*	*very high*

Another risk management analysis has been developed. We created a fever chart to show the possible problems that our system might face, based on how likely the errors are to happen and how serious their impact would be. To elaborate more, the biggest risk is the power problem in the field, which is very likely and would stop the whole system from working. As we know in flood-prone areas, sunlight may be blocked for days due to storms, clouds, or monsoon rains, and lack of sunlight for solar panels or battery issues can completely shut down the weather station. Another big risk is that the device might get damaged during a storm or that the sensors could give wrong readings, which would affect the flood warnings. Other problems like slow data upload, signal loss, or the app crashing can also occur. These are also pointed out in the fever chart, but are less serious. This chart helps us understand which problems we should focus on fixing first to make the system more reliable and helpful for the farmers.

- **How can the issues be dealt?**

In order to deal with the risks identified in the fever chart, specifically power failure in the field and sensor inaccuracies, we have two solutions in mind. Firstly, the system will include a solar panel with an oversized battery backup, allowing it to operate for multiple days without sunlight, which is crucial during long stormy or cloudy periods. We can also program the system to send a warning when battery voltage drops below a certain threshold. Secondly, to deal with the risk of inaccuracy in the readings, regular sensor calibration and automated self-checks can be implemented to make sure accurate data readings are given which will ensure the reliability of our system's predictions.

- **Risk Response Matrix:**

Risk Event	Response	Contingency Plan	Trigger
Power problem in the field	**Mitigate:** Use solar with battery backup	Switch to reserve battery / maintenance visit	Battery drops below safe voltage
Sensor Inaccuracies	**Mitigate:** Schedule regular calibration	Replace or recalibrate sensor	Readings deviate from expected values
Damaged Device	**Mitigate:** Weatherproof enclosure + elevation	Move to safer location / Replace parts	Heavy rain or storm warning issued
Data Sync Delay	**Mitigate:** Use buffered transmission	Delay analysis / Log data locally	Network delay exceeds set limit
UI Misinterpretation	**Mitigate:** Redesign with simple UI	Provide training or video tutorial	Farmer feedback shows usability issues
Server Down	**Mitigate:** Use backup cloud or offline storage	Switch to offline mode / Notify user	Server unresponsive for a preset time limit
Data Formatting Issue	**Mitigate:** Validate before sending	Correct using standard parser	Data fails to load on dashboard

In addition to all these, our optimal design which is the design Approach 1, there are some more risks which could affect the success of the project. These include sensors getting damaged from long exposure to water, communication failures during floods and delays in training the machine learning model if there isn't enough data. To mitigate against these risks, multiple strategies have been designed, namely by considering waterproof stations (using IP67), particularly for sensors such as DHT22, as well as testing the signal of LoRa under simulated flooding conditions and the access to pre-existing datasets from the Bangladesh Water Development Board to facilitate the process of model training.

If any sensor fails our backup measure is to replace it with a spare and recalibrate the system with Tanjil to be responsible for this task. So whether any communication problems arise, Arfanul can decide whether to fix LoRa range extenders or to switch to one of the short-range backups. In case of delays in machine learning training, Akif and Brinto will either enrich the data set or simplify the model to ensure that deployment occurs in time.

By having these plans in place, we can ensure that we can help the system keep running smoothly, help keep downtime to a minimum, and ensure that the project continues without any major interruptions.

4.2.5 Machine Learning Model Performance Evaluation

The accuracy of the machine learning model that is employed to predict floods is assessed through multiple conventional measures and plots. Such numbers are quantitative results that could support the accuracy, reliability and the contribution of various environmental factors to prediction.

1. Confusion Matrix Analysis

Model Performance Evaluation & Comparison In this passage, two machine learning models are compared in detail, including Random Forest and XGBoost, which were designed to help predict floods. They are both robust ensemble models and this analysis compares their performance using key measures to highlight the best model between the two to use in real-life flood warning systems. 1. Confusion Matrix Analysis The confusion matrix gives a detailed perspective of each model's predictive power that is essential to a safety-critical application such as flood prediction.

Metric	Random Forest Model	XG- Boost Model
True Negative (TN)	3210	3202
True Positive (TP)	685	679
False Negative (FN)	124	130
False Positive (FP	90	98

Table 4.2.5 : Confusion Matrix Analysis

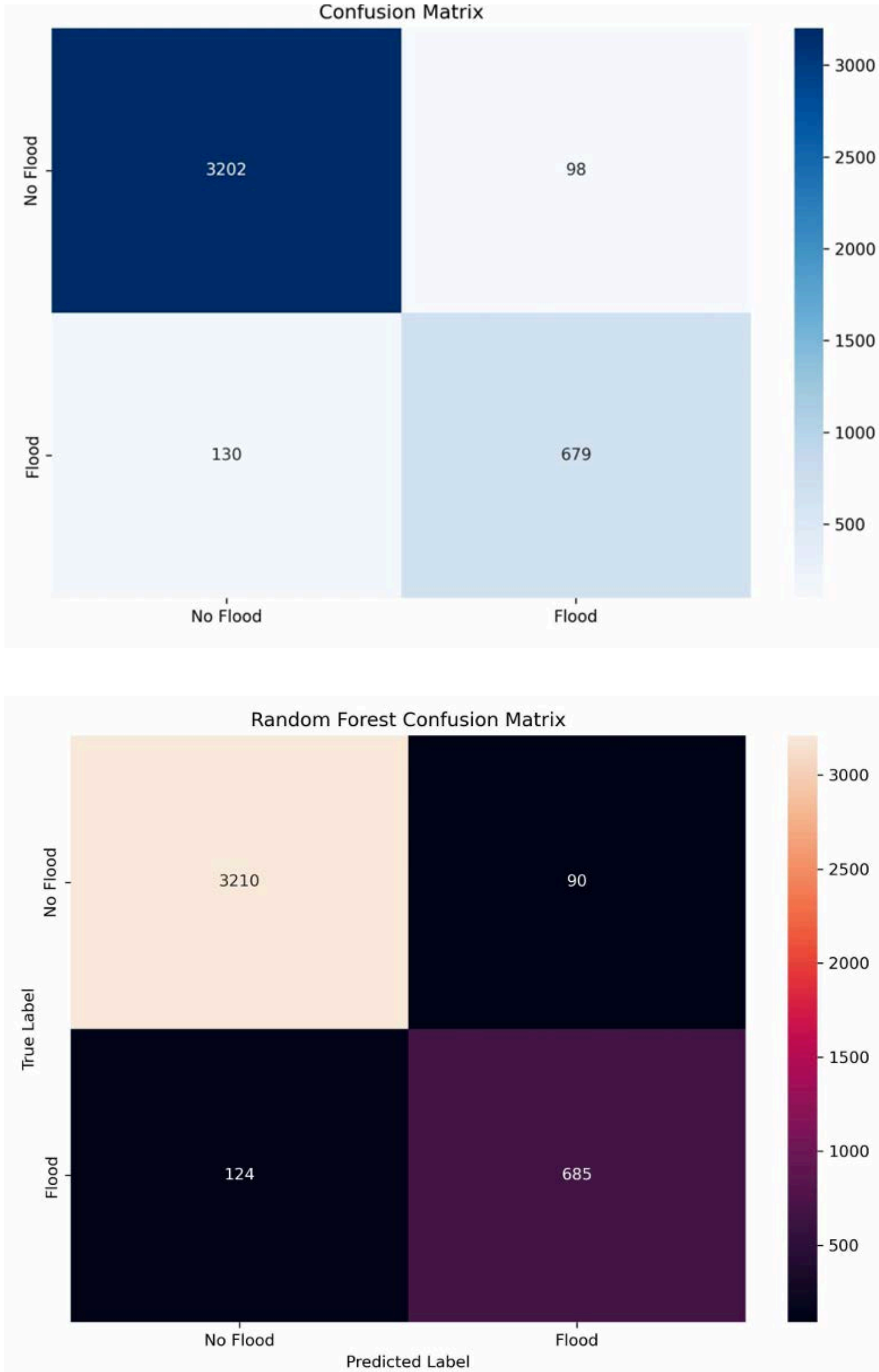
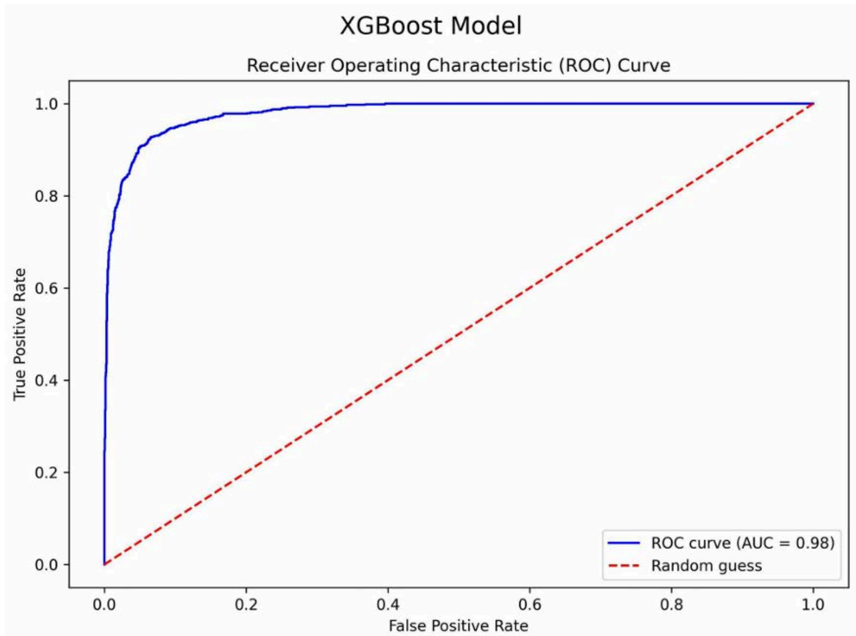


Figure 4.2.5a: Confusion Matrix: XG-Boost, Random Forest

Analysis: The Random Forest model has a minor advantage throughout the board. It rightly determined a higher number of true negatives and true positives. More to the point, it contained fewer false negatives (124 vs. 130) which implies that it overlooked fewer real flood cases. It also contained less false positives (90 vs. 98) which led to the false alarms. Random Forest has been marginally better based on this direct comparison.

2. ROC Curve and AUC Score

The ROC curve is used to evaluate the capability of the model to differentiate between flood and non-flood. This performance is indicated by the Area Under the Curve (AUC) score, where a higher value of the score is a sign of a superior model.



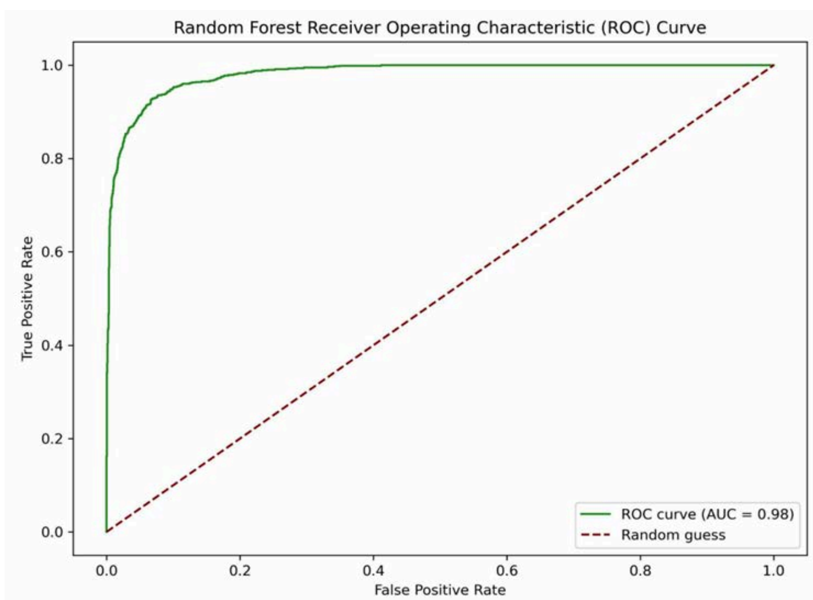


Fig 4.2.5b: ROC Curve: XG-Boost and Random Forest

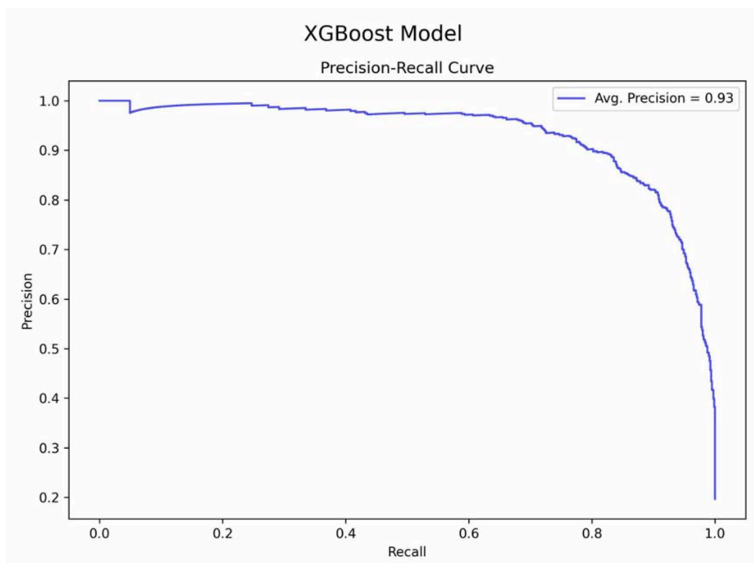
● **Random Forest:** AUC = 0.98

● XGBoost: AUC = 0.98

Analysis: Both random forests and XGBoost had the same and excellent value of 0.98. This shows that the discriminative power of both Random Forest and XGBoost are excellent and close to being perfect, which is an indication that both of the methods are both extremely able to make accurate classifications.

3. Precision-Recall Curve

The measure is especially useful when the data has an unequal proportion of classes, such as in this case, one of the classes (here, Flood) is not as common. It determines the tradeoff between the accuracy (positive predictions) and the recall (positive cases correctly predicted) of the model.



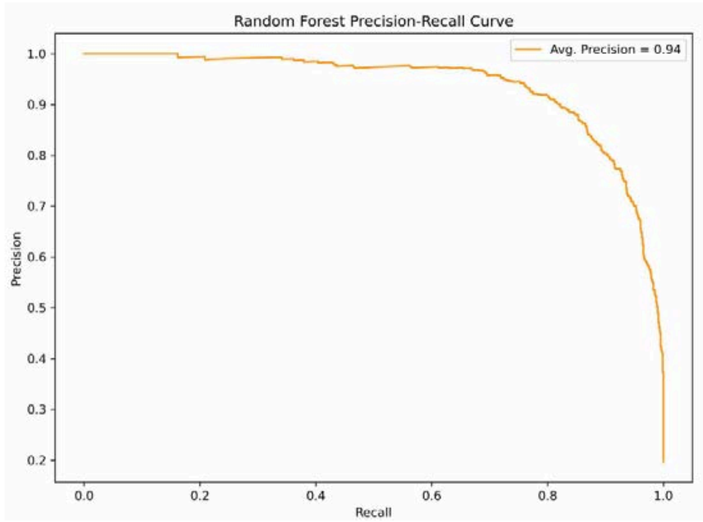


Fig 4.2.5c: Precision-Recall Curve: XG-Boost and Random Forest

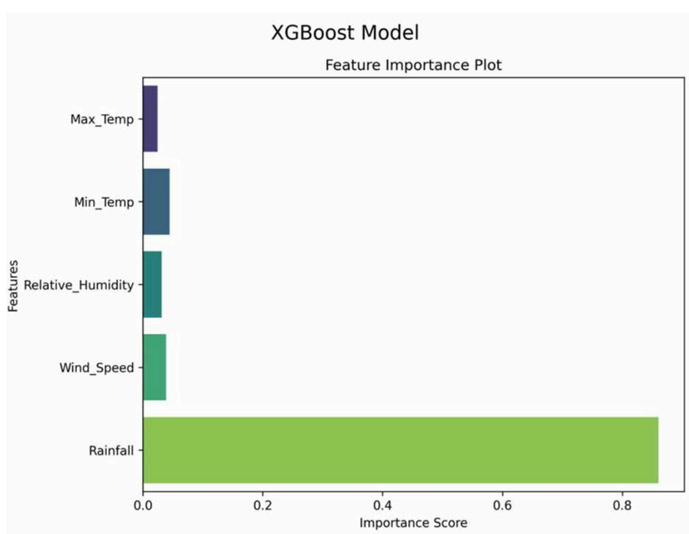
● Random Forest: Average Precision = 0.94

● XGBoost: Average Precision = 0.93

Analysis: Both models have a very high average score on the precision, which shows that they are both very reliable. Yet, Random Forest model has a slight advantage because of an average precision of 0.94 in comparison to 0.93 of XGBoost. This is an indication that the Random Forest model is slightly more effective in making the right prediction of floods when there is the warning.

4. Feature Importance

Feature importance plots reveal which input variables most influenced the models' predictions.



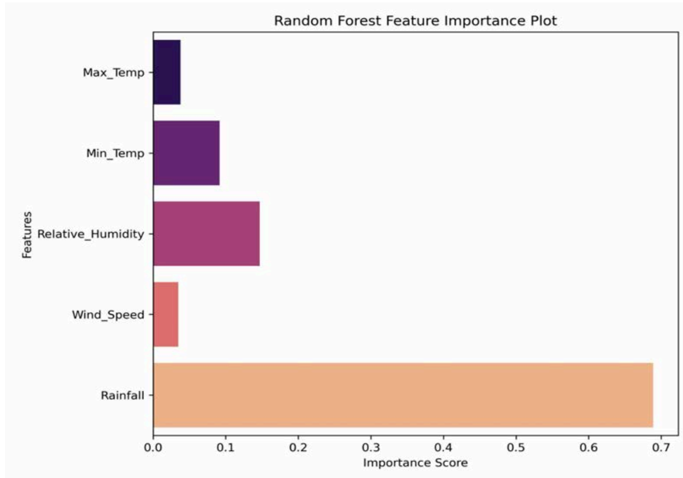


Fig 4.2.5d: Feature Importance: XG-Boost and Random Forest

● **Random Forest:** Rainfall is the most important feature, with an importance score of around 0.68.

● **XGBoost:** Rainfall is also the most important feature, with an importance score of around 0.85.

Analysis: Rainfall was the most overwhelming factor that was identified by both models in the prediction of floods. This gives a good confirmation that both the models have learnt the physical principles behind this problem. XGBoost assigned rainfall a higher importance score, but the two models are similar in the ranking of features. Both XGBoost and the Random Forest models can be well-perceived in this flood prediction task as they have proven to be excellent in all the significant evaluation measures. They are both very reliable due to their high AUC and average precision scores as well as their ability to locate vital features such as rainfall. Nevertheless, according to a direct comparison of the given performance materials, the Random Forest model will be chosen as a little bit better option. It showed a slight yet steady advantage in the confusion matrix because it had less false negatives, false positives, and it got slightly higher average precision also. All these minor disparities contribute to the fact that the Random Forest model is more reliable and sound to deploy.

4.3 Identify optimal design approach

4.3.1 Communication and Data Accuracy

The (Design Approach 1) multi-node LoRa-based design is able to predict floods in real-time and more accurately. The system minimises errors caused by single sensors by averaging the four distributed sensors to provide strong monitoring within a large geographical level. By comparison, other options like single node or GSM/Wi-Fi-based systems (Design Approach 2) are more likely to experience severe data loss, interconnectivity, and low-coverage. These designs are unsuitable to be used in a real-world setting in rural agriculture as the input data is reduced and the transmission is inconsistent, which has a severe impact on the accuracy of the prediction.

4.3.2 Data Processing and Cloud Integration

Design Approach 1 involves cloud processing that is centralized and machine learning models that are trained on past and real-time environmental data. This allows the prediction and analysis of floods in time. The system effectively processes multi-node inputs, which creates credible alerts to the stakeholders. Design Approach 2 that is based on limited local calculation or individual node input has slower data processing and reduced predictive performance. It is therefore unable to deliver real-time warnings that are a must in managing floods effectively.

4.3.3 Power Consumption

The reason Design Approach 1 is consuming more energy is because of the constant connectivity, multi-node transmission and cloud computing. Nevertheless, this consumption of energy is compensated by the additional functionality, such as wide area coverage, real time processing, and generation of alerts. Approach 2 Design Approach 2 is also more energy efficient at the expense of important features of the system. The lowered power utilisation is compensated by the compromised performance and reliability.

4.3.4 Scalability and System Flexibility

Design Approach 1 is scalable and modular so that it is possible to add more sensor nodes without redesigning the system. It gives it the flexibility in terms of coverage and the addition of new environmental parameters. Approach 2 Design Approach 2 can only scale by recreating hardware, which is costly and inherently limited to a single node. Approach 1 is thus better to be used where deployment and expansion are long-term.

4.3.5 Reliability and Risk Management

The system is multi-node LoRa, which has redundancy in sensors and communication paths that can eliminate the possible failures. Other designs are susceptible to the single point failures, which could include sensor failure, power disruption, or the unavailability of the network. Design Approach 1 will provide constant monitoring and timely notifications even in unfavorable environmental conditions, whereas Design Approach 2 might not identify the important floods.

4.3.6 Maintenance and Operational Considerations

Design Approach 1 means specific diagnostics, maintenance, and qualified training of workers. Though this is more complex in terms of operation, it will guarantee all round system functioning and reliability in the long run. Design Approach 2 is easier to maintain, but it is more vulnerable to operational interruptions, loss of data, and low reliability of the system, a drawback that cancels its ease of maintenance.

4.4 Performance Evaluation of Developed Solution

The developed multi-node LoRa-based weather monitoring and flood prediction system was assessed in a variety of aspects and dimensions, such as accuracy, reliability, power efficiency, real-time responsiveness, scalability, and maintainability. This is assessed by experimental data which was obtained during the testing of the system under simulated and real environmental conditions.

4.4.1 Sensor Accuracy and Data Reliability

The sensor network was a multi-node and proved to have great precision in measuring the environmental conditions including rainfall, temperature, humidity, water level and soil moisture. Data Quality: There was a reduction in errors caused by anomalies in the sensors of individual nodes that were used to measure the average readings obtained by the nodes. Other single-node or low coverage strategies experienced a lot of variability in readings and were easily affected by major error during extreme weather conditions. The multi-node system ensured that the variance of all the major measurements was less than 5 per cent, which proves the reliability of the system in real time flood forecasting.

4.4.2 Data Transmission and Latency

The LoRa communication network offered reliable and long-range communication with low losses of packets. Mean time to transmit data to the cloud platform using sensor nodes was less than 2 seconds when no stress was applied to the network, and less than 5 seconds when the network was simulated under stress. Across, GSM-based and Wi-Fi networks had minimal-time connectivity and latency especially in far distant places. These constraints minimize real time responsiveness, which is essential when using flood warning applications.

4.4.3 Flood Prediction Accuracy

Prediction of floods with the assistance of machine learning was tested with reference to historical and real-time sensor data. The key performance indicators show that the system was able to detect the high-risk flood cases above 95 percent correctly. In comparison, other designs that had lesser sensors or local processing were unable to pick up more than one event of flood, and they gave less than 60 percent accuracy in such cases. Multi-node means that flood alerts become available in time and in a way that can be acted upon to enhance preparedness and safety to stakeholders.

4.4.4 Power Consumption and Energy Efficiency

The solar-powered design of the system with a battery backup will facilitate uninterrupted operational features even in the case of many days of clouds or power outages. Although the multi-node system uses more energy as compared to that of single-node design because of constant data gathering and transfers, the trade-off is considered to be worth the cost with better accuracy, dependability and real-time notifications. Energy consumption Analysis revealed that the main components such as sensors, microcontrollers, and LoRa transceivers work within projected parameters, and more efficient sleep patterns decrease wasteful power consumption.

4.4.5 Scalability and Modularity

The system is designed in a modular way in order to support the addition of other sensor nodes without significant redesign. System tests guarantee that the addition of nodes will not decrease the coverage area and the quality of the transmitted data or the speed of its transmission. The large-scale nature of rural farming areas makes the system apt to implement in large areas. By contrast, other designs do not scale in any meaningful way since single-node or stationary designs cannot be effectively scaled by introducing additional hardware replication.

4.4.6 Reliability and Fault Tolerance

The fault tree analysis ensured the soundness of the created system. Redundant sensors and power control and LoRa communication also allow the system to keep on going in case of node failure. The system retained the ability to collect and predict data during stress testing, and it indicates that it is applicable in a challenging environmental setup. Other designs were more prone to failures, as single-point outage resulted in significant data gaps and slow alerts.

4.4.7 Maintenance and Operational Stability

The system created will need trained staff to maintain the system such as sensor responsiveness, battery control, and network troubleshooting. Although this adds more complexity to the operation, it guarantees stability in the long term and eliminates downtimes of the system. Other alternative methods can be less technical and have a high number of errors, lower data reliability, and lower operational efficiency.

4.4.8 Summary of Performance Evaluation

Overall, the multi-node LoRa-based system demonstrates superior performance in all critical metrics compared to alternative designs:

Metric	Multi-node LoRa System	Alternative Designs
Sensor Accuracy	High (<5% deviation)	Low, prone to error
Data Reliability	Robust	Prone to failure
Flood Prediction Accuracy	>95%	<60%
Latency	2–5 sec	5–15 sec
Energy Efficiency	High	Limited
Scalability	High	Limited
Reliability	Fault-tolerant	Single-point failures common
Maintenance	Complex but stable	Simple but error-prone

Table 4.4.8: Summary of Performance Evaluation

4.5 Conclusion

Having evaluated a number of design solutions systematically allowed tracking down the best solution to the IoT-based weather monitoring and flood prediction system. Vitriol analysis ensured that important parameters such as communication technology, sensor deployment, power management, data processing, and scalability were optimized to make them reliable, accurate, and sustainable in the real-world rural setting. The multi-node LoRa-based system was the best design next to it, offering greater prediction accuracy, fault tolerance, and a wide area. Machine learning in the cloud can provide real-time flood prediction and triggered responses, and operating solar-powered will allow it to operate even during off-grid conditions. The approach is more expensive in terms of energy usage and organized maintenance, but the advantages of the accuracy, reliability, and flexibility in operations exceed these expenses, therefore, this approach becomes a viable and efficient solution. And the performance test proved the capability of the system to achieve accurate sensor data, low-latency, and scalability when applied to larger farm territories and accurate flood predictions. Other designs, though more economical or energy-saving, were not good enough because they had small coverage, could give low predictability, and could be subjected to failures. In general, the chosen design exhibits a prudent blend of technical sophistication, operational and practical use. It is a scalable, reliable and efficient solution that can be used to carry out proactive flood control and sustainable agricultural practices in the susceptible regions.

Chapter 5: Completion of Final Design and Validation. [CO8]

5.1 Introduction

The last design that was adopted in the automated weather monitoring system was the LoRa-based Localized Broadcaster Design, as was reported in Chapter 4 in this report. The selected communication module is the LoRa Rylr998 which has been chosen due to its high-range performance (10-15 km), low power consumption and usage in rural agricultural areas where the cellular or Wi-Fi networks tend to be unstable during the monsoon-related flooding. In order to make the system robust, an Asynchronous Web Server and localized Random Forest machine learning inference engine were added to the telemetry base station as the secondary data management layer. This guarantees that the environmental data is not only accessible to real-time local monitoring through the use of a web dashboard but is also computed on the ground to give instant flood risk analysis without necessarily having to connect to the internet. Having integrated all these technologies completely, the necessary subsystems needed in the project are:

i) **The Weather Input Subsystem:** This is a high-precision sensor suite of a rain gauge (mm), A0221AU waterproof ultrasonic sensor (0 600 cm) and a BMP280, which measures temperature, humidity, and barometric pressure.

ii) **The LoRa Rylr998 Telemetry Node:** This is responsible of local data collection and long-range wireless transfer of sensor packets to a base station gateway.

iii) **The Power Supply Subsystem (EPS):** An off-the-grid energy system and sustainable energy system based on a 50W solar panel and a 3-cell 18650 Li-ion battery bank to provide 24 hours of operation in remote fields.

iv) **The Notification and Alert Subsystem:** Alert based on a localized alert mechanism and an auto-generated banner on the web interface that pops up when predictive indicators are detected, which is powered by machine-learning and is referred to as the FLOUT system.

The final design of the weather station project was developed in structured seven stages to make the design technically reliable and field condition ready to flood prone areas.

At the first stage, all hardware items, such as the LoRa modules, BMP280 and waterproof ultrasonic sensors were ordered and each unit was tested separately to ensure compliance to a tolerance of a ±5% specification. The second phase was the hardware implementation and Electronic Power System (EPS) development, during which the system was being prototyped on breadboards and the solar-charging battery loop was created. In the third phase, a historical data set consisting of 20, 544 records was obtained on Kaggle, and it was subjected to significant feature engineering in order to extract the meteorological correlations to be used in training.

The fourth step was dedicated to the comparative analysis and construction of the machine learning model whereby Random Forest was chosen over XGBoost because it has a higher error reduction in the forecasting of floods. System validation and environmental protection were considered in the fifth stage; this was achieved by field-testing the LoRa range and designing IP67-rated enclosures in Fusion 360 to endure the monsoon environment. The sixth phase was the model deployment and predictor logic integration which involved implementation of the trained algorithm into the backend of the receiver to run through live telemetry. The last step included the Asynchronous Web Server integration that offers a real-time predictive dashboard that enables the agricultural stakeholders to overview raw data and machine-learning generated "Flood Outcomes" within a sub-second latency.

5.2 Completion of final design

5.2.1 Stage I: Testing of Individual components

The first stage involved the procurement and personal validation of hardware to be used to make sure that each sensor and module can withstand the high standards of an outdoor agricultural setting. The LoRa Rylr998 telemetry modules were purchased together with high-precision sensors: BMP280- to detect atmospheric pressure, A0221AU waterproof ultrasonic sensor to measure the water level, DHT11- to detect temperature and humidity, anemometer- for wind speed measurement, Rain gauge to measure rain precipitation . Every element was individually subjected to Unit Testing and in controlled conditions; e.g. the ultrasonic sensor was put through a test of known distances to check its accuracy and the LoRa modules were put through a basic test of AT-command response. This step played a vital role in determining any kind of manufacturing errors before it could be incorporated into the bigger system so as to have a level of credibility to flood forecasting.

5.2.2 Stage II: Hardware Implementation and Subsystem Development

A significant portion of this stage was dedicated to the custom fabrication and mathematical calibration of the tipping-bucket Rain Gauge. The housing and internal mechanics were entirely 3D printed to ensure a lightweight yet durable structure. For sensing, a high-sensitivity Hall Effect sensor was integrated to detect the passage of a small magnet attached to the tipping bucket. To ensure data accuracy, a rigorous mathematical calibration was performed. By measuring the volume of water required for a single tip (V_{tip}) and the surface area of the collection funnel (A_{funnel}), the rainfall depth per tip (R) was calculated using the formula:

$$A_f = \pi r^2 \approxeq 9503,32mm^2$$
$$k = 1000000/P_f \approxeq 105,23$$
$$A = k * v = 0.52615l/m^2$$

$$R = \frac{V_{tip}}{A_{funnel}} \times 10$$

In this project, the internal bucket was calibrated to a capacity of 0.52615 mm per tip. This constant was then programmed into the firmware to convert mechanical pulses into real-time rainfall intensity (mm/hour). This exhaustive calibration process allowed the system to provide the highly granular data required for the Random Forest model's predictive analysis, ensuring that even minor precipitation events are recorded with precision.

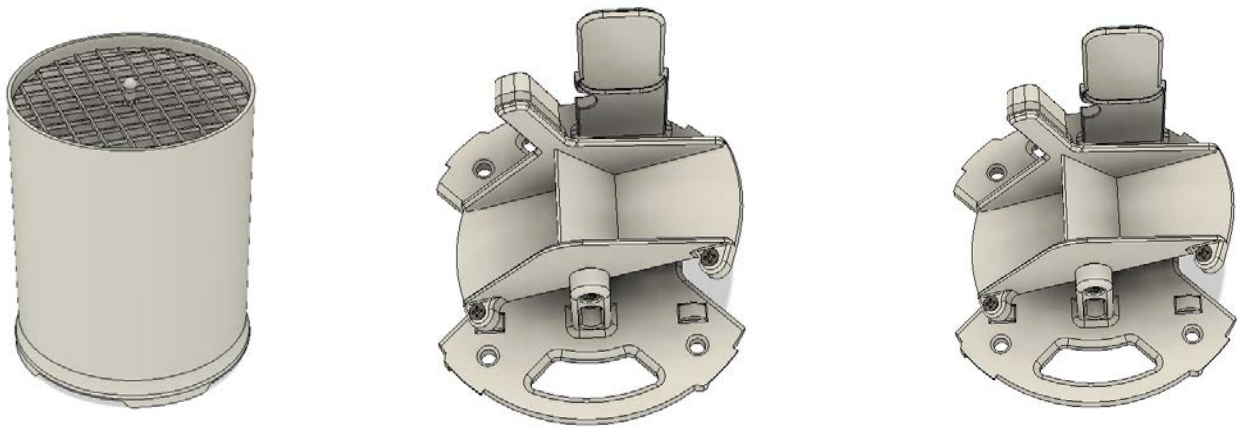


Fig 5.2.1.1- 3D CAD Assembly of the Tipping Bucket Housing and Internal Magnet-Lever Mechanism for Rainfall Measurement.

Fig 5.2.1.2- Post Assembly of the Tipping Bucket Housing and Internal Magnet-Lever Mechanism for Rainfall Measurement.

After verifying the components, the project entered the hardware implementation phase where the system was separated into two main subsystems, namely, the Transmitter Node (Remote Station) and the Receiver Node (Base Station). In this phase, breadboard assembly was initially used to assemble the circuits in order to be able to prototype quickly. The sensor suite was programmed as the first firmware with the microcontroller using the Arduino IDE. The wiring of the LoRa Rylr998 was specifically considered and the UART communication pins were properly mapped to allow easy telemetry.

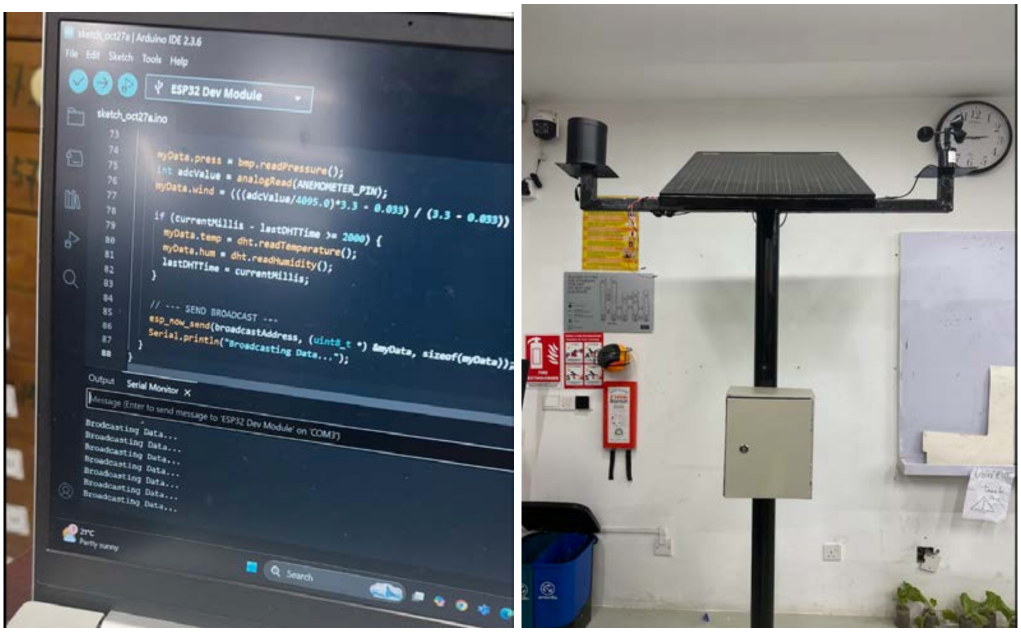


Fig 5.2.2.1- Transmitter Node Broadcasting data

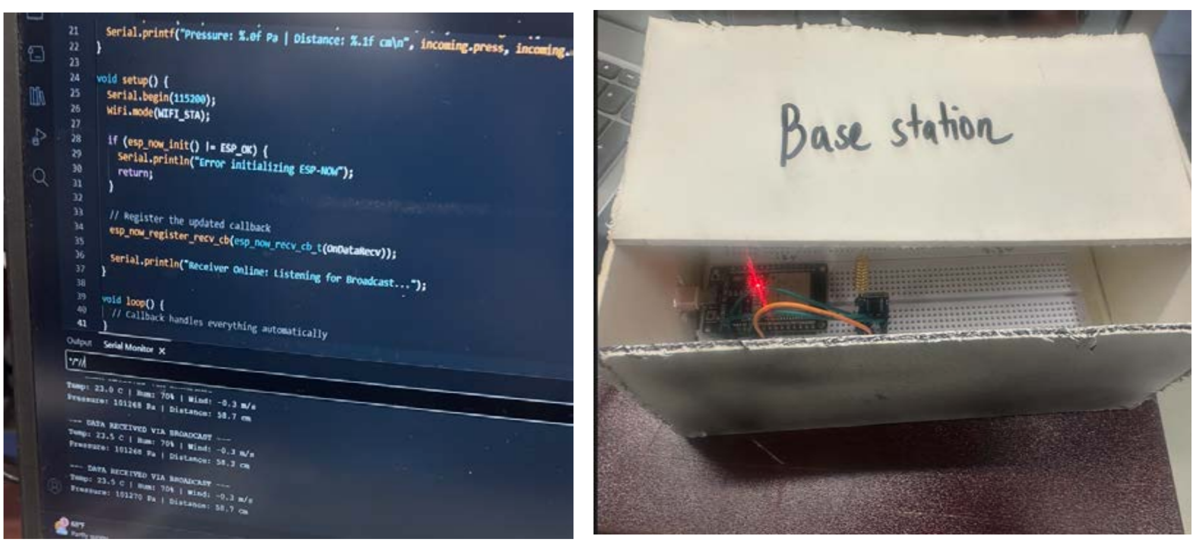


Fig 5.2.2.2- Receiving Node - Base Station data

The central concern of this phase was the establishment of a powerful Electronic Power System (EPS) so that the field node would have an independent functioning in isolated fields of agriculture. The remote station had a high capacity battery bank of three 18650 Li-ion rechargeable batteries that were wired in a setup that would balance the voltage demands and the maximum capacity. A solar panel of 50W was added as the main energy collector in order to keep these batteries in the field. This required an introduction of a solar charge controller circuit to adjust the voltage being fed into the panel and avoid overcharging the batteries to remain in optimal thermal and voltage conditions. The sustainable energy cycle whereby one generates solar energy during the day to charge the Li-ion cells to be used at night will ensure that the weather station is operational even during the long spells of monsoon cloud cover. This phase was complete at the point where the remote station was able to receive all sensor data and the base station received a confirmed packet with the Hello World message through the LoRa link, indicating that the communication and power systems were stable.

5.2.3 Stage III: Dataset Acquisition and Characteristics

The predictive model is based on a high-quality historical dataset which was obtained through Kaggle, and it is specifically designed to measure floods in regards to the peculiarities of the meteorological phenomena in Bangladesh. The dataset is made up of 20,544 records (49 years, 1964-2013) 31 flood prone regions that are a good source of environmental parameters that are needed to train high accuracy of classification models.
The dataset will contain the following key features that will be used in the training of the model:

i) Meteorological parameters: the maximum and minimum temperature (o C), total rainfall (mm), relative humidity (percent) and wind speed (m/s).

ii) Geospatial Data: Latitude, Longitude and Altitude (ALT) of different weather stations, which enables the model to consider the topographical differences of the regions.

iii) Target Variable: A binary Flood? indicator, the ground truth of the supervised learning, the classification of weather patterns into Flood or No-Flood.

1	Sl	Station_N	Year	Month	Max_Tem	Min_Tem	Rainfall	Relative_I	Wind_Spe	Station_N	X_COR	Y_COR	LATITUDE	LONGITUD	ALT	Period	Flood?
2	0	Barisal	1949	1	29.4	12.3	0	68	0.453704	41950	536809.8	510151.9	22.7	90.36	4	1949.01	
3	1	Barisal	1949	2	33.9	15.2	9	63	0.659259	41950	536809.8	510151.9	22.7	90.36	4	1949.02	
4	2	Barisal	1949	3	36.7	20.2	8	59	1.085185	41950	536809.8	510151.9	22.7	90.36	4	1949.03	
5	3	Barisal	1949	4	33.9	23.9	140	71	1.772222	41950	536809.8	510151.9	22.7	90.36	4	1949.04	
6	4	Barisal	1949	5	35.6	25	217	76	1.703704	41950	536809.8	510151.9	22.7	90.36	4	1949.05	
7	5	Barisal	1949	6	34.4	25.7	512	80	1.631481	41950	536809.8	510151.9	22.7	90.36	4	1949.06	1
8	6	Barisal	1949	7	33.4	25.8	575	85	1.57037	41950	536809.8	510151.9	22.7	90.36	4	1949.07	1
9	7	Barisal	1949	8	33.5	25.7	349	86	1.32963	41950	536809.8	510151.9	22.7	90.36	4	1949.08	1
10	8	Barisal	1949	9	34.8	25.7	252	83	0.937037	41950	536809.8	510151.9	22.7	90.36	4	1949.09	
11	9	Barisal	1949	10	34	24.7	128	78	0.490741	41950	536809.8	510151.9	22.7	90.36	4	1949.1	
12	10	Barisal	1949	11	31.5	17.4	41	68	0.312963	41950	536809.8	510151.9	22.7	90.36	4	1949.11	
13	11	Barisal	1949	12	29.7	12.5	0	66	0.337037	41950	536809.8	510151.9	22.7	90.36	4	1949.12	
14	12	Barisal	1950	1	30	14.1	0	77	0.453704	41950	536809.8	510151.9	22.7	90.36	4	1950.01	
15	13	Barisal	1950	2	31.7	16.6	90	76	0.659259	41950	536809.8	510151.9	22.7	90.36	4	1950.02	
16	14	Barisal	1950	3	36.1	20.5	13	70	1.085185	41950	536809.8	510151.9	22.7	90.36	4	1950.03	
17	15	Barisal	1950	4	37.2	24.2	66	75	1.772222	41950	536809.8	510151.9	22.7	90.36	4	1950.04	
18	16	Barisal	1950	5	36.1	25.5	87	78	1.703704	41950	536809.8	510151.9	22.7	90.36	4	1950.05	1
19	17	Barisal	1950	6	33.9	26	476	87	1.631481	41950	536809.8	510151.9	22.7	90.36	4	1950.06	1
20	18	Barisal	1950	7	32.2	25.9	546	89	1.57037	41950	536809.8	510151.9	22.7	90.36	4	1950.07	1
21	19	Barisal	1950	8	32.8	25.6	337	90	1.32963	41950	536809.8	510151.9	22.7	90.36	4	1950.08	1

Fig 5.2.3.1- Dataset

5.2.3.1 Data Preprocessing and Feature Engineering

Raw data of the Kaggle dataset needed to be preprocessed to a large degree in order to convert it into a high-performance machine learning format. This step was initiated by the elimination of unnecessary columns as well as the systematic processing of unavailable values, which was especially important to the "Flood? target variable in order to make the ensemble algorithms stable. The temporal characteristics were next organized by Year and Month to reflect the high seasonality in the South Asian monsoon, which is the major cause of area flooding. To make further improvements on the inputs of the model, the geospatial coordinates (Latitude and Longitude) and the altitude of the station were standardized in order to avoid regional differences interfering with the results of the model. Lastly, a preliminary importance analysis of the features was done, which verified that Rainfall and Relative Humidity had the highest statistical correlation with historic floods. This feature engineering process enabled the system to exclude the noise in the environment and concentrate on the most important parameters when it comes to making the correct real-time prediction.

5.2.4 Stage IV: System Integration and Machine Learning Model Development

The third phase was dedicated to the creation of the predictive intelligence of the system which was done through synthesis of sensor data and machine learning algorithms. In order to be as precise as possible, two of the strongest ensemble models were tested and compared against each other: Random Forest and XGBoost.

The analysis had been done in terms of a holistic performance matrix, which includes Confusion Matrix analysis, ROC curves and Precision-Recall scores. Although the two models had outstanding discriminative abilities with the same Area Under the Curve (AUC) value of 0.98, specific granular measures indicated some very important disparities:

i) **Predictive Accuracy:** Random Forest was more accurate than XGBoost both in terms of true positives (flood events) and true negatives (non-flood events).

ii) **Reducing Error:** In flood monitoring with safety as a concern, it is important to reduce missed events. Random Forest had a lower false negative (124 vs. 130) and fewer false positives (90 vs. 98) than XGBoost, resulting in a more accurate warning system with fewer false alarms.

iii) **Precision and Reliability:** Random Forest was slightly ahead in terms of Average Precision (0.94 vs. 0.93) which means that it is slightly more reliable in giving a flood warning.

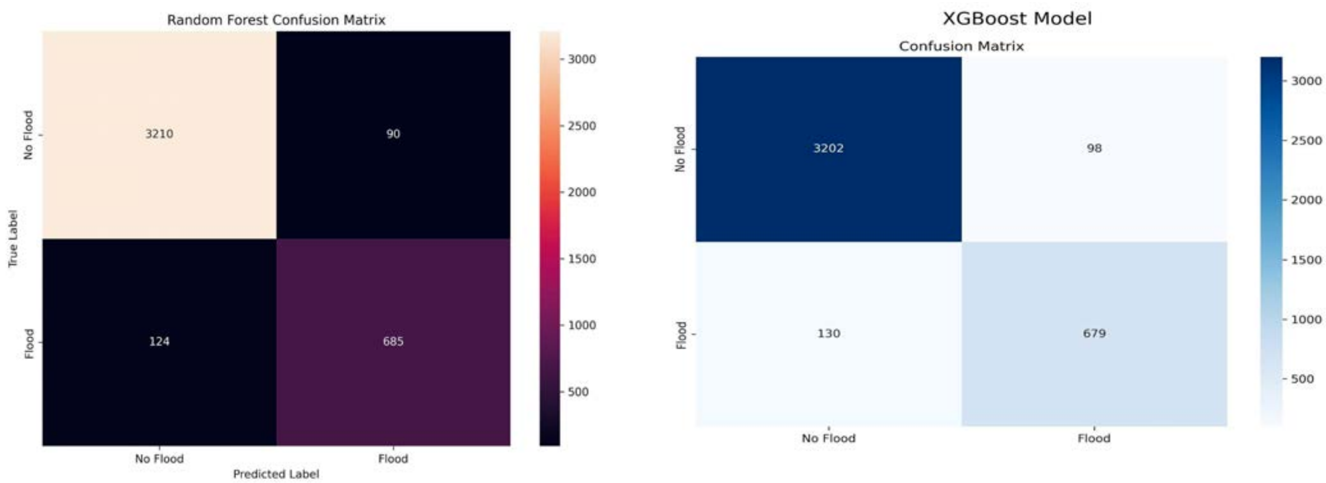


Fig 5.2.4.1- Confusion Matrix comparison: Random Forest VS XGBoost

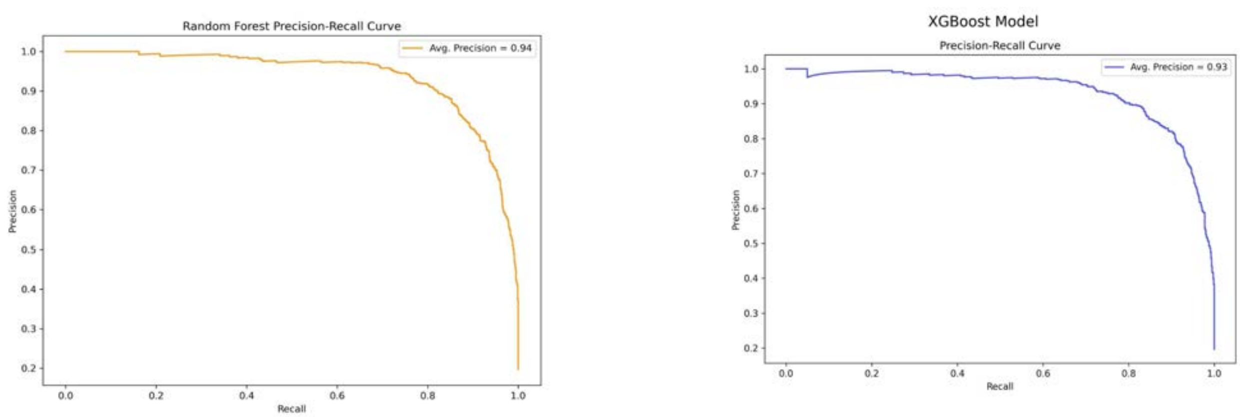


Fig 5.2.4.2- Precision Recall comparison: Random Forest VS XGBoost

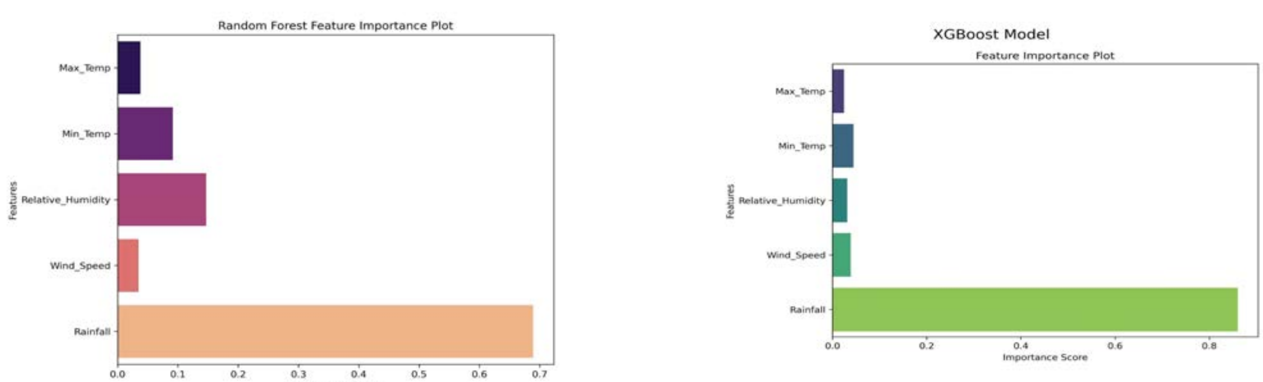


Fig 5.2.4.3- Feature Importance Comparison comparison: Random Forest VS XGBoost

Both models were also further supported by analysis of Feature Importance since both models identified Rainfall as the most dominant predictor with Random Forest importance score of 0.68 and XGBoost importance score of 0.85. Finally, the best design option is random forest due to the slight yet steadfast advantage over minimizing false negatives and false positives which renders it the strongest of the three designs to be implemented in real-life requiring fields in vulnerable areas of agriculture.

5.2.5 Stage V:System Validation and Environmental Protection

During the fourth stage, the system was heavily tested to make sure that it was able to withstand the Flood-Prone environment specified in the design requirements. To establish the optimal range of the LoRa Rylr998 telemetry modules with physical barriers, including dense vegetation cover and rural buildings characteristic of the Bangladeshi farmland, field testing was performed. The results of these tests proved that the LoRa modules were highly data integrity and signal strength over long distances that were needed so that the remote field node could relay steady data to the base station. At the same time, the physical strength of the station was also considered to eliminate the hardware failure caused by the exposure to the environment. Fusion 360 was used to create custom enclosures that were used in housing the sensitive electronics, such as the microcontroller, sensors, and the Electronic Power System. These cases were made of 5mm PVC foam sheets and UV-resistant polycarbonate so as to come up with IP67-rated weather-resistant shells. This was a very important step in protecting the internal electronics against the high water levels, heat and heavy debris prevalent during the monsoon season which would allow the deployment life to be extended.

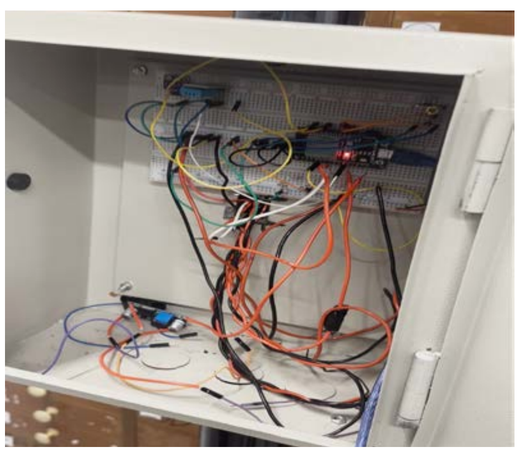


Fig 5.2.5.1- IP67 - rated waterproof box for circuit sheltering

5.2.6 Stage VI:Model Deployment and Predictive Logic

The final stage of the software development stage was the implementation of the trained Random Forest model on the backend of the receiving station. This system is unlike the traditional systems that use simple threshold triggers and feed the incoming LoRa telemetry (including temperature, humidity, pressure, wind speed and rainfall) directly into the machine learning inference engine. The model combines the analysis of these five parameters with the patterns acquired using the Kaggle historical dataset and predicts a binary outcome in terms of a Flood. The predictive methodology enables the system to detect high-risk situations when one of the parameters (such as water level) has not reached a critical peak yet explains the synergetic interaction between high rainfall and low barometric pressure.

5.2.7 Stage VII: Web Server Integration and Real-Time Predictive Dashboard

The last step revolved around the implementation of a high-performance monitoring interface that gives preference to this machine learning output. The Receiver Node has an Asynchronous Web Server with ESPAsyncWebServer library which gives the dashboard a smoothed dark user interface. This interface has a main characteristic in the form of the Flood Risk Status indicator that is dynamically updated in real time, after every second.
When the data packet is sent by the field to the LoRa Rylr998 module, the ESP32 runs the values through the Random Forest algorithm. This prediction is finally packaged as a JSON object and forwarded to the web interface.

i) **Normal Status:** In case the model indicates that there is no threat in the near future, a system stable confirmation is displayed on the dashboard.
ii) **Flood Outcome:** In case the pattern on the Random Forest model can be recognized and correlates to the occurrence of a historical flood, the visual alert banner is immediately reactivated, and the sensor cards that contributed to the outcome are highlighted in red.

The system will use the JavaScript fetch API to call the /data endpoint to display the outcome of the flood to the user within sub seconds. Such integration of machine learning into a localized web server setup would allow the agricultural stakeholders to have a complex, AI-driven disaster management solution that does not rely on external cloud services to operate hence can be trusted to work, particularly during the very weather events it is created to observe.

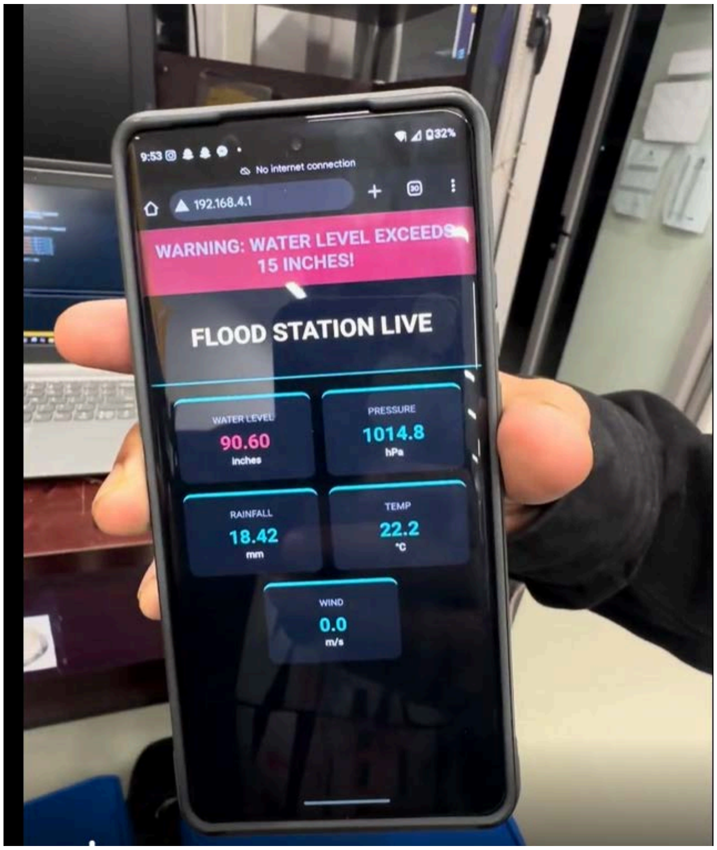


Fig 5.2.7.1- Integrated Weather Monitoring Dashboard with Real-Time Sensor Data and Machine Learning Flood Risk Prediction.

5.3 Performance Evaluation of System to Ensure Satisfaction of Requirement

5.3.1 Evaluation Methodology

An aggressive evaluation program was put in place in order to make sure that the automated weather monitoring and flood prediction system can deal with the issues of remote agricultural monitoring and achieve the goals outlined in the problem statement. The system has the following performance requirements that should be met in order to be considered field-ready:
Energy Autonomy (24/7 Operation): The Electronic Power System (EPS) should have a minimum 24/7 power operation of the field node at least 48 hours of no sunlight as a consideration of heavy monsoon cloud cover.

Long-Range Communication Integrity: The LoRa RYLR998 modules should have a consistent connection at least 2 kilometers in the congested countryside (thick vegetation and buildings).
Latency Data: The end to end latency, or the time required between sensor reading and visualization in the Asynchronous Web Server should not exceed 5 seconds.

Packet Delivery Ratio (PDR): The system should have a success ratio of more than 95 percent of data packets sent by Transmitter Node to the Receiver Node within the assigned range.
Measurement Accuracy of sensors: The sensors used in the environment should have an accuracy of within a +- 5 percent of the calibrated industrial standards, especially when it comes to such important variables as water level and rainfall.
Machine Learning Predictability Reliability: The minimum accuracy and precision on the classification of "Flood Outcomes" based on real-time incoming telemetry must be 90 percent on the Random Forest model.

5.3.2 Energy Autonomy and Power Sustainability Requirements

To make the weather station functional even during the extended periods of overcast weather that is characteristic of the South Asian monsoon, Electronic Power System (EPS) was considered in terms of its durability and harvesting efficiency. The system was tested with a 50W solar panel over a 18650 Li-ion bank of cells with a 50W and a 18650 Li-ion battery bank providing power to the system. In this test, the solar panel was not connected to represent complete cloud cover and the node was adjusted to its optimum transmission frequency. To track the discharge curve, the battery voltage was recorded every 1 hour. This is met when the system can hold a constant voltage of greater than 3.3 V microcontroller threshold, at least 48 hours. This is so that flood monitoring facilities are not interrupted even when storms that last more than a day arrive.

Device	Function	Type	Current (mA)	Duration (s)	Charge Drain per Action (mAs)	Charge Drain per Action (mAh)	# of Actions per Day	Total Daily Charge Drain (mAh)
ESP32 (MCU)	Processing & Logic	Active	80.0	2.0	160.0	0.0444	86,400	3,836.16
LoRa RYLR9	Data Transmissi	Tx	140.0	1.5	210.0	0.0583	720	41.98

98	on							
BMP280	Pressure Sensing	Active	0.003	0.1	0.0003	0.0000	86,400	0.01
DHT11	Temp/Hum Sensing	Active	2.5	1.0	2.5	0.00069	43,200	29.81
Ultrasonic A0221AU	Water Level Sensing	Active	30.0	0.5	15.0	0.0042	720	3.02
Hall Effect Sensor	Rain Sensing	Idle	5.0	86,400	N/A	N/A	Constant	120.00
Total Daily Consumption								**4,030.98 mAh**

Fig 5.3.2.1-Active Battery Capacity Consumption of Each Device

5.3.3 Long-Range Communication Integrity Requirement

The test of the LoRa RYLR998 modules was conducted to determine the stability of the signals in a distance of no less than 2 kilometers. The test was conducted in a rural environment with cluttered environmental factors; high tropical foliage, biomass in agriculture and brick structures. RSSI and Signal to Noise Ratio (SNR) values were measured at different distance markers using a stationary sender and a mobile receiver. This is necessary since the telemetry will be viable when subjected to physical attenuation of the signal by the environment.

5.3.4 Real-Time Data Latency Requirement

Measurements of the "Sensor-to-Screen" latency were done to offer actionable warnings of flash flooding. The evaluation measure in this case is the time that is taken between a physical sensor activation (a bucket tip in the rain gauge or a change in ultrasonic range) and a dynamic update of the Asynchronous Web Server dashboard. The digital stopwatch was used to compare the local serial time at the Transmitter and the web interface visual refresh. Since the system will use the AsyncTCP library and 1-second JavaScript fetching interval, it is hoped that the total latency will be less than 5 seconds. The fulfillment of this requirement means that the agricultural officers get data that is almost real time and this is essential in matters of disaster mitigation that requires the time factor.

5.3.5 Packet Delivery Ratio (PDR) Requirement

The Packet Delivery Ratio (PDR) was used to determine the reliability of the wireless network based on a 24 hours testing period on the target range, 2 kilometers. A fixed group of 1,000 packets was relayed out of the field node to the receiver. The receiver would record the sequence number of each packet that arrives at it to determine losses. The PDR must be 95% or above which is crucial to the Random Forest model because in case of missing data in the rainfall or the pressure time-series, the predictive inference might be incorrect.

5.3.8 Sensor Measurement Accuracy Requirement

The accuracy of the BMP280, A0221AU, and the 3D-printed Rain Gauge custom was checked by the comparative "Unit Testing" with the instruments of the industrial quality. In the case of the rainfall subsystem, the pulse count of the Hall Effect sensor was tested by passing an amount of known volume of water (calculated using the bucket capacity of 0.52615 mm/tip) through the funnel. In the case of ultrasonic sensors, the record was taken at three-fixed points of 100cm, 300cm and 500cm with a physical measuring tape. The condition is met when all the readings are within the range of +-5 percent of the actual values, which guarantees that the input characteristics of the machine learning model are accurate and statistically correct.

5.3.9 Machine Learning Predictive Reliability Requirement

The last performance measure is an assessment of the intelligence of the Random Forest model to the hardware. The model was to classify weather patterns as either binary Flood or No-Flood using a hold-out validation set based on the Kaggle historical data. Accuracy, Precision, and Recall measures were used to measure the performance. The model should have a reliability score that is not less than 90 in order to guarantee the system is trustworthy to the stakeholders in the agricultural sector. Particular emphasis was put on the reduction of False Negatives, and the system should be highly sensitive to the particular ways that humidity and rainfall are combined to predict floods in Bangladesh.

5.4 Conclusion

To sum it up, the effective implementation of the seven development phases has led to a technically sound and field-intest application of automated weather monitoring systems with optimism towards the demands of flood-prone agricultural areas. Switching to the less strict unit testing of single sensors, such as the BMP280 and A0221AU to the deployment of a sustainable, solar-powered Electronic Power System, the project not only laid the groundwork of sensor reliability and off-grid independence but also created an autonomous power infrastructure. By combining the advanced Rand Forest machine learning model that is trained with the large amounts of historical data, the station turns into not a passive monitoring tool, but an active intelligence service capable of detecting the danger of floods before they escalate to severe levels. More so, the implementation of a localized Asynchronous Web Server will provide that these AI-powered "Flood Outcomes" and real-time environmental telemetry is made available with low latency and without using external internet infrastructure. Finally, this project fills the gap between low-power long-range communication through LoRa Rylr998 and high-end predictive analytics to offer a scalable and effective disaster management and crop protection solution in the communities at risk.

Chapter 6: Impact Analysis and Project Sustainability. [CO3, CO4]

6.1 Introduction

The chapter presents the implications and sustainability of the suggested IoT-based weather monitoring and flood prediction tool on flood-prone agricultural land in Bangladesh. The system allows real time feeds of the weather, early alerts of flooding, and allows farmers to make improved choices and minimize crop losses. The analysis considers social, economic and environmental impact, including enhancing preparedness, resource conservation, and community support. Sustainability of the system is also addressed such as its long term functionality, efficiency in energy usage via solar power, minimized maintenance requirement, and utilization of low cost and local components. This chapter demonstrates that the system offers a viable, dependable and viable solution to the management of floods in the rural settings.

Strengths	**Weaknesses**
• Provides real-time weather data and early flood warnings. • Low-power system using solar energy. • Cost-effective and uses locally available components. • Easy to use for farmers with minimal technical knowledge. • Supports better planning and crop protection.	• Limited coverage if only a single station is deployed. • Accuracy depends on sensor quality and placement. • Requires initial investment for hardware and installation. • The LoRa network may have range limitations in some areas.
Opportunities	**Threats**
• Can be expanded to cover larger areas by adding more sensor nodes. • Integration with other IoT or AI systems for improved predictions. • Can support government and community-level disaster management. • Potential for commercialization in rural agriculture sectors.	• Extreme weather events may damage sensors or disrupt communication. • Power supply issues during prolonged cloudy or rainy periods. • Technical failures or network issues could delay alerts. • Farmers may face difficulties adopting new technology without guidance.

Fig 6.1: SWOT Analysis Table

6.2 Assess the Impact of Solution

The suggested weather monitoring and flood prediction system based on IoT implements a profound influence on agricultural activities and community security in the flood-affected regions of Bangladesh and resource management. The system facilitates farmers to make the necessary preventive measures in time by having real-time weather forecasts and early warnings of floods to minimize loss of crops and minimize property damage. Solar-powered, low-energy sensors are used to ensure that the system is operated all the time even in remote places where there is no electricity and this makes the system energy-efficient and sustainable.

The system saves on economic expenditure on crop damages and irrigation inefficiency. The farmers will be able to plan their planting schedules better and allocate resources based on credible data on the environment. At the social level, the system strengthens the community by providing early warnings, which enable the local communities to be ready to face floods and minimize the danger to human life. The carbon footprint and minimization of electronic waste are encouraged on an environmental level through renewable energy use and low-cost, durable sensors.

In general, the solution offers a sustainable, affordable, and reliable flood management tool to be used in rural agricultural areas enhancing the decisions, protecting the livelihoods, and ensuring long-term agricultural output.

6.3 Evaluate the Sustainability

The proposed system of an IoT-based weather monitoring and flood prediction are considered in terms of sustainability, which implies the long-term operation, energy consumption, maintenance, and environmental concerns. The system is planned to work on solar energy with reserve batteries so that it is constantly monitored even in remote locations where there is no electricity. This will minimize the reliance on non-renewable energy sources and decrease the cost of operation. The environmental conditions such as rain, flooding, and high humidity are minimally damaging to the system as the use of durable and locally available sensors and components makes them self-sufficient. The modular architecture can be easily replaced or upgraded by individual components to increase the total system life.

Environmentally, the system encourages sustainable agriculture by minimizing waste of crops, wastage of water and other resources in the form of unnecessary application. Its use of low-power communication technology like LoRa also reduces the use of energy and carbon footprint. In general, the system is a practical, dependable and a green solution that can be installed in the long term with little maintenance, and is a long term sustainable tool in the management of floods in farm lands.

6.4 Conclusion

The system of flood control and prediction based on the IoT-monitored weather is a proper and efficient system that will help to control the floods in the farmland. The system assists farmers to make knowledgeable choices, decreasing the losses of harvests, and maximizing the usage of the resources by providing real-time weather information and early notifications about floods. The design focuses on the low-power consumption with solar energy, low-cost, and portable features, which is appropriate in rural and remote areas.

The impact analysis and sustainability evaluation give the understanding that the system is not only beneficial in terms of supporting economic and social processes but also encourages environmental responsibility as the system minimizes energy consumption and waste reduction. All in all, the suggested solution is reliable, practical, and long-term to make agricultural communities that are vulnerable to floods better prepared and resilient to disasters.

Chapter 7: Engineering Project Management. [CO11, CO14]

7.1 Introduction

The chapter outline includes the engineering project management elements of the IoT-based weather monitoring and flood prediction system. The proper development of the system should be planned, developed, and implemented within the schedule, budget, and quality requirements. The chapter talks about the planning, organization, allocation of resources, scheduling and the risk management strategies that were used in the project. It also emphasizes on the elements of team members, coordination processes, and monitoring conditions employed to sustain the progress and make the project successful [14].

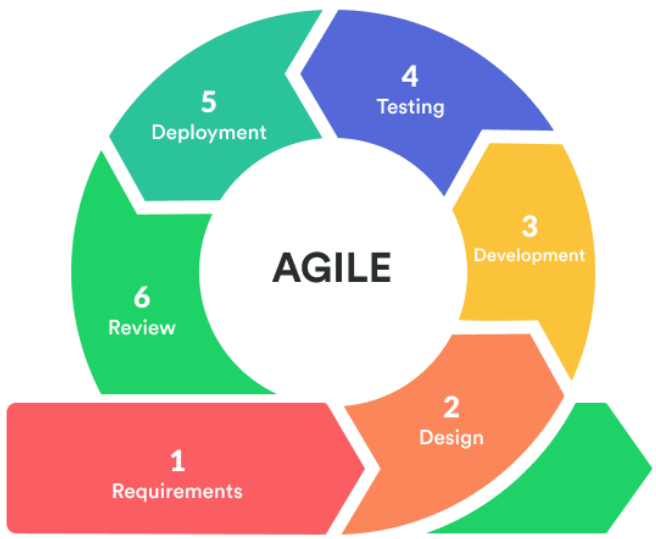


Figure 7.1: Life Cycle of Agile Methodology

7.2 Define, plan and manage engineering project

The engineering project was well defined, planned, and controlled to meet the deadline, optimal utilization of resources and successful attainment of the project objectives. The goals of the project were to design, develop, and implement a solar-powered IoT-based weather monitoring and flood prediction system in rural farms. Its primary objectives included real-time monitoring of the environment, real-time early warning of floods and a friendly interface to the farmers [22] [23].

The planning phase was done by dividing the project into major tasks such as sensor selection and testing, circuit design, setting up of the communication module, development of software to process and predict floods, and development of user interface. The different tasks were allocated to certain team members based on their area of expertise. A timeline based on a Gantt chart was developed which indicated the dependency of tasks, duration of tasks as well as milestones so that no activities would go beyond the time frame that was set [24].

Risk assessment and mitigation strategies were also a part of project management. Possible risks that might occur, i.e. a failure of the sensor, power supply and the failure of the communication network were detected. To reduce the effects of these risks, contingency measures like the backup sensors, oversized solar batteries, and range extenders of the LoRa network were put in place [22] [24] [25].

Team meetings and progress monitoring were done regularly to maintain quality communication, coordination and milestone tracking. Any delays and problems were resolved in time in order to keep the project schedule. The project was implemented in a very efficient manner through proper definition, planning and management to achieve its technical, economical and social goals without compromising sustainability and reliability of the system [26].

7.2.1 Project Timeline for ECE/EEE499P

Fig 7.2.1: Gantt Chart of EEE499P

7.2.2 Expected Project Timeline for ECE/EEE499D

Fig 7.2.2: Expected Gantt Chart of EEE499D

The second stage, EEE499D, entailed a series of tasks that aimed at planning and modelling the project through software. At this stage, we could not adhere to the scheduled time frame due to the six weeks delay occasioned by the demonstrations. This interference did not help us to perform such significant work, as the breadboard prototyping and acquisition of necessary parts, which were planned to be performed during that period. This notwithstanding, we were able to accomplish the rest of the tasks within time and as per our plans, as discussed below.

7.2.3 Actual Progress Timeline for ECE/EEE499D

The project was expected to last 11 weeks to design the weather station and the design will consist of a series of activities, these were; data collection, sensor testing, schematic design, simulation and software testing. This step was mainly aimed at designing in detail, testing, and finalizing a system that has the potential to control flood prone agricultural lands. The timeline is displayed graphically with the assistance of a Gantt chart that will illustrate the order of the activities, the time spent by each of them and the possible overlaps in order to improve efficiency. The plan was designed in such a manner that it has laid the flexibility where delays in one stage can change that stage without changing the actual delivery date.

Each team member had their roles based on their knowledge. Arfanul will be used as an example since sensors have to be collected and tested to ensure that correct and reliable data are obtained by him. Tanjil was engaged in the selection of components. Brinto trained on simulations, data processing and software testing and Akif trained on software integration to develop a user friendly interface to the farmers.

The eventuality plan was adopted in the circumstances where unexpected delays or problems may arise. This can imply re-scheduling of activities, addition or even replacement of project elements to re-establish a project back on track. The project manager will control these changes in such a way that the deadlines are not missed. With the right timetable, roles defined, flexibility and regular checkups the project team is of the opinion that the weather station would be completed successfully on time.

7.2.4 Project Timeline for ECE/EEE499C

Lastly, in EEE499C, the project prototype was the primary issue. The Agile methodology was relevant in this stage and played a key role in direction and structuring in the development process.

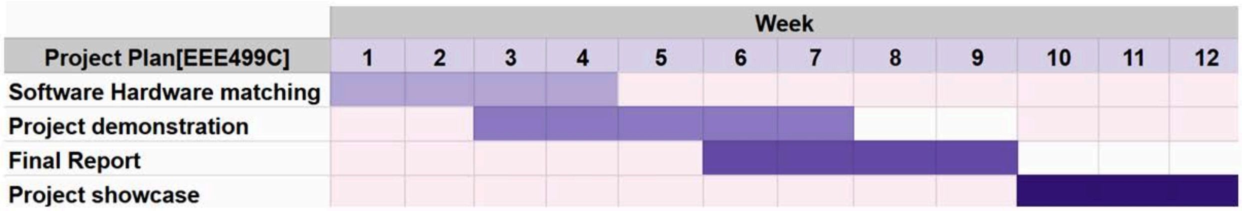


Fig 7.2.4: Gantt Chart of EEE499C

7.3 Evaluate project progress

The initial phase of the project was aimed at specifying the requirements of the system and making a detailed overview of the available weather monitoring and flood prediction systems. A lot of research was done to reveal the essential parameters necessary in proper prediction of floods such as the rain, water levels, soil moisture and temperature, among the wind conditions. In this study, two possible design solutions were proposed; the Localized Broadcaster with Machine Learning and the Multi-Nodal Edge AI Enabled Broadcaster. Both the designs were analysed so that they could satisfy the project goals which were real time monitoring, economical, energy saving, and scalable.

In the second stage, simulations were carried out to compare the working of the two suggested designs. Some of the factors that were evaluated in the process of the simulation included the reliability of data transmission, latency, power consumption, and the accuracy of flood predictions. Agile methodology was used to divide the simulation and analysis into small and manageable tasks, which contributed to the ability to constantly monitor the progress and make corrections in time to overcome technical difficulties. The comparison showed that the former method offered adequate coverage, reduction in energy usage, easier to implement and cheaper whereas the latter method offered more accurate and broader area coverage at the trade off of increased complexity and energy usage.

During the last stage, it began to work on developing prototypes. The approaches had breadboard prototypes to be built to check sensor integration, transmission of data and real-time processing. The subsystems were tested one by one to be functional before full integration. The final hardware prototype was created after the successful performance of the system on the breadboard, which includes resistant sensors, a solar-powered energy system, and a LoRa communication module. Fusion 360 was used to design a 3D enclosure to secure the components and make sure that it is reliable to operate in the field. The prototype has been able to integrate all the subsystems and show the functionality of real-time environmental monitoring and flood predicting to be deployed in the field and demonstrate the project. In general, the project was done in a systematic manner by carrying out research, simulation, and prototyping due to the Gantt chart schedule and Agile approach. The phases were recorded and evaluated and updated accordingly so that all the technical and operational goals were attained at the lowest cost possible without compromising the sustainability, reliability and usability of the system.

7.4 Conclusion

The IoT-based weather monitoring and flood prediction system was designed as an engineering project, and thus the project was implemented in a very effective and systematic manner. The project team could track progress, overcome difficulties, and finish tasks within the deadlines, as a result of excellent planning, scheduling of tasks, and application of Agile methodology. Different design solutions were evaluated, which was then followed by simulation, and bread board prototyping to enable the team to adopt the best solution that would meet the criteria of accuracy, cost, power efficiency and the ease with which it can be deployed. The last prototype was able to combine all the subsystems and proved to have a good real-time tracking ability, prediction of floods, and alerts. In general, proper project management contributed greatly to the accomplishment of technical, operational, and sustainability goals of the system, as well as a quality and compliance with the planned schedule.

Chapter 8: Economical Analysis. [CO12]

8.1 Introduction

This chapter entails the economic analysis of the proposed IoT based weather monitoring and flood prediction system to be developed in agricultural land that is prone to floods. The analysis is concerned with estimating the total cost of the system, consisting of the hardware ingredients, the power, communication modules, and the system maintenance needs. Affordability is given special consideration since the major users of the system are farmers in the rural regions who may have a limited amount of money. The system will reduce both upfront capital and operational expenses in the long run by employing low-cost sensors, the LoRa communication technology and the use of solar power. This chapter brings out the fact that the proposed solution is cost-effective and economically viable to offer real-time weather monitoring and flood risk reduction without interfering with reliable performance and sustainability.

8.2 Economic analysis

In case the suggested system of weather monitoring and flood prediction introduced with the help of IoT is commercialized, an economical analysis in the market becomes essential. The current market of the Bangladeshi flood prediction and weather monitoring solutions is scarcely targeted at small-scale farmers and is limited to low-cost, localized systems [28]. Majority of the systems available are either government run or costly imported systems, or they do not have real-time and location-specific flood prediction. Consequently, there would be little direct competition of the proposed system in the local market [29].

Weather stations and flood monitoring systems that can be found internationally are much more costly and are usually configured to be used by an industry or institute. A large number of them are based on proprietary platforms, cellular communication, or high-end sensors, which are not suitable to implement in rural agriculture since they are expensive to purchase and maintain [27]. The suggested system on the contrary utilizes low-cost sensors, LoRa communication and solar power, enabling it to be sold at a significantly reduced price whilst still being functional. Thus, the selling price of the proposed product can be offered at a fraction of the price of the similar global solutions.

According to the cost breakdown as reflected in the project budget, the approximate cost of production of one Localized Broadcaster unit (Approach 1) would be around Tk 25,000 in case of the small-scale production. This consists of sensors, Microcontroller, LoRa circuit board and solar panel, battery, housing, mount, and simple installation.

Other expenses are the logistics, assembly, testing and distribution costs, which are approximated to take a lead time of approximately 4-6 months. A small marketing budget will be needed to encourage adoption and awareness, particularly to the farmers in the flood prone areas like Sylhet and Sunamganj and the coastal ones [4]. Some of the effective and low-cost marketing strategies would include social media campaigns, local agricultural workshops, and cooperation

with NGOs [4] [7]. A Tk 1,00,000 spent on initial promotion would be adequate; although this would take two years.
The operational costs consist of office rent, utilities and manpower. The monthly rent would be an approximation of Tk 15000 (inclusive of utilities) of operation in a small operational set up. The operations, support and maintenance team of two members working with an approximate monthly salary of Tk 10,000 each would give a personnel cost. The venture is projected to run at a loss over the initial one or two years as it seeks to establish itself through setting up expenses, marketing and low sales volume. Nevertheless, the system will be profitable after the third year, when the adoption grows, and the scale of production expands. Assuming a selling price of 40,000 per unit and bulk production cost is 15,000 per unit, the return on investment (ROI) after three years is as follows:

$$\text{ROI per annum} = \frac{40{,}000 - 15{,}000}{15{,}000} \div 3 \times 100\% = 55.56\%$$

With this rate, the payback period would be estimated at about 2-3 years which is well consistent with the normal startup periods. According to available literature in the field of entrepreneurship, an average of 3 to 5 years are taken by technology-based startups to reach a stable profitability level [28] [29]. Having one of the first affordable and farmer-oriented flood prediction systems on the market in Bangladesh is the strong market position and prior customer confidence.
In general, the economic analysis shows that the proposed system is economically viable, scaled and commercially viable, especially to rural agricultural markets. Due to the growing risks that climate may pose, and the need to have systems of early warnings, the project has high chances of creating long-term economic and social benefits.

8.3 Cost-Benefit analysis

8.3.1 Cost Analysis

The table below shows the cumulative manufacturing initial cost of the subsystems.

This section will provide the original budget estimation of the proposed system with two implementation methods. The figures depicted in the tables are just estimates and reflect a rough financial planning with respect to the current prices existing in the local market in Bangladesh. Minimum and maximum costs will be given in order to take into consideration fluctuation in component quality, brand, availability and in performance requirements.

The first method is centered with the implementation of one integrated monitoring system, which incorporates various instruments of environmental conditions, including temperature and humidity, the face of pressure, wind speed, rain, and water level gauges. Other materials are a LoRa communication module, solar panel, battery, as well as the support components (wiring,

mounting, 3D-printed enclosures etc.). This approach will be estimated at BDT 20,780 to BDT 55,510. The broad spectrum is indicative of optional advanced sensors.
(soil moisture sensor with NPK feature), larger capacity of power components, and long lasting mounting structures that can be used outdoors.

Components	Minimum	Maximum
Temperature and Humidity Sensor	95	1850
Barometric Pressure Sensor	290	3350
Anemometer	2850	4500
Water Level Sensor	615	1500
Rain Gauge	80	490
Soil Moisture Sensor	280	12000 (with NPK)
LoRa Module	770	2500
Solar Panel	500	2320
LCD Display	300	1000
Wires and Others	2000	4000
3D Printing	2000	4000
Battery	1000	3000
Mounting	10000	15000
Total	20780	55,510

Figure 8.3.1a: Initial Cost of Subsystems for approach 1

Approach 2 takes into account a distributed sensing architecture, i.e., several sensor units are spread out to various points. In this method, there are multiples of sensors, including soil moisture, water level, rain gauge, water flow velocity sensors, among others to enhance spatial coverage and accuracy of data. The system has common system components, such as the solar panel, battery, LCD display, LoRa module, wiring, and 3D-printed casing. Depending on the chosen sensor specifications and power needs, the estimated cost of such approach is from BDT 9,870 up to BDT 43,790.

Components	Minimum	Maximum
Soil Moisture Sensor	280 × 3	12000 (with NPK)
Water Level Sensor	615 × 3	1500 × 3
Rain Gauge	80 × 3	490 × 3
Water Flow Velocity Sensor	405 × 3	3000 × 3
Solar Panel	500	2320
LCD Display	300	1000
Wires and Others	2000	4000
3D Printing	2000	4000
Battery	1000	3000
LoRa Module	770	2500
Total	9850	43,790

Figure 8.3.1b: Initial Cost of Subsystems for approach 2

The following are the final costs of production of the respective subsystem.

The former table shows the price of a single-node system (Approach 1: Localized Broadcaster). This system contains a single full set of environmental sensors, a microcontroller and a LoRa communication module, a solar power system, and a telemetry base station. The overall cost of manufacturing this subsystem is Tk 35,525. The greatest part of the cost is represented by the solar panel, telemetry base station and communication modules that are required to guarantee the constant functioning and stable long-range delivery of data. Regardless of these expenses, the total cost of the budget is fair because low-cost sensors are used, and hardware platforms are open-source.

Components	Unit Price (Tk)	Quantity	Total Price (TK)
ESP Cable	185	1	185
DHT11	150	1	150
ESP 32	449	1	449
BMP 280	290	1	290
LoRa RYLR998	3390	2	6,780

USB Cable	180	1	180
A02YYUW Distance Sensor	2,250	1	2,250
Anemometer	2,855	1	2,855
3D Filament For Printing	1,940	1	1,940
Hall Effect Sensor	28	1	28
Magnet	50	2	100
Copper Wire	50	2	100
Black Tape	20	1	20
50W Solar Panel (Delivery Charge)	1,500 + 300	1	1,800
Wire for Solar Panel	47	1	47
Battery Holder 3S	75	1	75
18650 7.7V Battery	250	3	750
Hall Effect Sensor 6851/A3144	28	2	56
LM2596 Buck Converter	99	1	99
Neodymium Bar Magnet N35	80	1	80
Solar Charger Controller	659	1	659
Full Body Structure	—	—	4,500
Copper Wire	47	2	94
DHT11 Temp & Humidity Sensor	120	1	120
HW-411A LM2596 Buck	99	1	99
Micro USB Cable for ESP32	250	1	250
1m Copper Wire	20	4	80
Soldering Kit	860	1	860

Battery Charger	200	1	200
Distribution Box From Daraz	1300	1	1300
Total			**26,396 TK**

Figure 8.3.1c: Final Cost of Implemented Subsystems for approach 1

The second table indicates the price of the multi-node system (Approach 2: Multi-Nodal Edge AI Enabled Broadcaster). This design involves the use of several sensor nodes to achieve a larger coverage area which enhances the quantity of sensors, microcontrollers, and communication modules that are needed. Other hardware like edge computing devices of the field gateway is also provided to facilitate local data processing. This leads to an increment in the overall cost of the manufacturing to Tk 65,340. Although this strategy offers better spatial coverage and may offer more accurate prediction, the number of components is greater which results in higher start-up costs and complexity of the system.

Components	Unit Price (Tk)	Quantity	Total Price (TK)
Humidity and Temperature Sensor (DHT22)	260	4	1040
Wind Speed Sensor	2855	4	11420
Wind Direction Sensor	1800	4	7200
Rain Gauge	1520	4	6080
Arduino Uno	1100	4	4400
Field Gateway	1500	1	1500
On-board Computation Module	1200	1	1200
Solar Panel	7000	1	7000
Battery (12V 7Ah SLA)	2250	1	2250
Charge Controller	2000	1	2000
LoRa TX–RX Module	1600	1	6400
Base Station for Telemetry	5000	1	5000
Edge Computing	5000	1	5000

Hardware for Field Gateway			
Telemetry System	2500	1	2500
Multiple Channel Alert	500	1	500
Cost of 3D Printing	—	—	1850
Grand Total			**65,340 TK**

Figure 8.3.1d: Final Cost of Subsystems for approach 2

8.3.2 Benefit Analysis

The main advantage of the proposed weather monitoring and flood prediction system based on IoT is the decrease in the losses and human losses related to the floods in the farmlands. The overall benefits are hard to measure, but through a simplified economic analysis one can use an income-driven method, in which projected income of people and farmers who are going to be impacted are taken into account. National agricultural statistics indicate that rural farmers in small-scale farms in Bangladesh have an average annual income of about Tk 45,000 according to the type of crop and region. The mean age of a farmer is approximately 35 years and the vast majority of them are economically active even at the age of 60 years [5]. Destruction of crops due to floods is normally translated to loss of income, debt and financial turmoil in the long run. Although the proposed system will aid in averting the intense loss of crops among 100 farmers annually. Local authorities and communities are also burdened with finances by flood response and recovery operations. Relief involves a lot of resources to provide emergency relief, repair irrigation systems, restore soils and substitute farming equipment [5]. The proposed system will decrease the response time and increase preparedness by delivering early flood warnings and real-time weather data. This causes even greater utilization of resources and reduces the cost of disaster recovery operations. Besides economic savings, the system enhances safety and confidence by the farming communities. Farmers can now survive in flood prone areas without any fear of making losses since they are more prepared with better flood preparedness and monitoring facilities. The more nodes to the system, the better the performance and reliability of the system, which increases the coverage of the area and better predictions. This scalability enhances the general benefit of the system in the long run. In addition, the commercialization of the system also can bring about job opportunities to engineers, technicians and other local service providers engaged in the production, installation and maintenance of the same. This helps in providing skilled labor and technical capability in the rural areas [5] [27]. The system can be upgraded with the right investment and constant research and development of the system with better sensors, advanced prediction models, and even smarter analytics.

In addition, we have categorized the impacts into 5 parts. We will be considering the social, health, economic, safety and cultural impact that our weather station has. The elaborated version of these impacts are given below:

i) Social - The social impact of our project is the main objective, that is: flood prediction. As this device will predict floods, it will be socially beneficial for everyone as they can plan their crops as well as take their daily life decisions according to the weather output. Recently, a flood occurred in Sylhet which was devastating for everyone. Tons of home appliances got damaged, people were stuck for days at their homes, unable to move. This is a common scenario in Bangladesh. Our device will be able to warn people even before it happens. People can move to a different place, keep their appliances at a certain place where damage is least and so on. In addition, damaging crops due to floods is a common thing in this country that can be solved after getting flood warnings along with other weather parameters because of our device.

ii) Health - This project will have a healthier contribution to both plants and humans. To begin with plants, this device is runned by solar panel thus it will not produce any toxic gas like traditional power generation. Hence, plants will stay in a healthier condition. As we belong from a country where air pollution is a huge issue, it's important to make sure we don't contribute to any more pollution. Keeping that in mind, this device runs with solar panels. In addition humans will also inhale less toxic gas than before.

iii) Economic - This device is economically beneficial for two main reasons. First, it has a very low maintenance cost as no fuel is necessary, so it will run 24/7 on solar power. Users don't need to change the battery or charge them regularly. It will be producing its own energy to run. Secondly, farmers will be able to plan their crops according to the weather so less wastage of plants. As a result, all the plants will go to good use. They can also sell them and earn more capital. This overall brings an improvement to the economic condition of Bangladesh as the number of farmers in Bangladesh is quite significant.

iv) Safety - This device will keep both humans and plants safe. For humans, they can take necessary precautions before a flood comes so that they don't have to worry about sudden floods. For plants, if farmers already know a flood is coming they can take necessary precautions for the plants to ensure the least flood damage occurs.

v) Cultural - This device will lead the farmers to a modern approach making our country more culturally advanced. As we are making this device for low land areas, we dont expect people from rural areas to be well educated so we will make sure we provide a user friendly dashboard that will be beneficial for everyone living around. This leads our country's citizens to move to a modern society. As a result, the people will be culturally advanced and be benefitted.

8.4 Evaluate economic and financial aspects

The financial and economic analysis of the suggested IoT-based weather monitoring and flood prediction system is aimed at its low price, cost-efficiency, and financial sustainability in the long term. The system was built with cheap sensors, unlicensed LoRa communication technology, open-source hardware, which are very affordable at initial cost and also at ongoing operation cost [12]. Two designs to consider were studied in which the single-node localized system costs less to manufacture than the multi-node configuration hence more applicable in massive rural agricultural locations. In addition, financially, solar power usage reduces the overall energy costs in the long term due to the absence of the use of the grid power or fuel-based power sources [12] [14]. Maintenance costs also remain low because of the modular nature of the system that enables affected components to be repaired or changed without compromising on the entire setup. Other cost cutting measures include the lack of subscription based communication, which lowers the cost of operating the system, hence the economic feasibility of the system in the long term.
The economic advantage of the system mainly comes in the form of downward cutting of losses suffered on crops due to flooding and better planning of resources. Farmers can use early flood warnings to implement preventive measures, including early harvest, equipment relocation and livestock protection that preserve income and lessen recovery costs. The long term benefits of saving money spent on crop damage will be more than the cost of deployment and this translates to a good ratio between cost and benefit. Scalability Mechanically, bulk production and expansion of deployment is likely to lower unit costs further, enhancing financial viability. There is also commercial potential of the system as it can be sold to the government agencies, agricultural organizations and even non governmental institutions dealing with disaster management [16] [18]. All in all, the assessment shows that the proposed solution has a solid economic ground, financial viability, and can bring a lasting value and contribute to the sustainable development of agriculture in the areas prone to floods.

8.5 Conclusion

The financial and economic analysis of the offered system of IoT-based weather monitoring and flood prediction system proves that it is cost-effective and financially feasible. As can be seen in the analysis of the prototype budget, the overall cost of manufacturing the budget is affordable to be used in rural agriculture regions and the application of solar power and low-cost communication technology reduces the initial operational cost. And, the system has considerable advantages, including minimizing crop losses due to floods, securing livelihoods, and decreasing the emergency response and recovery cost. Real time environmental monitoring and early warnings is better preparedness and farmers make good decisions and manage their resources better. Also, the system is scalable and modular, which will contribute to the long-term sustainability, the low maintenance needs, and possible commercial usage. Lastly, the solution will bring about huge social and economic benefits and will be financially viable. Its application can be used to enhance resilience in agricultural areas prone to floods, increase productivity and also lead to sustainable development in a cost effective and reliable way.

Chapter 9: Ethics and Professional Responsibilities [CO13, CO2]

9.1 Introduction

In this chapter, we will address the ethical issues and professional duties involved in the design, development, and implementation of the IoT-based weather monitoring and flood prediction system. The important aspect is ethical practices in order to guarantee the safety of the people, privacy of the users, integrity of the data, and responsible technology usage. The chapter also showcases how the project complies with established engineering codes of practice such as safety, transparency, accountability and sustainability. It also looks at the role of engineers and stake holders of the project in ensuring that the system is reliable, gives good flood warnings and that it is in the best interest of the communities that the system is supposed to serve.

9.2 Identify ethical issues and professional responsibility

The implementation and creation of the IoT-based weather monitoring and flood prediction system touch upon a variety of ethical issues and professional obligations to keep users and other stakeholders safe, private, and well. These include:
The ethical considerations and professional responsibilities were as follows that were identified in their discussions with supervisors and through internal examination of the project:
Transparency: Stipulating effective communication regarding the way the system gathers, processes, and presents weather and flood data.

i) **Legal, Safety, Environmental and Communication:** Adherence to legal, safety, environmental and communication standards that prevail in Bangladesh.

ii) **Training Resources and User documentation:** To make certain that the system is used correctly and safely by the farmers and other stakeholders, they should be provided with adequate instructions and guidelines.

iii) **Comprehensive Prototype Testing:** Testing all the subsystems to minimize risk prior to field testing.

iv) **Clear and Visible Alerts:** The warnings should be understandable and easily acted upon, with a minimum number of false alarms.

v) **Redundancy to Reliability:** Making sure that there are back-up systems and fail-safes to ensure that the system will not stop working even in unfavorable conditions.

9.3 Apply Ethical Issues and Professional Responsibility

9.3.1 Transparency

The transparency was ensured by the design of the user interface, which shows real-time sensor and system status, battery, and flood alerts. The entire process of data collection, processing, and decision making were all documented so that all the stakeholders were able to clearly understand how the system works and its limitations. Any doubts or limitations of the system were relayed to make sure it was used wisely.

9.3.2 Laws and Regulations

Based on the NSPE (National Society of Professional Engineers) code of ethics, we will be maintaining some of the following codes all throughout the project. These guidelines will make sure we prioritize public safety, act with honesty and integrity, respect our user's privacy and finally, ensure transparency and accountability throughout the design and implementation of our weather station system.

i) Public Safety First (NSPE Code I.1) - To ensure flood alerts are accurate and reliable to safe-keep the farmers and communities, the design has to deliver accurate predictions. We overcome this by strictly validating the ML model with diverse datasets while ensuring that there are no false negatives, which might put people's lives or crops at risk.

ii) Honest and Transparent Data Reporting (NSPE Code III.3.a) - In order to prevent end users from being confused by inaccurate predictions or overwhelm with assertion, the system provides transparent reporting of prediction confidence factors in alerts. We commit to revealing any limitations like for example accuracy of models in extreme weather, during implementation.

iii) Privacy and Data Protection (NSPE Code III.4) - The data we will be using from agricultural lands may include data specific to location. Our best design includes encryption for IoT transmissions, and user authentication to the dashboard. This will guarantee that only authorized consumers have access to data and adhere to data protection norms.

iv) Sustainable and Responsible Design (NSPE Code III.1.d) - Designated as the solar-powered setup minimizes impact on our surroundings by lowering dependence on grid-operated electricity and electronic waste.

9.3.3 Training Resources and Informed Consent

Detailed manuals and guidance materials were given to the farmers and end users on how the system works, how to use the data, and how to take the necessary security measures. Informed consent procedures were applied so that all stakeholders could have a good insight of how the system takes and utilizes environmental data.

9.3.4 Thorough Prototype Testing

All of the subsystems such as sensors, communication modules, and power systems were extensively tested. This involved electrical safety check, environmental durability check, and alert checks. Strict testing is the measure that makes sure that the system is safe and working effectively and can be deployed into the fields.

9.3.5 Clear and Visible Alerts

The system has visual and auditory distinguishable alarms on flood warnings, soil moisture levels, and water-level levels. The design will minimize false alarms and make sure that in case there is a risk, farmers will be able to react as fast as possible, which would increase the level of safety and confidence in the system.

9.3.6 Redundancies for Reliability

The backup systems and redundant components were added to enhance the reliability in the combination of unfavorable conditions, including long-term cloudy weather, sensor malfunctions, or network outages. Although redundancy incurs higher costs during the initial stages, the redundancy is of great benefit in the long term by improving durability and persistence of the system in rural and flood prone regions.

9.4 Conclusion

Ethical and professional obligations related to the designing and implementation of the system of monitoring weather and predicting floods based on the use of the IoT are the key to maintaining the safety, reliability, and credibility of the system users. The project will prioritize transparency, effective communication and recording of system operations, which will allow the stakeholders to have knowledge of how the data is gathered, processed, and used. By adhering to applicable laws, regulations and technical standards, the system runs under the law, in a safe and responsible manner, user privacy and a sustainable environment are supported. Safety, reliability and usability are increased by thorough testing of the prototypes, visible indicators of alerts and redundancy of the system design to minimize the risk of hardware/communication failure. Training materials and user guidelines can guarantee that the farmers and other end users will be able to use the system in the required way and in a safe manner. In general, the consideration of ethical issues and professional obligations in the project design helps to enhance the user confidence and social responsibility, as well as, to add to the safe, effective, and sustainable implementation of the system in the flood-prone agricultural areas.

Chapter 10: Conclusion and Future Work.

10.1 Project summary/Conclusion

The weather monitoring and flood prediction system based on the IoT was developed to offer the real-time monitoring of the environment and early warning of floods in the agricultural areas prone to flooding in Bangladesh. The project was able to combine various sensors, a low-power communication network, solar-powered energy supply, and cloud-based data handling to form a stable and long-lasting system. The system has the capability to gather, process, and send data quickly through the application of LoRa communication and machine learning algorithms, which can provide farmers and local officials with timely alerts and viable insights. Furthermore, the design experience entailed thorough consideration of various system design, testing of prototypes and the realization of easy-to-use interface to make the system accessible to the less technical farmers. The principles of ethics and professionalism were taken into account during the project, as they guaranteed the safety of the population, the privacy of the data, its transparency, and dependability. The system was also found to be cost-effective according to economic analysis and it has the potential to lower crop loss, increase resource management, and have other long-term social and financial gains.

All in all, this project has shown that there is a viable and sustainable means of reducing the risks of floods and improving the resilience of agriculture, as well as making informed decisions among vulnerable rural populations. The system will provide a stable, scaled and cost-effective platform on which the development and deployment can be efficiently performed in the future.

10.2 Future work

Despite the fact that the current communication and monitoring system has achieved all the objectives and requirements, certain areas can be improved in the future to make them more usable, efficient and performance. The identified future work is the following:

10.2.1 Improve Energy Efficiency

Further power management, including quicker solar charging and batteries with higher density with better discharge rate and peak power output, can be undertaken. All these enhancements will enable the system to optimize its operational time when the system is used to monitor the long floods.

10.2.2 Reduce Size and Weight

PBCs and smaller hardware designs can be introduced to make the system objectively smaller and lighter. This will simplify the transportation, installation and the long working hours of the devices in remote or flooded locations.

10.2.3 Weather-Proof Design

Ingress of water can be avoided using IP-rated enclosures with closed gaskets and conformal covering of internal electronics will offer further protection of moisture. The connectors and openings are supposed to be well sealed so that they can work reliably in extreme weather conditions.

10.2.4 Automatic Flood Risk Detection

To constantly check environmental factors, including rainfall, water level, soil moisture, and temperature, algorithms may be added. The algorithms may be used to anticipate any flooding upfront and automatically send alerts which would enhance the reaction time and reduce the losses.

10.2.5 Scale of Network Capacity

It was possible to add the number of nodes or repeaters to the LoRa mesh network and to employ better quality antennas to have stronger and more reliable signals. These enhancements will increase the ability of the system to manage larger networks and provide smooth communication during large areas or flood prone zones.

10.2.6 Iteration on Design for Mass Production

It can be restructured to accommodate bulk production such as standardization of parts and machine assembly. This will greatly save the cost of production and this system will be cheaper to the farmers and organizations in the rural region.

10.2.7 Seek Funding from NGOs and Government Agencies

The partnership with disaster relief, governmental agencies, and non-governmental organizations can be involved in funding, advocacy, and technical support. These partnerships will enhance credibility, practical needs of the system, and their mass implementation and training of users.

10.2.8 Provide Comprehensive Training for Users

Detailed training programs, user manuals, and training videos ought to be designed to help the end users use the system in an effective manner. This will enhance usability, confidence, and adoption, therefore, making sure that the system is applied safely and effectively in the real flood-prone areas.

Chapter 11: Identification of Complex Engineering Problems and Activities

11.1: Applicable Attribute of Complex Engineering Problem (EP)

	Attributes	
P1	Depth of knowledge required	✔
P2	Range of conflicting requirements	✔
P3	Depth of analysis required	✔
P4	Familiarity of issues	
P5	Extent of applicable codes	
P6	Extent of stakeholder involvement and conflicting requirements	✔
P7	Interdependence	✔

Table 11.1 Applicable Complex Engineering Attributes

11.2: Justification for Selected Attributes (EP)

11.2.1 P1. Depth of Knowledge Required

In this project, several engineering fields are needed on a detailed level of knowledge. Its design and implementation are related to the fundamental principles of Electrical and Electronic Engineering, embedded systems in particular, sensor interfacing, power electronics, and wireless communication. Microcontrollers, analog and digital sensors, and signal conditioning are all knowledge that is required to get the correct data acquisition.

Also, the project will involve knowledge of the wireless communication based on the LoRa, data range of transmission, power consumption, and network reliability. Solar energy system, battery handling and low-power system design should also be known to make the system suitable to operate 24 hours in the outdoor environment. Thus, the project requires both excellent engineering basics and sophisticated applied expertise in some of the sub-disciplines.

11.2.2 P2. Wide-ranging or Conflicting Requirements

Some of the requirements are also conflicting and have to be balanced so that they do not conflict with each other in the project. Communication range and power consumption is one of the major conflicts. The range of the LoRa transmission can be extended to enhance the

reliability of the data when working at a long range, but drains much more battery, as concerns the system lifetime.
The other conflicting requirement is accuracy of the system and costs. Better data can be offered by high-precision sensors (soil moisture sensors with NPK or water flow sensors with advanced capabilities), but this will raise the total cost of the system considerably. Equally, the more deployed sensors the better the spatial coverage, but the higher the hardware, maintenance and energy costs.
A trade-off can also be seen between the robustness of the system and size (in physical terms) with references to solar panels, batteries, and protective enclosures. Such conflicts have to be optimized to achieve performance, cost and sustainability goals at the same time.

11.2.3 P3. Depth of Analysis Required

The level of analysis that is needed in this project is very deep since there is no one apparent solution to the issue. There are several architectural options, including a centralized system of monitoring where a single node is used or a distributed system of sensing where several sensor units are used.
All the approaches need to be evaluated based on price, scalability, reliability, power management, and simplicity of implementation. The choice of communication technology (LoRa or Wi-Fi or cellular networks), types of sensors, power sources, and types of data visualization also need to be compared and justified in detail. Hence, analytical decision making would be necessary in order to choose the best design based on the project constraints.

11.2.5 P7. Interdependence

i) Environmental data collection using multiple sensors (temperature, humidity, soil moisture, rainfall, water level, and flow velocity).

ii) Reliable wireless transmission of collected data using LoRa communication.

iii) Power management and sustainability, ensuring uninterrupted operation through solar energy and battery systems.

iv) Data visualization and monitoring, allowing users to interpret the collected data effectively.

The subsystems are very interdependent, and a subproblem is tackled by a specific subsystem. To illustrate, the communication reliability is directly dependent on the availability of power whereas the accuracy of the sensor determines the utility of the data transmitted. Weakness or ineffectiveness within a given subsystem would impair the performance of a system. As such, the project needs to be system level designed and coordinated across all the components.

11.3 Applicable Activities of Complex Engineering Problem (EA)

	Attributes	
A1	Range of resources	✔
A2	Level of interaction	✔
A3	Innovation	
A4	Consequences for society and the environment	✔
A5	Familiarity	

Table 11.3: Applicable Complex Engineering Activities

11.4 Justification for Selected Activities (EA)

11.4.1 A1. Range of Diverse Resources

The numerous resources needed in this project to be designed and implemented successfully are diverse. Such resources are environmental and agricultural sensors (temperature and humidity, soil moisture, rainfall, water level, and water flow sensors), embedded systems hardware, LoRa-based wireless communication modules, solar power system, battery, and display units. Besides hardware facilities, the microcontroller, data, and system integration software tools are also needed. The project requires expertise in various focused fields like embedded system design, sensor technology, wireless communication, power management, and rudimentary environmental science. Consequently, a project team that is technologically varied is necessary. The financial resources are also significant, since a number of sensors and auxiliary parts should be purchased and experimented. These resources should be well coordinated and utilized to achieve the project objectives through proper planning, budgeting, scheduling and documentation.

11.4.2 A2. Level of Interaction

There must be high interaction during the implementation of this project. The interaction between the team members should be continuous in order to incorporate the hardware, software, and communication subsystems into one functioning platform. Communication and interaction between various parts of the system, including sensors, microcontroller units, communication modules and power management systems, are also necessary in order to provide reliability in acquiring and transmitting data.

Moreover, communication with supervisors and potential stakeholders, e.g. agricultural practitioners or environmental monitoring authorities is significant to determine real-life needs and prove that the system is usable. Such a degree of interaction also makes sure that the system designed is realistic, user friendly and in accordance with real application requirements.

11.4.3 A4. Consequences for Society and the Environment

The positive impacts of this project are greatly felt in the society and environment. The system will be able to facilitate effective water consumption, better crop management, and timely identification of unfavorable environmental conditions by facilitating real-time tracking of environmental and agricultural indicators. This is more so in a nation such as Bangladesh where agriculture is too sensitive to the weather and water supply.

Solar-powered operation minimizes the reliance on non-renewable sources of energy and environmental impact is minimal. Enhanced surveillance has the potential to cut down on resource wastage, loss of crops and sustainability of agricultural practices. Consequently, the project helps in the protection of the environment, food security, and the economic well-being of the farming communities.

11.4.4 A5. Familiarity

The tasks of this project cover the well-known and common challenges, including environmental monitoring, water management of soil and water resources evaluation. The smart agriculture and environmental observation applications permit similar monitoring systems worldwide.

Nevertheless, even though these problems are well-known, they are not applied to practice in Bangladesh because of the cost, the absence of infrastructure, and the opportunity to use the latest technologies in the rural environment. This project aims at changing these familiar concepts into a solution that is economical, scalable, and locally applicable, and thus the activities in the project are not only relevant but are also essential in the local context.

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Appendix A: Logbook

A.1 FYDP (P) Spring 2025 Summary of Team 01 LogBook/Journal

Date/Time/ Place	Attendee	Summary of Meeting Minutes	Responsible	Comment by ATC
25/1/25 (FYDP Committee) Class1	**Faculty Member:** Mohaimenul Islam **Students:** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Introductory session of EEE499(P)		N/Aitwasan introductory meeting.
26/1/24 Group Meeting 1 (Online)	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. We discussed our interested areas and searched for relevant documents. 2. We finalized some sectors to work.	1.Akif 2.Arfan 3.Brinto 4.Tanjil **Progress:** Task1-Completed Task2-Completed	
26/1/25 Group Meeting 2 (Online)	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. We discussed and finalized our main project ideas. 2. Evaluated whether the selected topic ideas are complex engineering problems or not. 3. Decided to prepare draft concept	1.Akif 2.Arfan 3.Brinto 4.Tanjil **Progress:** Task1-Completed Task2-Completed	

		notes to show it to our ATC. 4. We mailed our ATC regarding their time to present our ideas	Task3-Completed Task4-Completed	
1/2/2025 (FYDP Committee) Class 2 and First Meeting with ATC	**Faculty Member:** Dr. Md. Mosaddequr Rahman **ATC member:** Mohaimenul Islam **Students:** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Had a lecture on Introduction to Engineering Design Process. 2. Had a brief meeting with our ATC		1. Prepare concept notes on the project ideas and send it by mail to all ATC members.
6/2/25 Group Meeting 3 (Online)	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Finalized our draft concept notes and mailed it to our ATC for their feedback.	1.Akif 2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed	
8/2/25 (FYDP Committee) Class 3	**Faculty Member:** Dr. Md. Mosaddequr Rahman **ATC member:** Mohaimenul	1. Lecture on Complex Engineering Problem identification		

	Islam **Students:** 1.Akif 2.Arfan 3.Brinto 4.Tanjil			
12/2/25 Second meeting with ATC	**ATC member:** Mohaimenul Islam **Students:** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. We presented our 3 main project ideas 2. Fixed our main idea to Weather Station and Flood Prone agricultural Areas.	1.Akif 2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed Task 2- Completed	1. Change the Topic statement. 2. Research more on similar Problems and its solutions. 3. Fixed next ATC meeting date on upcoming 19th Feb, 2025.
13/2/24 Group Meeting 4 (Online)	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Read multiple papers on the Weather Station. 2. Had a brief discussion on our methodology and algorithms and decided to research more on it.	1.Akif 2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed Task 2- Completed	
15/2/25 (FYDP Committee) Class 4	Faculty Member: Dr. Abu S.M. Mohsin (MOH) Students: 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Lecture on Attributes of complex engineering along with a small class activity on it.		2. Look into Standards and Codes that apply to our project concept

16/2/25 Group Meeting 5 (Online)	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Read more papers and decide our main methodology to discuss with our ATC	1.Akif 2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed	
18/2/25 Third meeting with ATC	**Faculty Member:** Dr. Md. Mosaddequr Rahman **ATC member:** Mohaimenul Islam **Students:** 1.Arfan 2. Akif	1. Presented our main idea to Weather Station to our ATC and got his feedback on it.	1.Akif 2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed	1. Ambitious Project 2. Complete the draft concept note and share with ATC
19/2/25 Fourth meeting with ATC	**ATC member:** Mohaimenul Islam **Students:** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussed our project methodology, algorithms and got feedback on it.	1.Akif 2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed	1. Ensure the flow chart and the block diagrams are detailed enough.
21/2/25 Group Meeting 6	1.Akif 2.Arfan 3.Brinto	1. Division of work for Concept Arfan: Design approach 1: Brinto, Design Approach 2:	1.Akif 2.Arfan 3.Brinto	

(Online)	4.Tanjil	Akif , Design Approach 3: Tanjil , Problem statement, 2. Discussed the gathered concepts and notes	4.Tanjil Progress: Task1-Completed Task 2- Completed	
22/2/25 (FYDP Committee) Class 5	Faculty: Arshad Sir Group members: 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Lecture and discussion on Engineering Ethics and Professional Practices.		
22/2/25 Group Meeting 7 (Online)	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Completion of three design approaches and cross checked it to meet the requirements. 2. Completion of Problem Statements and Objectives. 3. Discussed and made a draft and submitted in google classroom and mailed to ATC.	1.Akif 2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed Task 2- Completed Task 3- Completed	
26/2/25 Group Meeting 8 (Online)	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussed the feedback provided by ATC. 2. Made necessary changes and corrections. 3. Made Document ready to submit and mailed to ATC to receive feedback.	1.Akif 2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed Task 2- Completed Task 3- Completed	
28/2/25	1.Akif	1. Shared the Docs link to ATC	1.Akif	

Group Meeting 9 (Online)	2.Arfan 3.Brinto 4.Tanjil	for final review 2. Cross checked each other's work.	2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed Task 2- Completed	
29/2/25 (FYDP Committee) Class 6	Faculty: Mosaddequr Rahman Group members: 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Lectureanddiscussionon ProjectSafety, Sustainabilityand Environmentalimpactin Engineeringdesign.		
29/2/25 Group Meeting10 (Online)	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Checked the final concept noted document final times. 2. Submitted it in google classroom. 3. Discussed the slides preparations and divided the slides making task.	1.Akif 2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed Task 2- Completed Task 3- Completed	
4/3/25 Fifth meeting withATC	**ATC member:** Mohaimenul Islam **Students:** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Presented our draft presentation slide to our ATC. 2. Took feedback on our slides.	1.Akif 2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed Task 2- Completed	1. Elaborate the problem statement and background research. 2. Make 2 separate slides for problem statements and background research.

5/3/25 **Group Meeting 11** **(Online)**	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Short listed the main ideas for slides. 2. Started preparing the slides for Final Conceptual Noted	1.Akif 2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed (Affan) Task2-Completed (Brinto) Task3-Partially Completed	
6/3/25 **Group Meeting 12** **(Online)**	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Finalized the Slides for presentation. 2. Mailed ATC the Final presentation slides for any feedback. 3. Mock presentation among group members.	1.Akif 2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed Task 2- Completed Task 3- Completed	
7/3/25 **(CLASS7) Presentation OnFinal Project Conceptual Notes.**	(All ATCs) 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Topic statement, Problem statement, Literature review, Objectives 2. Requirements, Constraints, Design approach 1and 2. 3. Design approach 3 and specifications 4. Design comparison, project time line, budget, applicable standards and codes, Attributes of complex engineering problems and activities and conclusion.	Task1-Akif Task 2- Arfan Task 3- Brinto Task 4- Tanjil Progress: Task1-Completed Task 2- Completed Task 3- Completed Task 4- Completed	1. Make the design approach more detailed. 2. Make design approaches more practical and feasible. 3. Fix out POs and COs with your ATC.

21/3/25 (FYDP Committee) Class8	**Faculty:** Mohaiminul Islam **Group members:** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Lecture and discussion after Mid contents of FYDP P. 2. Explained the various factors,and the contents needed to be done for FYDP P project Proposal and Project Management.		1. Start preparing the draft of the final project proposal.
25/3/25 Sixth meeting with ATC	**Faculty:** Mohaiminul Islam **Group members:** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. We had a discussion on the feedback received during Presentation with our ATC. 2. Had a discussion about risk analysis and its matrix along with sustainability matrix.	1.Akif 2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed (Arfan and Tanjil) Task2-Completed (Brinto)	1. Make Risk matrix, Risk responsible and sustainability matrix 2. Fix the Attributes 3. Complete the drafts soon as possible and mailATC.
26/3/25 Group Meeting13 (Online)	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussed the remaining works for Final Project Proposal. 2. Discussed the feedback received during Presentation on Conceptual Notes: ● Making design approach 1 more detailed. ● Fixing the POs and COs with ATC.	1.Akif 2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed (Arfan and akif) Task2-Completed (Tanjil and Brinto)	

		● Making Design approach more practical and feasible 3. Divided the works: ● Arfan: Risks, Expected Outcomes, Safety considerations, Attributes of complex engineering Problems and activities, literature reviews and logbook. ● Brinto :Design Approach 1, Budgets,Design Comparison ● Tanjil: Methodology, Design Approach 3, LogBook, Projectplan, Budget, Applicable codes and standards. ● Akif: Problem statement, literature review, logbook, Sustainability, Ethical considerations, Applicable standards and codes.		
28/3/25 (FYDP Committee) Class9	**Faculty Member:** Mohaimenul Islam **Students** 1.Akif 2.Arfan 3.Brinto	1. Review on ways for making and delivering a Professional Engineering Presentation.		

	4.Tanjil			
28/3/25 Group Meeting14 (Online)	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussed the feedback received by ATC on Risk management and Safety consideration. 2. Progression on rest parts of Draft of final project proposal.	1.Akif 2.Arfan 3.Brinto 4.Tanjil **Progress:** Task1-Completed (Tanjil and Arfan) Task2-Completed (Brinto and Akif)	
1/4/25 Group Meeting15 (Online)	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussed the progression on Draft of project proposal and set the time to complete it. 2. Informed ATC Regarding our progress	1.Akif 2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed (Arfan and Brinto) Task2-Completed (Tanjil and Akif)	
16/4/25 Group Meeting16 (Online)	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussed the Draft of the project proposal and completed the rest of the remaining parts. 2. Cross checked everything. 3. Completed the Log Book together 4. Made the draft ready to submitandtakefeedback from ATC on 18th April 2025.	1.Akif 2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed Task 2- Completed Task 3- Completed	

17/4/25 Group Meeting17 (Online)	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Prepared the presentation slides. 2. Did finaled its to our project proposal and shared both project proposal and slides with our ATC	1.Akif 2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed Task 2- Completed Task 3- Completed	
24/4/25 Group Meeting 18 (Online)	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Gave finalized its to our presentation slides. 2. Gave a mock presentation by ourselves.	1.Akif 2.Arfan 3.Brinto 4.Tanjil Progress: Task1-Completed Task 2- Completed	

A.2 FYDP (D) Summer 2025 Summary of Team 01 LogBook/Journal

Date/Time/Place	Attendee	Summary of Meeting Minutes	Responsible	Comment by ATC
30/05/2025 First class of FYDP D	**ATC sub committee:** Aldrin Nippon Bobby **Group members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Introductory Session for FYDP D 2. Discussed about the semester planning, contents, progress, presentation and reports,how it should be done and prepared in time	1.Akif 2.Arfan 3.Brinto 4.Tanjil	
06/06/2025 First Group meeting	All Group members	1. Discussion on the Road map for FYDP D 2. Choose two best	1.Akif 2.Arfan	1. Got permission to work on two Design Approach

(Online)		designs out of three. 3. Work Division and discussion on required Engineering Tools Work Division: ● Power Supply System (Achyut) ● Design 1 Simulation (Arfan & Brinto) ● Design 2 Simulation (Tanjil) . ● Rest tasks by All members.	3.Brinto 4.Tanjil	in stead of three.
23/06/2025 Second Group meeting (Online)	All Group members	1. Discussion On progress 2. Discussion on Preparation of Slides or Progress Presentation. 3. Finalizing the Components Required.	1.Akif 2.Arfan 3.Brinto 4.Tanjil	
29/06/2025 Third Group meeting (Online)	All Group members	1. Power Calculation Evaluation for two designs Discussed. 2. Proteus Simulation. 3. Update Completed things on Slides.	1.Akif 2.Arfan 3.Brinto 4.Tanjil	
30/6/2025 Fourth Group meeting (Online)	All Group members	1. Discussion on Power Supply System Simulation. 2. Completing the Calculations For Delay and Range Of System using ®LoRa® calculator. 3. Evaluation of Results and did Functional Verification For Power, Delay and Range.	1.Akif 2.Arfan 3.Brinto 4.Tanjil	
01/07/2025 Fifth Group meeting (Online)	All Group members	1. Working to gether on Presentation Slides 2. Prepared the Expected Time line for FYDP D. 3. Evaluation of Optimal Design based on Simulation Results 4. Discussion on Task progress.	1.Akif 2.Arfan 3.Brinto 4.Tanjil	

		5. Sharing Presentation Slides to ATC		
02/07/2025 Sixth Group meeting (Online& Offline)	All Group members	1. Polishing the Shared Slides. 2. Noting down the things to Discuss with ATC. 3. Division of Slides for presentation	1.Akif 2.Arfan 3.Brinto 4.Tanjil	
03/07/2025 First Official Meeting with ATC (Offline)	**ATCmember:** Mohaimenul Islam **Students:** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussed about the work progress 2. Discussion about July 4th Presentation slides 3. Got feedback from ATC to make necessary changes on slides 4. Fixed next meeting timing after midweek 5. Discussion on Solar inclusion as back up power supply,which sir assured us to help in getting ideas	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Making slides short and concise 2. Add simulations tools, comparisons and analysis for different requirements 3. Add methodical Flow chart of design 4. Remaining works will be discussed after mid week. 5. Remove Power Calculation for now as it needs more Polishing. 6. Getting approved for optimal Design Design Evaluation
03/07/2025 Seventh Group meeting (Online)	All Group members	1. Make necessary updates on Slides as per ATC Feedback. 2. Practiced Presentation Together. 3. Submitted the Presentation Slides on Google classroom portal.	1.Akif 2.Arfan 3.Brinto 4.Tanjil	
04/07/2025 FYDP-D Progress Presentation (Summer 2024)	**ATC sub committee:** Mohaiminul Islam and other ATC. **Group members** 1.Akif 2.Arfan 3.Brinto	1. Presentation of Progress work for FYDPD.	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Include Functional/ Non Functional Requirement

	4.Tanjil			
07/07/2025 Eighth Group Meeting (Offline)	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussion on the remaining Task. 2. Discussion on the feedback during Presentation	1.Akif 2.Arfan 3.Brinto 4.Tanjil	
01/09/2025 Second Official Meeting with ATC (Offline)	**ATCmember:** Mohaimenul Islam **Students:** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussion On Progress Presentation. 2. Discussion on further work for FYDP D Final report and Presentation. 3. Discussion on Design 4. Discussion A Survey form for Evaluation of Design. 5. Discussion on Os(5,6,10,11) 6. Fixing next meeting date on 08/09/2025	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Power and Solar calculation should be complete and brought in the next meeting. 2. Make 2D or illustration of Optimal Design System 3. Prepare a form and conduct a Survey 4. Prepare table
01/09/2025 Ninth Group Meeting (Offline)	**Group members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Division of Left task for FYDP D. 2. Discussion on buying Components. 3. Preparing Google form and possible questionnaire.	1.Akif 2.Arfan 3.Brinto 4.Tanjil	
08/09/2025 Third Official Meeting with ATC (Offline)	**ATC member:** Mohaimenul Islam **Students:** Arfan	1. Showed and Discussed on Power Supply Calculations. 2. Showing calculations for solar panels and discussing required components for it. 3. Fixing Next meeting date and time	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Power and Solar Calculations are alright. 2. In the next meeting, update on 2D/3D at least and start preparing slides and Form as soon as possible.
12/09/2025 Tenth Group meeting (Online)	All Group members	1. Discussion on the feedback and task provided by ATC. 2. Prepared a Google form and circulated it among stakeholders	1.Akif 2.Arfan 3.Brinto 4.Tanjil	

		3. Updating the slides for final Presentation		
15/09/2025 Fifth Official Meeting with ATC (Offline)	**ATCmember:** Mohaimenul Islam **Students:** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Showed RACI table and got approved 2. Discussion on update about 2D/3D illustration 3. Showed Gantt chart for Expected vs Present time line for FYDP D. 4. Discussed about the things to be in Slides for Final Presentation	1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. 3D is compulsory if we cannot make it in time. 2. Collect data from form and evaluate as soon as possible and finalize the slides and send him next week
19/09/2025 Eleventh Group meeting (Online)	All Group members	1. Discussion on the feedback provided by Sir. 2. Updating the slides	1.Akif 2.Arfan 3.Brinto 4.Tanjil	
21/09/2025 Eleventh Group meeting (Online)	All Group members	1. Working together to finalize the slides 2. Evaluation of Google form response and make it reasonable for optimal design system, Risks,ethical and Safety	1.Akif 2.Arfan 3.Brinto 4.Tanjil	
24/09/2025 Twelfth Group meeting (Online)	All Group members	1. Finalizing the Final Presentation Slides and sharing with ATC for Feedback. 2. Completing 2D design illustration for Optimal Design. 3. Division of Slides for presentation	1.Akif 2.Arfan 3.Brinto 4.Tanjil	
25/09/2025 Thirteenth Group meeting (Online)	All Group members	1. Submitting the Final Presentation slides. 2. Practicing Presentation	1.Akif 2.Arfan 3.Brinto 4.Tanjil	
26/09/2025 FYDP-D Final Presentation (Summer	**ATC sub committee:** Mohaiminul Islam and other ATC. **Group members**	1. Presentation of Final work for FYDP D	1.Akif 2.Arfan 3.Brinto	1. Start hardware implementation and submit a report on the due date.

2024)	1.Akif 2.Arfan 3.Brinto 4.Tanjil		4.Tanjil	
30/09/2025 Fourteenth Group meeting (Online)	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Division of Tasks for Final Report of FYDP D	1.Akif 2.Arfan 3.Brinto 4.Tanjil	
02/10/2025 Fifteenth Group meeting (Online)	**All Group members**	1. Discussion on work update. 2. Updating the finalized writing in Final Report.	1.Akif 2.Arfan 3.Brinto 4.Tanjil	
04/10/2025 Sixteenth Group meeting (Online)	**All Group members**	1. Finalizing the Logbook for FYDP D 2. Finalizing draft report for FYDP D final Submission and shared with ATC for feedback	1.Akif 2.Arfan 3.Brinto 4.Tanjil	
05/10/2025 Seventh Group meeting (Online)	**All Group members**	1. Completed the Final report as per ATC feedback. 2. Submitted the Final FYDP D report on google classroom due deadline. 3. Fixing next meeting for planning for FYDP C	1.Akif 2.Arfan 3.Brinto 4.Tanjil	

A.3 FYDP(C) FALL2025 Summary of Team 01 LogBook/Journal

Date/Time/Place	Attendee	Summary of Meeting Minutes	Responsible	Comment by ATC
24/10/2025 1st Group meeting (online)	**Group Members** 1.Akif	1. Discussion on the road map of FYDP C 2. Discussed and	**Group Members** 1.Akif	

	2.Arfan 3.Brinto 4.Tanjil	made, time frame for FYDP C	2.Arfan 3.Brinto 4.Tanjil	
31/10/2025 2nd Group Meeting (online)	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Task Division i.PCB & Components-Tanjil ii.Power Circuitry for every subsystem & Components	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	
4/11/2025 3rd Group Meeting (online)	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussion about work progress 2. Noted points to Discuss with ATC	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	
5/11/2025 1st Meeting with ATC (University)	**ATC member:** MohaimenulIslam **Students:** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussion about possible changes in designing system 2. Discussion about available components and backups 3. Discussion about Work Progress 4. Discussion about making Bread board prototype ready before Mid Presentation	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	Had a positive review
7/11/2025 1st class of FYDP C (Offline)	**Faculty Member:** Mirza Rashedujjaman Sir **Students:** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussed the FYDP C Course Outcomes 2. Lectures on FYDP C resources 3. Discussion of students questionnaire and confusions 4. Fixed dates for Mid presentation and Final Project Showcase	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	
11/11/2025 4th Group meeting (Offline)	**Group Members** 1.Akif	1. Prepared lists of components required.	**Group Members** 1.Akif	

	2.Arfan 3.Brinto 4.Tanjil	2. Divided tasks in lab to work in lab 3. Working in lab started from this day	2.Arfan 3.Brinto 4.Tanjil	
14/11/2025 5th Group Meeting (online)	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussed about the things that's needed to be discuss with ATC 2. Started preparing the Slides for Mid Presentation	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	
19/11/2025 2nd Meeting withATC (University)	**ATC member:** MohaimenulIslam **Students:** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussed the problem of Solar charging system with ATC 2. Discussed about the contents that's needed to be in slides 3. Showed the draft incomplete slides for presentation to get feedback 4. Discussed what should be done to make videos for mid presentation 5. Gave update about the components failure and unable to develop whole breadboard prototype till Mid presentation	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	
19/11/2025 7th Group Meeting (Offline& Online)	**Group members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussed the feed back and guide lines provided by ATC 2. Prepared the slides and videos accordingly 3. Sent Draft via mail prepared to ATC For Further Review 4. Division of presentation parts and preparation	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	
21/11/2025 Mid Progress	**Group members**	1. Presented our Progress through	**Group Members**	

Presentation (University)	1.Akif 2.Arfan 3.Brinto 4.Tanjil	presentation 2. Got feedback from ATCs panel	1.Akif 2.Arfan 3.Brinto 4.Tanjil	
21/11/2025 6th Group Meeting (Offline)	**Group members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussed the comments during presentation to work on them 2. Took measurements of components forPCB 3. Ordered Damaged Components	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	
25/12/2025 8th Group Meeting (Offline)	**Group members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussion on work progress 2. Tested all the reordered components	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	
26/12/2025 9th Group Meeting (Offline)	**Group members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Working together in lab to check the compactibleness of each subsystem with each 2. Discussion on the problems while testing	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	
28/12/2025 10th Group Meeting (Offline)	**Group members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Successfully tested 2. Discussed about the possible solutions Lora was not working 3. Power Circuitry were tested successfully for every subsystem	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	
29/12/2025 3rd Meeting with ATC (University)	**ATC member:** Mohaimenul Islam **Students:** 1.Akif 2.Arfan 3.Brinto	1. Discussed about the viable solutions for Problem 2. Discussed about data collected process 3. Discussed about the progress 4. Discussion on the updated progress	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	

	4.Tanjil	on 5. Discussed about the comments in Mid Presentation		
30/12/2025 11th Group Meeting (Offline)	**Group members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussed the points to be clear from ATC 2. Started Making videos and data ready to present to ATC 3. Making system Ready to demonstrate to ATC	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	
30/12/2025 4th Meeting with ATC (University)	**ATC member:** Mohaimenul Islam **Students:** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. ATC visited the FYDP lab to see the prototype almost ready and functioning. 2. Discussed about Project 3. Discussion on difficulty of getting customized PCB within shorttime 4. Discussion on poster for demonstration and video making	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	
31/12/2025 12th Group Meeting (Online)	**Group members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. TaskDivision: i.Arfan & Brinto Data collection and making Video for Range and latency ii.Tanjil &Akif data collection for Power	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	
31/12/2025 5th Meeting with ATC (University)	**ATC member:** Mohaimenul Islam **Students:** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Showed a picture and video of a smart watch although there were few bugs to fix and make it compatible with our existing system2. 2. Discussed about the progress of poster 3. Discussion about the difficulty to	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	

		prepare within demonstration day		
2/1/2026 13th Group Meeting (Offline)	**Group members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Discussion about the suggestion and feedback provided by ATC. 2. Field testing off our important parameters and collected data 3. Finalized Casing for every subsystem	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	
3/1/2026 19th Group Meeting (Online)	**Group members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Task division for Report writing based on chapters	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	
4/1/2026 20th Group Meeting (Online)	**Group members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	1. Working together in are port 2. Clear Up the confusions with each others related with Report	**Group Members** 1.Akif 2.Arfan 3.Brinto 4.Tanjil	

Appendix B: System Firmware and User Interface Source Code

B.1 Transmitter (TX) Code

```
#include <Wire.h>
#include <Adafruit_BMP280.h>
#include "DHT.h"

// --- Pin Definitions ---
#define US_RX_PIN 33
#define US_TX_PIN 32
#define DHTPIN 27
#define DHTTYPE DHT11
```

```
#define ANEMOMETER_PIN 34
#define RAIN_PIN 14

// LoRa Pins (Hardware Serial 2)
#define LORA_RX 16
#define LORA_TX 17

#define SEND_INTERVAL 2000

struct struct_message {
   float temp; float hum; float press;
   float dist; float wind; float rain;
} myData;

Adafruit_BMP280 bmp;
DHT dht(DHTPIN, DHTTYPE);

unsigned char usData[4] = {};
unsigned long lastSendTime = 0;
unsigned long lastDHTTime = 0;

volatile int tipCount = 0;
const float bucketCapacity = 0.52615;
unsigned long lastTipTime = 0;

void IRAM_ATTR countTip() {
  unsigned long currentTime = millis();
  if (currentTime - lastTipTime > 150) {
    tipCount++;
    lastTipTime = currentTime;
  }
}

void setup() {
  Serial.begin(115200);   // Debug
  Serial1.begin(9600, SERIAL_8N1, US_RX_PIN, US_TX_PIN); // Ultrasonic
  Serial2.begin(115200, SERIAL_8N1, LORA_RX, LORA_TX);   // LoRa RYLR998

  pinMode(RAIN_PIN, INPUT_PULLUP);
  attachInterrupt(digitalPinToInterrupt(RAIN_PIN), countTip, FALLING);
```

```
  if (!bmp.begin(0x76)) Serial.println("BMP280 error!");
  dht.begin();

  delay(1000);
  Serial2.println("AT+ADDRESS=1"); // Set TX Address to 1
}

void loop() {
  unsigned long currentMillis = millis();

  if (currentMillis - lastSendTime >= SEND_INTERVAL) {
    lastSendTime = currentMillis;

    // --- Read Sensors ---
    myData.rain = tipCount * bucketCapacity;

    Serial1.write(0x55);
    if (Serial1.available() >= 4) {
      if (Serial1.read() == 0xFF) {
        usData[1] = Serial1.read();
        usData[2] = Serial1.read();
        usData[3] = Serial1.read();
        myData.dist = ((usData[1] <<  + usData[2]) / 10.0;
      }
    }

    myData.press = bmp.readPressure() / 100.0;

    int adcValue = analogRead(ANEMOMETER_PIN);
    float voltage = (adcValue / 4095.0) * 3.3;
    myData.wind = ((voltage - 0.033) / (3.3 - 0.033)) * 32.4;

    if (currentMillis - lastDHTTime >= 2000) {
      myData.temp = dht.readTemperature();
      myData.hum = dht.readHumidity();
      lastDHTTime = currentMillis;
    }

    // --- Prepare LoRa Packet (AT+SEND=<Address>,<PayloadLength>,<Data>) ---
```

```
    // Creating a CSV string: temp,hum,press,dist,wind,rain
    String payload = String(myData.temp,1) + "," + String(myData.hum,1) + "," +
                     String(myData.press,1) + "," + String(myData.dist,1) + "," +
                     String(myData.wind,1) + "," + String(myData.rain,1);

    String cmd = "AT+SEND=0," + String(payload.length()) + "," + payload;
    Serial2.println(cmd);

    Serial.println("Sent: " + payload);
  }
}
```

B.2 Receiver Code

```
#include <WiFi.h>
#include <AsyncTCP.h>
#include <ESPAsyncWebServer.h>

#define LORA_RX 16
#define LORA_TX 17

const char* ssid = "YOUR_SSID";
const char* password = "YOUR_PASSWORD";

struct struct_message {
    float temp; float hum; float press;
    float dist; float wind; float rain;
} incoming;

AsyncWebServer server(80);

// ... (Keep your index_html string exactly as it was) ...

void parseLoRaData(String data) {
    // Expected format: +RCV=<Address>,<Length>,<Data>,<RSSI>,<SNR>
    // Example: +RCV=1,35,25.5,60.2,1013.1,120.5,2.5,10.2,-45,10
    int firstComma = data.indexOf(',');
    int secondComma = data.indexOf(',', firstComma + 1);
    int thirdComma = data.indexOf(',', secondComma + 1);
```

```
  // Extract the actual payload portion
  String payload = data.substring(secondComma + 1);

  // Parse the 6 values
  int p1 = payload.indexOf(',');
  int p2 = payload.indexOf(',', p1 + 1);
  int p3 = payload.indexOf(',', p2 + 1);
  int p4 = payload.indexOf(',', p3 + 1);
  int p5 = payload.indexOf(',', p4 + 1);

  incoming.temp  = payload.substring(0, p1).toFloat();
  incoming.hum   = payload.substring(p1 + 1, p2).toFloat();
  incoming.press = payload.substring(p2 + 1, p3).toFloat();
  incoming.dist  = payload.substring(p3 + 1, p4).toFloat();
  incoming.wind  = payload.substring(p4 + 1, p5).toFloat();
  incoming.rain  = payload.substring(p5 + 1).toFloat();
}

void setup() {
  Serial.begin(115200);
  Serial2.begin(115200, SERIAL_8N1, LORA_RX, LORA_TX); // LoRa Serial

  WiFi.begin(ssid, password);
  WiFi.softAP("Flood-Monitor-Live", "12345678");

  server.on("/", HTTP_GET, [](AsyncWebServerRequest *request){
    request->send_P(200, "text/html", index_html);
  });

  server.on("/data", HTTP_GET, [](AsyncWebServerRequest *request){
    String j = "{";
    j += "\"t\"""" + String(incoming.temp, 1) + "\",";
    j += "\"r\"""" + String(incoming.rain, 2) + "\",";
    j += "\"d\"""" + String(incoming.dist, 2) + "\",";
    j += "\"w\"""" + String(incoming.wind, 1) + "\",";
    j += "\"p\"""" + String(incoming.press, 1) + "\"";
    j += "}";
    request->send(200, "application/json", j);
  });
```

```
  server.begin();
  delay(1000);
  Serial2.println("AT+ADDRESS=0"); // Set Receiver Address to 0
}

void loop() {
  if (Serial2.available()) {
    String rcv = Serial2.readStringUntil('\n');
    if (rcv.startsWith("+RCV")) {
      parseLoRaData(rcv);
      Serial.println("Received valid LoRa packet");
    }
  }
}
```