A Thesis

on

Design and Development of IoT Based Fuzzy Expert System for Flood Detection and Avoidance

by

NEERAJ KUMAR

Department of Information Technology

School for Information Science and Technology

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Lucknow, Uttar Pradesh, India

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DECLARATION

I, Neeraj Kumar, solemnly declare that this thesis of research on **“Design and Development of IoT Based Fuzzy Expert System for Flood Detection and Avoidance”** is my original work. The study has been conducted under the guidance of Prof. Raees Ahmad Khan and Dr. Alka, at the Department of Information Technology, Babasaheb Bhimrao Ambedkar University (A Central University), Lucknow. It is further declared that to the best of my knowledge and belief, it has not been submitted earlier for the award of any degree. I also undertake that the thesis is essentially free from all kinds of plagiarism.

Dated:

(Neeraj Kumar)
Research Scholar
Department of Information Technology
Babasaheb Bhimrao Ambedkar University
(A Central University), Lucknow
Uttar Pradesh, India

CERTIFICATE

This is to certify that the thesis entitled **''Design and Development of IoT Based Fuzzy Expert System for Flood Detection and Avoidance''** submitted by Mr. Neeraj Kumar is an original research work and has not been previously submitted in part or full for the award of any other degree or diploma to this or any other University.

This thesis submitted to Babasaheb Bhimrao Ambedkar University, Lucknow satisfies all the requirements as stipulated in the Doctor of Philosophy (Ph.D.) regulations-1999 as amended in 2013 and it is fit for submission and evaluation for the award of the degree of Doctor of Philosophy of the University.

Co-Supervisor **Supervisor**

Dated: **Head of the Department**

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Neeraj Kumar

ABSTRACT

Every year, flood claims several lives in India and abroad. Floods are caused by several factors, including heavy precipitation, tsunamis, or failure of structures (i.e. dams, levels, retention ponds), that contained the water. A flood can be categorized in a periodic flood or in an aperiodic flood. Periodic floods occur on rivers while aperiodic floods happened due to heavy rain or waterlogging in raining seasons.

Flood control has been an important step in the flood management process. It is performed by many techniques including installation of rock berms, sandbags, maintaining normal slopes with vegetation and construction or expansion of drainage channels. In this row, after Katrina (2005), the research community has started seriously focusing on drainage structures. Though drainage structures of different shapes have been designed and installed by various researchers, but the problem is still not resolved. Hence, the researcher has proposed two grid structures, including hexagonal and octagonal based on the cellular automata (CA). In addition, a procedure to find out the best grid pattern for a drainage system to avoid flood or waterlogging has also been proposed. For the same, evaluation of different grid shapes of CA has been performed to find out the most suitable patterns for various cases. This evaluation is done on the basis of a number of exit paths available in grid patterns. The researcher has analyzed and compared three grid patterns including a square grid, hexagon grid, and octagon grid. Linear and bilinear elevations of flood plain have been considered for comparison. After this evaluation, a suitable grid pattern with the tanks at each corner of the drainage mechanism has been suggested. The validation of the proposed method to develop the drainage system has been performed using the Paired T-Test.

Though there have been many approaches for flood detection, but results are not satisfactory as the number of casualties due to flood is increasing year by year. Hence, there is a need to develop an appropriate technique for the detection of a flood. To cater to the need, the researcher has proposed techniques for flood detection based on the Internet of Things (IoT) and Artificial Intelligence. IoT, WSN, and MANET are key technologies generally used for the detection of a flood. Out of these three, IoT is an efficient technology able to communicate and analyze the problem. This technology involves many devices to sense. In the thesis, a new terminology has been proposed for the IoTs used to monitor real-time environment i.e. The monitoring of real-time environments using IoT is referred to as the Internet of Environmental Things (IoET).

Device design is a fundamental issue in implementing IoET. To overcome the issue, the researcher has selected the appropriate components. It is done on the basis of the Systematic Literature Review (SLR). The SLR has determined the types, numbers, and usefulness of components in order to build an effective flood detection device in the real-time environment. Components of devices in IoET have been selected according to their applicability extracted through SLR, and have been incorporated to design low-cost flood detection devices. The researcher has designed various flood detection devices by integrating suitable components. The devices designed during this research are tested for their accuracy. The researcher has also analyzed the properties of the components, including current requirements and power consumption. The cost of deployment of these devices has also been analyzed. Validation of the proposed transmitting device has been performed by using F-test.

Further, the deployment strategy of devices is also an issue in IoET as well as in Wireless Sensor Network (WSN) applications. The researcher has addressed the issues of deployment of devices for flood detection. Deployment strategies have been proposed to deploy sensing devices in flood plain of newly developing cities as well as existing cities. These strategies determine the quantity and locations of devices in order to build an effective system. It decides many intrinsic properties of an IoET, such as the number of devices and cost, etc. Sensor nodes form Things of IoET network are responsible for providing sensed data to the application. For sensor node deployment, a Cell Elimination Algorithm (CEA) and Cellularly Deployment Algorithm (CDA) have proposed for existing and newly developing cities, respectively. Both techniques fill the research gap observed during the literature review. In addition, these can serve as guidelines for IoT designers, solution providers and system integrators of IoT applications. The validation of the proposed CEA and CDA has been performed using the T-Test and F-test in one way ANOVA.

The location of device installation will also affect the accuracy of sensed data. Hence, tanks of drainage structure and path of water flow have been assumed as appropriate locations for device deployment. The researcher has made an attempt to utilize sensory data in an expert system after receiving it from IoT. This expert system provides information about the risk of the flood before it happens. A risk assessment is performed based on a threshold that may vary from city to city because the level of peak rainfall for the different cities may differ. So, the threshold is assumed as a variable in designing of an expert system. While the simulation of an expert system, an evaluation of fuzzy rules and impacts of input rules on output has been done. Based on the evaluation, a Web-based expert system (Risk finder system) has been developed. Validation of the proposed method to develop an Expert System has been performed by finding a relationship between water level and rainfall using Multiple Linear Regression.

ABBREVIATIONS

IoT	Internet of Things
ITU-T	Institute of Telecommunication Union-
IEEE	Institute of Electrical and Electronics Engineers
WSN	Wireless Sensor Network
VANET	Vehicular Ad hoc Network
NASSCOM	National Association of Software and Services Companies
USD	US Dollar
LCD	Liquid Crystal Display
LTE	Long Term Evolution
GSM	Global System for Mobile Communications
3G	Third Generation
RFID	Radio Frequency Identification
METHWORK	Methodology With the Opted Related Keywords
MANET	Mobile Ad Hoc Network
IoET	Internet of Environmental Things
FES	Fuzzy Expert System
ANN	Artificial Neural Network
CA	Cellular Automata
NN	Neural Network
VPN	Virtual Private Network
ES	Expert System
PVC	Poly Vinyl Chloride
JDK	Java Development Kit
GPRS	General Packet Radio Services
LED	Light-Emitting Diode
EWS	Early Warning System

DBMS	Database Management System
UDP	User Datagram Protocol
WPAN	Personal Area Network
WMAN	Wireless Metropolitan Area Network
4 G	Fourth Generation
TDR	Time Domain Reflectometry
FDR	Frequency Domain Reflectometry
SLR	Systematic Literature Review
ISMS	Information Security Management System
SNR	Sound to Noise Ratio
dBm	decibel-milliwatts
GUI	Graphical User Interface
VCC	Voltage at the Common Collector
DO	Digital Output
NH	Neighborhood
UG	Underground
2D	Two dimensional
GND	Ground
AO	Analog Output
M2M	Machine to Machine
CAFFG	Central America Flash Flood Guidance System
FIS	Fuzzy Inference System
SIATA	SIstema de Alerta Temprana de medellín yel valle de Aburrá
ELDEWAS	Early Landslide Detection and Warning System
IDSS	Intelligent Decision Support System
DSS	Decision Support System
TSD	Tank Size Descriptor
GMS	Google Mobile Services
RF	Radio Frequency
HSPF	Hydrological Simulation Program – FORTRAN

ASCE	American Society of Civil Engineers
BRB	Belief-Rule-Base
RIMER	Rule-Base Inference Methodology using the Evidential Reasoning
USB	Universal Serial Bus
WD	Water level detection device
RD	Raindrop detection device
^{W}WD	Wired Water level detection Device
^{W}RD	Wired Raindrop detection Device
$^{\omega}$WD	Wireless Water level detection Device
$^{\omega}$RD	Wireless Raindrop detection Device
$^{\omega}$WD$_{T}$	Water level detection Device (Transmitting device)
$^{\omega}$WD$_{R}$	Water level detection Device (Receiving device)
$^{\omega}$RD$_{T}$	Raindrop detection Device (Transmitting device)
$^{\omega}$RD$_{R}$	Raindrop detection Device (Receiving device)
FSD	Flood Sign Detector
$^{\omega}$FSD$_{T}$	Wireless Flood Sign Detector(Transmitting device)
KCL	Kirchhoff’s Current Law

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 | INTRODUCTION

Google and Wikipedia are reasonable places to begin your research, but not good places to end it.

—Rosemary G. Feal

1.1 Background

The rainfall related disasters sometimes are found to be very deadly. As per M. Kanda [1], Uttarakhand, Himachal Pradesh, and J&K in North, North East, including West Bengal and Western Ghats of Maharashtra, Kerala, Tamilnadu, and partially Karnataka are the high-risk regions for landslides among all the other states in India. These landslides happen mainly in the rainy season that comes generally due to heavy rains. Recent disasters, including Uttarakhand flood [2,3], J & K flood [2], and Malin Landslide [4] indicate the criticality of the problem. Waterlogging, rainfall-induced floods, rain-induced landslide, tsunami, and cloud burst are a few examples of water caused disasters. Floods are the most frequent disasters that provide high loss. Flood due to rainfall occurs frequently and presents a tough picture of daily life during it. All the rainfall-induced disasters, including, are the global problems that need urgent and serious attention. Outside India, a recent landslide struck the Fujian province of Southern China [5], in which 17 have been missing with 22 deaths. It was caused by only 20 cm of rainfall within 24 hours. To overcome problems of food, few activities are in use, all these activities are known as flood control. In all kinds of floods, a well-defined mechanism for disaster management is in practice. The disaster management process has four phases indicated in figure 1.1 are planning, mitigation, preparedness and response/recovery [6]. These four phases help to manage all the disasters, but unfortunately, no approach is able to support all four phases of a disaster. In this thesis, the researcher tried to provide help in most of the phases.

Figure 1.1: Phases of Disaster Management

Table 1.1 indicates the major losses due to different rainfall related disasters in India as discussed by Neeraj et al.[7,8].

Table 1.1: Rainfall related disasters in India with causes and effects

Disaster	Cause and effects
J&K flood [2, 9] 2014	Heavy rain and flash floods have killed about four hundred and have rendered hundreds of thousands homeless.
U. K. flood [3] 2013	Cloudburst based flood and landslide struck Uttarakhand that killed more than 580 people, while 5474 missing assumed dead.
Malin landslide [4] 2014	Heavy rain-induced landslide taken the lives of all 134 people of Malin, Ambegaon, Pune.
Assam flood [10]	Due to rainfall-induced flood, about 1725730 people were affected in 23 districts in the year 2016.
Kurseong [11], Tindharia, 1998	250 houses damaged, NH-55 damaged, 10 people died.
Darjeeling Sadar [11], 2000	11 people died.
Maharashtra flood [12], 2005	1094 deaths, 167 injuries, 54 are missing.
Kosi flood [12], Bihar, 2008	557 deaths, 3.3 Million affected, 223000 houses damaged.
Surat flood [13], 2006	150 died by drowning, 100 died due to leptospirosis, and 3000000 affected.
Nilgiri’s landslide [14], 2009	1150 landslides were reported in the Nilgiri district. This was dangerous in terms of lives.

Table 1.1 also indicates a few sudden impacts during the event. Post-event, it spreads side effects of various kinds, including waterlogging, landslides, and many more diseases behind it. However, the floods are very tough to avoid, but its

probability of happening can be minimized at least in newly developing cities using plain and drainage modeling.

1.2 Flood Management

Flood management is a significant issue to resolve, but unfortunately, any machine or technique cannot control flood without human intervention. However, its appropriate management may reduce losses. In an initial study, flood management phases are identified according to disaster management phases as:

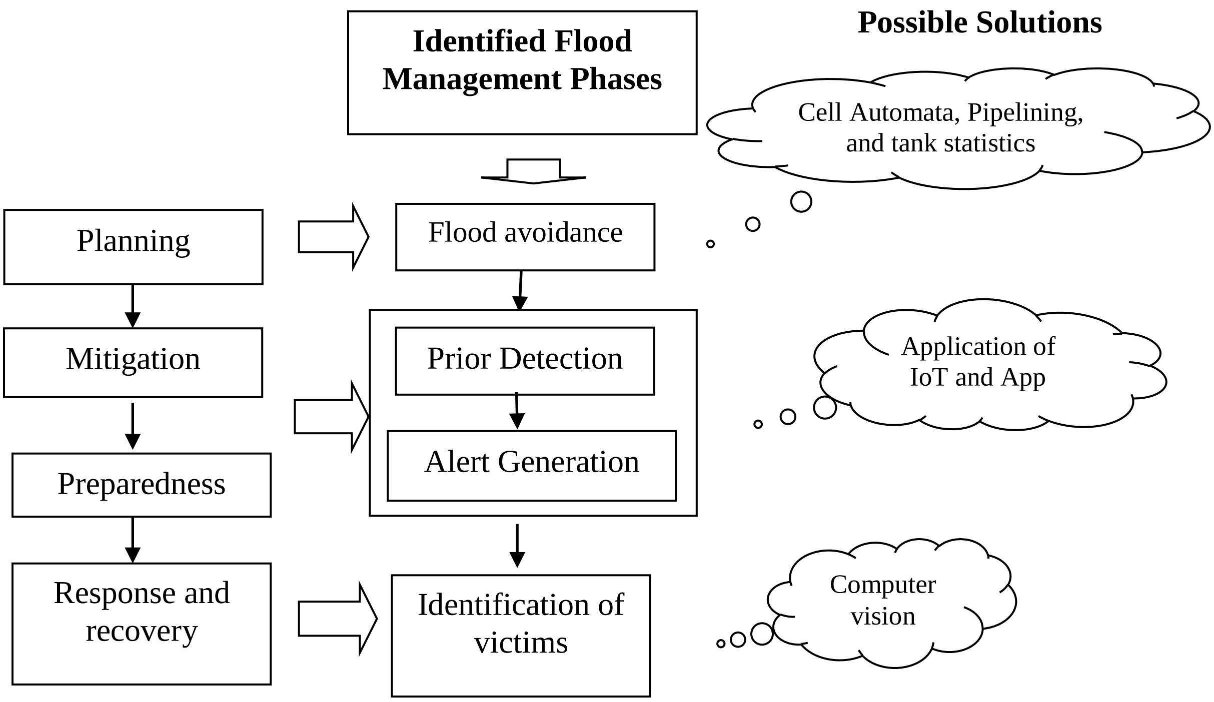


Figure 1.2: Identified flood management phases and possible solutions

In figure 1.2, technologies and concepts of Cellular Automata (CA) have assumed for flood management. After implementation, these assumptions may play a crucial role, to minimize the impact of a flood. Flood avoidance or its modeling is very tough for existing cities. However; few theories of computer science, including CA are in use for flood modeling. In these days, flood management is in practice using the installation of rock berms, sandbags, maintaining normal slopes with vegetation and construction or expansion of drainage channels, etc. There are four kinds of techniques, which directly affect the flood management process including:

- Techniques for Flood Avoidance;
- Techniques for Flood Detection;

- Techniques to deploy detection devices;
- Techniques to use sensed data.

Techniques for flood avoidance and detection have discussed below in brief:

1.2.1 Techniques for Flood Avoidance

Floods have been classified into two categories including periodic flood and aperiodic flood. Periodic floods happen due to rivers in pre-decided flood plains. On the other hand, aperiodic floods are random and happen in forms of waterlogging, heavy rain-induced floods, flash floods, and cloudburst-induced floods. Many flood avoidance strategies are in practice to avoid these floods but no one helps appropriately. In all the flood, urban flood always harms humans. These never provide any benefit as periodic provides in agriculture while instead of benefits, aperiodic floods sometimes create deadly disasters as indicated in table 1.1. To avoid both kinds of flood many techniques are in use. For avoiding periodic floods, two main techniques are available on which organizations and governments have focused including river connectivity projects and dam development projects. On the other hand, to avoid the aperiodic flood, different techniques are in use. These techniques include drainage management by developing a drainage system, installation of sandbags or dike development.

In this study, the researcher has focused on the second one, and tried to improve the design of the drainage system because a perfect design of the drainage system is only able to avoid waterlogging or urban flood at least in newly developing cities.

1.2.2 Techniques for Flood Detection

Traditionally, Wireless Sensor Network (WSN), Geographic Information System (GIS), and Internet of Things (IoT) perform the flood detection. Here, WSN is useful after dense deployment of sensors, GIS detects events using remote sensing with heavy infrastructural support, and IoT assumed as an extension of WSN. Few technologies are dedicated to supporting flood management after pre-detection, including sensing mechanisms, risk finders or alert mechanisms. In this, pre-detection is based on a few technologies known as WSN, and IoT as discussed by Neeraj et al. [15]. Accurate and timely flood detection is possible using three steps as:

- Suitable Sensing Device;
- Suitable Device deployment strategy;

- Way of utilizing sensed data.

Out of both the technologies involved in sensing, IoT only assumed due to ease of use. IoT easily enables monitoring stations to get data using a device to device communication. For monitoring, IoT needs sensors and actuators with a gateway to connect it with web servers. Now, to develop a solution using sensors, there is a need to find out the performance of devices involved. IoT is considered to be more useful in the early detection of an event by sensing. IoT has a need to reframe the argument of Uslaender et al. [16] with MANET devices, who argued for the standardized approach of sensor-based information management with an example of a Tsunami early warning project and OpenIoT for IoT software platform. He paved a path to do research to provide help by finding a risk of rainfall-induced disasters.

To save people from rainfall-induced disasters, the role of Expert System (ES) is to provide an accurate risk of disaster before the event. The losses may reduce using proper alert based on exact risk. By focusing on this fact, researches were conducted to determine the information about a possible flood. The conditions of possible floods can be determined using ES because the monitoring and decision of alert type are easy and accurate using ES based on real-time data. Until now, the real-time data collection is performed manually or by sensors. Data collection using sensors is in practice using WSN and IoT because both technologies can perform the task in real-time. Here, WSN is a network developed using a combination of various sensor devices, where its powerful node can act as a router only while IoT is defined as a group of interconnected things, communication protocols, and associated techniques to solve particular problems with the capability of data processing in a particular application.

The IoT and WSN both depend on the working of sensing nodes. In IoT, dependency on tiny sensors has been increased tremendously in the last few years. This increase in dependency on sensors directs us towards selecting good quality of components for designing a detection device, while choosing a good component may increase the cost of deployment. In IoT mechanisms, devices must be capable of connecting to the internet by which they can send data to the server. In this case, non-seamless connectivity may pose a problem that is solvable using IoT based on various kinds of sensors, boards, and communication protocols. However, the choice of components to use in devices, the choice of communication mode, and choice of the deployment strategy for devices affect the cost and ease of the solution. An increase in cost is the main reason by which an organization may hesitate to deploy IoT as per the deployment strategy of WSN. It means the deployment strategy for an IoT is important to acquire quality data. A few factors affecting deployments have been shown in the next section.

1.3 Factors Affecting IoT Deployment

A variety of devices can use different communication modes in a project. The selection process to choose devices and communication modes for any application is a typical task, while the deployment of devices without appropriate planning affects the cost. The working, installation, and budget of each technology depend on various factors. IoT also has issues related to deployment, including the cost of the deployment depending on different factors enlisted below:

1. The required data source;
2. The technique to use gathered data;
3. The data storage manner;
4. The communication mode;
5. The deployment strategy for devices;
6. The cost of devices.

Description of these factors is as follows:

- **The required data sources:** A requirement of data source affects the quality of data and budget of an IoT solution. For example, in environmental monitoring of a room, at least one device is required to get the data of room or four devices placed at various corners of the room. In this case, it may be detected using eight sensing devices or maybe using a single device. In the same way for flood detection application, the deployment strategy may depend on the types of flood plain that sometimes affects the requirement of devices or nodes. For example, to detect flood caused by the river, the device can be installed at the dike in different numbers or the devices should be placed on the bank of the river to measure the water level of the river if it is the cause. When it is to be installed on the Dam, it can be installed at the corner or in the center of the Dam. In this research, the problem of rainfall-induced flood detection in urban areas has been chosen. In this case, the requirement of devices may be in the way of exit of logged water, or in tanks of a drainage system for timely and accurate data collection. It is to be noted that the term node or detection device are used interchangeably for the data sources in this thesis.

- **The technique to use gathered data:** Data analysis depends on its appearance as well as on other factors; it may be on a laptop, smartphone, or web page. So, the cost of an application to see the data is an essential part of the budget, while the budget affects the implementation of any technology. In IoT, data should be collected at the device only when the analysis is performed at the edge level. This data can be collected at a monitoring station or at the cloud and can be analyzed from other stations placed afar from the deployed devices. Thus, how to use the gathered data has importance.
- **The data storage manner:** Deployment also depends on the storage methods used for data management. It may include the cost of software used for data storage, the cost of cloud utilized for data storage, etc.
- **The communication mode:** The deployment of a solution might be affected by the cost of hardware, infrastructure, application, and maintenance. All these costs may vary with the communication modes. Communication mode plays a vital role in the selection of components to develop a detection device while the budget of the project depends on the components chosen. In wired mode, it requires only one device while the cost of the wire increases the budget. On the other hand, in wireless mode, at least two devices are required to accomplish the task, including a transmitting device and a receiving device.
- **The deployment strategy:** The number of devices to be deployed depends on the deployment policies. Various networks having different deployment strategies, it is also true for sensor-based technologies. The strategy may be different and may vary as per the need. For example, a WSN works with different routing protocols. It sends data from source to destination one by one in the network. WSN works in a harsh environment using dense deployment. It has the capability of self-organization, but the node does not have any dedicated communication between source and destination. This is the reason behind its dense deployment policy. So, generally, its deployment policy advocates a dense population of devices. But, for the deployment of IoT devices, dense

deployment policy may be costly because it can't deploy densely due to the high cost of devices or nodes. In dense deployment strategy, deployment requires a large number of nodes that might be costly for IoT.

- **The budget of devices:** For monitoring, the use of different kinds of devices is possible to accomplish the same task. Sometimes, a new design of devices may be required. In this case, the cost of designing new devices depends on the chosen component. It may be less to design a high number of devices and may be higher for less number of devices. Apart from the selection of components, the quantity of purchasing of components has importance. It means cost may vary as per the number of devices developed. Concisely, the cost of the device depends on the number of devices designed within a slot, lifetime of devices and facilities provided by devices.

1.4 Pertinent Issues

Indian society has two major flood-related issues, including the absence of an effective flood avoidance system, at least in a densely populated area, as well as the absence of a low-cost flood detection mechanism. As per the discussion, it is evident that in order to avoid life-threatening tragedies, there should be some ways to avoid or at least to detect the flood and its risk in advance. Hence, the researcher has raised the following questions:

- Which design is better for a quick exit of water to avoid flood?
- In case of failure in avoidance, how is flood pre-detection possible?
- What will be the method of finding the symptoms of a flood?
- What kinds of technologies are in use to sense data of symptoms of a flood?
- Which sensors will be able to detect the symptoms of a flood?
- How the development of flood detection devices is possible on a low budget?
- How can we use detected data to decide flood risk?
- If the arrangement of devices is possible in wired and wireless modes, then what will be the difference in the cost?
- What will be the device deployment strategy for effective flood detection? Will it affect the minimum number of devices to be deployed?
- What will be the intelligent method to find out the chances of a flood?

- How can we develop an Expert system to provide flood risk?

1.5 Research Problem

Available approaches for flood avoidance and detection are not sufficient to avoid or at least detect the flood in order to minimize life and asset loss. Initial study indicates that flood avoidance is not an easy task, but its capacity to hurt can be minimized using proper planning of a drainage system. However, a good drainage system can avoid urban flood at least for newly developing cities. Detection of a flood is important in case of a failed drainage system because using a detection mechanism a timely assessment of flood risk is possible that may reduce the losses. The losses due to floods are reducible by appropriate actions just after pre-detection. There are two technologies found capable to sense symptoms of a flood, including WSN and IoT.

WSN has a network, aggregation, localization and QoS related issues in working due to its ad-hoc nature while IoT does not have such kind of issues due to its capacity for connecting with internet at anytime, anywhere. However, both technologies are facing cost issues because designing a low-cost network depends on the cost of devices while designing a low-cost device is a tedious task. This sensing device works as a source node in the network, so the designing of the device has importance. Any kind of sensing device cannot utilize its data without any external support for analysis. The sensing devices in IoT are also not an exception in that way, however, they can display their acquired data. They can compute using little programming on their own controller board. The devices in IoT provide a rich amount of accurate data on devices or monitoring stations. Thus, the choice of the way for data utilization is a matter of course, and it varies according to the need. The way of data utilization has importance as sensing and deployment strategy. Thus, finding out a way to utilize the sensed data intelligently is a problem.

For the purpose of flood sign detection, IoT devices start acquiring data after appropriate designing and deployment. Here, timeliness of data acquisition depends on the location of the device deployed, while this acquired data will be used to decide flood risk using an expert system. Thus, keeping the requirement of an efficient flood management mechanism in mind, the researcher has formulated a problem as under:

"Design and Development of IoT Based Fuzzy Expert System for Flood Detection and Avoidance"

1.6 Objectives of the Research

The research has been conducted to handle questions raised in the pertinent issues while the research problem has been chosen to solve these questions within a single study. So, the research conducted to achieve many objectives rather than a single objective. The research tried to find out the approach to avoid an urban flood, and in the absence of flood avoidance, to find out the way to gather and use the data of symptoms. To achieve the goal, the following objectives have been decided:

- To review and critically examine literature in the area.
- To design an approach for flood avoidance.
- To test the proposed approach for flood avoidance.
- To develop devices at low cost for flood detection.
- To test the proposed device by comparing it with others.
- To develop a device deployment strategy.
- To find the minimum number of devices required for flood detection.
- To test the device deployment strategy.
- To find out the difference in the cost of devices.
- To design a Fuzzy Expert System for flood risk assessment.
- To validate the concept of designing an IoT based FES.

1.7 Research Methodology

To achieve the desired objective, a solution is assumed using CA, IoT, and Fuzzy Based Expert System, in which CA for flood avoidance and device deployment strategy. IoT is assumed for sensing symptoms for flood and risk finding using a fuzzy-based Expert System. The main tasks involved in methodology are:

1. Review and critical examination of available literature;
2. Conceptualization and design of flood avoidance mechanism;
3. Review of flood avoidance mechanism and revision (if any);
4. Validation of flood avoidance mechanisms;

5. Conceptualization of flood detection mechanism;
6. Selection of components to design flood detection devices;
7. Design and development of flood detection devices;
8. Assessment of the effectiveness of devices designed;
9. Development of a deployment strategy for device installation;
10. Design and development of an Expert System to find Flood Risk;
11. Experimentation and discussion of results;
12. Validation of approaches;
13. Documentation and Finalization.

1.8 Expected Deliverables

At the end of the thesis, the following outcomes are expected to be delivered including:

- An improved method to design a drainage system to avoid an urban flood.
- A suitable grid pattern for the structure of a drainage system for the quick exit of rainwater.
- Low-cost arrangement to develop flood level detection devices and raindrop detection devices.
- The comparative study on detection devices.
- A scheme to find out the suitable position to install the devices for existing cities.
- A scheme to find out the suitable position to install the devices for newly developing cities.
- Budget analysis to install devices on the University campus.
- Assessment of budget in the deployment of devices in both modes.
- Design and development of a Fuzzy Expert System (FES) for finding the flood risk.
- Impact of various input rules on outputs in FES.
- Relationship between various signs of a flood.

1.9 Thesis Outline

The thesis has been arranged in seven chapters including a chapter of Introduction. Following is the chapter wise summary of the thesis:

- **Chapter 2: Literature Review**

  The researcher reviews the plentiful amount of papers and reports discussing the technology involved in flood avoidance, sensing and expert systems to use the data taken. This section covers the structure and existing developments for flood avoidance and sensing methods, and Expert systems to utilize the sensed data. In this section, the researcher has shown the main technologies in trends only.

- **Chapter 3: Cellular Automata-based Flood Avoidance System**

  Chapter 3 discusses existing methods of flood avoidance and the proposed solution to improve avoidance methods to urban flooding using CA. So, before presenting a detection mechanism and deployment strategy, a solution to avoid flood at least for newly developing urban areas has been presented. In this, an efficient drainage system has assumed sufficient to avoid a flood. The researcher suggests different grid patterns to design a structure of the drainage system, and analyze their different aspects. At the end of the chapter, the researcher recommended Hexagonal design better than others and validated this theory by applying the T-test.

- **Chapter 4: IoET Devices for Flood Detection**

  In chapter 4, the environmental data generation has been performed using IoT enabled devices at the edge. This environmental detection using IoT called IoET and focuses on studying the environmental data generated in IoET for a specific case of floods. The researcher has provided a summary of various projects, helpful in flood management to find out the most popular and suitable components to be used in detection devices. Apart from it, the researcher has presented a few circuits and prototypes of devices. Now, to check the working of the circuitry, data generation performed using the developed prototypes. Apart from the existing circuits, the researcher has proposed Flood Sign Detector to acquire meaningful data. In this chapter, research has also shown the proposed device better than others after the hypothesis testing using one way ANOVA and F-test.

- **Chapter 5: Deployment strategies for IoET devices**

  Deployment strategies to install the IoET devices have been proposed in this chapter. There are two different deployment strategies proposed to install detection devices, one for existing cities and second for newly developing cities. Validation of both proposed schemes has been performed. Apart from the strategies, cost estimation to deploy devices in the campus has been indicated to show the cost of devices installed in the worst case.

- **Chapter 6: IoT based FES**

  Chapter 6 enlightens expert systems involved in decision making under a popular way of soft computing, including the fuzzy logic-based Expert System, and provides a framework to use the sensory data in a Fuzzy Expert System after a comparative study between both kinds of Expert Systems. This chapter discusses the ways to use sensory data determined by IoT devices, within an expert system. In this, the operators, operations, and rules to design a Fuzzy Expert System have been discussed. The researcher presented an FES for flood risk estimation and validated the concept using multiple linear regressions.

- **Chapter 7: Conclusion**

  This chapter represents a summary of the research conducted. It includes the benefits of different grid structures, use of these structures in the drainage system, flood sign detector and expert system in sequence following:

  1) Advantages of the different grid patterns to be used in the drainage system for flood avoidance.

  2) Recommended hexagonal grid pattern to be used in the drainage system for better services.

  3) Advantages of the proposed device than others using a statistical test, and comparative study.

  4) The researcher has presented two deployment strategies for both kinds of cities, and shown hexagonal design better to find locations for the deployment.

  5) The researcher has discussed the impacts of rules used to design the inference engine of the Fuzzy based Expert System (FES).

6) A prototype based on the given concept has been indicated at the end of the chapter.

CHAPTER 2 | LITERATURE REVIEW

A systematic review sometimes produces results which, inconveniently, contradict common beliefs.

—Robinson, P., & Lowe, J.

2.1 Background

As the literature review forms the basis for any study, the researcher has performed an in-depth study of available literature in the area to provide a strong foundation for the proposed research. The chapter consists of a summary of a study conducted for flood management expert systems based on their method of data acquisition (i.e. Sensing). Apart from flood management expert systems, various sensing technologies have been studied, including Wireless Sensor Networks (WSN), and the Internet of Things (IoT). A branch of IoT that has environmental applications referred here as an Internet of Environmental Things (IoET). IoET has a few unique characteristics, challenges, and different limitations from other types of IoT. IoET has various applications in environmental monitoring, including pollution monitoring, inside environmental monitoring, water level monitoring, water flow monitoring, and flood monitoring, etc. As the domain of the proposed research is the flood management expert system, the researcher has chosen to study IoET based flood management systems. In these sections, a study is performed for flood avoidance, and detection with an objective to choose components to design low-cost devices for flood detection, to examine the deployment strategy, and to find out the ways to utilize the sensed data.

A systematic literature review (SLR) has been conducted after a rich collection of literature. The reviews found in an SLR are arranged in several categories as discussed below:

- Flood avoidance methods;
- Flood detection methods;
- Existing work for flood detection by sensing;

- Application and challenges of flood detection technologies;
- Sensory data-based expert system.

2.2 Flood Avoidance Methods

Before about 5000 years, few cities were developed with a plan of water drainage using a perfect geometry of cellular automation, i.e. Harappa and Mohenjo-Daro. These cities are examples of good drainage planning, but they had no mechanism of water flow or storage. This is an assumed possibility behind the end of these cities due to the water-related disaster because floods or droughts were assumed for demolishing these cities by historians.

Parkinson [17] discussed the drainage management strategy for helping in flood management. However, the infrastructure was required to implement their strategy. He has discussed a participatory approach for urban stormwater planning. He argued that conventional drainage systems are inappropriate that is why they fail sometimes. He has mentioned a preventive response to avoid the flood.

Croke et al. [18] argued about flood risk avoidance strategies. His approach improved flood risk avoidance methods by interpretation of modeling. They have suggested hydraulic modeling using HEC-RAS software provided by the US government. This software was able to provide a map of a flood plain.

Spector [19] invented a method of arranging weighted bags to form dikes to hold floodwater. He has suggested bags made by fiber with the rings and clips at the corner to lock with each other. It was a method to avoid a flood in a particular area.

Ellis et al. [20] have assumed the importance of sustainable water management using flood avoidance in an urban area. They have worked over the existing approach of canalization by considering growth in the urban population of developing countries. Miguez et al. [21] considered a subdivision approach for designing the integrated network using links for water discharge. They have considered runoff volume and rates in his work. His drainage management system was based on a Water Sensitive Urban Design (WSUD). In their work, they have considered the natural terrain with artificial structure placed over it. With this structure, he has suggested to maintain a drainage network and analyzed the discharge. He has considered discharges from other sources too. In this row, to avoid urban flooding, a structure given by Wang et al. [22] for their drainage model can be considered. In their model, tanks were suggested between the path of water flow. Mugume [23] discussed the causes of failure of a drainage system using the Global Resilience Analysis (GRA) approach. In which, they have considered local topography of drainage mechanism. They have shown the cases of failure by a blockage in pipelines indicated by links. This work directs us to see the probability to maximize water exit and to minimize the probability of drainage system failure.

Cellular Automata-based modeling was assumed to predict flood plain and direction. Ghimire et al. [24] discussed CA as a tool to predict flood by a method of transferring rainwater from one plain to another. In this row, after Katrina (2005), the research community preferred the improvement of drainage structures. As per Liu et al.[25], the drainage design is governed by factors including distance, constructability, affordability, environmental impacts.

2.3 Flood Detection Methods

WSN and IoT assumed for environmental monitoring, whereas WSN is useful for disaster monitoring and IoT considered for sensing symptoms easily. IoT enables monitoring stations to receive data using a device-to-device communication. For monitoring, IoT requires sensors and actuators with a gateway to connect them to the internet or a web server. To see the difference between monitoring using WSN and IoT, an extensive literature review was performed. Let us see both kinds of technologies:

2.3.1 Wireless Sensor Network

The era of the last decade was witnessed for rapid advancement in tiny hardware technologies that enabled the development of sensing nodes with low power consumption. These nodes are capable of sensing and computing in a wireless environment. WSN utilized the tiny device, known as a sensor node that consists of a radio transceiver, microcontroller, power supply, and the actual sensor. WSN is applicable for various types of monitoring, including applications of military, civil, and disasters. A WSN has characteristics of self-configuration, densely deployed, and it is a battery-operated network able to communicate between each other and with another kind of network or node like MANET.

For long-time applications such as flood monitoring, limitation of battery life is a challenge. Data collection, processing, and security operations consume a high amount of power due to continuous processing. The main task of WSN is to gather information from the event site using a sensing node and transmit it to a base station for further processing. The concept of a sensor node deployment in WSN is bound to data dissemination in all the directions. Due to the self-organizing nature of WSN, it activates the network on the occurrence of events and starts working in collaboration to perform a task. The strength of a WSN is flexibility, scalability, self-organizing nature, low cost, easy deployment, and the ability to work efficiently in a hazardous location without any infrastructure. These features made it popular for monitoring applications. It was the only single suitable network for monitoring of remote areas till the development of IoT. However, it had a flaw that it did not last lifetime because the maximum part of the energy was consumed by data transmission, signal processing, and hardware operation. In this regard, Kumar et al. [26] said that 70% of energy consumption found due to data transmission.

Wireless sensor network based on P2P communication with Zigbee or other protocols. The various protocols provide efficient communication by utilizing multi-hop communication. In multi-hop communication, a sensor node can transmit data to other sensor nodes situated far away in the network. This property of a sensor node provides a chance to add other nodes in the network that enhances the reach of the network and makes it scalable and flexible. Now, sensed data goes to the monitoring station through various cluster heads for further processing. In this way, each node forwards its data to the next nearest node situated between the sensor node and the sink node. For efficient working, the installation of sensors performing using many special techniques including dense deployment is the most popular approach. Due to the dense deployment, sensors sometimes produce similar kinds of data by few closed sensors within a neighboring region, and transmission of that data is generally redundant; this redundancy of data is another issue in WSN.

- **Pros:** WSN has features including self-organizing capabilities, dynamic network topology, short-range broadcast communication, multi-hop routing, dense deployment, remote monitoring, low cost, and zero maintenance cost. These features are the strengths of WSN.

- **Cons:** Researchers from every corner of the world, including Dâmaso et al. [27], accept that processing of instruction and the functionality consume a high amount of energy rather than the data transfer or arithmetic operations performed by the processor in WSN. This consumption of energy is the single reason to drain a battery and limits the lifetime of the network. Limited power, node failures, failure in the mobility of nodes, and the large scale of deployment Sonule et al. [28] are other limitations of a WSN.
- **Challenges:** Wireless sensor network faces several challenges such as physical resource constraints, ad-hoc deployment, fault-tolerance, scalability, and quality of service. The main challenges with wireless sensor network are:
    1) How to extend the life of a network?
    2) How to make a network robust?

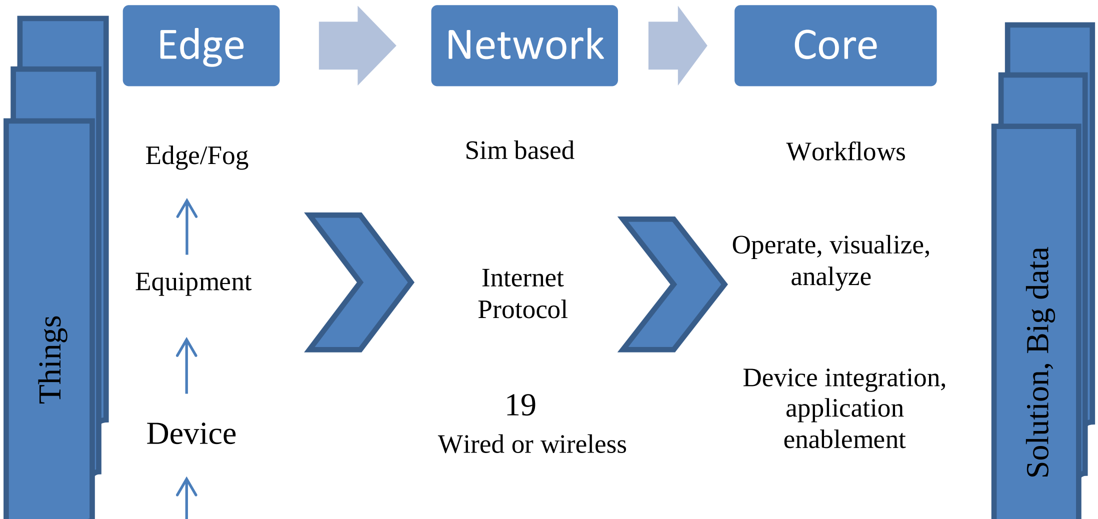
When a sensor network relies on battery power, the main aim of minimizing the consumption of battery power is to maximize the lifetime of the network.

2.3.2 Internet of Things

As per Fang et al. [29], IoT was rapidly conversing into a reality from a theoretical concept using WSN, sensors, and gateways integrated with cloud platforms. The development of both critical components enlarges the sharpness of technology, including various developments in sensing components, data fusion, aggregation, refinement, collection. Apart from this, development in handling data at cloud platforms helped in the popularity of IoT. Fang et al. [29] assumed the system architecture of IIS with four layers, including the perception layer to collect data, network layer for connectivity, a middleware layer with its sub-layers for the management of data, software/tools, models and platforms. They have assumed a middleware layer between the network layer and the application layer. The last layer assumed to help the users as an application layer. They have considered IIS as an IoT, while both may differ.

As per Yongrui et al. [30], a thing may provide better data to monitor the environment than traditional mechanisms. Poslad et al. [31] discussed IoT mechanisms to develop EWS for natural crisis management. This mechanism collected data with sensors like an ultrasonic sensor, rainfall sensor, temperature, humidity sensor, and transmit data from one end to another. An IoT solution may enable the irrigation or disaster management department to monitor, analyze, and forecast flood situations, centrally. This process was able to alert the administration and the population about the risk of a flood event. In the future, this would help to take necessary measures to minimize the loss of lives and mitigate the damage to properties. The mechanism acquired and utilizes sensor data from various sites, including reservoirs, dams, canals. This mechanism consolidates sensory data for monitoring in real-time through a central dashboard using maps. In this mechanism, an alert is calculated based on parameters (i.e., Rainfall, water level, and discharge levels), and threshold breach. A predictive algorithm used to forecast a flood risk after its chance of occurrence. This procedure has the potential to save the property and lives of citizens by accurate flood risk forecasts.

As per MAIT [32], IoT is a network of battery-powered devices or things that can be connected to the network by any mode, here communication mode is generally wireless however wired is also possible and suitable for some applications. An IoT based system requires data storage, transmission, and processing. Different phases of IoT utilize various technologies in development, including edge devices that are capable of sensing and transmitting its data. Connectivity technologies provide connections for data transmission using various protocols to interpret these retrieved data. The data management platform provides data storage capacity while the application platform enables services that provide integration to use device data libraries with the core application. Figure 2.3.2 indicates the main component of IoT, including Edge, Network, and Core. Here, Edge deals directly with the things while core deals with the big data and the network deals with various communication mechanisms. Devices at the edge may convert into fog or may send data to the cloud using networking technologies. The sensed data can be stored and analyzed at the edge, fog, or cloud.



Work as per the first three layers of the seven-layer reference model of Cisco [33] has been performed in research. However, layers of reference model adopted by Cisco have been illustrated in Appendix B.

2.4 Applications of WSN and IoET

Talari et al. [34] assumed WSN with IoT architecture, including three layers sufficient for monitoring. The model had a perception layer with various kinds of sensors, including RFID, cameras, NFC, WSN; network layer with communication protocols, including Zigbee, Wifi; and Application layer to facilitate interaction with the users in smart home applications. Djajadi & Wijanarko [35] performed environmental quality monitoring with single board computers and sensors. They have used ambient light sensors, DHT 11 for temperature and humidity sensor, sound sensor, sensor MG811 for carbon dioxide, sensor MQ7 for carbon monoxide, sensor MQ6 for LPG, and sensor MQ3 for alcohol. Talavera et al. [36] discussed the classification of researches performed in agriculture and the environment. They found work with various communication technologies, including WPAN, Bluetooth and Zigbee, WMAN, GPRS/GSM/3G/4G, edge computing with microcontrollers, storage in the cloud, and self-managed data storage.

As per Talavera et al. [36] visualizations were found on the web, mobile, and local display. Monte et al. [37] proposed a database implementation to handle a large amount of data taken by sensors deployed to make a city smart by environmental monitoring. For database implementation, they have designed IMMS with MongoDB as a database, Raspberry Pi as a gateway.

Therefore, applications of both technologies are possible for environmental monitoring. Here, researches performed for flood detection using both technologies have mentioned and comparison of them performed one by one as:

(1) Researches using WSN for flood detection;

(2) Researches using IoT for flood detection;

(3) Comparison between IoT and WSN.

2.4.1 Researches using WSN for Flood Detection

Few WSN projects for detection got popularity, and few not. All these researches are discussed below:

Marouane and Mostafa et al. [38] proposed a model that detected flood based on data retrieved by WSN to forecast the information. It also examined the history to check the occurrence of the flood while it works using agents that could forecast flood information in the form of an alert message. This ES decided alert based on rules formed to use the Knowledgebase of ES. In ES, Knowledgebase and rules both are designed to take the final decision. In their architecture, sensors in WSN provided data after sensing the rainfall, water level, and runoff. The monitored data by WSN is sent to a unique database of server through VPN or the internet; and after calculations, the decision is transferred to stakeholders. A flood monitoring project using Xbee nodes is developed by Degrossi et al. [39] to monitor flooding in Brazil. This project worked efficiently and found success in the objective. Another flood monitoring and warning system [40] was deployed to collaborate between authorities and experts of the flood. It was designed to provide information using a web-based information source for the public. STARflow sensor and precipitation sensors were used in their project to perform sensing. RTFMS [41] was developed for flood monitoring in the river basin using MicaZ, SunSPOT JDK.

Elizabeth A. Basha [42] developed a low-cost sensor network to provide alerts to possible victims after an early flood detection. They have presented a solution to alert people in Honduras after completing four tasks, including event prediction, authority notification, community alert, and community evacuation. They performed the validation by testing the usability of the 144 MHz radios for communication to different ranges. Results found WSN better than other flood detection in developing countries. E. Basha et al. [42] gave a fourth solution by suggesting a way to gather information about water in the river using WSN. They distributed the sensors in clusters on the basin of the river and computed the gathered data. Two kinds of nodes, including computational node and community nodes, were used in their project. A computation node was used to provide information to the government offices. They discussed the power consumption by considering a charging circuit on the board, allowing photo-voltaic charging of batteries. They used two-tier communication systems with 900 MHz and 144 MHz systems. They used a 900 MHz system between a computational node and sensor node while the 144 MHz system used between a computational node to the community interface node and government offices. Here, the community interface node used for communication was a laptop.

With the use of a WSN along with a server, Baez et al. [43] performed flood monitoring due to a river. For continuous monitoring of a flood level, a WSN was deployed while the server was used to collect and analyze the data sent by WSN. A threshold value was adopted to analyze data at the server end. These researchers deployed sensor nodes within a PVC pipe and transmitted the data to the server using a sink node (i.e., A sink is a more powerful node than the sensor). A flood monitoring project completed by researchers [40] using WSN of Xbee motes. Similar kinds of projects were performed by Ueyama et al. [44] using the motes and API to detect flood over a river. Sunkhpho et al. [40] discussed a flood monitoring system made using the Starflow sensor and precipitation sensor, deployed in the southern part of Thailand to make collaboration between authorities of disaster management and experts to watch the possibility of flood closure. Kavi[41] discussed a mechanism of MicaZ motes to monitor river flooding. This project utilized powerful motes along with SunSPOT and JDK platforms.

Jagadeesh and Chandrasekhar [45] developed a real-time flood monitoring using the wireless sensor and other components, including Raspberry Pi, flow sensor, level sensor, and temperature sensor. They found coordination between the sensing device and the receiving device as a challenge due to the installation of sensing nodes at various geospatial locations. They have developed a way to manage flood monitoring and alert using the wireless sensor with other components In their work, they have used tableau software to collect data in the spreadsheet before sending an alert message. They have not discussed the way of sensor deployment while having many loopholes to cover. Castillo Effen et al. [46] suggested architecture for flood prediction systems but did not discuss any essential characteristics and hardware.

One paper found closest to our work was published by Hughes et al. [47] that described a flood-prediction mechanism based on the sensor network. This network uses Gumstix sensor nodes, which requires significant power, but its nodes were Linux dependent. The working of their system was tested only in the lab conditions, and no field test was conducted. Another solution was conducted with the use of various sensors in a wireless sensor network, few people tried to sense alternatives, including Rashid et al. [48]. Rashid et al. [48], who have designed a rain gauge using various LEDs, potentiometer, infrared distance sensor with a combination of Arduino Uno microcontroller, Arduino shield, and an XBee wireless module with a receiver module by trying to identify water levels. Though the study of a monitoring technique was found necessary as per the "guide to IoT development" by GSMA. Shah & Mishra [49] discussed IoT enabled environmental monitoring system for smart cities and said wireless sensors could monitor the temperature, humidity, and CO2. They have monitored and analyzed the data after the implementation of this network, on Labview.

2.4.2 Researches using IoET for Flood Detection

IoT with the cloud is in existence for environmental monitoring. In Thingspeak based sensing and monitoring system [50], Thingspeak API works as a host for the sensors in monitoring. Thingspeak facilitates as an app on the cloud and porting the sensed data to the MATLAB R2016a using a channel ID and read API key assigned by services that help to process and transfer the sensed data to the Thingspeak Cloud. In this, MQTT protocol was used for communication, while Thingspeak to facilitate and maintain connectivity and analysis. In this row, few monitoring applications found helpful to achieve objectives of the thesis are:

- **Hydrological Monitoring:** Han et al. [51] discussed hydrological monitoring by focusing on communication reliability and lightning protection. S. Pasha [50] designed an application using a single-board computer along with the various sensors and sent recorded data to monitoring devices using the Thingspeak application of Matlab cloud. He used Air quality, DHT, BMP, LDR, and rain sensors to monitor the situations. Visconti et al. [52] developed a project powered by a solar source to monitor water conditions in agriculture. In this project, researchers used TDR, FDR, and GMS sensors to measure parameters.

In the other work [53], they have predicted flood by measuring the presence of water in the soil. The water monitoring system [54] was discussed to provide information about all the connected water tanks. It has utilized MQTT protocol along with the different components, including Ultrasonic, water level, turbidity sensor, Wi-Fi module, Arduino Uno.

- **Flood monitoring:** Ghapar et al. [55] proposed a mechanism for data management of a disaster management system. It was only a conceptual prototype. Leon et al. [56] proposed an early warning system to monitor the river overflow using a Raspberry Pi and ultrasonic sensor. In this system, sensing node transmitted information to the receiving node, using LoRa modulation. Their system publishes the output using social media, i.e. Twitter. They have measured distances from 20 cm to 2 meters while placing the receiver 500 meters away from the transmitter. Sauza et al. [57] developed a flood warning system for critical regions, in which they used various sensors along with a single board computer and sent the retrieved data to the Ubidot server for analysis. The smartphone was used to send and receive an alert message in the form of SMS. In this row, Maurya and Kumar [58] have discussed the problem of localization to find out the exact location of flood due to the running nature of the flood. They have discussed problems with the MDD app. Satria et al. [59] developed a Web-based flood monitoring information system using Arduino Uno microcontroller and sensors in which ultrasonic, and raindrop sensor was used to detect the flood level.

- **Water Level Monitoring:** Mysar, D., Babu, M.J. [60] developed a water level monitoring system to detect variations in rivers and tried to provide alert using Arm7. They used Arm 7 board with the temperature sensor, flow sensor, raindrop sensor, GSM/ GPRD modem, buzzer, and power supply with the software setup in the application; and used GPRS logger to maintain data from various sensors. In their work, data was shown on web pages. Sivaiah et al. [61] developed IoT enabled water monitoring system to monitor and analyze continuous real-time reading on the screen. They utilized the ultrasonic sensor to measure the water level. Rismayana et al. [62] developed a prototype model for early flood warning and gave the idea to send data on social media. They suggested a way to use social media for monitoring purposes. Parimala et al.

[63] developed monitoring mechanisms for water storage using the Arduino Uno with a water level sensor and sent data to a web-based application using GSM. In the continuity of the discussion, two tables presented in this section that represents a summary of the work performed by various researchers and the layer-wise breakup of a few good papers. These summaries are indicated in table 2.4.2 (a) and in table 2.4.2 (b), to show the development in IoET.

Table 2.4.2 (a): Summary of the work in IoET

	Google Citation	**Database**	**Research type**	**Application**
Visconti, P., et al., [52]	9	ARPN journal	Prototype discussion	Agriculture monitoring
Parimala et al., [63]	1	Researchgate	Prototype implementation	Water level monitoring
Rismayana et al, [62]	0	Publisher site	Prototype discussion	Water level monitoring
Sivaiah et al, [61]	0	Publisher site	Prototype implementation	Water level monitoring
Satria et al., [59]	0	Emrald	Prototype implementation	Flood monitoring
Pasha, S. [50]	26	Publisher site	Prototype implementation	Water Level monitoring
Perumal et al, [64]	17	IEEE	Prototype implementation	Water monitoring
K. Andersson and M. S.Hossain [65]	14	IEEE	Theoretical and simulation.	DSS
P. Mitra et al., [66]	13	IEEE	Method simulation	Flood Forecasting
Hernández Nolasco, et al., [67]	11	IEEE	Prototype implementation	Water level meter for alert
H. Tai et al., [68]	10	IEEE	Theoretical Prototype	Water risk management
Mercado, [69]	5	IEEE	Real-time Implementation	Flood early warning
Gourbesville et al., [70]	4	Researchgate	Review and Study	A study
Rajurker et al, [71]	2	IEEE	Real-time implementation	Water flow meter
Supani et al, [72]	1	Researchgate	Prototype	Flood early

			implementation	warning
Kamal et al, [73]	1	Researchgate	Real-time implementation	Flood Monitoring via blink app
Jayasree et al., [74]	1	IEEE	Review and discussion	Approach for EWS
Noymanee et al., [75]	0	Springer	Review	Framework for EWS
Leon et al., [56]	0	Researchgate	Prototype implementation	Early warning
Mysar, D., babu, M.J., [60]	0	Researchgate	Prototype implementation	Water level monitoring
Han et al., [51]	11	Sciencedirect	Discussion	Hydrological Monitoring
Sauza et al., [57]	2	Sciencedirect	Prototype implementation	Flood warning
Damor et al, [54]				Water monitoring
Neeraj et al. [76]	0	Google Scholar	Approach	Rain disaster monitoring
Babu et al., [77]				Flood Alert
Ghapar et al., [55]	1	Google Scholar	Prototype discussed	Flood data management
Maspo et al., [78]	1	Semantic Scholar	Prototype development	Flood prediction and EWS

Table 2.4.2(b): Layerwise discussion in key papers found

Author /Year	**Board**	**Comm. Protocol**	**Analyze at Edge/ cloud**	**DBMS /Cloud**	**Application /Processing**	**Business model**	**Layer**
	Layer 1	**Layer 2**	**Layer 3**	**Layer 4**	**Layer 5/6**	**Layer 7**	
Djajadi & Wijanarko, 2016[35]	√	√	√	√	√		1 to 6
Shah,J., & Mishra,B.2016 [49]	√	√	√	√	√		1 to 6
Talavera et al., 2017 [36]		√	√	√			2 to 4
Talari et al.,2017 [34]	√	√			√		1,2,6

Do Monte et al.,2018 [37]	√			√	√		1, 4,5
Total	**4**	**4**	**3**	**4**	**4**	**0**	

2.4.3 Comparison between WSN and IoET

A comparison of IoT with others is not easy. However, after assuming IoET as a successor of WSN, a comparison is made, and that is indicated in table 2.4.3.

Table 2.4.3: Comparison between WSN and IoET

Comparative Aspects	**WSN**	**IoET**
Autonomous terminals	Yes	Yes
Self-configuration	Yes	No
Mobile host/router	Eventually, in a small range	Gateway used
Bandwidth constrained	Yes	Yes
Infrastructure-Based	No	Yes / No (Event-specific)
Power awareness	Yes	No
Security	Distributed	Having issues
Security at level[79, 80]	Sink and Routing	Cloud
Operation Type	Distributed	Sensor to a parent node
Routing	Difficult	Easy
Router performs	Routing only	Internetworking
Topology	Dynamic	Static
QoS guarantees	No	Yes
Typical Applications	Home, Emergency	Everywhere
Single hope / multi-hop	Multihop	Multihop, Tree
Communication	Point to Point/ Flooding	Point to Point/ Flooding

2.5 Sensory Data based Expert Systems

Many systems have been developed to find an appropriate decision using sensed data, including decision-making systems, and expert systems. The researcher considered the expert system to find his objective. As per Jackson [81], an expert system is a form of AI technology that is designed to provide help in the decision making of humans using existing knowledge that represented as “if-then” rules. Expert systems help to enhance the judgment capacity of humans and not to replace the judgment of humans. Various kinds of techniques are in use to develop decision making in an expert system, including neural networks, fuzzy logic, and genetic algorithms as well as others. Out of all these techniques, Fuzzy logic provides help to opt for a decision based on existing knowledge. A knowledge designer from the interviews of domain experts acquires this knowledge. Surveys using questionnaire set by experts, historical reports, existing research, and results of the calculation of the existing data, are the tools to acquire meaningful knowledge.

2.5.1 Expert System: Definition and Structure

An expert system consists of two essential parts, including an inference engine and a Knowledgebase. The Inference Engine is a portion of an expert system that provides new knowledge by applying logic rules. It has two modes of working, including forward chaining or backward chaining. To reach on a decision, forward-chaining works on the top-down manner by applying "if-then" rule on known data while backward chaining works in a bottom-up manner by applying "if-then" rules to generate new facts. The Knowledgebase provides strength to the expert system. As per Edward Feigenbaum [82], who was assumed as a father of expert systems, said knowledgebase is a source to provide strength for an expert system. Zhang et al. [83] believed that IT specialists are required from beginning to end while domain experts can provide expertise to knowledge engineers to develop applications of their field. Kaewboonma et al. [84] assumed knowledge acquisition as a bottleneck to encode knowledge in programming. Regarding the development of a knowledge base, Gustavo Cerda [85] said that a knowledgebase could be built with any programming language, while an inference engine is used to simplify the process of creating a knowledge base. So, we can say, the Inference Engine is a layer between the user and knowledge base to facilitate the solution to the particular problem. Based on the above discussion, the Inference engine assumed as a manager of an expert system to manage input and output.

2.5.2 Applications based on Sensory Data

The tools designed using AI techniques were found efficient than traditional techniques. Expert systems based on sensing data that were designed using AI may be classified into two categories as:

- ES with ANN (Based on sensory data);
- ES with Fuzzy (Based on sensory data).

(a) ES with ANN (Based on Sensory Data)

Artificial Neural Network (ANN) has a highly interconnected group of artificial neurons. These neurons work as a nerve cell and receive information from the external source as per Aqil et al. [86].

Robert J. Meijer [87] coordinated a European Union-funded project to design a DSS for flood control between 2009-12. After one year of first funding, they developed a prototype of the framework to allow easy access to sensor data, modeling, and simulated data with visualization. During the second year, they updated the user interface. In their project of designing an early warning system, they deployed sensors on the dike to capture real-time data through communication media to develop a decision by flood simulation. They found monitoring as the primary stage to decide the risk assessment. Their warning system worked efficiently for risk assessment after getting data from sensors.

An ANN can work efficiently for multiple inputs by processing them in parallel. Jirapon and Chaiwat [40] developed a real-time flood monitoring and warning system using STARflow and precipitation sensors with its deployment on the bridges. In their work, the STARflow sensor was used to measure the water level and velocity of water, while precipitation sensors were used to measure the intensity of rain. They sent data collected by sensors deployed on the bank of a river in the southern part of Thailand to the monitoring station using a GPRS module. Sensors of their system settled under a well-mounted case that was able to send data to the monitoring station using GPRS, while at the monitoring end, they used ANN to predict the flood using the possibility of maximum rainfall. They used SMS and FAX to issue an alert in society.

(b) ES with Fuzzy (Based on Sensory Data)

The researcher identified problems solvable using IoT based FES implementation. Several solutions found in the literature are enlisted below:

- ***To solve Estimation problems:*** In estimation applications, FES provides decision and analysis based on "If-Then" type rules and user data. Fuzzy can deal with the uncertainty associated with qualitative data set of inputs and provides a report of the Capability Assessment System for Flood Risk Management. A knowledgebase system for flood frequency analysis was designed by chaw and Watt [88] in which they have developed a mechanism to find out the frequency of flood. They used statistical methods for estimation.
- ***To solve risk assessment problems:*** After collecting input data from the user, fuzzy uses various standards to assess the risk, i.e., ISO/IEC Information Security Management System (ISMS) standard. In this, the FES may provide a recommendation in terms of accepting or rejecting to facilitate and assist decision-makers through real aspects, Hong & Lee [89].
- ***To solve site planning problems:*** FES helps to choose a location to plan a site to perform any task; for example, an FES could forecast the wind speed on the required system. The system can make reliable only after collecting correct wind speed, and collection of correct wind speeds only possible after deploying devices at suitable places. So, FES can help to find locations on site. Liebowit [90] discusses such kinds of FES used for forecasting speed in real-time.
- ***To provide Uncertainty:*** Aris et al. [91] proposed a flood warning model to provide accuracy about uncertainty issues consisting three techniques including fuzzy-based techniques to predict the uncertain situation, agents based techniques to provide alert and notification; and ontology-based techniques to organize flood knowledge in order to support the communication of the agent. Aris et al. [91] considered the data of river level and rainfall in Malaysia. In this model, two agents collected river level and rainfall data from a website which is an input to the processing module of the model and then processed data under the fuzzification process. Now, fuzzified data sent to an inference engine that takes a rule and data from the Knowledgebase to make a decision.

2.5.3 FES for Flood Risk and Monitoring

Few FES based mechanisms developed to find out the risk, and to monitor flood are listed below:

- In the US, few private companies developed the sensor, communication, and computation technology based on the ALERT protocol, which defined the data structure and policies of environmental monitoring systems as per Alert system organization [92].
- Second, in Honduras in Central America, E. Basha [93] completed a project in which they were relying on volunteers and limited technology to develop a mechanism with FES. Volunteers read the river level from a scale painted on bridges and the rain level with water collecting gauges (also emptying the gauge) at several intervals during a day. Those researchers sent information to a central office run by the government. In that office, a person listens to the radio, records the values in a book, and compares them according to a defined policy. After this process, a government branch decides the need for an evacuation alert in that region and implemented in some form of emergency alert procedures.
- The third solution developed by R. Chaudhury [94] in Bangladesh, was Flood Forecasting and Warning Response System that distributed the alert through reports submitted to various government agencies along with a variety of public media sources. This process takes advantage of the ubiquity of satellite information, which looks to provide input data for flood forecasting systems of the future, Hossain et al. [95].

CHAPTER 3 | CELLULAR AUTOMATA BASED FLOOD AVOIDANCE SYSTEM

An important part of sensor deployment strategy is a procedure for physically adjusting the sensor for calibration measurement.

— Gregory J. Pottie,

3.1 Background

In all the floods, floods in populated or urban areas are most harmful and it comes due to the heavy rain or sometimes in simple rain. However, in general, it happens due to waterlogging even in well-planned cities also. This waterlogging leads to flooding if happened for a long duration. Now, waterlogging or rain-induced floods in cities are increasing year by year in India due to the unplanned development of cities and the absence of planned drainage mechanism. These urban floods are avoidable by proper planning of plain and drainage systems because a planned drainage system may facilitate better. The idea of plain and drainage modeling is not new and has been in use before 5000 years. At that time, cities including Harappa and Mohenjo-Daro were developed with drainage planning using a perfect geometry of a square grid [96]. Apart from planning, these cities were not equipped with a detection structure to inform any possibility of water-related disasters before the event. Thus, the absence of prior information had a catastrophic effect on the cities and this led to the demolition of the city. Currently, in India, city development projects start with roads, which are generally, in a rectangular structure, where water drainage is to run on both sides. This chapter proposes other shapes and compares them with square grids to avoid a flood. The researcher has used Cellular Automata (CA) as a tool, to provide a mechanism for flood avoidance and to deploy devices (in case of flood detection). The contribution in this chapter has been organized three subparts:

- Cellular Automata (CA) for flood modeling;
- Existing drainage system for flood avoidance;
- A solution to urban flooding using CA.

3.2 Cellular Automata for Flood Modeling

As per Schiff J. L., [97], Ulam and Neumann discussed the first time CA in the 1940s. A Cellular Automata (CA) is a concept that has many applications to solve the real-life problems in various research areas such as mobile computing as per Chaudhury et al., [98], image processing as per Paul et al. [99], GIS & remote sensing as per Almeida et al. [100], Bioinformatics as per P.K et al. [101] & Gangully et al. [102], Parallel Computing as per Das et al.[103] & Gangully et al. [102], VLSI design as per Gangully et al. [102] & Das et al. [102], Pattern recognition as per Gangully et al. [102] & Das et al. [103], Social Science as per Gangully et al. [102]. A CA is made by a finite number of elements called cells which are characterized by several complicated properties such as color, shape, or size; these properties are known as tuples. It is a mathematical model for systems in which tuples can work together to make the change in the position of a cell by considering their impact on others. For plain modeling, CA is discussed by Packard et al. [104], and other researchers who have tried to solve various problems. A CA for a flood avoidance model can be written as per equation 3.1 as discussed by Kumar et al. [105]:

$$CA\ (C) = \{Ʊ, Ʊ_0, Ʊ_f, Ʊ_{a\text{-}b}, €, \$, k\} \qquad \ldots 3.1$$

Where, Ʊ = Set of cells;

$Ʊ_0$ = Cell at zeroth level;

$Ʊ_f$ = Cell at final height;

€ = Set of parameters to change the position of the cell;

$ = transition rules to change one state to another;

K = Number of cells considered in CA; and

$Ʊ_{a\text{-}b}$ = Flow sending from one to another cell.

In the case of flood modeling, a cellular automaton contains three identified properties, including totalistic rule, cell patterns, and neighborhood. CA-based modeling is performed by considering its properties including:

- **Totalistic Rule:** According to the totalistic rules, sites updated with a sum of the impact of their previous layers as indicated by equation 3.2. These rules work for all kinds of structures.

$$U_{a,b}^{t+1} = f\,[U_{a,}^{t} + U_{a,b+1}^{t} + U_{a+1,b}^{t} + U_{a,b-1}^{t} + U_{a-1,b}^{t}\ ] \qquad \text{... 3.2}$$

- **Cell types:** For developing a new city, the entire plain is assumed to be divided into various gridded structures. This plain can again be subdivided into various grid structures such as triangular, square, or hexagon. Other lattices are also applicable as per Dottori and Todini E. [106], Packard and Wolfram [104], Ghimire et al. [24] and Liu et al. [25]. Molina et al. [107] developed a CA-based model for urban growth based on grids. All these lattices of cellular automata have approximately the same kind of characteristics except the shape-related effects. The researcher has chosen three grid shapes for analysis, including Square, Hexagon, and Octagon. A CA may consist of the homogeneous lattices of various sites in which every cell must be considered with its neighborhood and the value of a cell is updated with the position of its neighbor. A neighborhood cell provides an impact on each lower cell. These impacts of the neighborhood are easy to describe through the CA in two different ways as shown in figure 3.2 (a) and 3.2 (b). These neighborhoods are referred to as the Von Neumann and Moore neighborhoods, respectively. A neighborhood cell provides an impact on every cell that can be easily understood through cellular automata. A Cell changes its states, depending on the states of a set of cells of the same kind. These cells situated at a certain distance, called the vicinity index as discussed by Schiff J. L. [97].
- **Neighborhood:** A Cellular Automata consists of a grid (any shape) of cells, and it has a finite number of states. The grid can be in any finite number of dimensions. Generally, one dimensional and two-dimensional CA are in use. For each cell, a set of cells called its neighborhood (usually including the cell itself) defined relative to the specified cell. Cellular automation appears as a fundamental tool for water or flood modeling. The models are designed to work with various general grids such as rectangular, hexagonal, along with different neighborhood types (e.g., the five cells of the von-Neumann (VN) neighborhood or the nine cells of the Moore neighborhood).

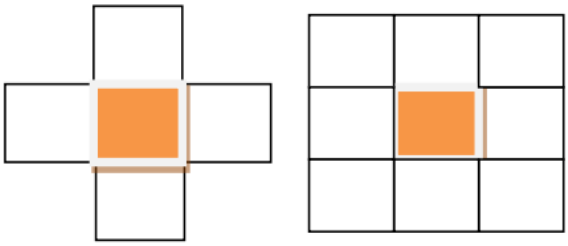
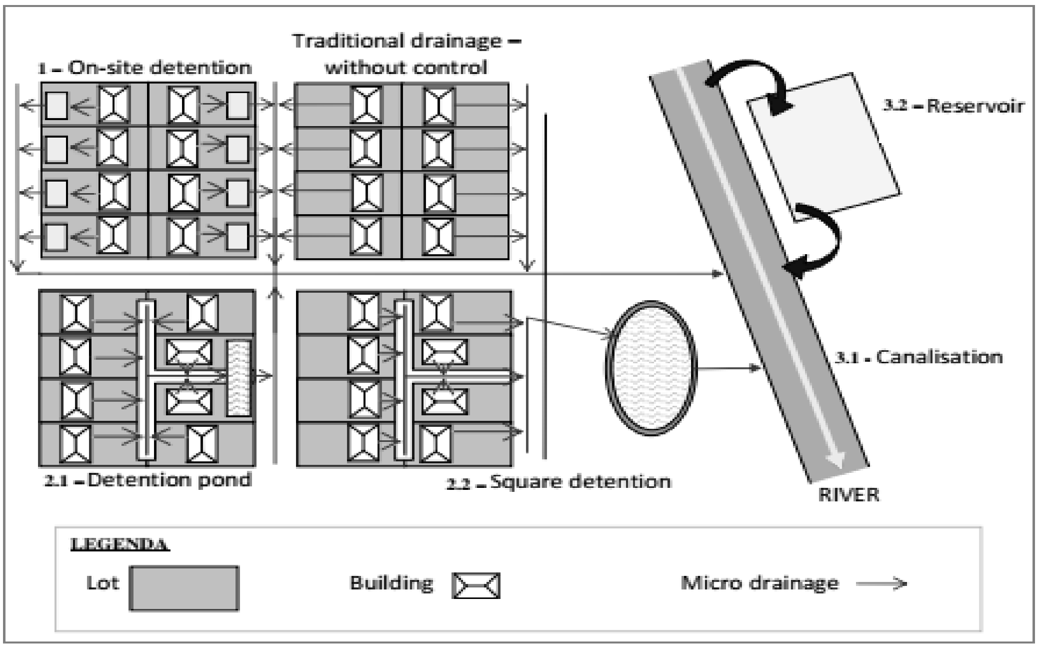


Figure 3.2 (a): 5-neighbor square Figure 3.2 (b): 9-neighbor square

In our solution, NH cells are ranked according to the water level, as *i* for the cell with the lowest level and *i+n-1* for the highest level, to determine the direction of flow between cells. Only the outflow fluxes from the central cell to its neighbors with lower ranks are calculated. Any inflow towards the cell under consideration is calculated as the outflow from its neighbor that has a higher water level on the opposite of the cell interface. Previously, the states of NH cells determined the fluxes through the interfaces of the central cell. The states of the water level of all cells are updated simultaneously when all interface fluxes are determined.

3.3 Existing Drainage System for Flood Avoidance

Sustainable water management may play an important role in flood management as discussed by Ellis et al. [20]. Traditionally, canalization based urban drainage design is in practice. With the urban growth that increases year by year, the importance of sustainable drainage mechanism is growing. The design comprises subdivision of the area into sub-catchment, design of network integration, natural flow and step by step calculation of water discharge. It can be designed using a rational method and a convenient hydrological method. Miguez [21] considered the management of runoff volume and rates as a key component. They have presented an urban drainage



management system based on water sensitive urban design (WSUD). The concept was centered on the integration of water resources. Figure 3.3 (a) shows the concept:

Figure 3.3 (a): Structure with drainage direction towards river & reservoir [21]

The figure shows the structure of the building. The direction of water flow is indicated by lines going to the rivers and then into the reservoir. This is based on the structure over a terrain of a different slope as indicated in figure 3.3 (b) discussed by [21].

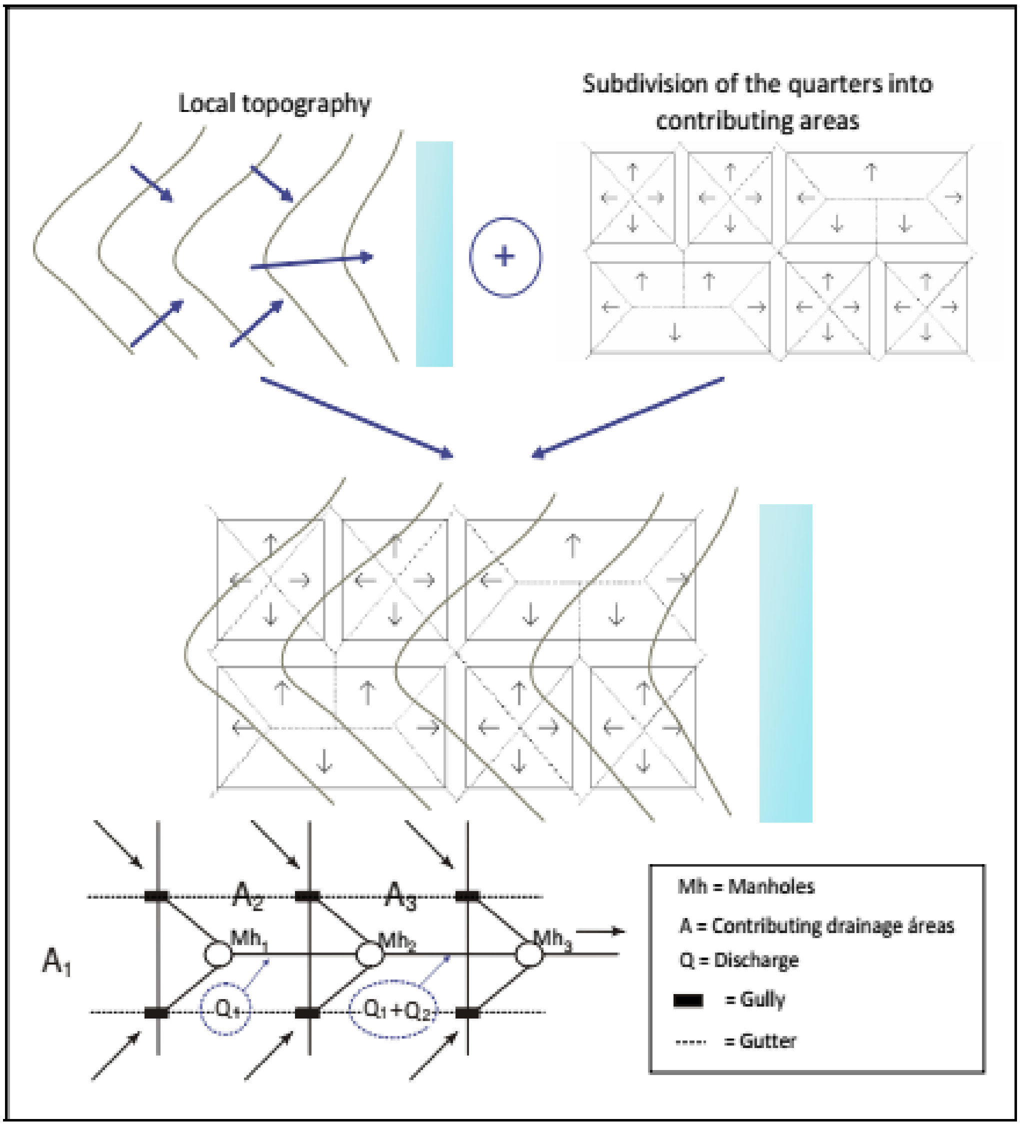


Figure 3.3 (b): Structure with terrain and drainage system [21]

The figure indicates the local topography with the general structure in various regions. It indicates the way of water exit in general scenarios. In general, today, rectangular design is in practice. In this kind of architecture, the failure of a single drainage link can affect the whole process of drainage that leads to water logging or urban flood. These conditions of failure are discussed by Mugume [23], using the Global Resilience Analysis approach. In this, they have shown different cases of random link failure. Let us consider their work to understand the cause of failure using figure 3.3 (c), in which eight lines indicate eight links of the drainage system while eight black dots indicate the place of the tank in this drainage mechanism. They have shown 1, 2, and 3 link failures in three different cases. They have indicated how few link failures led to failing the entire drainage system as indicated in figure 3.3 (c).

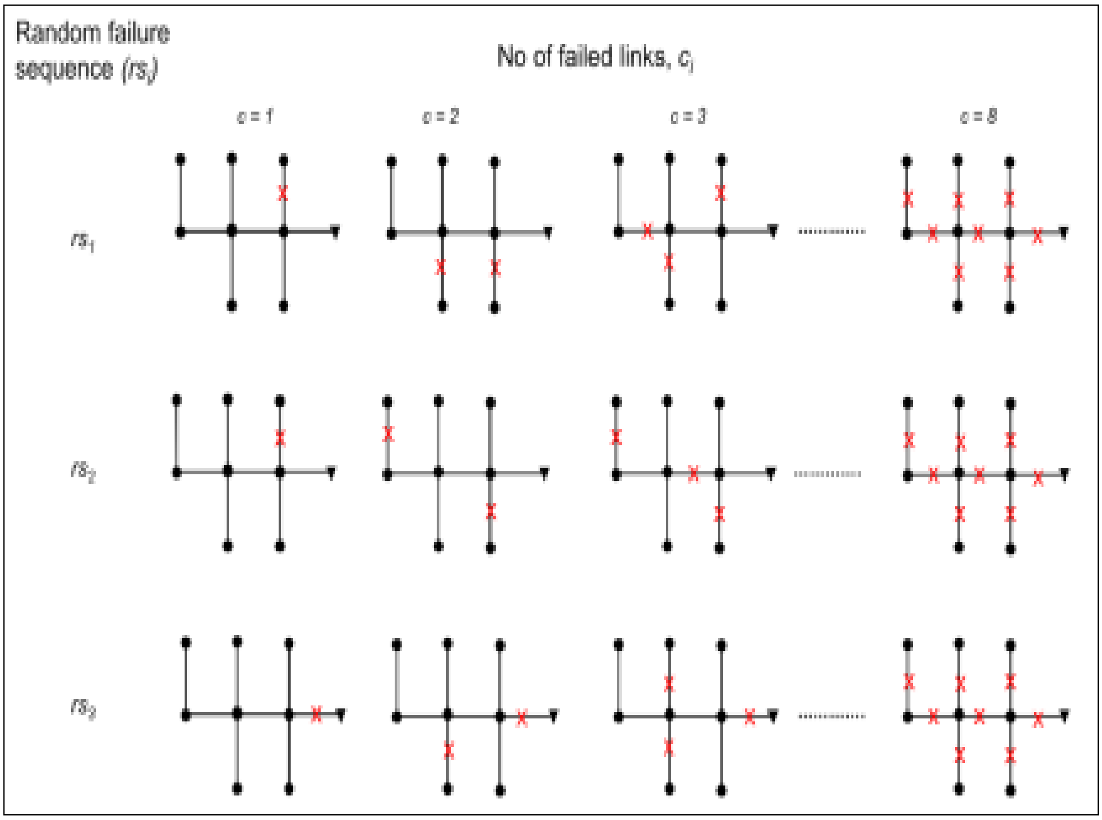


Figure 3.3 (c): Structure of drainage system with eight links and tanks

Wang et al. [22], have discussed the storage tank locations by considering the importance of tanks. From both figures, it can be concluded that rectangular or approximately rectangular shape is in practice to develop a drainage model. But the model is not as successful as the problems of the flood are increasing that may be possible due to the failure of the drainage system caused by link failure in it. Thus, the researcher has chosen to find out grid design or shapes with maximum links suitable for a drainage system and tried to:

- Find out the impact of the grid design pattern on exit because the number of exit paths will affect the rate of discharge of logged water.

- Find out a suitable shape for drainage development in order to let maximum water exit quickly.

To give answers to the above questions, a solution presented in the next section.

3.4 The Solution to Urban Flooding using CA

Cellular automata have earlier been used to predict the flood direction. The technique proposed by the researcher for flood avoidance is an extension of that idea. That idea was initially discussed by Ghimire et al. [24]. As per the concept, CA is used as a tool for flood avoidance by assuming that transferring rainwater from one plain to another is a solution for waterlogging. This transfer of water is possible by a drainage system, while the drainage system design is governed by various factors including distance, constructability, affordability, and approachability as per Liu et al. [25]. However, for the sake of easiness and limited resources, the researcher has focused on finding the impacts of various grid patterns to be used for designing a drainage mechanism. The researcher has chosen to compare grid patterns with a square grid pattern generally used in designing drainage systems. In all figures of this chapter, i+n-1 indicates as a top layer on CA and leveled it down to the level of reservoir situated. This square grid pattern has indicated in figure 3.4 as given below:

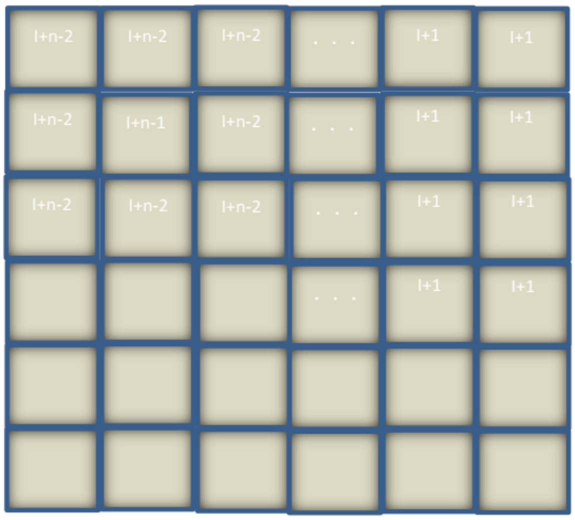


Figure 3.4: Upper view of square gridded plain

This section presents the drainage mechanism's patterns, including rectangular, hexagonal, and octagonal grid pattern. The drainage mechanism is assumed to have a fast and orderly exit of rainwater and storage of the same to the reservoir for later use. Traditionally, the drainage mechanism suggested tanks/ponds at the boundaries of cellular plains. As per the proposed research, tanks are suggested at the joint corner of cells to avoid the flood. Ponds/ tanks are assumed to be fed by rainfall water. In order to avoid the flood, our study focuses on the impacts of different grid designs on the water exit.

3.4.1 Square Pattern for Drainage System

A square grid is the most common structure used by real estate projects that is responsible for passing the massive amount of water. Here, a pipeline with tanks in the drainage system has assumed. Cellular Automation of a geographical area for flood modeling is considered with the totalistic rule, in which the volume of water from the center/top is added to the lower neighbor and directly affects the other neighborhood. The drainage system as per [21,22] assumed at boundaries.

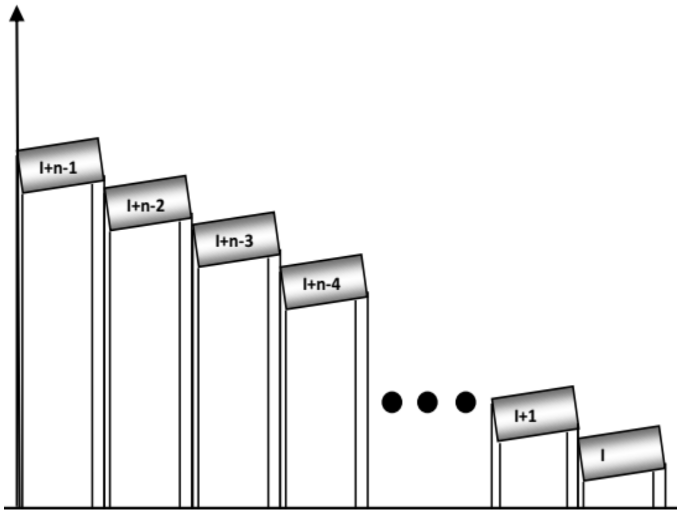


Figure 3.4.1 (a): Side view and layer ordering of square gridded plain

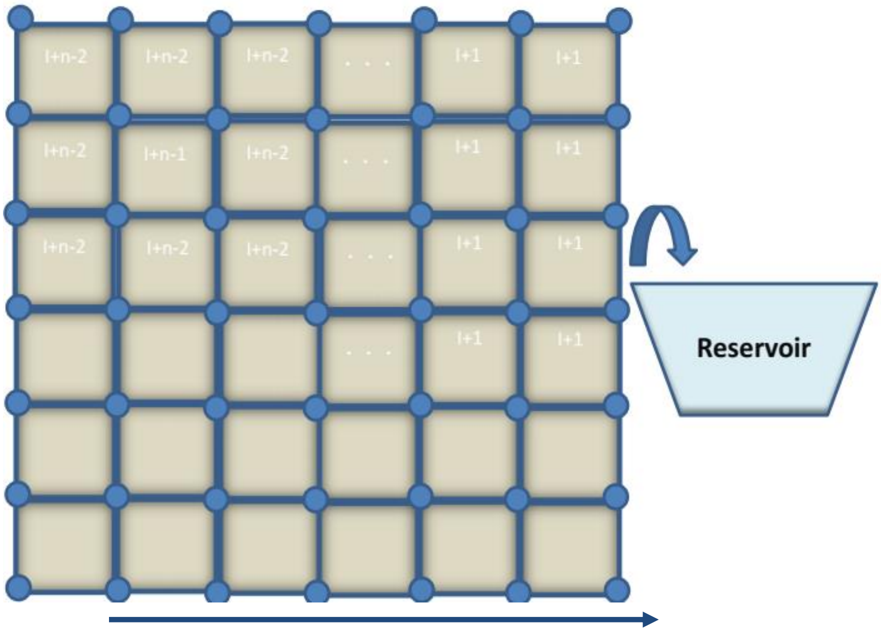


Figure 3.4.1 (b): Upper view of square gridded plain with tank positions

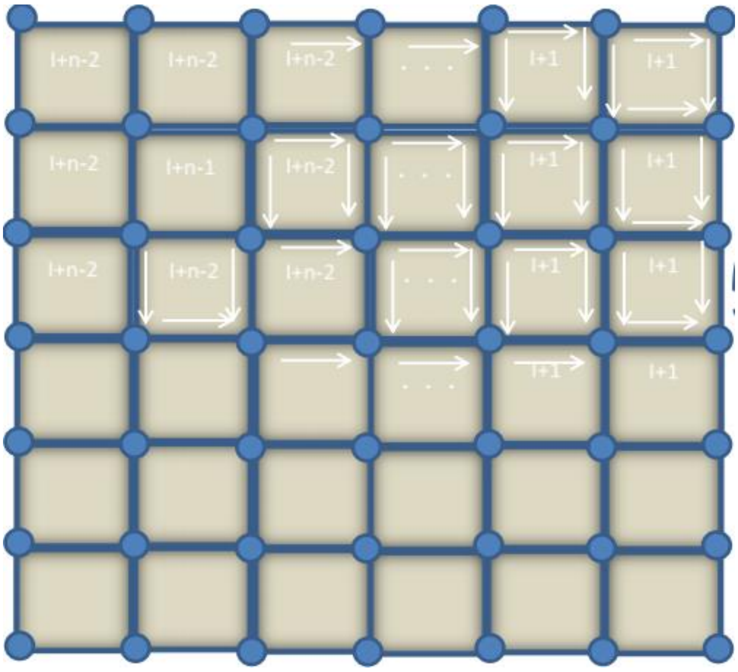


Figure 3.4.1 (c): Square gridded plain with tank positions and possible flow direction

The blue lines indicate the structure of the drainage system in figures 3.4.1 (b) and (c). In these figures, the positions of tanks are shown at each corner. The numbering is assumed from the cell on the maximum height *(i+n-1)* to the reservoir below 1. In these figures, Blue bubbles on joints indicate the possible positions of tanks. Here, a white arrow within a cellular structure indicates the direction where water may flow in an emergency. As per figure, tanks are also positioned to deploy IoT devices as discussed by [105, 108 and 109] to find out the possibility of flood risk. In this mechanism, water will transfer from the height to the lowest place, wherein at bottom a reservoir is positioned that will collect this water for further use. For simplicity, the assumption of rainwater flow is linear. The positioning of tanks is assumed on different heights from the i+n-1 layer to the lower layer while if the plain of the lower layer is not on the sufficient slope, then it should be maintained.

3.4.2 Hexagonal Pattern for Drainage System

The drainage system on boundaries is assumed as per [21] with hexagonal cell and shape of pipeline grids over a cellular plain. In this pipeline of the drainage system, water tanks are positioned at the corner just as per [22]. The numbering of a cell is assumed from the cell on the top of the reservoir. The assumption of rainwater flow is linear. The flow of water will transfer from tanks situated at the upper layer to tanks at a lower layer, i.e., Tank 1 is situated on tank i+n-1 layer while tank two is situated on i+n-2. In figure 3.4.2 (b) and (c), (d) and, the lines indicate pipelines; Blue bubbles on joints indicate the positions of tanks. In this, the red arrow indicates a natural flow direction towards the reservoir. Here, a white arrow within a cellular structure indicates the direction where water can be transferred in emergencies.

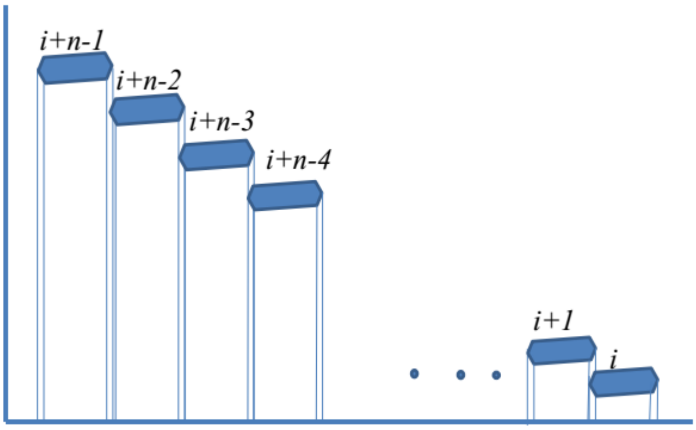


Figure 3.4.2 (a): Side view of hexagonal gridded plain in layers

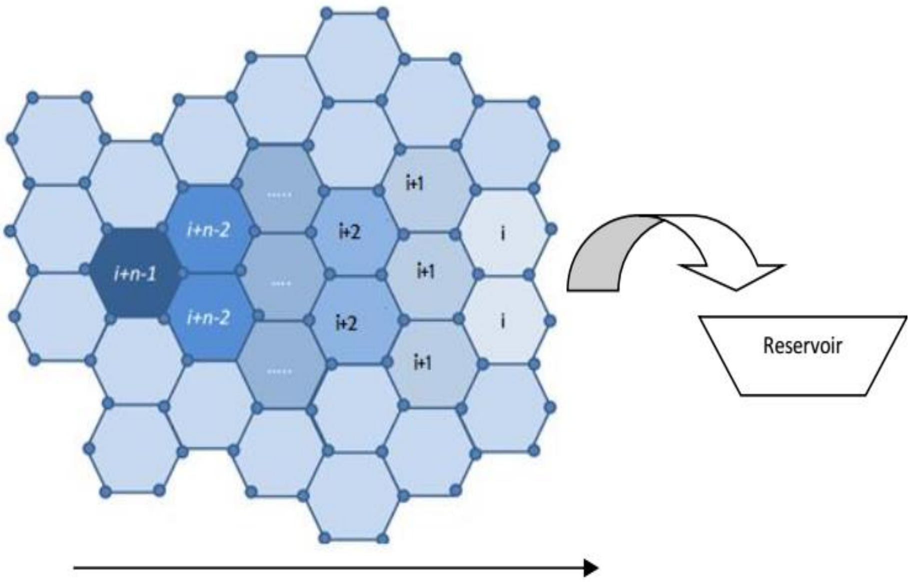


Figure 3.4.2 (b): Direction of flow and tank position in hexagonal gridded plain

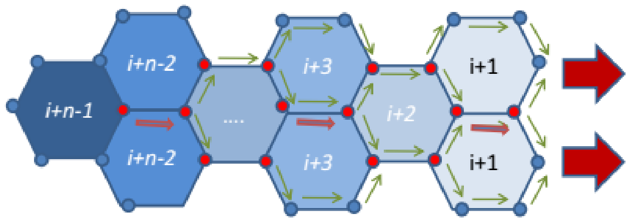


Figure 3.4.2 (c): Direction of water flow in one direction

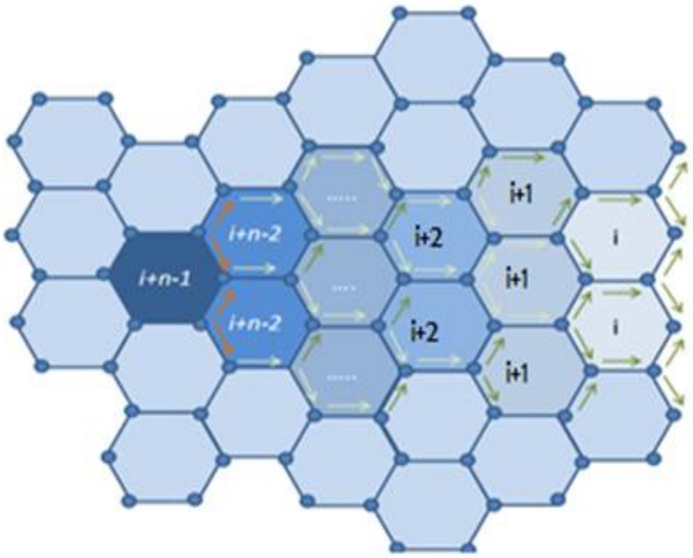


Figure 3.4.2 (d): Direction of water flow in hexagonal gridded plain

3.4.3 Octagonal Pattern for Drainage System

This pipelining of the drainage system indicates the positions of water tanks at the corners of the octagonal plain. The direction of water flow is assumed from the higher layer to lower as per 3.4.3 (a). For the sake of simplicity, the assumption of rainwater flow is linear. Tank 1 is situated on the tank i+n-1 layer while tank 2 is situated on i+n-2. The lower tank 2 is fed by water from the exit water of tank 1 and rainwater of their cell. The pipeline of drainage is assumed on the boundaries of the octagonal cell. This pattern suggests the position for water tanks at the corners. The numbering of the direction of a cell is imaginary. In figure 3.4.3 (b), (c), (d), lines indicate symmetry of pipelines, Black bubbles indicate tank positions, a blue arrow indicates the natural direction, and black arrow indicates the direction of flow in drainage pipe of the plain.

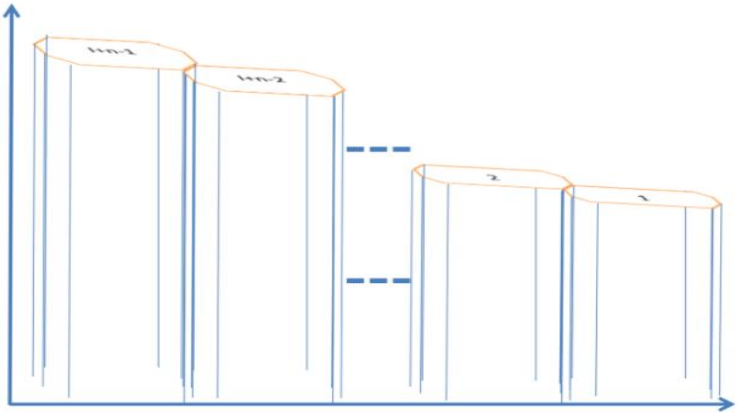


Figure 3.4.3 (a): Side view and layer ordering of octagonal gridded plain

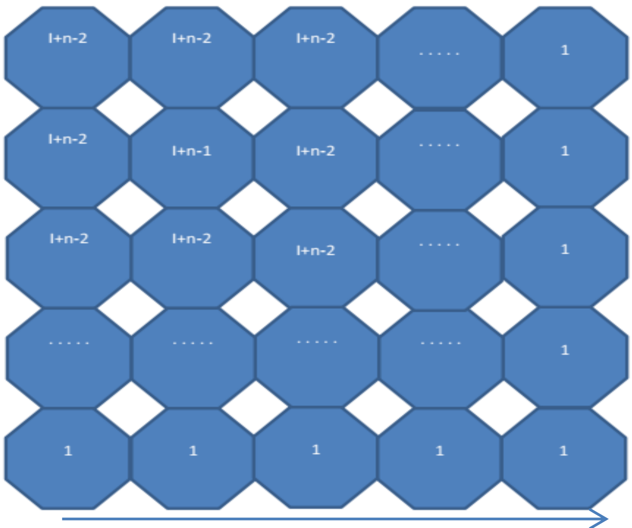


Figure 3.4.3 (b): Top view of cellular plain with flux direction

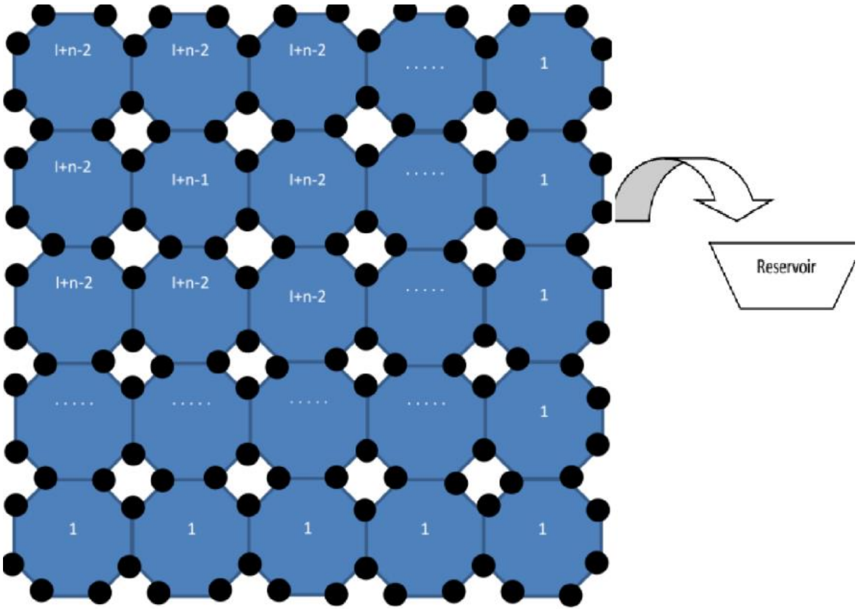


Figure 3.4.3 (c): Direction of flow and tank position in octagonal gridded plain

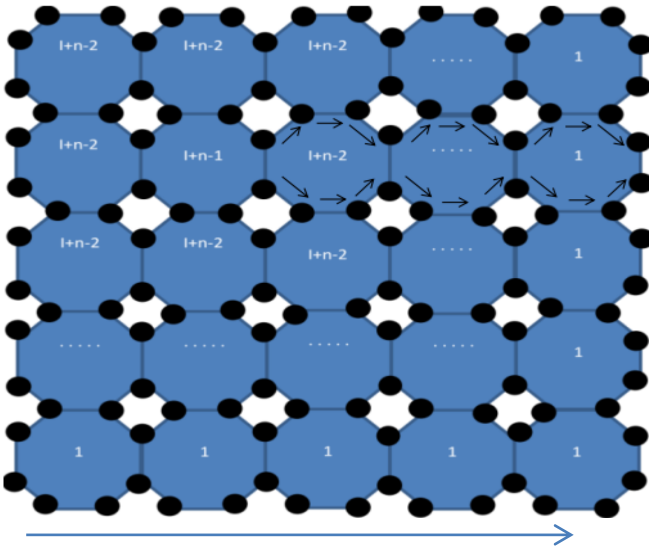


Figure 3.4.3 (d): Direction of flow in octagonal gridded plain

Figure 3.4.3 (d) represents an identical pattern according to the height of the plain into a layer of CA. According to this, water flows downward. The figure shows a hybrid-octagonal shape from layer L_i to L_{i+n-1} from bottom to top. This structure is explained for newly developing sites.

3.5 Evaluation of CA-based Design

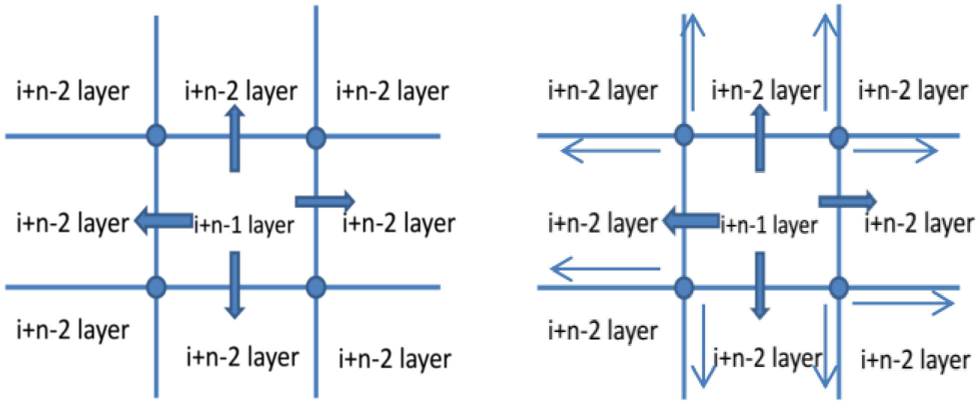
This section evaluates the square, hexagon and octagon-based CA by comparing them in terms of way of exit with various grid patterns and impact of layers on the tank.

3.5.1 Ways of Exit in Various Patterns

Rectangular, hexagonal, and octagonal patterns of drainage design are considered here. The evaluation performed by the method discussed by Kumar et al. [105] as:

(a) Rectangle grid

The performance of the drainage system will depend on the way of an exit from the top layer into reservoirs. In the case of a square grid pattern, the path will be on the one side, if the slope is 50% and on two sides if it is at 75%.

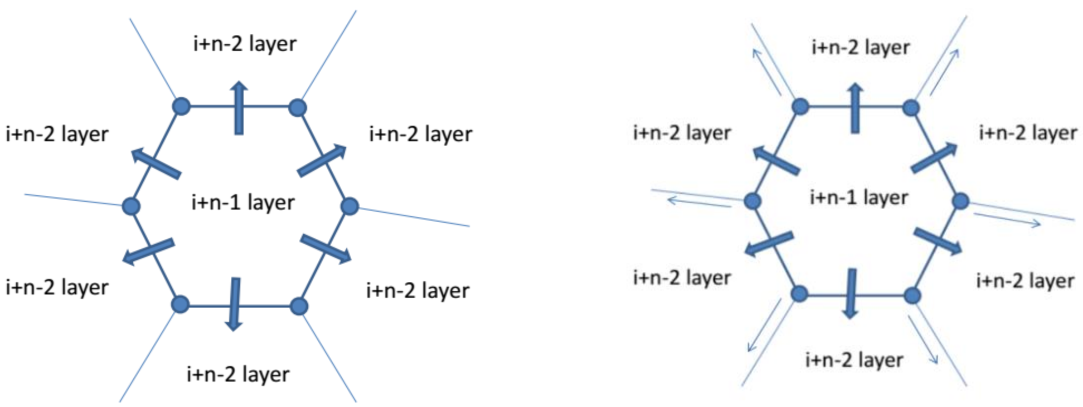


(i): Square grid (ii): Flow path by square Grid

Figure 3.5.1 (a): Possible flow directions in a square grid

(b) Hexagonal Grid

The performance of a drainage mechanism in hexagonal shapes will depend on the way of an exit. The way of exit of water from a cellular plain has been shown by figure 3.5.1 (b). So, these ways of exits can be calculated by connecting the way of an exit from the top layer to the reservoir in a direction.

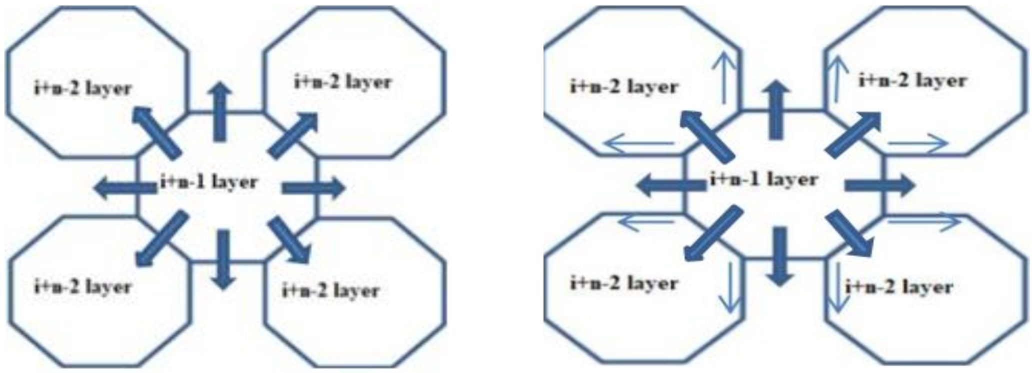


(i). Hexagonal grid (ii). Low path by a hexagonal grid

Figure 3.5.1 (b): Possible flow direction in a hexagonal grid

(c) Octagonal Grid

The performance of a drainage mechanism in hexagonal shapes will depend on its way to exit the water. The way of exit of water from a cellular plain has been shown by figure 3.5.1 (c). These ways of exits can be calculated by connecting the way of an exit from the top layer to the reservoir.



(i) Octagonal Grid (ii) The flow path of the Octagonal Grid

Figure 3.5.1 (c): Possible flow direction in an octagonal grid

These ways of exits shown by figures 3.5.1 (a), 3.5.1 (b) and 3.5.1 (c) pave a path to calculate the performance of the drainage mechanism using its number of paths in different shapes.

3.5.2 Comparison between Ways of Exit

Flood freeness of a plain depends on the paths of exit of the logged water amount to the outside. Only one condition has been considered for comparison because water runs only in one direction. However, bilinear elevated plain possible, but in that case, water will flow in a single direction only. The principle of replication as per Kothari [110] was adopted and applied the same for the different possible layers from 1 to 4.

(a) When plain has Unilinear Elevation

In this case, water flows through any one side of the plain, where two exit points exist in the square grid, two in the octagon grid while 3 in the hexagonal grid at the top layer. Here, paths of exit are assumed with an elevation of 50% on one side.

Table 3.5.2 (a): Ways of exit on grid per layer for unilinear elevation

Grid type / layer	I+n-1	I+n-2	I+n-3	I+n-4
With square Grid	2	2	2	2
With Hexagon	3	6	8	10

With Octagon	2	2	2	2

Let us see figure 3.5.2 (a), in which rectangular and octagonal shaped structure show having an equal number of way of exit, but the hexagonal shape has more ways.

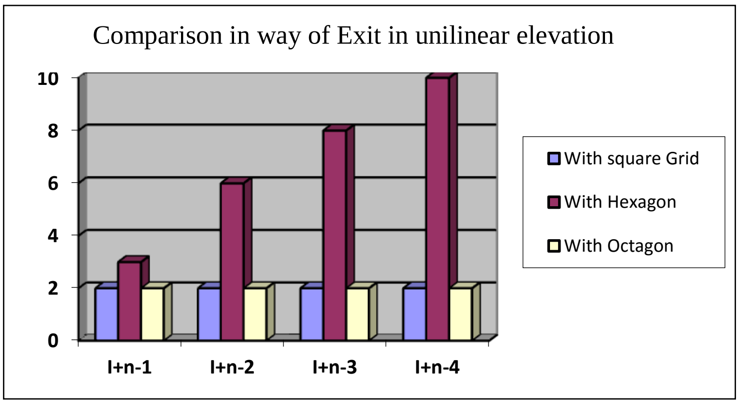


Figure 3.5.2 (a): Ways of Exit in unilinear elevation

(b) When plain has a Bilinear Elevation

In this case, water flows through two consecutive sides of the plain and 75% plain is elevated, where four exit ways meet for the square grid, four exit ways meet in the hybrid-octagon grid while similarly four at the hexagonal grid at the top layer but in subsequent layers, it is increasing.

Table 3.5.2 (b): Ways of exit on grid per layer for biilinear elevation

Grid type / layer	I+n-1	I+n-2	I+n-3	I+n-4
With square grid	4	6	8	10
With Hexagon	4	8	12	16
With octagon	4	6	8	10

Figures 3.5.2 (b) derived from table 3.5.2 (b), in which rectangular and octagonal structure shows having an equal number of exits, but the hexagonal shape has more ways. However, in this case, the number of exits is increasing in all three shapes.

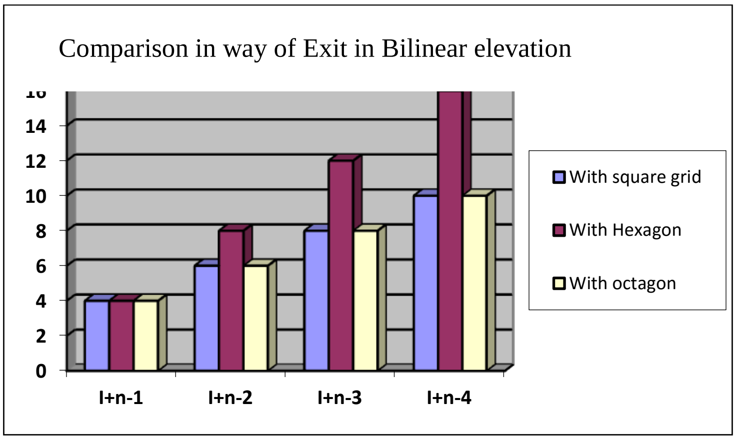


Figure 3.5.2 (b): Ways of Exit in bilinear elevation

In a nutshell, it is concluded that the hexagonal grid pattern in the designing drainage system will be better than the design based on Square gridded pattern or Octagonal gridded pattern.

3.5.3 Hypothesis and Validation

A hypothesis was assumed based on the comparison in way of exits shown by figure 3.5.2 (a) and (b).

(a) Hypothesis

- **Null Hypothesis (H_0):** There is no significant difference between the way of exits of drainage system developed with square or Octagonal gridded pattern and System developed with Hexagonal gridded pattern.
- **Alternate Hypothesis (H_a):** There is a significant difference between the way of exits of drainage system developed with square or Octagonal gridded pattern and System developed with Hexagonal gridded pattern.

(b) Validation

Null hypothesis saying that there will be not any improvement in drainage system design after implementing it with a hexagonal shape. The improvement shown by data and figure are might be wrong. Thus to check the hypothesis T-test has been performed, as it has been discussed by Chun et al. [111] to test their experiments earlier. The improvement in way of exit has been investigated for two scenarios, but we know in natural direction water flows in a linear direction, that is why hypothesis only tested for a natural flow of water or for the case when a plain is linearly elevated.

Thus, Validation has been performed using t-test for cases of plain in unilinear Elevation. Let the way of exit with square/octagonal shapes that are represented as *X* and the way of exit using hexagonal shape as *Y* and then taking the null hypothesis that hexagonal shape does not bring any improvement in way of exit, we can write:

H_0: = $\mu_1 = \mu_2$ which is equivalent to test $H_0 : \bar{D} = 0$

H_a: = $\mu_1 < \mu_2$ (As we want to conclude that the Hexagonal grid pattern is beneficial)

Because of the matched pairs we use paired *t*-test and work out the test statistic '*t*' as under:

$$t = \frac{\bar{D}-0}{\sigma_{diff}/\sqrt{n}}$$

To find the value of *t*, we first work out the mean and standard deviation of differences as:

Table 3.6.1: Calculation of difference for T-test

Layer	**Unilinear elevation**		**Difference**	**Difference squared**
	Square/Octa(X_i)	Hexa (Y_i)	(Di = Xi-Yi)	D_i^2
1	2	10	-8	64
2	2	8	-6	36
3	2	6	-4	16
4	2	3	-1	1
n =4			ΣDi = - 19	ΣD_i^2 = 117

Thus,

$$\bar{D} = \frac{\Sigma Di}{n} = -19/4 = -4.75$$

$$\sigma_{diff} = \sqrt{\frac{\Sigma D_i^2-(\bar{D})^2.n}{n-1}}$$

$$= \sqrt{\frac{117-(22.5625).4}{4-1}} = \sqrt{\frac{26.75}{3}}$$

$$= 2.986$$

Hence, $$t = \frac{-4.75-0}{2.986/\sqrt{4}}$$

$$= \frac{-4.75}{1.493} \quad = \quad -3.18$$

Degrees of freedom = $(n - 1) = 4 - 1 = 3$

As *Ha* is one-sided, we shall apply a one-tailed test (in the left tail because *Ha* is of less than type) for determining the rejection region at 5% level of significance which come to as under, using a table of *t*-distribution for 3 degrees of freedom:

$$R: t < -2.353$$

The observed value of *t* is – 3.18 which falls in the rejection region and thus, we reject H_0 at a 5% level and conclude that the hexagonal pattern will be beneficial.

CHAPTER 4 | IoET DEVICES FOR FLOOD DETECTION

"Consumers are increasingly looking for one app for one integrated smart ecosystem."

—Jessica Ekholm

4.1 Background

The term IoET (Internet of Environmental Things) has been coined from IoT, while the term IoT (Internet of Things) is almost 20 years old. However, the original idea of connected devices had been since the 70s. Back then, the idea was often called "Embedded Internet" or "Pervasive Computing." However, Kevin Ashton's first time shaped the actual term "Internet of Things" in 1999 during his work at Procter & Gamble [112]. According to the report published by ITU-T [113] in 2005, IoT is a ubiquitous network in which internet connectivity is assumed, while a report published by IEEE in March 2014, defined IoT as "A network of items embedded with sensors in which nodes are connected to the Internet" [114]. As per these definitions, network connectivity easily possible for IoT at all the time and everywhere. Currently, IoT enabled applications are developed to solve the problems of various fields, including manufacturing, healthcare, hospital, logistics, and safety, as per Vongsingthong, S., and Smanchat, S. [115]. IoT is making lifestyle easy in every sphere due to its accuracy, timeliness, and interpretation based on data analysis. As per the report of NASSCOM [116], global IoT revenue is expected to grow to 3 Trillion in 2020, while installing base is expected to grow to 20.8 billion by 2020. Now, installation is growing to facilitate society in typical projects of disaster management and smart city.

4.2 Architecture of IoET

The architecture of IoET is taken from the architecture of IoT. However, three identified architectures of IoT are discussed in the literature, including 3, 5 and 7 layers. As per many scholars, including Sethi and Sarangi [117], IoT has 3 and 5 layer architecture which is shown by the first two blocks in figure 4.2, whereas the Cisco reference model [33] consists of 7 layers shown by the third block in figure 4.2.

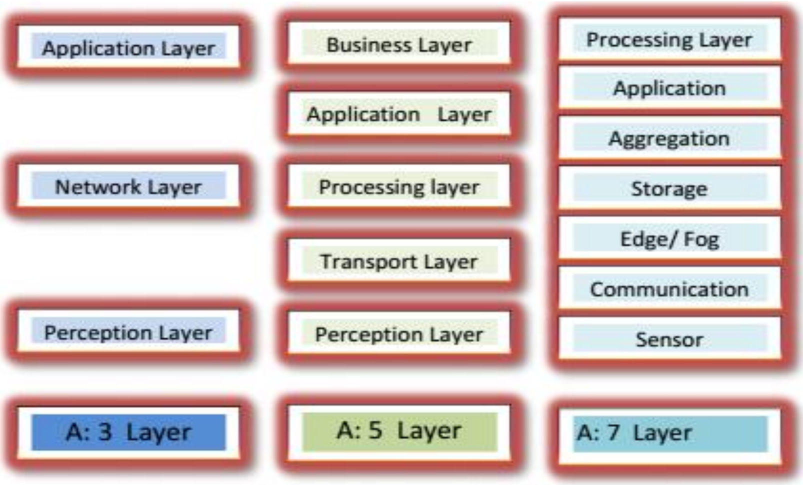


Figure 4.2: Various IoT architecture with different number of layers

4.2.1 Devices

Each IoT model includes Devices / Sensors, Networks, and Tools for Analytics. The devices sometimes are known as Things because sensing devices are attached to things that provide data. It means these Things in the IoT gather data using sensors, which are used to produce data to convert it into rich information at a later stage. The architecture of an IoT device has been shown in figure 4.2.1, discussed by Elijah et al. [118]. As per this figure, the structure of an IoT device made of various components, including sensors, actuators, and embedded systems. The embedded system is fabricated with a processor, communication module, memory, and Input-output module. The system is developed using a controller board or single-board computer in an IoT mechanism. A device or things in IoT must have few components to use it as a source of data as shown in figure 4.2.1.

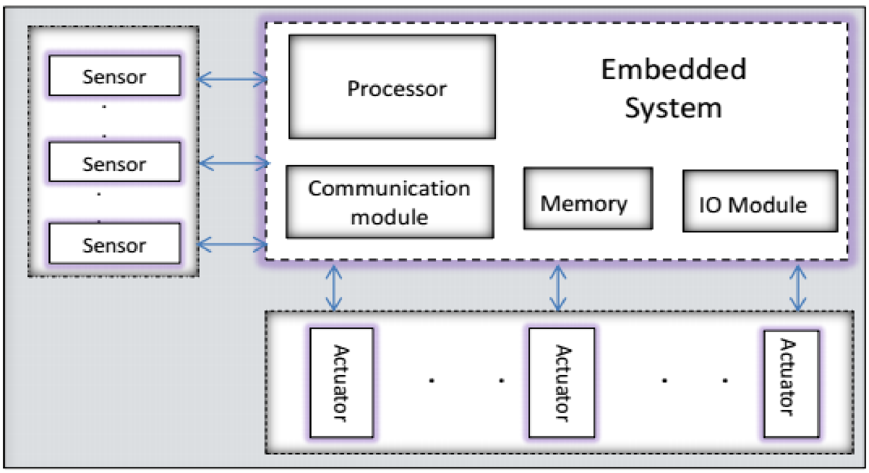


Figure 4.2.1: Architecture of the IoT device

Components indicated in the architecture of the IoT device have discussed below:

- **Sensor:** A sensor is a device to sense physical parameters and to generate useful data. It has the capability to sense alone, but not able to form a solution. In designing an IoT based solution, a sensing node should be able to connect to a device and the internet, analyze, and manage the sensed data. These connections can be made using various communication protocols. The interactive devices developed to sense parameters having sensing components in the form of sensors. Different sensors are in use to gather different environmental data, including Ultrasonic, Raindrop, Water flow, Light, Temperature, Humidity, Flow, and Pressure. All these sensors are based on different principles, but all these can gather and transmit data to the controller unit.
- **Controller Board:** Various manufacturers are involved in developing boards. These boards are used to gather, transfer, and process the data. When the collected data is processed at controller board, the computing paradigm is called edge computing; if it is within a network, it is considered as fog computing; and if the acquired data is processed at data centers and analyzed at other systems, the computing paradigms are considered as cloud computing. In this case, the controllers work as a gateway and processing units. These are used to process and transfer data to the monitoring unit for analysis. Several types of controllers are in use, including Arduino, Raspberry, Netduino, Arm 7 and NodeMCU, etc. These controllers work, based on different principles but useful as a gateway in IoT.
- **Display Unit:** It is an essential unit to display the acquired data that can set up in an arrangement with a gateway. A computer screen, laptop screen, smartphone screen, or only an LCD unit can work as a display unit.
- **Power Unit:** A power unit provides a lifetime to the node using a battery or a connecting device like a computer or laptop. It is the only part that provides power to keep the device activity that is why it is assumed as an essential part of the node.

4.2.2 Communication Methods

Ashton, who was involved in supply chain optimization, wanted to attract senior management’s attention to a new exciting technology called RFID [112]. After the RFID researchers and industry used other standards. In this regard, Abbasi et al. [119] argued about various technologies to provide communication facilities including

Ethernet, RFID, and Zigbee where RFID assumed as a basic option. As per Mervat et al. [120], things in IoT generate data to be further used by applications in the later stage. These days, this data is sent to the data center or a monitoring station using various new communication technologies including LTE, GSM, and 3G.

These sensors in the devices continuously collect the data and create a massive amount of data. This data has a continuous increment in volume with velocity while different kinds of sensors generate heterogeneous types of data. The three characteristics of data, including Volume, Velocity, and Variety, convert this data into the Big data. The analysis of this data has performed at different levels, including at the device level, at the monitoring station level, or at the data center. Further, this data accessed in the digital domain using cloud services managed by various data centers. The quality of all the features of an IoT solution depends on the components used in the device. When IoT mechanisms developed to use in environmental monitoring, these referred as an IoET. Now, the question is:

1) On which layer of IoET, a contribution possible to sense the flood?
2) Which components should be utilized to sense the symptoms?

The answer to these questions was found using METHWORK as mentioned in Appendix A attached at the end, and published in Neeraj et al. [121]. This technique suggested the first layer of IoT to handle the node design and data acquisition. This technique provided a rich literature to find a solution for flood detection, the feasibility of this solution, the existing designs, and components of nodes.

4.3 Issues to be Solved and Devices

By ranking of research trends, the researcher observed the bottom layer of the reference model as most popular among all the IoT research community. However, the bottom layer with layers two and three provide a solution at the level of Edge/ Fog and considered as Edge/ Fog computing. Thus, the researcher has decided to work on the edge level to solve the detection issues.

4.3.1 Issue to be Solved

A sensing node of IoET may have one or more sensors and transmitter connected to its processing unit, in which sensor was used to sense the environmental conditions, processor to process the data and a transmitter to transmit data to the workstation. The design and localization of these devices are two main factors affecting the efficiency of the system. On the other hand, the cost of sensing nodes depends on the configuration and components used in the design. To analyze the devices and their working, the researcher has chosen a widespread application of disaster management problem known as 'flood detection' because the flood was found the most frequent type of disaster that harms human for a long duration, so analysis of devices for its detection was assumed fruitful for the society. This chapter discusses the answers to a few basic queries, including:

1) Which components are most suitable in a device for flood detection?
2) What are the designs of Things for flood detection?
3) How can a Thing generate the data from the environment?
4) What will be the methodology to find suitable space in a layer of reference model using ranking?

The next section presents findings of reviewing the literature to find out suitable components of devices to choose the design of nodes.

4.3.2 Application, Layer and Devices utilized Earlier

Table 4.3.2 consists of IoET applications for various problems having different gateways and sensors arranged. This table indicates the applicability of existing research, the layer of the IoT reference model on which work has been performed by these researches, the board and sensors used in the device, and the pros and cons of the work performed.

Table 4.3.2: Summary of elements of devices used in IoET applications

Authors/ Year	Application	Layer	Boards used	Sensors used	Output	Pros / Cons
Perumal et al.,2015 [64]	Water monitoring	1, 2, 3	ATmega328P	Ultrasonic, water sensor	Water level	Not given in detail.
Parimala et al., 2018 [63]	Water facility monitoring	1,2,3	Arduino Uno	Ultrasonic sensor	Water Level	Ok
Hernández-Nolasco et al., 2016 [67]	Water level meter	1, 2, 3	Netduino plus2 board, Laptop, Phone	LED as an indicator, Resister for sensing	Water level	Ability to show only 3 levels.

Sivaiah et al., 2018 [61]	Water level monitoring	1, 2, 3	Raspberry Pi	Ultrasonic sensor	Water Level	Ok
Pasha, S. (2016) [50]	Level monitoring	1, 2, 3, 4,5, 6	Arduino Uno	Rain, light, temp., pressure humidity.	All the data.	Ok
Mysar, D., babu, M.J., 2015 [60]	Water level monitoring	1, 2, 3, 4	Arm 7	Flow sensor, raindrop sensor	Water level by raindrop	Ok
P. Mitra et al., 2016 [66]	Flood Forecasting	-------	CC2650 Microcontroller	Water flow, Water level, Humidity, Pressure, Rain Gauge	Water level, rain, Pressure, humidity	WSN but they assumed it as IoT.
Mercado, 2016 [69]	Flood early warning system	1, 2, 3, 4, 5, 6	PSoC5LP-based controller	Ultrasonic, inclinometer, raindrop, temperature	Water level, rain	Costly. Lack of decision making.
Supani et al.,2017 [72]	Flood early warning system	1,2,3, 5, 6	Wemos D1 R2	Ultrasonic, Raindrop	Water level, raindrop signal	Ability to show only three levels.
Kamal et al, 2018 [73]	Flood Monitoring	1, 2, 3,4, 5, 6	NodeMCU	Water level	Water level	Ok
Leon et al., 2018 [56]	Early warning	1, 2, 3	RespberryPi	Ultrasonic Sensor	Water level on twitter	Ok
Sauza et al., 2017 [57]	Flood warning	1, 2, 3,4, 5, 6	ESP8266	Ultrasonic sensor	Alert in LED	Ok
Satria et al., 2018 [59]	Flood monitoring	1, 2	Arduino Uno	Ultrasonic, Rain.	Rainfal, flood	Ok
Neeraj et al., 2018 [108]	Water level monitoring	1, 2	Arduino Uno	Ultrasonic, Rain.	Rainfall , flood	Ok
Kumari et al.[122]	Flood monitoring	1 to 5	Arduino Uno	Ultrasonic, water flow.	Flood rate	Tested 1 case

* Note that the layers of IoET, are adopted from the IoT reference model of Cisco [33].

4.4 Flood Sign Detection using IoET

Single-board computers and various kinds of sensors are the backbones of the IoT; these devices together provide data for analysis at the monitoring station. When a device analyzes data in itself, it is considered on the edge. However, when it is used to be analyzed at another station using the Internetworking protocol, then it is considered as part of fog computing. In this way, when it uses internet facilities with infrastructure, it is considered as a part of cloud computing. IoT provides data from the Things to be used in applications and to receive at the data center or a monitoring station through various communication technologies, including LTE, GSM, and 3G, as discussed by Abu-Elkheir et al. [120]**.** The developed IoT devices are assumed as nodes. The designing of the nodes is, generally performed by the arrangement of the various components. To find out suitable components, the researcher studied the devices developed by other researchers and made a comparison to find suitable components.

4.4.1 Boards used for Flood Sign Detection

The researcher found different kinds of boards in different flood or water level monitoring projects, as indicated in the table 4.4.1:

Table 4.4.1: Summary of boards used in existing IoET applications

Application to monitor	**No. of application**	**No of Board used**					
		Arduino	**Raspberry**	**Netduino**	**Arm7**	**NodeMCU**	**Others**
Water level	6	2+1 = 3 (TMega328p)	1	1	1	0	0
Flood level	7	1	1	0	0	1	4

The researcher found Arduino Uno as a popular controller device based on data shown in this table.

4.4.2 Sensors used for Flood Sign Detection

The researcher found that various kinds of sensors were used for flood or water level monitoring, as indicated in the table 4.4.2:

Table 4.4.2: Summary of Sensors used in existing IoET applications

Application to monitor	No. of application	Sensor type used							
		Ultrasonic	**Raindrop**	**Water flow**	**Light**	**Temp.**	**Humidity**	**Flow**	**Pressure**
Water level	5	3	1	1	1	1	1	0	1
Flood level	7	5	3	1	0	1	1	1	1

Tables 4.4.2 indicates that most of the projects are using ultrasonic and raindrop sensors as sensing components of devices. So, it can be concluded that ultrasonic and raindrop sensors are the most popular sensors to develop flood detection devices.

4.5 Device Selection for Experiments

Experiments are set up as per the steps shown in figure 4.5. This figure indicates the strategy of data generation for flood detection. As per discussion, this is clear that each IoET solution varies from problem to problem. Therefore, the identification of parameters has importance in the selection of components to be used in designing a device. Thus, specific components are required to design the nodes for experiments. The selection of components is summarized as:

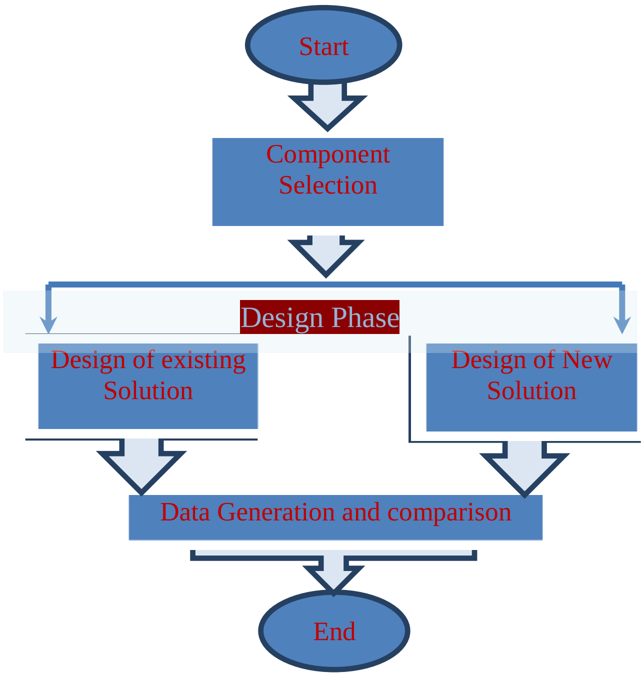


Figure 4.5: Method of comparative analysis

4.5.1 Component Selection

The researcher had options to choose components from the list of the controller board and sensors from tables 4.4.1 and 4.4.2. So, components are chosen based on the popularity as indicated in figure 4.5.1 (a) and 4.5.1 (b), and utility for application.

- **Choice of Sensors:** To accomplish the desired objective, the researcher has chosen the two most popular sensors used in flood or water-related existing projects, including the ultrasonic sensor and raindrop sensor.

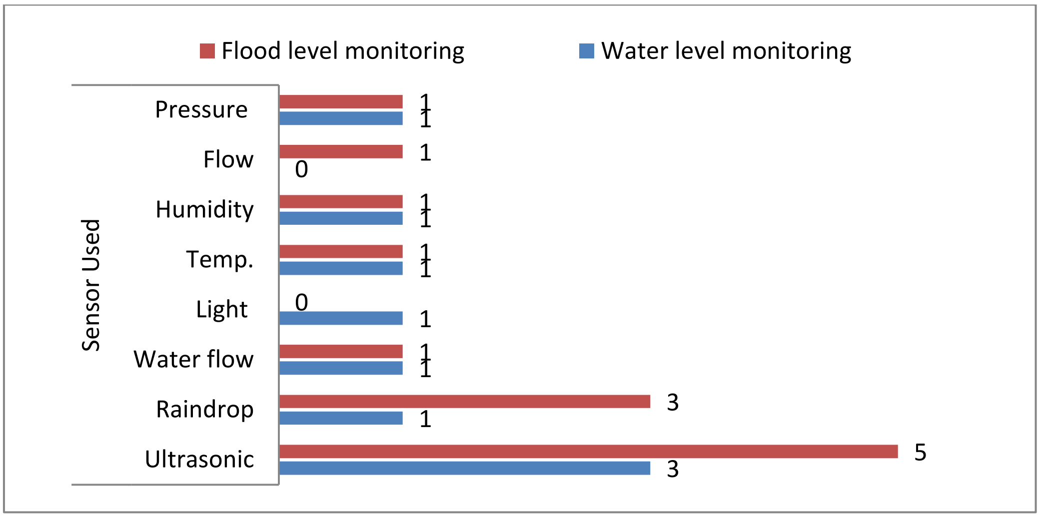


Figure 4.5.1 (a): Sensors used in flood monitoring

- **Choice of Boards:** Generally, device development is possible for both modes of communication, i.e. wired and wireless.

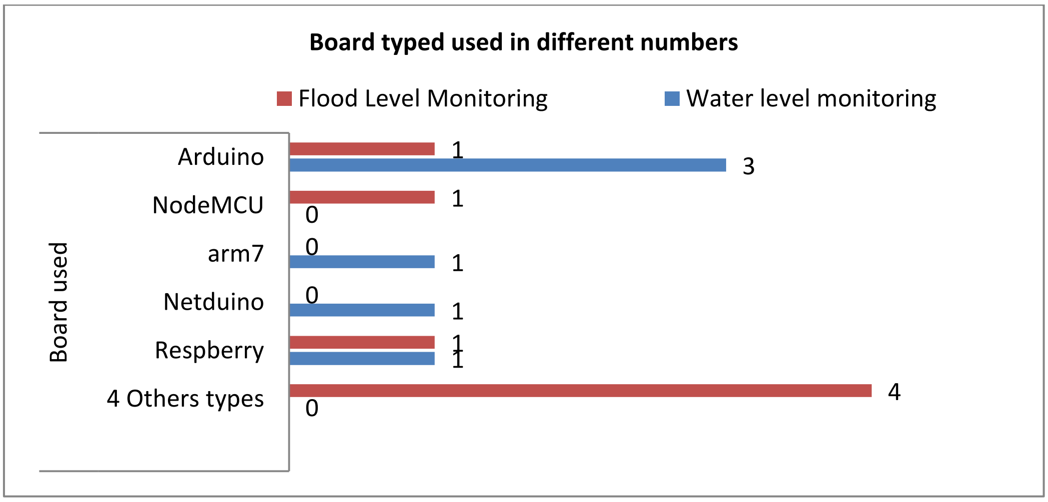


Figure 4.5.1 (b): Boards used in flood monitoring

The next section indicates the details of components, including sensors and boards utilized in the experiments.

4.5.2 Details of Components

The main components to develop the devices are sensors and board. Sensors including ultrasonic sensor and raindrop sensor while in the boards, Arduino Uno board and its software are elaborated in this section.

(a) Ultrasonic Sensor

The working of this sensor is based on formulae of distance using time and the speed of sound [123]. Applicability, principle, and sensing properties of the ultrasonic sensor are mentioned below:

Figure 4.5.2 (a): Ultrasonic Sensor

- ***Applicability:*** Ultrasonic sensor shown by figure 4.5.2 (a) has been chosen to measure the distance of the water level in the device. This sensor has many applications in various fields, including electrical, smart garbage bin alert system, psychological monitoring, shape recognition, robotics, process monitoring, and chemical analysis, obstacle detection by using in robots as discussed by Hongjuan et al. [124], Sidam et al. [125], Roland Cheng et al. [126], Kozo Ohtani and Mitsuru [127], Christofer et al.[128], Hauptmann et al. [129]. Charles and Kai [130] suggested utilizing an ultrasonic sensor for environmental perception due to its range of data production in a cost-effective way. Hauptmann et al. [129] presented a review on ultrasonic sensors, in which they presented the physical background for ultrasonic wave propagation and its applications. To make an ultrasonic property beneficial in sensing applications, they give reasons to use transmitter and receiver for data acquisition. They have addressed the way of examining distance, flow, level, and direction in the process monitoring, water monitoring, and other applications.
- ***Working Principle:*** Ultrasonic sensor works on the principle of ultrasonic waves based speed of sound and distance to the object, which is calculated by the formula discussed by Juan et al. [131]. Ultrasonic waves generate a high-frequency sound wave signal to return is called echo. An ultrasonic sensor contains a transmitter and receiver where the transmitter sent a chirp signal while echo returned after touching an object. In our experiments, water is an

object, so, by the time consumed by chirp and echo, equation 2 helps to provide the distance from the water.

- **Sensitivity [132]**: Ultrasonic **s**ensor uses echo signals to sense, and its sensing is based on the working of the transmitter and receiver. The sensitivity (S_{ul}) of this sensor depends on the receiver's capacity to receive the signal that is directed by SNR(signal to noise ratio), Nf (noise figure), and N_{in} (noise at the input). Here, SNR is a function of Eb/No, R and B, where SNR is sound to noise ratio, Eb/No is Energy per bit to the noise density ratio, R is data rate, and B is receiver bandwidth. Here, the Noise figure describes the capacity of the system to process a little signal noise-free. All these terms are involved in the sensitivity of the Ultrasonic sensor as per equation 4.1 given below:

$$\boxed{S_{ul} = NF + SNRout + Nin} \qquad \text{.... } 4.1$$

Where, $SNR_{out} = \frac{E_b}{N_0}\frac{R}{B}$ .... *4.1(a)*

Noise Figure (NF) $= \frac{SNR_{in}}{SNR_{out}} = \frac{S_{in}/N_{in}}{S_{out}/N_{out}}$ .... *4.1(b)*

SNRout = Minimum SNR that guarantees the target error rate.

Nin = 10.log (*kTB*) .... *4.1(c)*

where *k* = Boltzman's Constant = 1.38 × 10–23 Joules/Kelvin;

T = absolute temperature = 298°K, *B* = noise bandwidth.

Then, Nin = – 174 +10 log(B)

(b) Raindrop Sensor

This section indicates applicability, principle, and sensing properties of raindrop sensors as:

- ***Applicability:*** It can send data to the cloud or a system or can show its captured data using any attached display.
- ***Working Principle:*** On a raindrop sensor, Nickel is coated in the form of lines, and works on the principle of resistance. In the absence of a raindrop or water drop, a high resistance remains on the board, and we get high voltage according to V= IR. However, in the case when raindrops hit the panel, the resistance will be less, because water is a conductor of electricity. So, water makes a connection between two parallel lines of nickel that reduces resistance and voltage drops in the circuit.

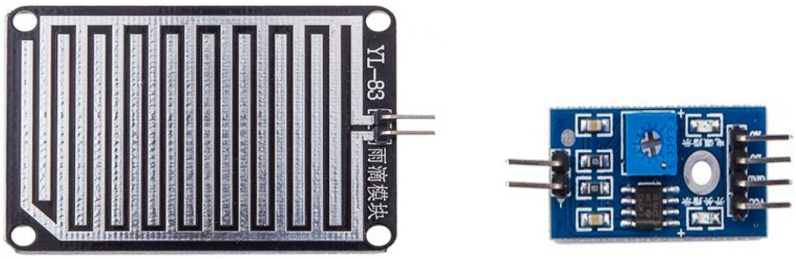


Figure 4.5.2 (b): Raindrop sensor

- **Sensitivity:** As raindrops are dropped on the circuit panel, they create paths on the panel and provide resistance to be measured. Here, lower the resistance (or, the more water), indicates lower the voltage output. Conversely, lesser water indicated by higher the voltage output on the analog pin. A completely dry board, for example, will cause the module to generate five volts. This board has the ability to adjust the sensitivity and provides digital and analog Output

(C) Board and Software

- **The Arduino Uno Board:** It is a single-board computer with a microcontroller and set of digital/ analog i/o connection to be used as a gateway, to process and convey data. It is a microcontroller based single board computer, used to design a digital device. As per the Nayyar, A [133], all the programmable boards come from the microcontroller family of embedded systems to perform tasks at a low cost than the microprocessor-based embedded systems. Arduino Uno is a low-cost programmable board developed with ATMega328 microcontroller based on 8-, 16-, 32 by AVR technology. It works using an Arduino software IDE that provides a platform to write and compile the program. This board works by installing a program which is loaded using computers to instruct it to work to process the data. In our case, it is used to process data taken by ultrasonic and rainfall sensors to inform the monitoring device.
- **Software:** Arduino IDE is a platform to write a program for developing a new application; it provides help in writing code and compiles them on the microcontroller. An IDE program is known as a "sketch," written in C or C+ + with few rules. It is open-source software, thus, available freely on the World Wide Web. It has a feature of easiness and user-friendliness as per Nayyar&Puri et al. [134]. These systems provide sets of digital and analog I/O to connect to the circuit. On this board, programs can be loaded from a

computer to accomplish the desired tasks. Arduino Uno provides data collected by ultrasonic and raindrop sensor to the computer. *Arduino IDE is a* cross-platform application written in the programming language Java to help the new programmers in development.

4.6 Detection Devices in Experiment

Various technologies are in use to transmit data from one end to another. To develop devices, different components have been chosen. Before analysis, devices have been designed using the Fritzing software, and then the actual development was conducted. The design of these devices is possible in wired mode or wireless mode. The devices of both modes are useful for different scenarios if the device is installed at the place where regular power supply is possible just like the pole of street light (Solar), then wired setup of the device will be beneficial. For studying devices to generate data in both modes, it was necessary to make a comparison. Therefore, to compare, help taken from existing mechanisms described by Perumal et al. [64], Parimala et al. [63], Satria et al. [59] and Neeraj et al. [108]. However, two kinds of nodes are required, including devices to measure water level and devices to measure raindrop.

4.6.1 Device for Water Level Detection

The design is developed by Perumal et al. [64] and is used for comparison purposes by making a few changes to make it cost-efficient as shown by Neeraj et al. [108].

(a) Connections for Wired Mode

The existing redesigned device has shown in figure 4.6.1(a). It can send data to the cloud or a system or can show data with any attached display.

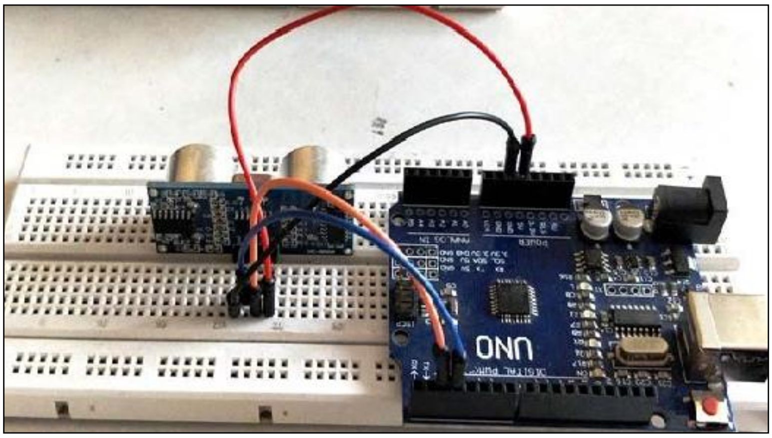


Figure 4.6.1 (a): Wired water level detection device

(b) Connection for Wireless Mode

In the development of the device for wireless communication, transmitter and receiver chips are required. A transmitter is required to design a transmission device and receiver to design a receiving device and to receive data at the monitoring station. By using the transmitter and receiver chip, the circuits of water level detection devices have designed. Transmitting node can send data to a receiver node. From the receiver node, data can be transferred to the cloud or can be visualized on any attached display.

- **The device in wireless mode:** The figure 4.6.1 (b) and (c) are diagrams of wireless connection using a breadboard to design a receiving device and a transmitting device with an ultrasonic sensor. The figures 4.6.1 (b) and (c) represent the nodes to work as sensing or transmitting node, and as a receiving node. Both devices work together for sensing and transmission/ reception of data. After receiving data, a display unit provides output as shown in figure 4.6.1 (d).

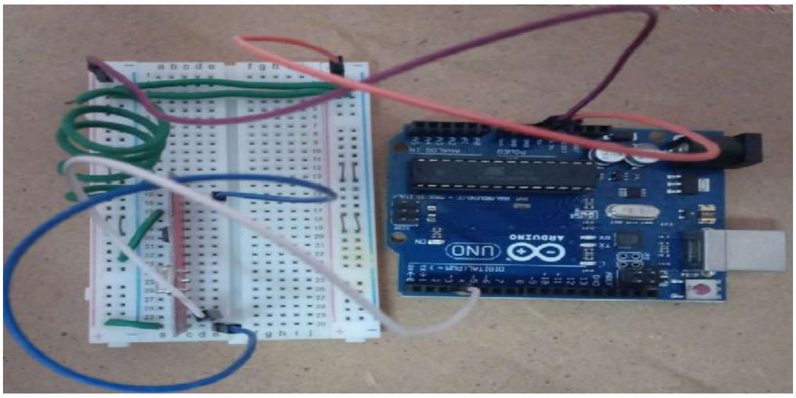


Figure 4.6.1 (b): Receiving node for water level detection

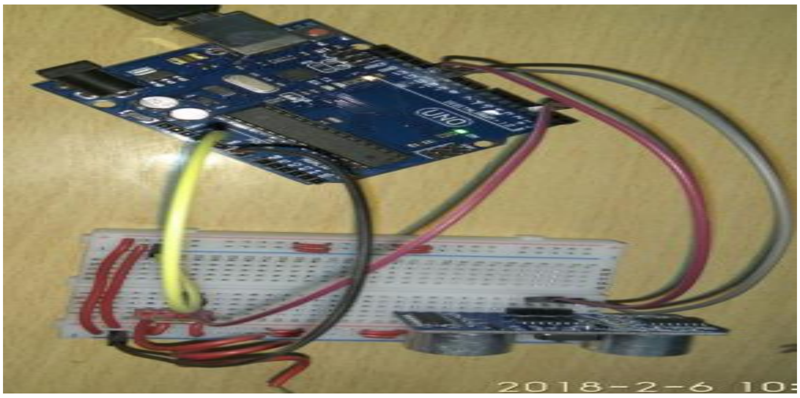


Figure 4.6.1 (c): Transmitting or detection node for water level

The ultrasonic sensor engaged with the transmitter provides the signal to calculate at the board, while the board calculates these signals in the form of distance. A transmitter attached in this node transmits data to the receiving node. This receiving node shows the distance on the screen attached to the receiving node as shown in figure 4.6.1 (d).

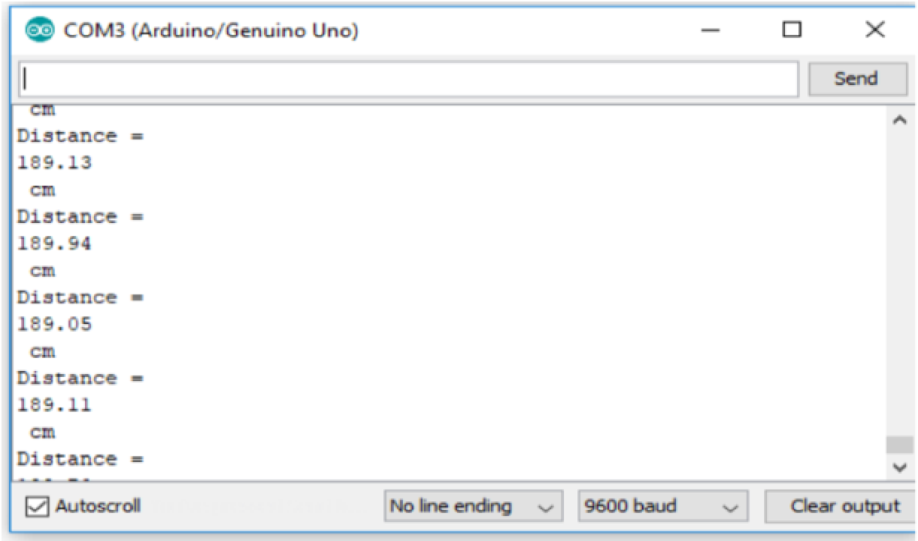


Figure 4.6.1 (d): A screenshot of data acquired by devices

- **Data acquisition for water level:** A sensing node is an embedded system made by a combination of different components, including Arduino Uno with sensors in case of wired setup, and with sensors and transmitter-receiver in case of wireless devices. The input and output pin of the Arduino Uno provides the connection between the ultrasonic sensor and the monitoring device. Arduino Uno is used to convert received pulses of a sensor into the distance and passes it to the monitoring station. An ultrasonic sensor works on the principle of ultrasonic waves based on the speed of sound and distance to the object, which is calculated by the formula discussed by Guerrero et al. [131].

In this work, the researcher used Arduino Uno kits, along with a breadboard as per figures 4.6.1 (a), (b), (c). Data of the transmitting and receiving device have been studied using the Laptop used as a display device. The output of both kinds of circuits was found the same as 4.6.1 (d). Transmitter nodes in wireless detection mechanisms provide data in the same way as provided by sensing node of wired mode on the output screen. The transmitter node transmits the same data to the receiving end, and the output window of the receiver program shows the same data at the same time or with a negligible delay.

4.6.2 Device for Raindrop Detection

Raindrop sensor provides information about the presence of rain and its intensity too, in both modes of communication. Both devices of wireless and wired mode are useful for different scenarios as discussed above in the last section. The researcher has taken data in wired mode while designed circuits of devices for both modes using Fritzing software, however, assumed that output in both the modes will be produced in the same format. So, the setup, connections, and working have been discussed below:

(a) Raindrop Detection in Wired Mode

A raindrop detection device is designed in wired mode as shown by documents of the raindrop sensor. It provides output by running a simple code, after connecting, this module with Arduino Uno through wires. This sensor provides data after connecting it as per the manual that has been shown in figure 4.6.2 (a).

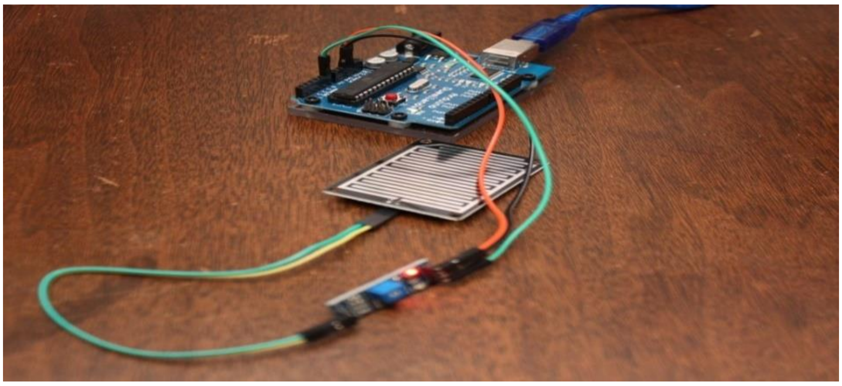


Figure 4.6.2 (a): Existing wired rainfall detection device

- **Connections:** The raindrop sensor module comes in two parts, including a rain board and a control board. In this module, the raindrop board captures rain data. Rain board is a simple plate that bears a drop of rain while the control board comes with a power indicator LED and an adjustable sensitivity a potentiometer. To detect and to transfer the data of a raindrop, the researcher used analog output, (A0) is connected to the A0 of Arduino Uno module. Here, the Gnd of control board connects to the Gnd of Arduino Uno and Vcc to 5V of Arduino Uno to get power supply.
- **Working:** It starts working with the induction board on which raindrop hits. This device provides information regarding a drop to the control board connected and integrated with the Arduino UNO board. This board shows data

using an ordinary IDE after running a simple scratch. In this detection, only analog output was used, so we connected it to the Arduino Uno kit for further computation.

- **Specifications:** As per the manual, it adopts RF-04 double-sided material with area 5cm x 4cm made of a nickel plate for prolonged use. It works on 15mA and has a potentiometer to adjust its sensitivity to the working voltage of 5 Volt. The output format is 0 and 1 in digital and analog AO, the plate has bolt holes for simple connection and joint. The control board is also a small circuit using an M393 comparator with a potentiometer and LED.
- **Pin configuration:**

GND-ground;	DO- High /Low output;
AO- Analog output;	VCC- 5V.

(b) Raindrop Detection in Wireless Mode

This design is found in literature in which B. Vidheya Raju [135] discussed the use of a raindrop sensor in a wireless mode in his farm monitoring system. They have discussed the transmitter and receiver module with sensors of raindrop, humidity, and temperature. He just used it using a GSM module. According to Raju [135], the transmitting device contains Arduino Uno, Moisture sensor, Temperature sensor, Raindrop sensor, LCD Display, GSM Module, Alarm., Power Supply, and Water flow system. While as a receiving node, they used a Smartphone. In his experiment, he used all the sensors and provided observations based on the data to the display of mobile phones using the GSM module. In his project, he used the same circuit of raindrop sensor to gather rain data but used a GSM modulation to transmit the data from a transmitter to a receiver while using a smartphone with GSM as a receiving device.

Though as we know data in Arduino is produced by detection node, thus researcher was interested in designing a transmitting or detection node to see the performance of the device. However, the researcher has designed a circuit of transmitting and receiving node using fritzing software as indicated in figure 4.6.2 (b) and (c). The design of the detection or transmitting node has also performed using breadboards.

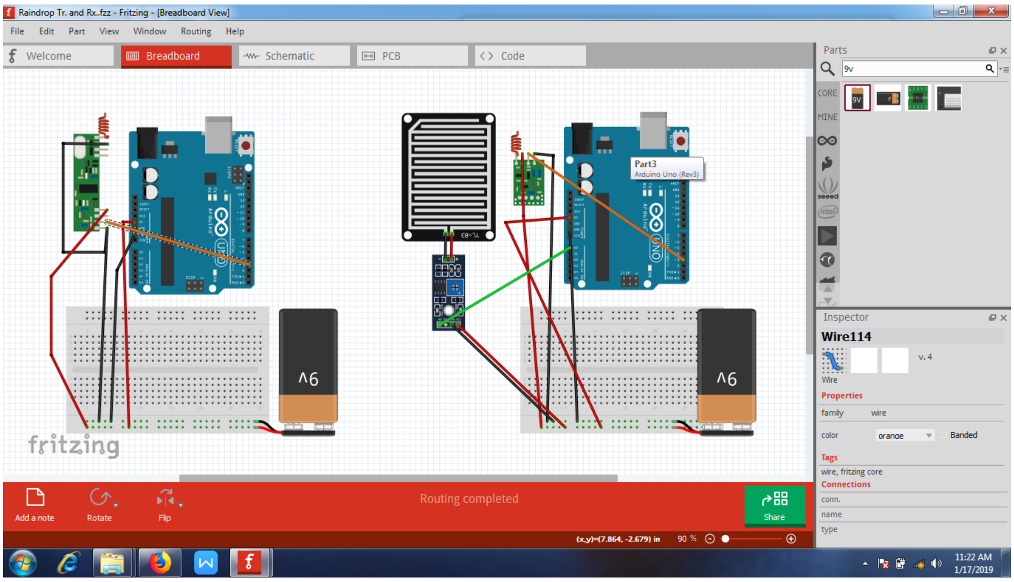


Figure 4.6.2 (b): Circuit of raindrop detection (transmitting & receiving) device

Raindrop Detection Node: Data acquisition is the task of a detector, from which a sensor sends data of the same kind in any mode of communication. That is why the researcher just acquired data using an existing mechanism and assumed that it will do work in the same way in both modes of communications. A transmitting device has shown in figure 4.6.2 (b) that is designed using Fritzing designing software. Here, the circuit of the transmitting device elaborated after adding an LED to provide an indication in figure 4.6.2 (c) that is useful to capture and transmit rainfall data. This circuit has the Arduino Uno board, transmitter, raindrop module, and a battery at transmitting module end, while the Arduino board, receiver, and battery will be placed to develop a receiving module.

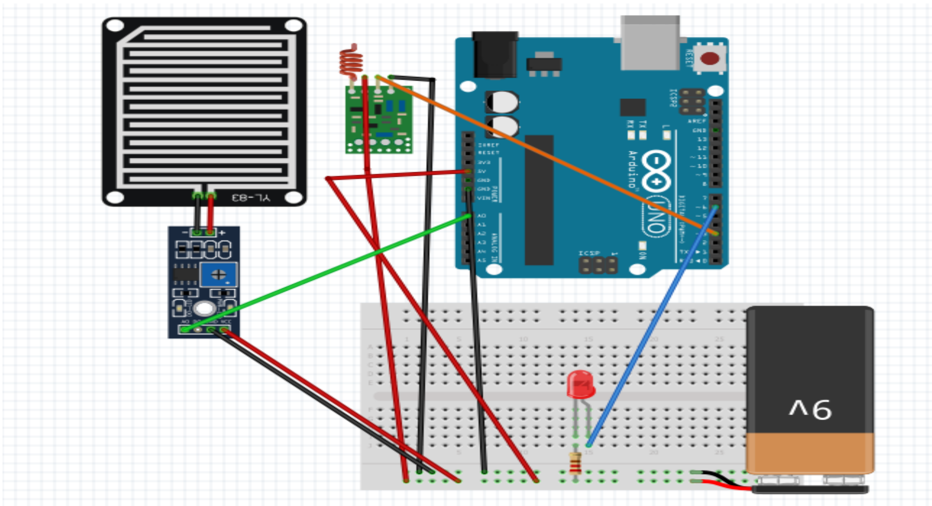


Figure 4.6.2 (c): Circuit of raindrop detection or transmitting device

- **Process of data retrieval:** Data retrieval starts from the programming on the Arduino IDE like other programs of water level data acquisition. After this a simple procedure is to be applied that is enlisted below:
  1) Start a simple scratch on Arduino Uno just after the connection;
  2) Connect USB from Arduino to the computer;
  3) Start and upload the program;
  4) The result will be shown on the serial monitor;
  5) It will give the value approximate to 1023, which is the highest in a dry state.
  6) After getting raindrop, the value of 1023 will go below 1000 and sometimes below 500 on the right amount of drop.
  7) When readings reach 500 or below, it indicates the presence of a raindrop.
- **Data acquisition:** Output comes in the form of decimal numbers from 1 to 1023 as indicated in figure 4.6.2 (d). As per program numbers of readings vary in two categories, it may be near 1023 or maybe nearby 500. When numbers of readings are nearby 500, it indicates drops of rain or water on the panel. But, when the numbers of readings are nearby 1000, it indicates no drops of rain or water on the panel and the panel is dry.

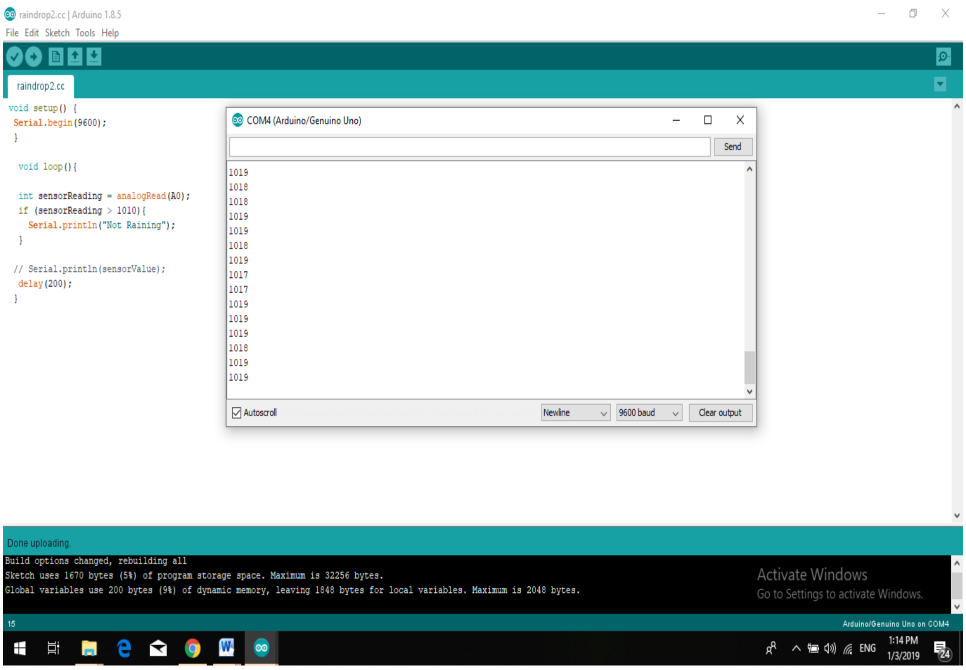


Figure 4.6.2 (d): Screenshot of output by raindrop sensor

Result: Results provided on display using COM3 port after running in the same way as other programs of Arduino.

4.6.3 Proposed Flood Sign Detector

The proposed node having features of water level measurement and raindrop presence detection using a single Arduino Uno board is indicated using figure 4.6.3 (a).

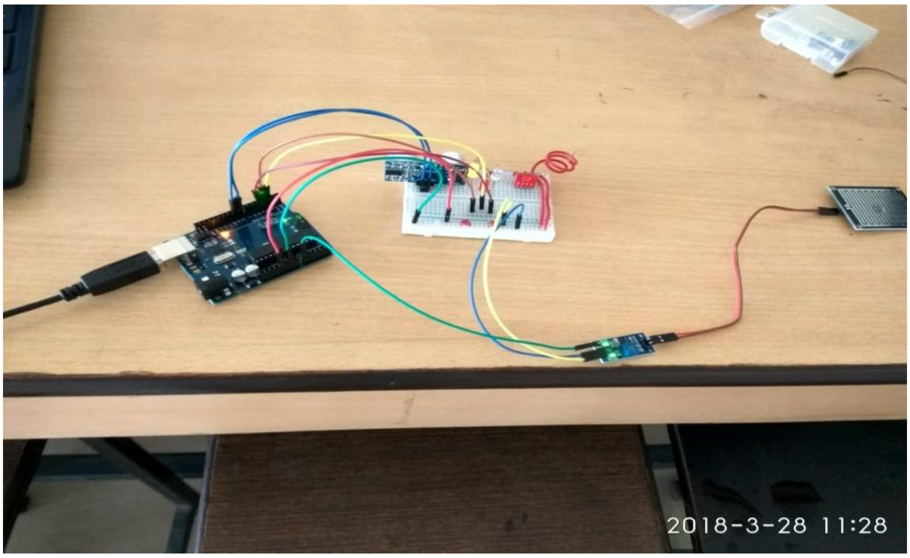


Figure 4.6.3 (a): Proposed flood sign detector

- **Data of both devices on the same port:** Output of proposed devices can be seen on the same port as indicated by figure 4.6.3 (b) that shows the presence of raindrop and water level on com 3.

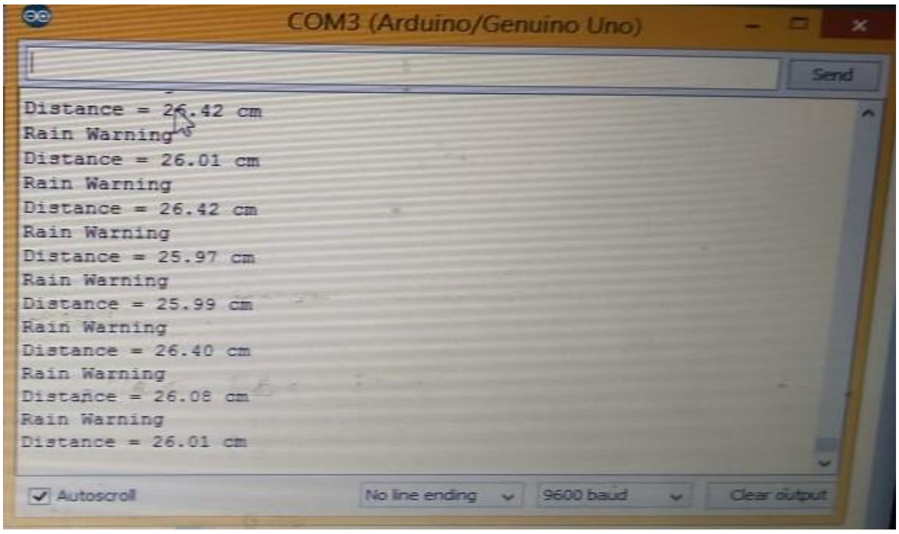


Figure 4.6.3 (b): Screenshot of both kinds of output on the same port

4.7 Comparison between Devices Considered in Experiments

Flood detection depends on the accuracy of data sent by Things involved. To find out the highest accuracy, the involved sensor with the Things plays a crucial role. To gather the data to be used in the proposed expert system, the use of water level and raindrop sensors have been suggested. On the other hand, the success of the project depends on the performance of the designed devices in terms of accuracy of data, current and power consumption by devices while the cost of projects depends on the cost of deployed devices for the whole project.

4.7.1 Cost Comparison between Detection Devices

The price of components used in devices found different in purchasing them in different quantities. This difference in cost made a difference in the costs of devices. To find out the budget of devices developed, prices of components were considered from the website of amazon.com.

Table 4.7.1 (a): Comparison in cost of detection devices

	n=1	n=5	n=10	n=20	n=30
Cost of a ^{W}WD Device	40.96	19.13	18.76	18.64	18.68
Cost of a ^{W}RD Device	42.96	20.55	19.71	20.05	19.91
Cost of a $^{\omega}WD_T$ Device	37.06	11.64	11.07	10.95	10.99
Cost of a $^{\omega}RD_R$ Device	38.06	12.06	11.02	11.31	11.22
Cost of a $^{\omega}FSD_T$	45.05	14.02	12.62	12.79	12.73

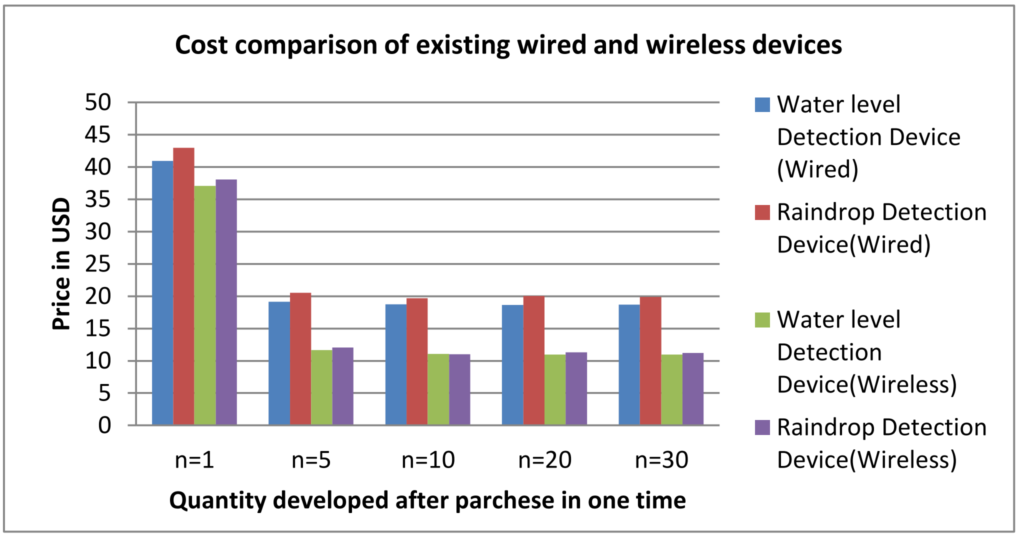


Figure 4.7.1 (a): Cost comparison between existing wired and wireless devices

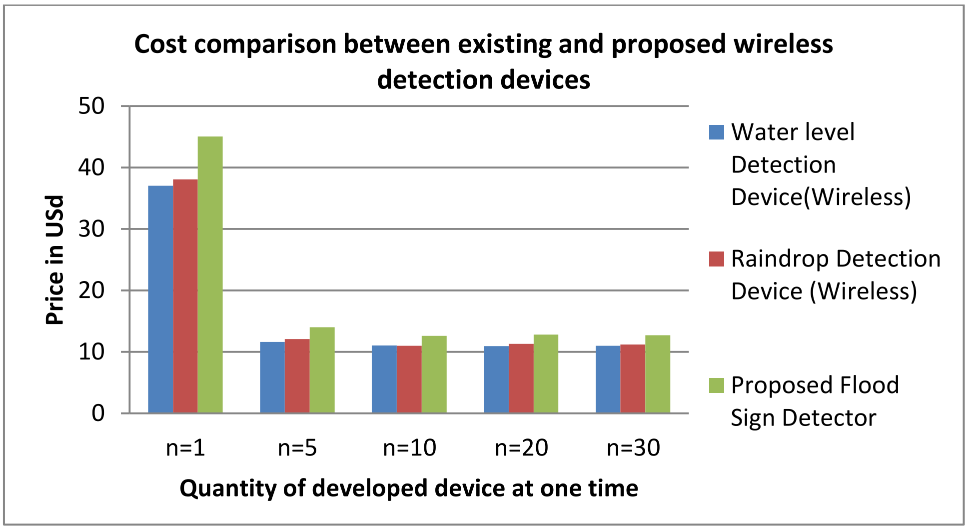


Figure 4.7.1 (b): Cost comparison between existing and proposed device

4.7.2 Current and Power Consumption

As per the methodology adopted by Catarinucci et al. [136], published by the IEEE Internet of Things Journal, consumptions can be calculated by finding the collective consumptions of all the components involved in the design of a device. Literature provided current and power consumption as per table 4.7.2 (a) table 4.7.2 (b). In this section W, Ꞓ, i and p stand for wired, wireless, current and power respectively.

Table 4.7.2 (a): Current consumption in Arduino Uno

Normally uses	**When powered by USB [138]**	**Per pin [139, 141]**	**Sleep mode [142]**	**At blink [140]**	
45 mA [137]	500 mA	40 mA	27.8	53 mA	55 mA

Table 4.7.2 (b): Power consumption in Arduino Uno

Device	**Power Consumption**
Ultrasonic sensor [143]	< 2 mA
Raindrop sensor [144,145]	< 20 mA
Transmitter Module [146]	11 mA
Receiver module [146]	3.5 mA
LED	5 mA

(a) Current Consumption

The current consumption of all the devices calculated here using Kirchhoff's Current Law (KCL) ,while current of LED has not considered for existing devices because its use was not mandatory. Current in devices are calculated as indicated below:

- **In Wired Mode**

  Current consumption in water level detection (WD) device and Rainfall detection (RD) device considered to be evaluated. As per the KCL, the current required for these circuits of parallel will be equal to the sum of current consumed by all integrated components.

  In Water level Detection device:

  ^{W}WD (i) in Sleep mode = 27.8 + 2 = 29.8 mA

  ^{W}WD (i) in Active mode = 45 + 2 = 47 mA

  In Raindrop Detection device:

  ^{W}RD (i) in Active mode = 45 + 20 = 65 mA

- **In Wireless Mode**

  Both kinds of devices included for evaluation with their transmitting and receiving devices. These transmitting and receiving devices will consume current as:

  In Water level Detection device:

  For transmitting device:

  $^{\omega}WD_T$ (i) in Active mode = 45 + 2 +11 = 58 mA

  For Receiving device:

  $^{\omega}WD_R$ (i) in Active mode = 45 + 2 +3.5 = 50.5 mA

  In Raindrop Detection device:

  For transmitting device:

  $^{\omega}RD_T$ (i) in Active mode = 45 + 20 +11 = 76 mA

  For Receiving device:

  $^{\omega}RD_R$ (i) in Active mode = 45 + 20 +3.5 = 68.5 mA

  In Proposed Flood Sign Detector (Transmitting Device):

  $^{\omega}FSD_T$=45(Board)+20(rain)+11(transmitter)+2(ultrasonic)+5(LED) = 83 mA

(b) Power Consumption

Power consumption considered by finding the collective power consumption of all components involved in the design of a device as per formulae in equation 4.2.

$$P = I * V \qquad .... 4.2$$

Where, P = Power consumed by the device; I = Current consumed by the device; V = Voltage consumed by the device = 5 volts (in our experiments).

- **In Wired mode**

  Both kinds of devices are considered for evaluation. As per the KCL, the current required for a circuit will be equal to the sum of all its components having. So, the power used by a water level and the raindrop detection device will be:

  In Water level Detection device:

  ^{W}WD (p) in Sleep mode = 29.8 * 5 = 149 mW

  ^{W}WD (p) in Active mode = 47* 5 = 235 mW

  In the Raindrop Detection (RD) device:

  ^{W}RD (p) in Active mode = 65 * 5 = 325 mW

- **In Wireless Mode**

  Both kinds of devices are considered for evaluation. As per the KCL, the current required for a circuit will be equal to the sum of all its components having. Therefore, the power used by Water Level and rainfall detection devices will be:

  In the Water level Detection device:

  For transmitting device:

  $^{\omega}WD_{T}$(p) in Active mode = 58 * 5 = 290 mW

  For Receiving device:

  $^{\omega}WD_{R}$(p) in Active mode = 50.5 * 5 = 252.5 mW

  In the Raindrop Detection (RD) device:

  For transmitting device:

  $^{\omega}RD_{T}$(p) in Active mode = 76 * 5 = 380 mW

  For receiving device:

  $^{\omega}RD_{R}$(p) in Active mode = 68.5 * 5 = 342.5 mW

  In the Proposed Flood Sign Detector (FSD):

  $$^{\omega}FSD_{T}(p) = 83 * 5 = 415 \text{ mW}$$

  Note that the transmitting device of FSD is proposed and due to its wireless nature referred to as $^{\omega}FSD_{T.}$

(c) Summary of Current and Power Consumption

After analyzing the current consumption, a power consumption arranged in the form of tables 4.7.2 (c) for Wired Devices and 4.7.2 (d) for wireless devices. Let us see the current and power consumption to compare devices:

Table 4.7.2 (c): Current and power consumption of wired devices

	Current consumed(i)	Power consumed(p)
Water level detection device (WD)	47	235
Raindrop Detection device (RD)	65	325

Table: 4.7.2 (d): Current and power consumption of wireless devices

		Current consumed (mA)	Power consumed (mW)
Water level detection device (WD)	Transmitting device (T)	58	290
	Receiving device (R)	50.5	252.5
Raindrop detection device (RD)	Transmitting device (T)	76	380
	Receiving device (R)	68.5	342.5
Proposed Flood Sign Detector (FSD)	**Transmitting device(T)**	**83**	**415**

As we know, the developed device is a device of wireless mode communication, so it popup our curiosity to compare all kinds of wireless transmitting devices. Thus, figure 4.7.2 has drawn to show the power consumption by the Flood Sign Detector.

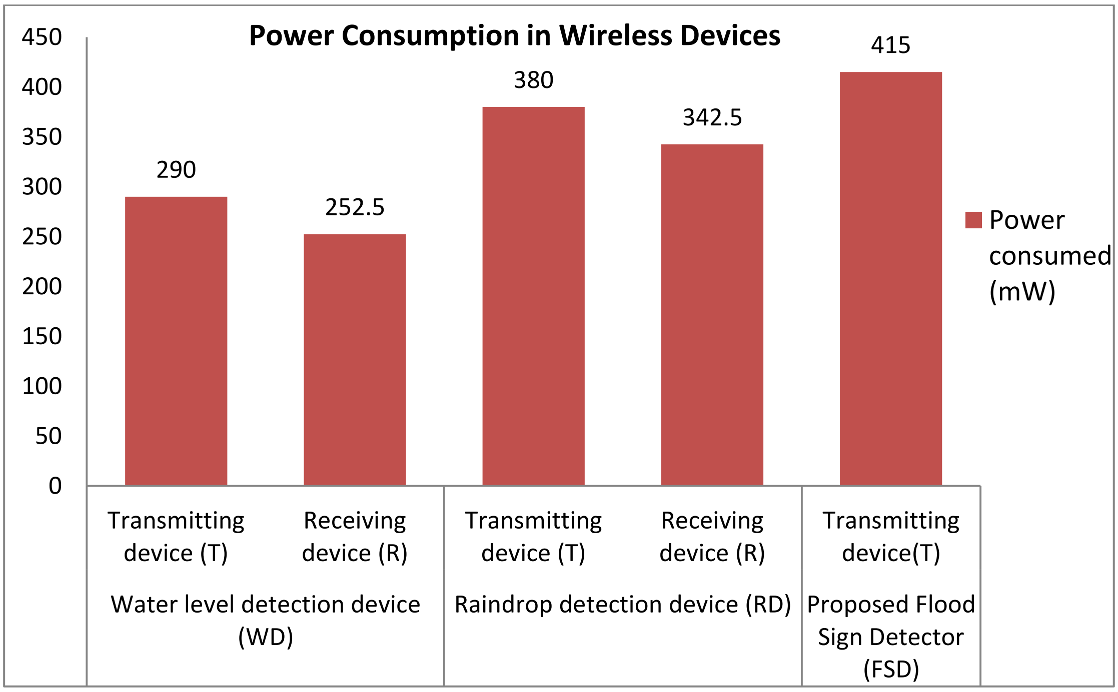


Figure 4.7.2: Power consumption in wireless devices

By seeing this figure, it can be concluded that the power consumption of the developed device is not so high because it is acquiring data of two kinds. It means by one battery, retrieval of two kinds of data has been possible using this new kind of device.

4.7.3 Comparison between Wireless Detection Devices

Now, a comparison between various detection devices can be compared easily. Therefore, after considering all the physical properties of all the detection devices of wireless mode, a general comparison performed. For comparison, the cost of devices, power consumption by devices, number of main components utilized in the device and type of data acquired, has been considered. The comparison has been shown in table 4.7.3.

Table 4.7.3: Comparison between all the wireless detection devices tested

Properties of Transmitting devices	***Data about Devices***		
	Wireless Raindrop Detection device ($^{W}RD_{T}$)	***Wireless Water level Detection device ($^{W}WD_{T}$)***	***Proposed Flood Sign Detector $^{W}FSD_{T}$***
Least Cost	***11.02***	***10.95***	***12.62***
Power consumed	***380***	***290***	***415***
Components utilized in design	***4***	***4***	***5***
Type of data acquired	***1***	***1***	***2***

4.7.4 Hypothesis and Validation

(a) Hypothesis

- **Null Hypothesis (H_0):** The proposed Flood Sign Detector (FSD) performs better than the same kinds of existing devices in terms of properties.
- **Alternate Hypothesis (H_a):** The proposed Flood Sign Detector (FSD) performs better than the different kinds of existing devices in terms of properties.

(b) Validation

To test this null hypothesis first we have to check the similarity of devices and then the type of data acquired. So, to check the similarity testing using One way ANOVA has been chosen one way ANOVA is a technique to compare means of two or more samples using F-distribution. As per the requirement of testing the hypothesis, physical properties and indication type of data both are included in the test. Note that all three devices having different properties that are measured in different units. Thus, to test the device, it is necessary to convert all the data of a different kind in the form of a single unit. This equality has been maintained using assumptions indicated by table 4.7.4 (a).

Table 4.7.4 (a): Equivalent weights for each property

Properties of Detection Devices	**Assumptions as per Experts**
Least Cost (1)	Cost < 11.02 = 3
	Cost = 11.02 = 2
	Cost > 11.02 = 1
Power consumed (2)	Power consumption< 380 = 3
	Power consumption= 380 = 2
	Power consumption> 380 = 1
Components utilized in design (3)	No. of Components < 4 = 1
	No. of Components = 4 = 2
	No. of Components > 4 = 3
Indication type (4)	Indication type < 1 = -1
	Indication type = 1 = 1
	Indication type > 1 = 2

Therefore, to make the data compatible with testing a piece of expert advice required. Table 4.7.4 (a) has been generated based on this expert advice using a threshold value that has provided data for the test.

Table 4.7.4 (b): Data table to be used in F- Test

Properties of Wireless Detection Devices	***Data about wireless detection devices***		
	Raindrop detection Device (Y_1)	**Water level Detection Device (Y_2)**	**FSD Device (Rain^water) (Y_3)**
Least Cost (1)	***2***	***3***	***1***
Power consumed (2)	***2***	***3***	***1***
Components utilized in design (3)	***2***	***2***	***3***
Indication type (4)	***1***	***1***	***2***

Steps to test F-ratio are:

Step 1: Mean calculation within each group:

$$\overline{Y1} = \frac{1}{4}\sum Y_{1i} = \frac{2+2+2+1}{4} = 7/4 = 1.75$$

$$\overline{Y2} = \frac{1}{4}\sum Y_{2i} = \frac{3+3+2+1}{4} = 9/4= 2.25$$

$$\overline{Y3} = \frac{1}{4}\sum Y_{2i} = \frac{1+1+3+2}{4} = 7/4= 1.75$$

Step 2: Calculate the overall mean:

$$\bar{Y} = \frac{\sum \overline{\boldsymbol{Y}}\mathbf{i}}{\boldsymbol{a}} = \frac{\overline{\boldsymbol{Y_1}}+\overline{\boldsymbol{Y_2}}+\overline{\boldsymbol{Y_3}}}{\mathbf{3}} = \frac{5.75}{3} = 5.75/3 = 1.91$$

Where a is a number of groups.

Step 3: Calculate the "between group" sum of squared differences:

$$S_B = n(\overline{Y_1} - \overline{\mathrm{Y}})^2 + n(\overline{Y_2} - \overline{\mathrm{Y}})^2 + n(\overline{Y_3} - \overline{\mathrm{Y}})^2$$

$$= 4(1.75 - 1.91)^2 + 4(2.25 - 1.91)^2 + 4(1.75 - 1.91)^2$$

$$= 4(-0.16)^2 + 4(0.34)^2 + 4(-0.16)^2$$

$$= 4*0.0256 + 4*0.1156 + 4*0.0256$$

$$= 0.1024 + 0.4624+0.1024 = 0.6672$$

Where n is the number of elements in the group.

The between-group degree of freedom is one less than the number of groups.

$$f_b = 3 – 1 = 2$$

So, the between-group mean square value is:

$$MS_B = 0.6672 / 2 = 0.3336$$

Step 4: Calculate the within-group sum of squares.

Table 4.7.4 (c): Within-group sum of squares

Y_1	Y_2	Y_3
2-1.75=0.25	***3-2.25= 0.75***	***1-1.75= -0.75***
2-1.75=0.25	***3-2.25= 0.75***	***1-1.75= -0.75***
2-1.75=0.25	***2-2.25= -0.25***	***3-1.75= 1.25***
1-1.75= -0.75	***1-2.25= -1.25***	***2-1.75= 0.25***

The within-group sum of squares is the sum of squares of all 12 values in this table.

$$S_W = ((.25)^2+(.25)^2+(.25)^2+(-0.75)^2)+((0.75)^2+(0.75)^2+(-0.25)^2+(-1.15)^2)+((-0.75)^2+(-0.75)^2+(1.25)^2+(0.25)^2)$$

$$= (0.0625+0.0625+0.0625+0.5625)+(0.5625+0.5625+0.0625+1.5625)+(0.5625+0.5625+1.5625+0.0625)$$

$$= (0.75) + (2.75) + (2.75)$$

$$= 6.25$$

The within group degree of freedom (f_W) is:

$$f_W = a\,(n-1)$$

$$= 3\,(4-1) \quad = \quad 9$$

Thus the within-group mean square value is

$$MS_W = \frac{SW}{fw} = \frac{6.25}{9} = 0.694$$

Step 5: the F-Ratio is

$$F = \frac{MSW}{MSB} = \frac{0.3336}{0.694} = 0.4806$$

Now, $F_{crit}(2, 9) = 4.26$ at 5% level of significance. Since $F = 0.4806 < 4.26$.

Therefore, the null hypothesis has been accepted. So on the basis of acceptance of the null hypothesis, it can be concluded that there is strong evidence that the design of the three devices does not differ while flood sign detector acquires data of two kinds. The p-value for this test is 0.002.

It means, our developed product is just the same as developed earlier. But, it can be seen that the proposed flood sign detector provides two kinds of data including water level and presence of rainfall. So, it can be summarized that the proposed device will be better.

CHAPTER 5 | DEPLOYMENT STRATEGY FOR IoET DEVICES

"However beautiful the strategy, you should occasionally look at the results."

—Sir Winston Churchill

5.1 Background

There are two kinds of technologies, including deterministic and nondeterministic strategies which are in use [147] for deployment. In a deterministic approach, deployment is based on fewer nodes to cover a large area while in non-deterministic strategy sensors were scattered in a random manner. A deployment scheme varies according to the requirement of the application, especially for sensing nodes of WSN or IoT. Lee et al. [148] discussed it for user localization, Sharma et al. [149] discussed for coverage in a large open area, Haule and Michael [150] discussed it for automating irrigation management, and Lin et al. [151] discussed for good performance in a limited capacity.

As per the requirements of our applications, strategy to deploy devices will be different for an existing city from the scheme for a newly developing city. In this section, two different algorithms are proposed to find out the location for the deployment. For timely information, the researcher suggested the deployment of IoT devices over the system for newly developing cities. Subramaniam et al.[152] has shown the use of their devices for flood detection for urban flooding. However, they have not suggested a particular strategy for deployment. Uslender [16] argued to use smartphones as a sensing device and as a classifier [153] to inform about emergencies. Smart devices are suggested to be deployed in the lake, dam, or rivers in review by Ackere et al. [154]. However, in the case of urban flood, there will be no benefit by such kind of deployment

5.2 Location for Deployment in Existing Cities

Here, a slightly different algorithm was proposed to deploy IoT nodes for existing developed plains. The position of the devices is decided to be deployed in the path of water flow after finding the point at the deepest place in the cluster of cellular plain using the Cell Elimination Algorithm indicated in figure 5.2 (a).

Cell Elimination Algorithm

Start

Step (a) Find the flow of water, flow (i, j) with the boundary of the cell

Depth of cell at point P,= $D_p(i)$

Set of cells in hexagon cluster(A)

Step (b) For cluster(A)

Calculate average (m)

$$m = \frac{h_c + \sum_{i \in A} h_t}{n_A + 1}$$

Where h_c = Height of a cell in the middle.

h_t = Average height of the non-eliminated neighbor cells

nA = Number of non-eliminated neighbor cells

If (cell X has height > Average height)

Eliminate X from A.

Step (d) If $D_p(i) = {}^{Max} D_p(i)$

Spot the position as $d_{(A)}$= 1 to deploy a device

In set A:

Step (e) If null cell ≠ 0,

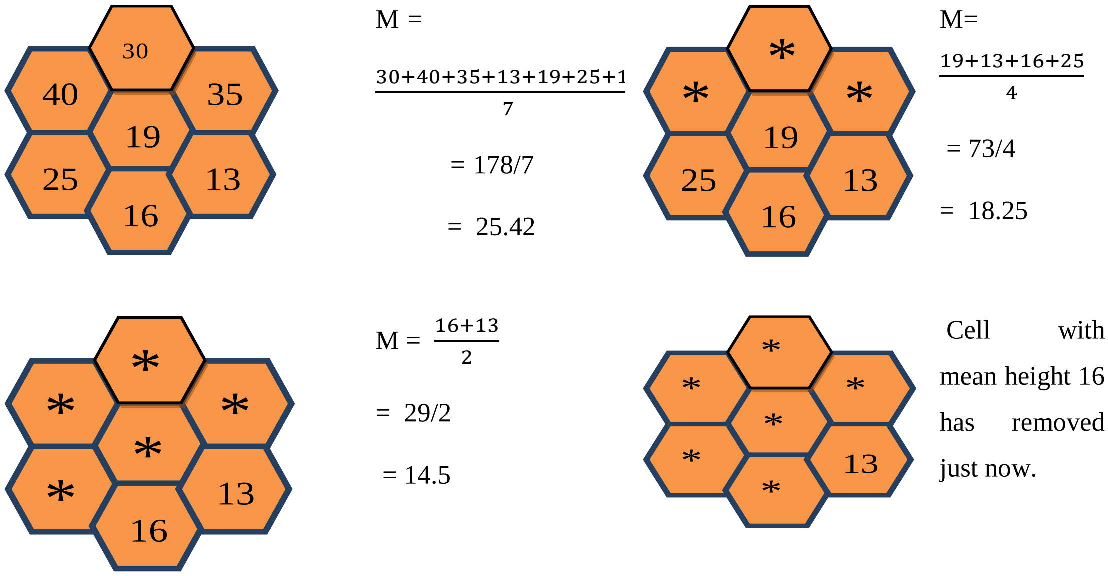
Go to step (c).

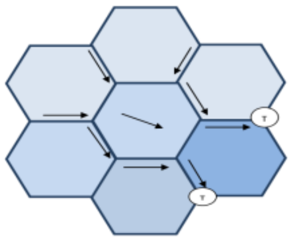
End

Figure 5.2: Cell Elimination Algorithm

5.2.1 Simulation of CEA

The Cell Elimination Algorithm (CEA) by Neeraj et al. [108] was proposed to find the direction of the water flow of rainwater in a hexagonal grid structure. It is useful for finding a natural path of water flow, for which device deployment for flood detection is adopted. The algorithm works with the removal of cells having a depth of more than an average of neighbor cells and find out a route in the direction of slope, as indicated in figure 5.2. In figure 5.2.1, the researcher has simulated the CEA algorithm. This algorithm provides the position to deploy node at every joint.





CEA gives the direction of water flow within a clustered area of cells. Using this direction, it will be elementary to find out a vulnerable place to design the reservoir/tank to deploy the detection device.

Figure 5.2.1: Simulation of Cell Elimination Algorithm

5.2.2 Hypothesis and Validation

(a) Hypothesis

- **Null Hypothesis (H_0):** There is no significant difference in a number of nodes deployed using CEA (Hexagonal) and without CEA.
- **Alternate Hypothesis (H_a):** There is a significant difference in a number of nodes deployed using CEA (Hexagonal) and without CEA.

(b) Validation

Least node requirement considered without CEA and with CEA for the case when nodes are spread in one direction.

Table 5.2.2 (a): Node requirement with CEA and without CEA

Layer	**1**	**2**	**3**	**4**
Node required without using CEA (in the best case)	3	10	20	33
Node required using CEA	4	8	12	16

T-Test applied to check the hypothesis as per the discussion in [155]. Thus, let the number of nodes required using CEA and without CEA that are represented as X and Y. Now, taking the null hypothesis that the required of nodes using CEA will be less.

$H_0 : = \mu_{1} = \mu_2$, which is equivalent to test $H_0 : \bar{D} = 0$

$H_a : = \mu_1 < \mu_2$, (As we want to conclude that the CEA is beneficial)

Because of the matching the difference between using CEA and without CEA, we use paired *t*-test and work out the test statistic '*t*' as under:

$$t = \frac{\bar{D} - 0}{\sigma_{diff} / \sqrt{n}}$$

To find the value of *t*, we first work out the mean and standard deviation of differences as:

Table 5.2.2 (b): Squared differences between the requirements with CEA and without CEA

Layer	**With CEA**		**Difference**	**Difference squared**
	CEA (Xi)	No CEA (Yi)	(Di = Xi-Yi)	D_i^2
1	4	3	1	1
2	8	10	-2	4
3	12	20	-8	64
4	16	33	-17	289
n =4			ΣDi = - 26	$\Sigma D_i^2 = 358$

Thus, $\bar{D} = \frac{\Sigma \text{Di}}{n}$ = - 26/4 = - 6.5

$$\sigma_{diff} = \sqrt{\frac{\Sigma D_i^2 - (\bar{D})^2 . n}{n-1}} = \sqrt{\frac{358-(42.25).4}{4-1}} = \sqrt{\frac{189}{3}} = 7.937$$

Hence, $t = \frac{-6.5-0}{7.937/\sqrt{4}} = \frac{-6.5}{3.968} = -1.6381$

Degrees of freedom = (n – 1) = 4 – 1 = 3.

Here, *Ha* is one-sided. Thus, a one-tailed test will be suitable to find out the rejection region at a 5% level of significance. Now when using a table of the *t*-distribution for 3 degrees of freedom:

R: $t < -2.353$

The observed value of t is – 3.18 which falls in the rejection region and thus, we reject H_0 at the 5% level and conclude that Hexagonal pattern will be beneficial.

5.3 Locations for Deployment in Newly Developing Cities

In cellular structured plain, water will flow in drainage designed as per cellular design. So, the detection devices can be installed in the path of water flowed. The deployment of IoT devices with this drainage mechanism may provide better detection of waterlogging. The algorithm 4.7.2(a) is based on the same thought.

Cellularly Deployment Algorithm (CDA)

Start

Find the direction of water flow, $flow_{(I,j)}$

Choose Square if

Step (a) If the area is small,

Subdivide the Plain (P) into P_i square

Arrange P_i cellularly in decreasing height order

Place small tanks at corner

Find flow path with CEA

Find position at every corner in the flow path

Step (b) Choose Hexagon grid if

The area is Medium,

Subdivide the Plain (P) into P_i hexagons

Arrange P_i cellularly in decreasing height order

Place small tanks on the boundary

Find flow direction with CEA

Find position at every corner in the flow path

Step (c) Choose Octagon if

The area is Large

Subdivide the Plain (P) into P_i Octagons

Arrange P_i cellularly in decreasing height order

Place small tanks at corner

Find flow path with CEA

Find position at every corner in the flow path

Step (d) Count the no. of positions to deploy

Show the positions to deploy the device

End

Figure 5.3: Cellularly Deployment Algorithm

5.3.1 Simulation of CDA

CDA provides the number of nodes required for deployment in square, hexagonal, and octagonal grid pattern for newly developing cities.

Step (a): Direction of water flow and possible deployment positions, if chosen square grid:

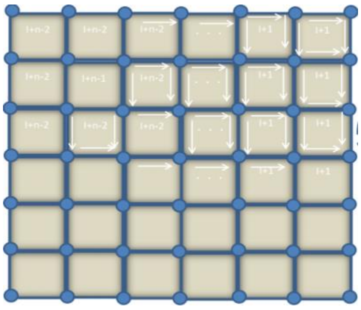


Figure 5.3.1(a): Deployment position in a square grid

Step (b): Direction of water flow and possible deployment Positions, if chosen hexagon:

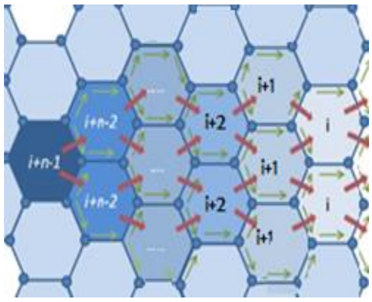


Figure 5.3.1(b): Deployment position in a hexagonal grid

Step (c): Direction of water flow and possible deployment positions, if chosen Octagon:

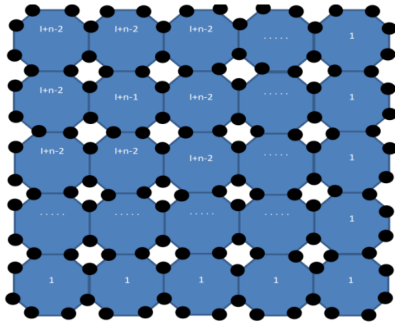
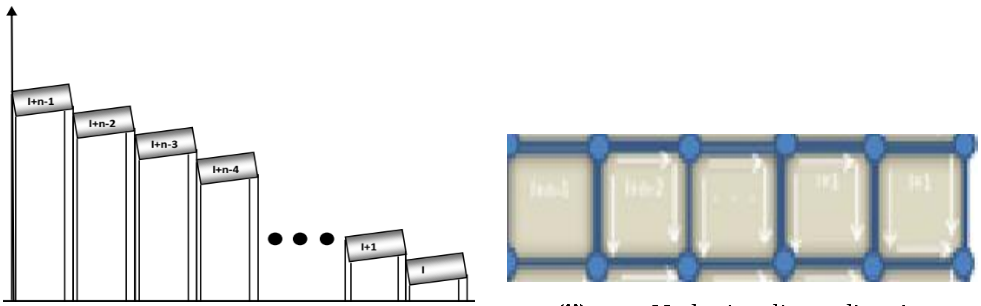


Figure 5.3.1(c): Deployment position in an octagonal grid

Step (d): Count the number of positions to deploy devices because the evaluation of the deployment strategy depends on the number of devices required.

- **In the case of Step (a)**



(i) Hierarchy of flow by setting cells **(ii)** Nodes in a linear direction

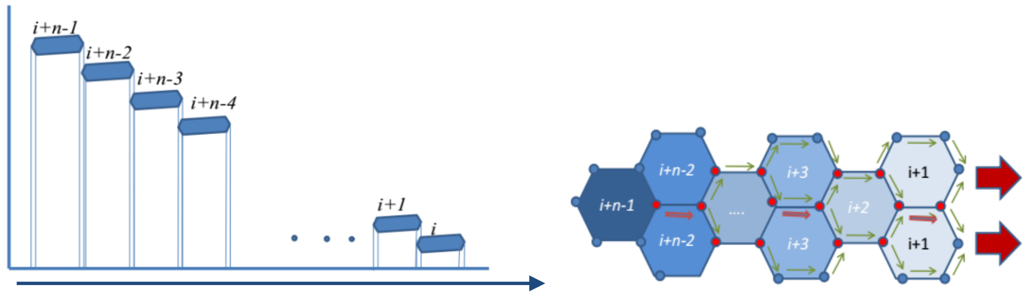
Figure 5.3.1 (d): No. of nodes in deployment using square grids

Sensing nodes required

Table 5.3.1 (a): Layer wise node requirement for square cell

	Layer i+n-1	Layer I+n-2	Layer I+n-3	Layer i+n-4
Node required	4	6	8	10

- **In the case of Step (b):**



(i) Hierarchy of flow by setting cells (ii) Nodes in a linear direction

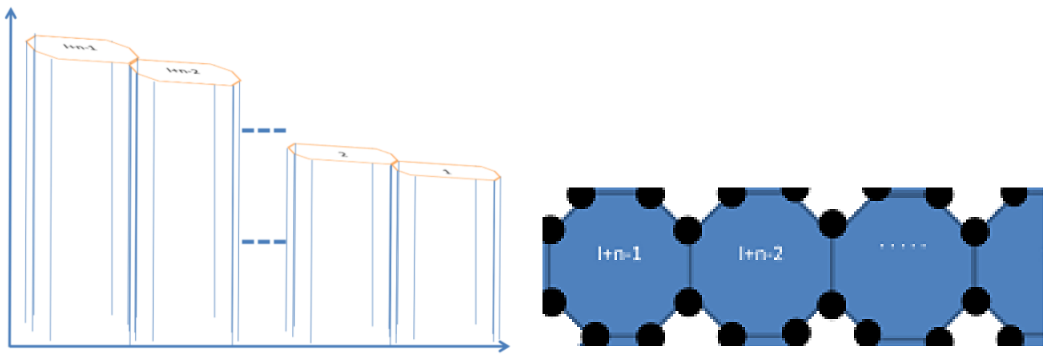
Figure 5.3.1 (e): No. of nodes in deployment using hexagonal grids

Sensing nodes required

Table 5.3.1 (b): Layer wise node requirement for hexagonal cell

	Layer i+n-1	Layer I+n-2	Layer I+n-3	Layer i+n-4
Nodes required	2	7	8	13

- **In the case of Step (c)**



(i) Hierarchy of flow by setting cells (ii) Nodes in a linear direction

Figure 5.3.1 (f): No. of nodes in deployment using octagonal grids

Sensing nodes required

Table 5.3.1 (c): Layer wise node requirement for octagonal cell

	Layer i+n-1	Layer I+n-2	Layer I+n-3	Layer i+n-4
Nodes required	8	14	20	26

5.3.2 Hypothesis and Validation

As per the node requirement shown in table 5.3.1 (a, b and c), we can easily see the scheme of deployment using the hexagonal grid required approximately equal node with the square grid but less than an octagonal grid. Therefore, the null hypothesis has an assumption about the requirement of nodes.

(a) Hypothesis

- **Null Hypothesis (H_0):** The number of nodes to be deployed using CDA with hexagonal cells and octagonal cells is equal.
- **Alternate Hypothesis (H_a):** The number of nodes to be deployed using CDA with hexagonal cells is less and different from the octagonal cells.

(b) Validation

The node requirements of proposed deployment strategies were simulated in chapter 5. To find out the requirement of nodes, the researcher utilized tables 5.3.1 (a), (b), and (c) to arrange in the form of table 5.3.2 (a).

Table 5.3.2 (a): Layer wise node requirement comparison

Nodes required / layer	Pattern	Layer i+n-1	Layer i+n-2	Layer i+n-3	Layer i+n-4
	Square (Y_1)	4	6	8	10
	Hexagon (Y_2)	2	7	8	13
	Octagon (Y_1)	8	14	20	26

Table 5.3.2 (a) indicates a picture of node requirement in a different grid pattern in a linear arrangement in one direction only because of the cellularly planned system. In this table, we can see a hexagonal pattern requires the least number of nodes in most of the cases.

The One–Way Anova is useful to check the equality, thus it is applied here also with the F-distribution. Steps to test F-ratio are:

Step 1: Mean calculation within each group:

$$\overline{Y1} = \frac{1}{4}\sum Y_{1i} = \frac{4+6+8+10}{4} = 7$$

$$\overline{Y2} = \frac{1}{4}\sum Y_{2i} = \frac{2+7+8+13}{4} = 7.5$$

$\overline{Y3} = \frac{1}{4}\sum Y_{2i} = \frac{8+14+20+26}{4} = 17$

Step 2: Calculate the overall mean:

$$\bar{Y} = \frac{\sum \bar{Y}i}{a} = \frac{\overline{Y_1}+\overline{Y_2}+\overline{Y_3}}{3} = \frac{7 + 7.5 + 17}{3} = 10.50$$

Where a is a number of groups.

Step 3: Calculate the "between group" sum of squared differences:

$$S_B = n(\bar{Y_1} - \bar{Y})^2 + n(\bar{Y_2} - \bar{Y})^2 + n(\bar{Y_3} - \bar{Y})^2$$

$$= 4(7 - 10.5)^2 + 4(7.5 - 10.5)^2 + 4(17 - 10.5)^2$$

$$= 4(3.5)^2 + 4(3)^2 + 4(6.5)^2$$

$$= 4*12.25 + 4*9 + 4*42.25$$

$$= 49 + 36 + 169 = 254$$

Where n is the number of elements in the group.

The between-group degree of freedom is one less than a number of groups.

$f_b = 3 – 1 = 2$

So, the between-group mean square value is:

$MS_B = 254 / 2 = 127$

Step 4: Calculate the within-group sum of squares.

Table 5.3.2 (b): Data for a within-group sum of squares

Y_1	Y_2	Y_3
4-7=-3	2-7.5=-5.5	8-17=-9
6-7=-1	7-7.5=-0.5	14-17=-3
8-7=1	8-7.5=0.5	20-17=3
10-7=3	13-7.5=5.5	26-17=9

The within-group sum of squares is the sum of squares of all 12 values in this table.

$$S_W = (-3)^2+(-1)^2+ (1)+ (3)^2+ (-5.5)^2+ (-0.5)^2+(0.5)^2+ (5.5)^2+ (-9)^2+(-3)^2+(3)^2+ (9)^2$$

$$= 9+1+1+ 9 +30.25+ 0.25+ 0.25+ 30.25+ 81+ 9+ 9+ 81$$

$$= 261$$

The within group degree of freedom (f_W) is:

$$f_W = a\,(n-1) = 3(4-1) = 9$$

Thus the within-group mean square value is

$$MS_W = \frac{SW}{fw} = \frac{261}{9} = 29$$

Step 5: the F-Ratio is

$$F = \frac{MSW}{MSB} = \frac{127}{29} = 4.379$$

Now, F_{crit} (2,9) = 4.26 at 5% level of significance. Since F = 4.371 > 4.26, so Null hypothesis (H_0) has been rejected that concluded that there is strong evidence that the value of the three groups differs. The p-value for this test is 0.002.

Here, differ between the three groups clearly illustrate the requirement in different grid patterns. So, after the rejection of the null hypothesis, we can conclude that in a hexagonal pattern of deployment, the requirement of a node will be less than the octagonal grid.

5.4 Cost Estimation

Cost estimation has been performed after the comparison between various flood detection devices.

- **Cost Comparison between detection devices:** To estimate the cost of FSD in deployment for an area of 250 acres, chosen from the map of BBAU campus, Lucknow (India) and indicated by 5.4 (a). The campus is generally not a flood-prone area just like a resourceful urban but sometimes waterlogged in heavy rainfall like an urban flooded city. For estimation, map of BBAU, Lucknow is taken. In the figure, it is assumed that the minimum deployment of devices is on a street light pole connected with homes that have a laptop or computer. Assume that device installed on a single pole of a street of a colony positioned over the deepest place. According to the map of BBAU indicated in figure 5.4 (a), with the respective depth, found in the different cluster that is designed with rectangles, we have imagined deploying devices in both modes, e.g. in wired and in wireless. In this figure, we placed red bubbles to deploy the devices, and the count for them was 30. Application of CEA in the best case provides a path with minimum nodes position in a cellular bifurcated plain, while in the worst case it may be maximum as per all the corners. Some CEA with cellular deployment provides node positions in the example; it goes to 30 as indicated with red dots in figure 5.4 (a).

Figure 5.4 (a): Position to deploy detection devices in BBAU campus

- **Cost of devices to be deployed:** To see the cost comparison between the cost of one device between various kinds of detection devices after developing these in quantity *n*, prices have been considered from Appendix B. In this, the deployment using the proposed device is found economically better as indicated in figure 5.4 (b).

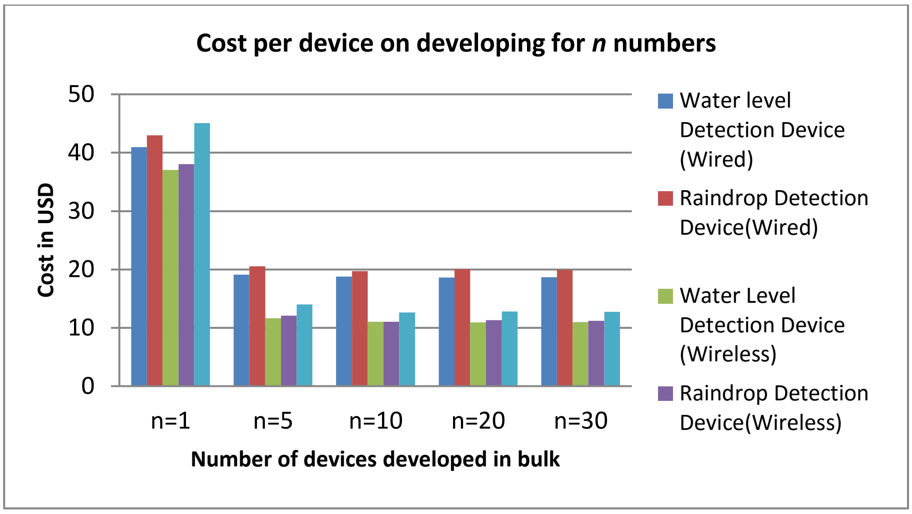


Figure 5.4(b): Cost comparison in deployment using proposed device and others

So, the cost of proposed devices = 30* Least cost of one device

= 30*12.736 = 382.08 USD

***Note:** The cost of the device with advanced transmitting components and receiving devices has not considered here.

CHAPTER 6 | IoET BASED FES

I and IoT are very symbiotic and will continue to have an interwined relationship moving forward.

—Ron Schmelzer

6.1 Background

Expert systems are the tools of AI to provide better decision than a non-expert human. These are the tools to automate the decision making by existing knowledge of Experts. John & Li Chen [156] designed an expert system in which a user interacted with ES through the user interface. Their user interface provided queries and data to the inference engine that was connected to the knowledge base. This knowledge-base had a history of the problem. The inference engine, knowledge base, and learning module were connected bi-directionally with each other. In this, historical data goes from the inference engine to a learning module for updating the knowledge base.

History of Expert Systems in Flood Management

Gaschnig, J., Reboh, R. and Reiter, J. [157] discussed the development of an expert system for water resource problems. They described an intelligent interface (HYDRO) for selecting numerical values of parameters that are input to a simulation program (HSPF). Cuena, J. [158] discussed the simulation models and human advice to build an expert system for the defense and controlling river floods. They provided a conceptual framework of an expert system to aid in the operation of flood control. The rules were described based on a set of mathematical models. Rehak, D. [159] reviewed all the systems till 1983 and explained expert systems in water resource management in a conference of ASCE.

Hridoy et al. [160] wrote about the work of Turbon [161] in which Turbon considered ES as a system to transfer domain knowledge from human to computer. To develop a good ES, its knowledge-base is based on a knowledge representation scheme and it was found able to handle issues related to the problems of flood risk. In designing an expert system for flood risk assessment, Hridoy et al. [160] suggested using a BRB inference methodology with RIMER in this regard.

6.2 Fuzzy Expert System

This kind of expert system works on the principle of data fuzzification. In this thesis, a tool of MATLAB was used to design FES and to find out the impact of the different rules. Let us see the design procedure of a fuzzy expert system:

6.2.1 Design

To design an expert system, various researchers have tried using different frameworks. Out of them, the researcher considered the method discussed by Helander [162] and Zimmermann [163]. Steps to design FES as per Helander [162], and Zimmermann [163] are:

- **Problem Specification:** It is a step to specify the problem by determining the input and output variable after assessing the nature of the problem.
- **Fuzzy sets:** Shapes of fuzzy sets are decided in this step, and it may be in different shapes such as a triangle or trapezoid to represent the expert knowledge.
- **Construct fuzzy rules:** In general, fuzzy rule constructions are performed by programmers with the help of a domain expert. Before defining the rule, the selection of the variable should be decided. However, at the time of finalizing the rules, a knowledge engineer may accept the rule from existing research, reports, and books, if he does not find existing rules better.
- **Encoding:** Encoding is the next step after the establishment of fuzzy rule and fuzzy sets. It is essential to design an actual building of the fuzzy expert system. Encoding may be performed using a programming language like C#, Java, Python or C, or by using a fuzzy development tool like Fuzzy Knowledge BuilderTM or MATLAB Fuzzy Logic Toolbox. In this thesis, the researcher used MATLAB Fuzzy Logic Toolbox for development due to its complete building and testing environment.

6.2.2 Fuzzy Process

In a fuzzy-based expert system, fuzzy processes are few mandatory parts to be designed, as per discussion by Hijji [164], the processes are:

- **Fuzzification:** It is a process to fuzzify data with the use of membership functions, i.e., a process of converting numerical values, from a quantitative variable to a qualitative variable in terms of no fuzzy input-output to fuzzy input /output. Fuzzification is not having a strict set of rules, but it works based upon the experience and analysis of the rules it infers from the conclusion made from inputs and output value made by calibration, testing, and validation over real input sent by sensors and history taken from an authentic source.
- **Inference Engine:** This is a portion to use a rule base and fuzzy set to solve the problem. It is a core part of problem-solving that is mapped from input to output. Hijji and Haroop [165], assumed it as the heart of an ES to analyze, suggest, predict, and process the data and information that has training capabilities. It is used to process the data stored in a knowledge base using the set of rules and methodology. To reach on outcome inference engine utilized rules to decide an option, Haddow [166]. Generally, a fuzzy inference engine designed with the 'Mamdani technique and the Sugeno technique, H. Ying [167], these techniques are efficient to design inference in ES. Due to the closeness with human input [168] Mamdani technique is more popular in engineers, while 'Sugeno' technique provides a close analysis, H.Ying [167].
- **Defuzzifcation:** It is a reverse process of 'Fuzzifcation' which is used to convert fuzzy inputs into output based on membership functions. The use of the defuzzification process depends on the context of decision making as per Zimmermann [163]. In defuzzification, an expert combines their knowledge by using membership functions towards the results. It can use techniques and graphical values to find the desired output. It offers a degree of flexibility that can combine with the knowledge of experts in order to find results close to reality.
- **User Interface:** It is an interactive screen between ES and User, the few factors that determine the quality of a user interface as per Helander [162] are that it is easy to understand, the interaction sequence between the machine of the user, a suitable display format, screen icon, and symbols.

6.2.3 IoET based Fuzzy Expert System

Fuzzy Expert Systems (FESs) are the systems designed using the principle of fuzzy logic and expert systems. This chapter contributes an effort to provide accurate flood prediction using fuzzy-based decision making by the real-time data provided by sensors.

- **Data flow:** Data flow of expert system starts from all the problem-related data to an expert system in a manner of reduction of the volume of the data. All the data related to the problem are collected through sensors and history in the data collection module. After filtration, meaningful data are sent to a central database that provides data to the dynamic model of expert systems. In this, data generates knowledge to create a decision in an expert system just as per the model of IDSS described by Saleh et al.[169].

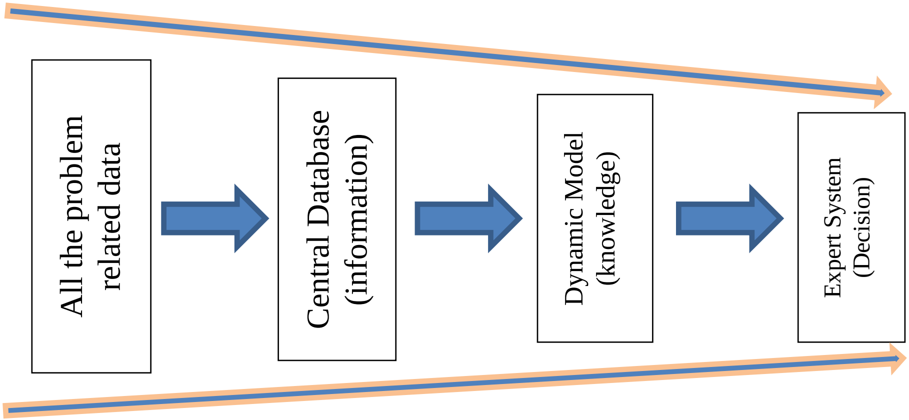


Figure 6.2.3 (a): Data flow of IoT based Fuzzy Expert System

- **Functioning:** Data were taken by sensors and history in FES to help us to reach a decision as per Wan et al. [170], as indicated by figure 6.2.3 (b). Researchers have retrieved different sensor data for accurate flood prediction, in the form of water level and raindrop data.

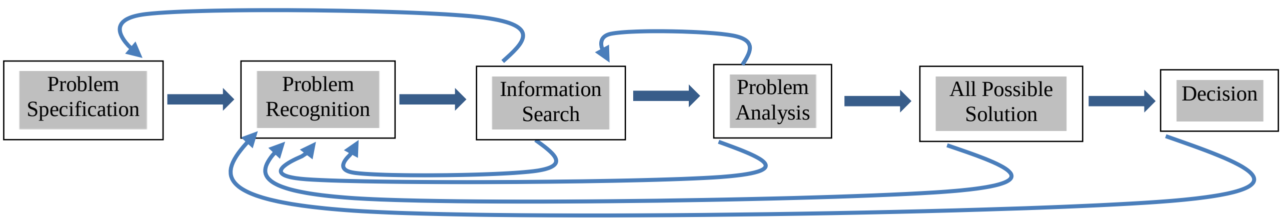


Figure 6.2.3(b): Major activities in IoET based FES

- **Working diagram:** The working diagram represents the working of IoT-based FES in which an expert system has many stakeholders, including domain experts, knowledge engineers, IT specialists, users, and IoT developers. IoT developer deploys devices on pre-decided locations to sense the data. From these locations, sensor D1, D2 and so on, gathers data in different samples s1, s2 and so on, respectively. After gathering this sensed data, this data is applied as input to the Flood detection method (FES) that decides the event by deciding the risk of an event. If a flood is detected by FES, it shows an alert message using the Expert system.

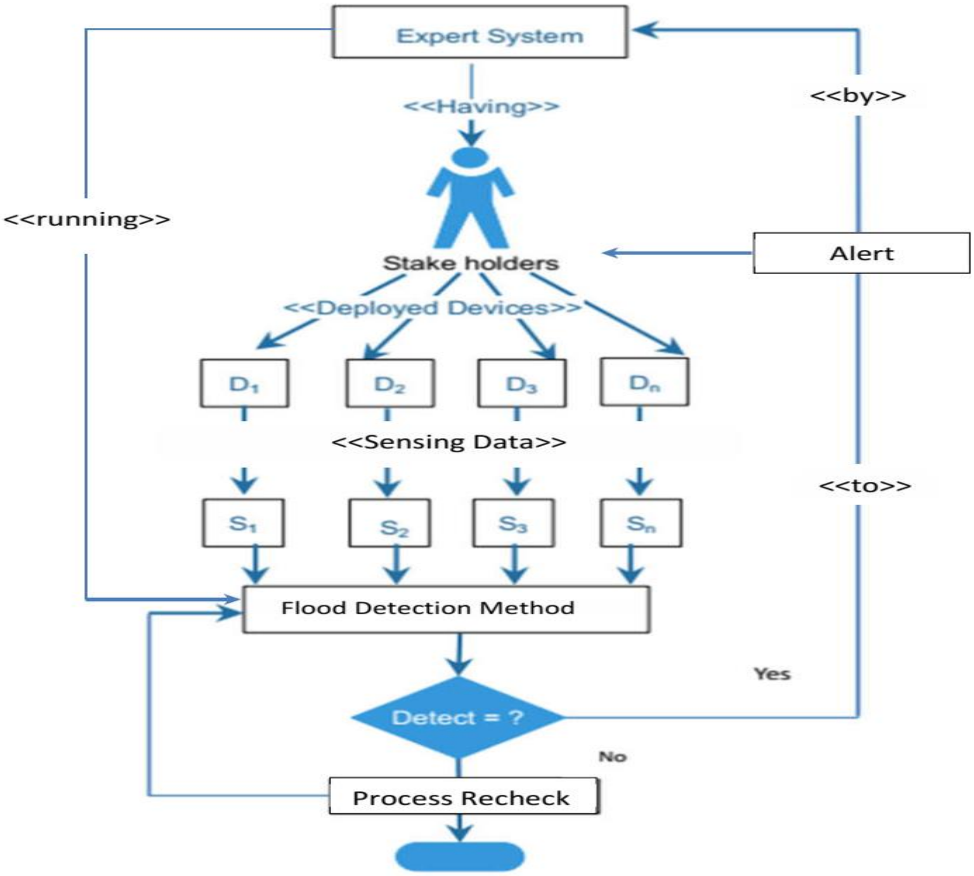


Figure 6.2.3 (c): Working diagram of IoT based Fuzzy Expert System

6.3 Architecture and Design of IoET based FES

This heading just elaborated in figure 6.3, indicates the idea utilized at the back end to develop our IoT based FES. In IoET based FES, it contains sensor data and historical data in the data collection subsystem that works to generate knowledge. In this data collection, dynamic data of sensor and static data of history suggested is being included. The Communication Subsystem gathered the data through telemetry and processed it in a database. Sensory data collected by sensors are to be provided for dynamic data integration, while historical data avails to static data integration. After integration, these data collected in the database are just for knowledge generation within expert systems.

FES utilizes fuzzy logic on inputs to determine the chances of an event. The advantage of using fuzzy logic is found to supply expert knowledge to the system. The main idea is to make an accurate prediction of flood risk using the water level and rainfall data. Data integration is performed after collecting the raw data and this raw data is converted into meaningful data to be stored in the database. Then after converting this data into meaningful data, it is ready to be utilized by the Expert System. This data is used by a knowledge base to provide data to the inference engine that is involved in providing outcomes using different conditions.

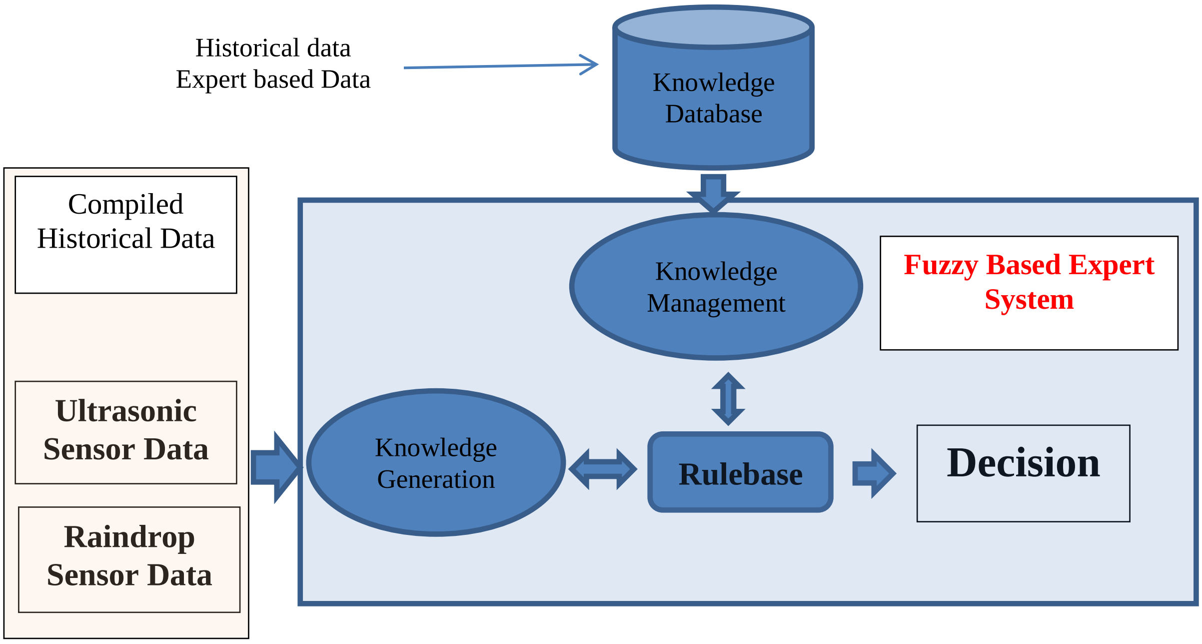


Figure 6.3: IoT based FES framework for flood risk

6.3.1 Design of IoT based FES

Fuzzy sets and fuzzy operators can be referred to as a subject and verbs of fuzzy logic. The work of fuzzy logic for flood warning is to map water level and presence of rain. The primary mechanism for mapping is if-then statements shown in figure 6.3.1 (b). Order of rules has no importance, but before building a system that interprets the rules, we must define all the terms and the adjectives. To say that the water is on danger level, we need to define the range of the water's average level. The diagram in figure 6.3.1 (c) provides a roadmap for the fuzzy inference process. It is essential to find out the risk of flood events in history, before developing an expert system for a particular area. Current rainfall and the water level, are assumed factors that are directly involved in risk measurement. So, in designing a fuzzy system, these two factors have been considered while historical data is used to decide a threshold value.

An FES generally utilizes few rules and operations. These rules are indicated below:

${}^{W}L_N$	=	0;	${}^{W}L_N$	=	1;
${}^{R}L_N$	=	0;	${}^{R}L_N$	=	1;
$!{}^{W}L_N \vee {}^{R}L_N$	=	1;	${}^{W}L_N \vee !{}^{R}L_N$	=	1;
${}^{W}L_N \wedge {}^{R}L_N$	=	0;	$!{}^{W}L_N \wedge !{}^{R}L_N$	=	1;

Few operations also used in the proposed FES are:

Table 6.3.1: Fuzzy operations

(i)AND Operation

Min(${}^{W}L_N, {}^{R}L_N$) or AND

${}^{W}L_N$	${}^{R}L_N$	${}^{W}L_N \wedge {}^{R}L_N$
0	0	0
0	1	0
1	0	0
1	1	1

(ii) OR operations

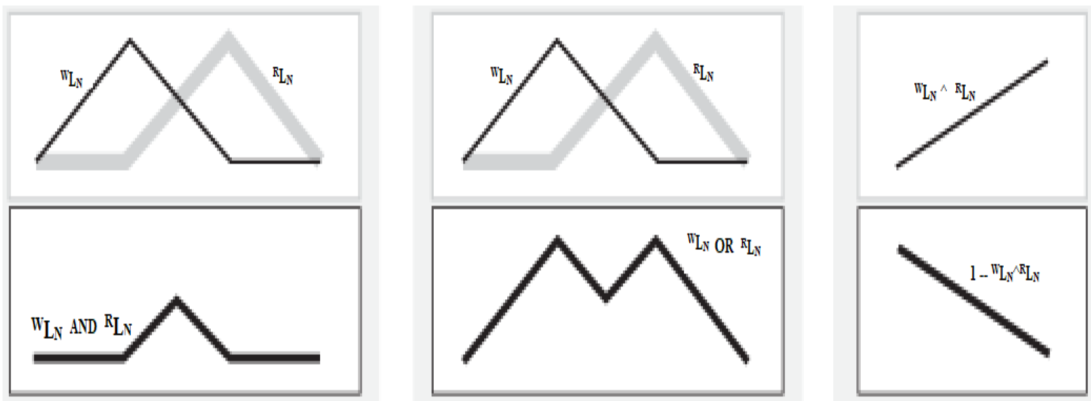
Max (${}^{W}L_N, {}^{R}L_N$) or OR

${}^{W}L_N$	${}^{R}L_N$	${}^{W}L_N \vee {}^{R}L_N$
0	0	0
0	1	1
1	0	1
1	1	1

(iii) Not on AND Operation

NOT on AND

${}^{W}L_N \wedge {}^{R}L_N$	$!{}^{W}L_N \wedge {}^{R}L_N$
0	1
1	0



Min (${}^{W}L_N, {}^{R}L_N$) or AND **Max (${}^{W}L_N, {}^{R}L_N$) or OR** **1 -- ${}^{W}L_N \wedge {}^{R}L_N$**

Figure 6.3.1: Graphical representation of logics

Min, Max, and Compliment function can resolve any fuzzy construction sets and can find using logic operations.

(a) Designed If-Then Rules

If-then rule statements are useful to design the conditional statements that constitute fuzzy logic, i.e.

If the Water level is below average then No risk.

If Rain level is below average then No risk.

If Water level and Rain Level are below average then No risk.

If Water level is more than Normal and Rain Level is normal then risk.

If Water level is Normal and Rain Level is more than normal then risk.

If Water level is More than Normal and Rain Level is more than normal then high risk.

All these if-then statements are in the form of: "if x is A then y is B." Where *"x is A" called ' Antecedent' while "y is B" called 'consequent.'* In the if-then statement "below normal, normal and dangerous" in antecedent or "No risk and No warning, Risk and Warning, high risk and warning" are represented as a number between 0 and 1 mapped by considering a particular condition to find a single number in antecedent or consequent for better interpretation from the scale between 0 to 1.

- **Antecedent and Consequent Generation Mechanism**

To find out the risk, the researcher has taken historical data of the last 100 years to find out the average rainfall of a day and assumed that more than the average rain is rain at danger level. By this historical data, the researcher has determined the past highest rainfall level and flood in this area. Then, the researcher considered rain and danger levels as important conditions to find out flood risk.

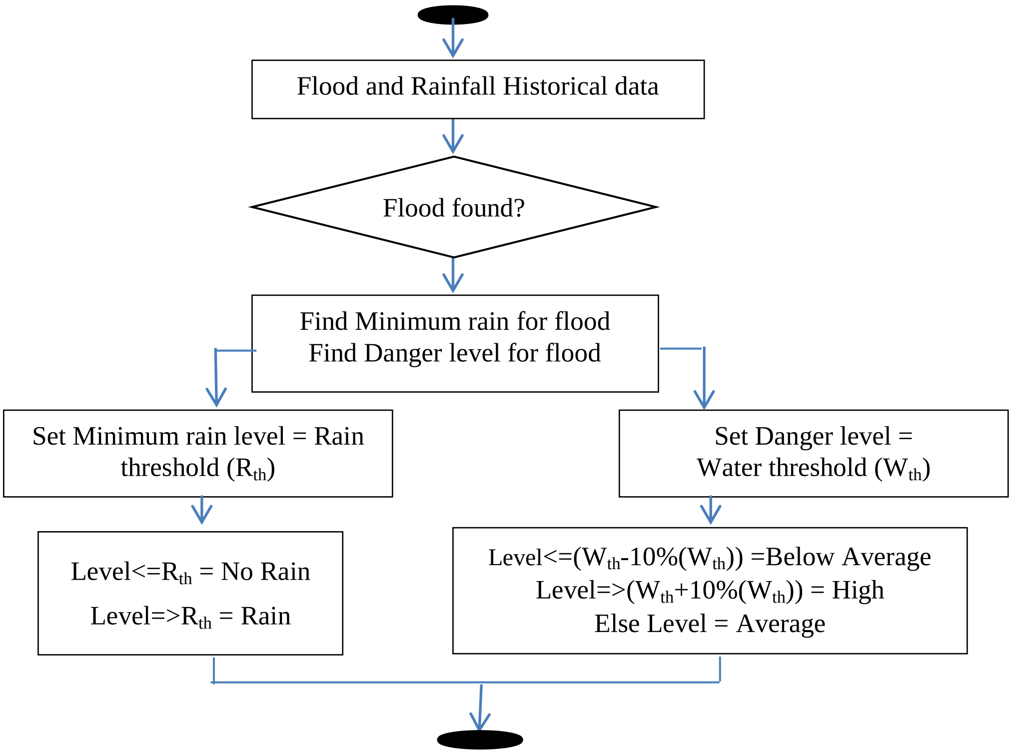


Figure 6.3.1(a): Antecedent and consequent generation mechanism

In the interpretation, all the antecedents in all the statements are evaluated first before applying a fuzzy operator on it and then the result of those statements is used.

- **Rules Development**

The method adopted to find out the chances of a flood using IoT based FES is shown by figure 6.3.1 (b). To find the chances of a flood, the system utilizes risk types drawn on the basis of water level and rain level. Let us see figure 6.3.1 (b):

Risk Type = = = = = = = => Chances of Flood Warning

If Water level is below average then No risk
If Rain level is below average then No risk
If Water level and Rain Level are below average then No risk
If Water level is more than Normal and Rain Level is normal then risk
If Water level is Normal and Rain Level is more than normal then risk
If Water level is More than Normal and Rain Level is more than normal then high risk

Antecedent: $^{W}L_{N}$ & $^{R}L_{N}$
Is interpreted as
{
Below Average
Average
Dangerous
}

Consequent: Risk & Warning
Is assigned to be
{
Low Risk and No Warning
Average Risk and Warning
High Risk and Warning
}

Figure 6.3.1 (b): Flow chart for risk finding

(b) Fuzzy Inference Process

Fuzzy inference, of our System performed in five subparts including:

(1) Fuzzification of the input variables;
(2) Application of the fuzzy operator (AND or OR) in the antecedent;
(3) The implication from the antecedent to the consequent;
(4) Aggregation of the consequents across the rules;
(5) Defuzzification using described Membership Functions, Logical Operations, and If-Then Rules.

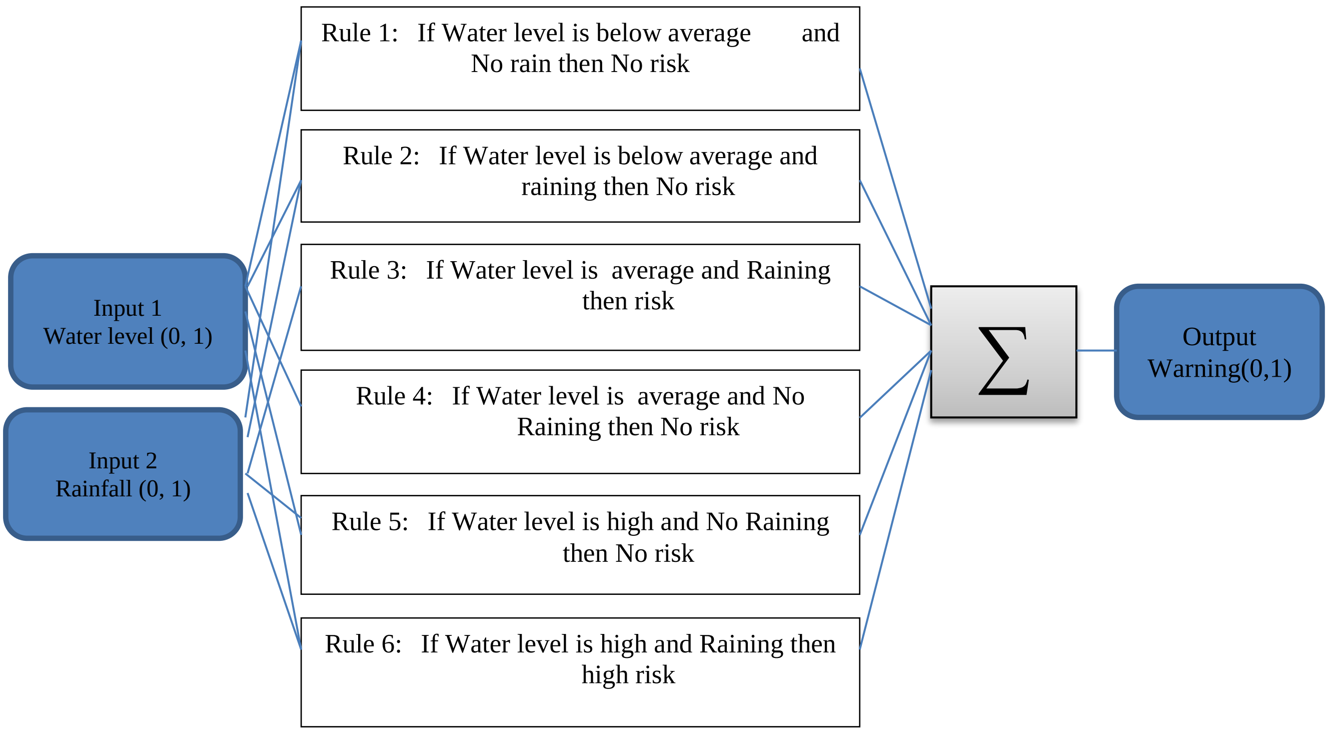


Figure 6.3.1(c): Fuzzy Inference diagram

6.3.2 Existing Fuzzy based Expert Systems

Samarasinghe et al. [171] proposed a system that was developed to control flooding in Lake Manapouri, where the knowledge base had flood rules and flood control operator's experience to deal with floods. The author collected initial flood data through the query from the operator and submitted it to ES using goal-driven backward chaining inference. In this, the problem domain is assumed as objects that have properties called attributes having various data. Other FES found in the literature are:

(a) CAFFG

Central America Flash Flood Guidance System (CAFFG) [172], [173] was started by participants of seven countries in 2004 by Hydrologic Research Center (HRC) with many other agencies. This project has used several tools to save lives. It is now growing its popularity in all the aspects, however, in other countries; it is not being used due to lack of clarity of commitment, lack of sufficient knowledge.

(b) SIATA

This system utilizes manual data acquisition as well as sensory data. It was run with the help of participants from SIATA, the Colombian Red Cross, interviewees, citizens and volunteers, and educational people from EAFIT children's university [174],

[175]. In this system, 71 rain gauges were deployed with 7 meteorological stations with several kinds of sensors. GPRS was used to transmit data from the sensing node to the SIATA tower. It also utilizes atmospheric observation and weather radar. This system was used to send alerts to the Disaster Response and Prevention Office (DPAD), the Civil Defense, the Red Cross, the local government and the population through different channels.

(c) ELDEWAS

Krol and Bernard [163] developed an online early warning system for landslide detection based on assessment. This system had an idea of merging statistical and dynamic information. Data of different parameters were merged using data fusion of fuzzy logic to reach on a decision in this system. It was developed with the idea given by Sugerno to develop a Fuzzy based expert system. Using fuzzy they have found the most important input and output variables, relevant value range, membership functions (fuzzification), Formulation of *if-then-rules* (inference), Selection of logical relationship.

6.4 Evaluation of Rulebase of Expert System

This section proposes a mechanism of Expert system developed using MATLAB Software. MATLAB has a tool to design fuzzy logic-based mechanisms known as Fuzzy Logic Designer. This tool is used to develop the Fuzzy based expert system to find the risk of flood. Fuzzy Logic Designer provides options to develop the expert system from Mamdani or Sugarno techniques. The researcher has chosen Mamdani System to develop their Fuzzy Based Expert System for finding the risk.

6.4.1 Risk Finder using Mamdani's Systems

Risk finder is a fuzzy-based expert system to reach on the decision of risk warning based on rules developed using a Fuzzy Logic Designer. This system is a Mamdani System built using Fuzzy Logic Toolbox Graphical User Interface Tools. In this, the researcher has designed a Fuzzy Inference System (FIS) that is the heart of any FES and is assumed here as a Flood Risk Finder to provide the status of Risk. Let us see the design of the ES by Fuzzy Logic Designer and its primary functions involved in the design:

(a) Fuzzy Logic Designer

This is a tool to handle high-level issues of deciding input and output variable and their names as:

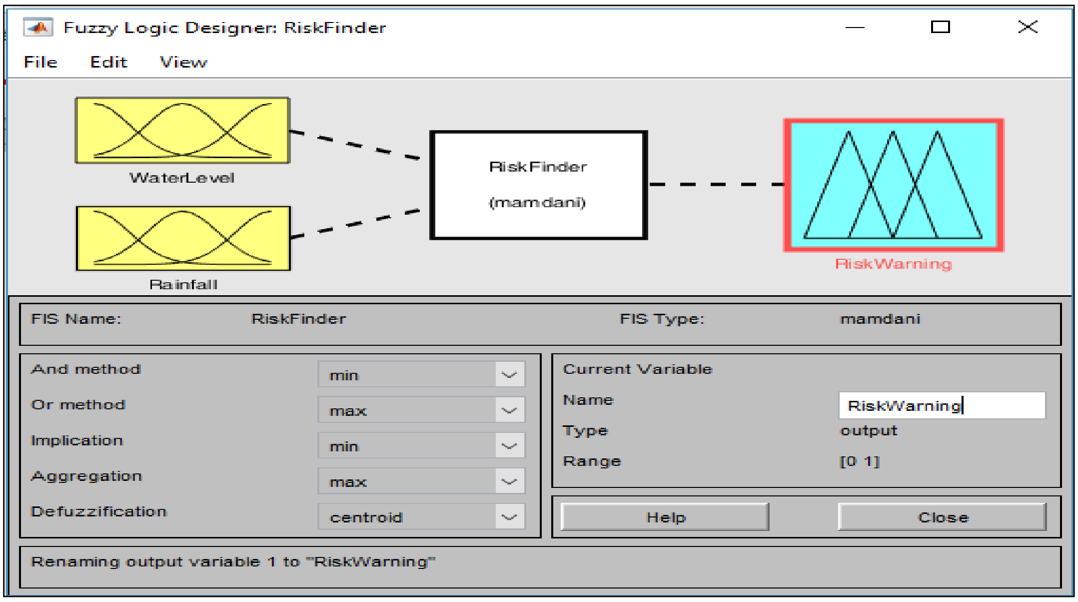


Figure 6.4.1 (a): Fuzzy Logic Designer for FES

- **Value assignment:** value assignment performed in fuzzy designing in two operations known as (1) Fuzzification; (2) Defuzzification.
  1) **Fuzzification:** gasification is a process of assigning a numerical value to a logical statement as discussed earlier. In this case, the water level by which flood happened in a particular city is considered as a threshold value. Water level less than half of a threshold value is considered as below average, water level less than the threshold, but more than half of the threshold is considered as Average while water level more than the threshold value is considered as Average.
  2) **Operation:** Operation is to be performed on the fuzzified values of two attributes, here, simple AND operation performed over a set of fuzzified values of attributes water level and rainfall situation.

$$\text{Water level} \wedge \text{Rainfall situation} = \text{Flood Risk} \qquad \text{... } 6.1$$

  3) **Defuzzification:** Defuzzification is a process to be performed over the results of the operation performed on the fuzzified values of attributes as discussed earlier. It is performed to reach a decision.

- If Water level is below average And No Rain =
  - ⇨ 0 X 0 = 0 implies that => No risk
- If Rain level is below average And Rain =
  - ⇨ 0 X 1 = 0 implies that => No risk
- If Water level is average And No Rain =
  - ⇨ 0.5 X 0 = 0 implies that => No risk
- If Water level is average And Rain =
  - ⇨ 0.5 X 1 = 0.5 implies that => Might be at risk
- If Water level is more than Normal and No Rain Level=
  - ⇨ 1 X 0 = 0 implies that => No risk
- If Water level is More than Normal and Rain =
  - ⇨ 1 X 1 = 1 implies that = high Risk

- **Membership Function Editor**

It is used to define the shapes of the membership function associated with each variable.

1) An input membership function defined for water level using a membership function editor.

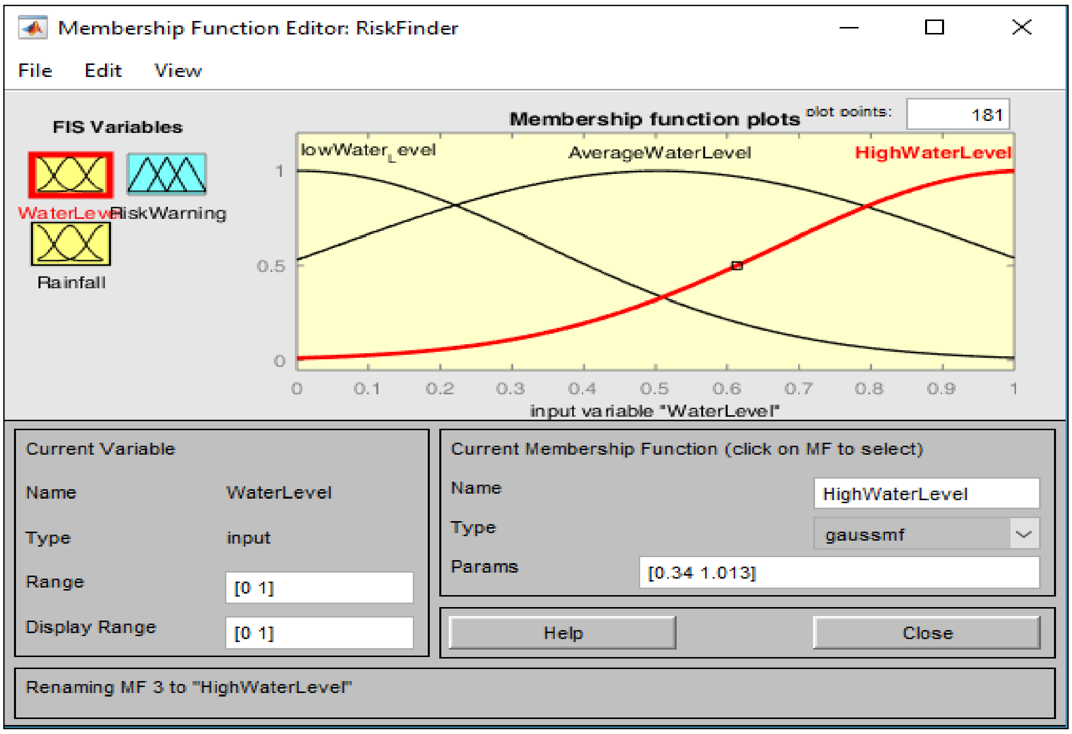


Figure 6.4.1 (b): Input membership function to define the water level for FES

2) An input membership function defined for rainfall detection using membership function editor

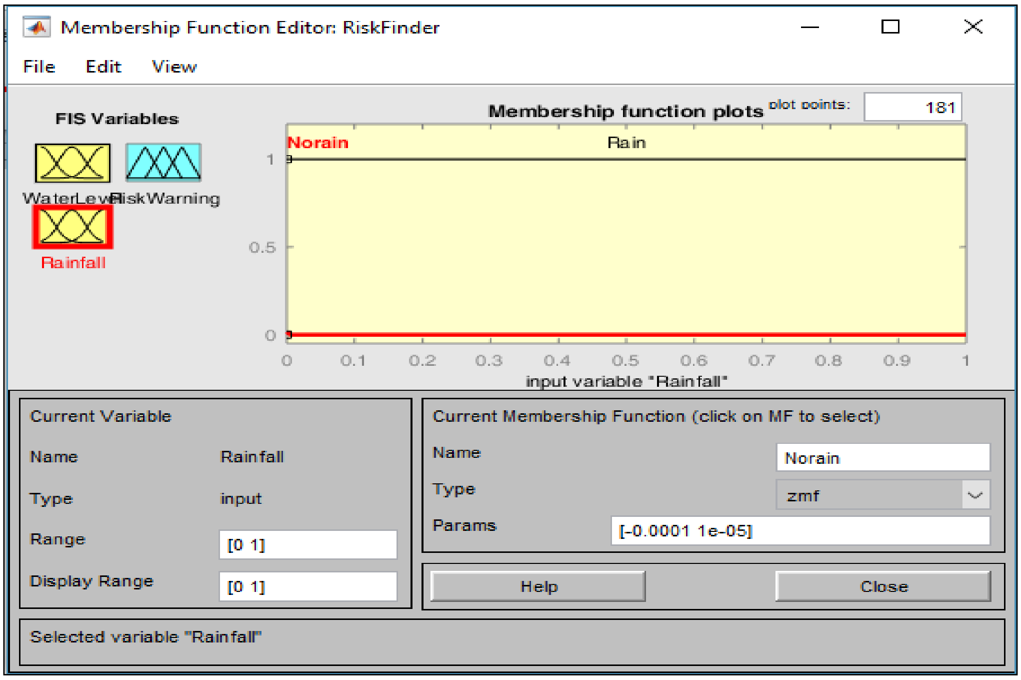


Figure 6.4.1 (c): Input membership function to define raindrop for FES

3) An output membership function defined for water level using the membership function editor,

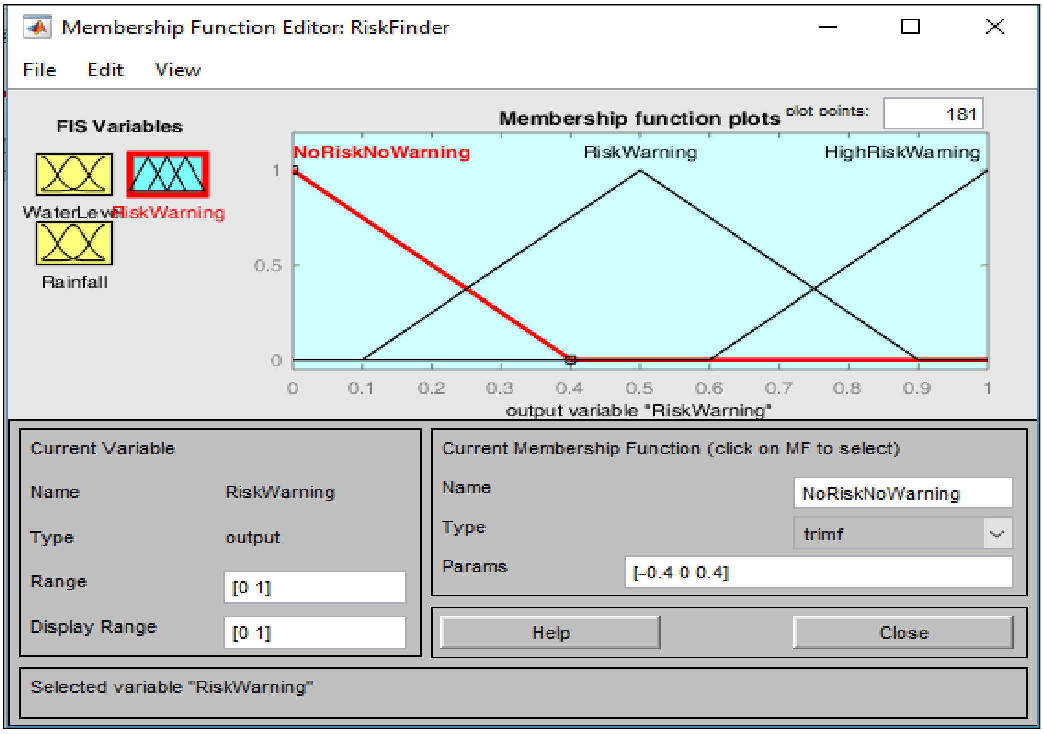


Figure 6.4.1 (d): Output membership function to find flood risk

- **Rule Editor**

The rule is edited using a rule editor. Rule edited using rule editor as:

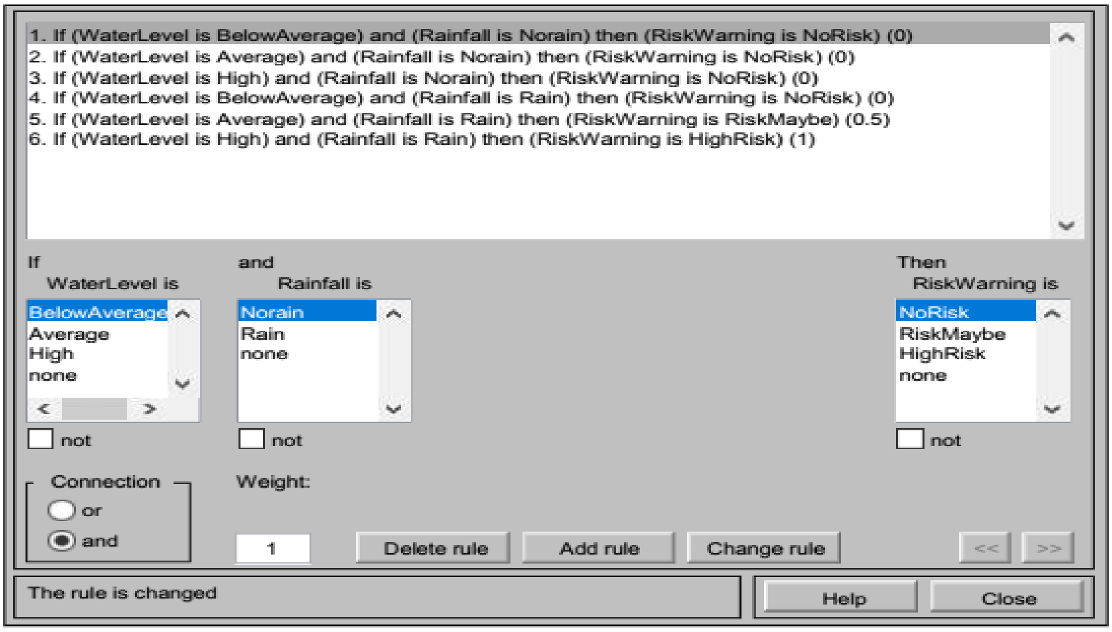


Figure 6.4.1 (e): Rule editor of FES to define flood risk

6.4.2 Impact of Rules

The efficiency of the FES depends on the working of rules employed. This impact can be viewed by finding the dependency of output rules on input rules. This dependency can be seen using rule viewer and surface viewer as discussed below:

- **Rule Viewer:** This viewer is used to analyze rules by finding activeness of the rules and influence of membership function's shape on the result.

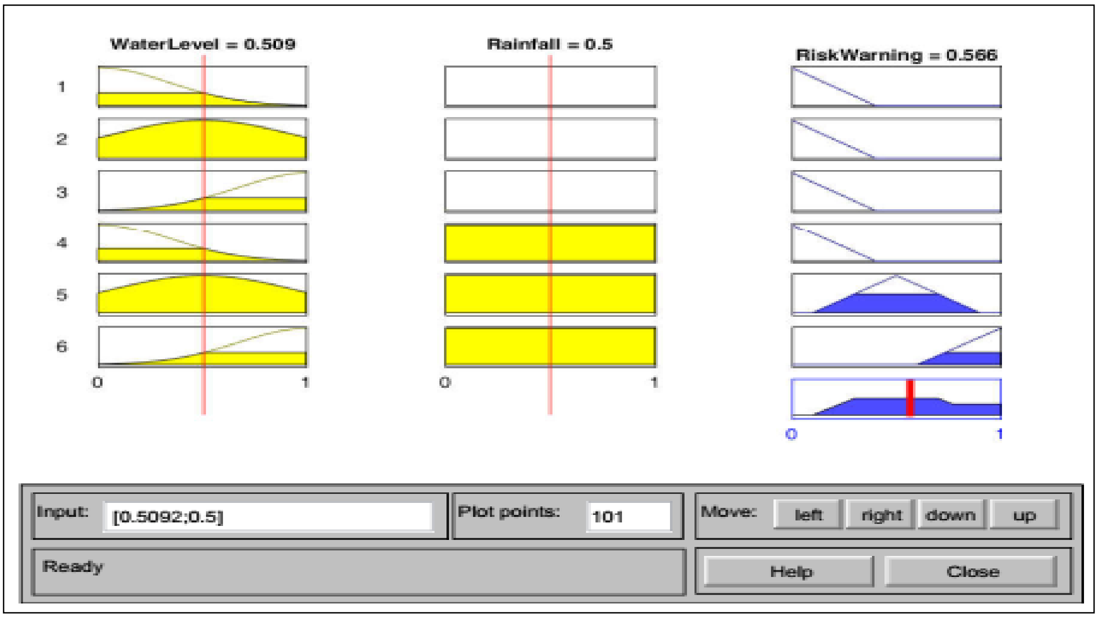


Figure 6.4.2 (a): Rule Viewer to see impact of the rule on risk warning

- **Surface Viewer:** This uses a tool to provide plot to view the dependency of the outputs on the inputs.

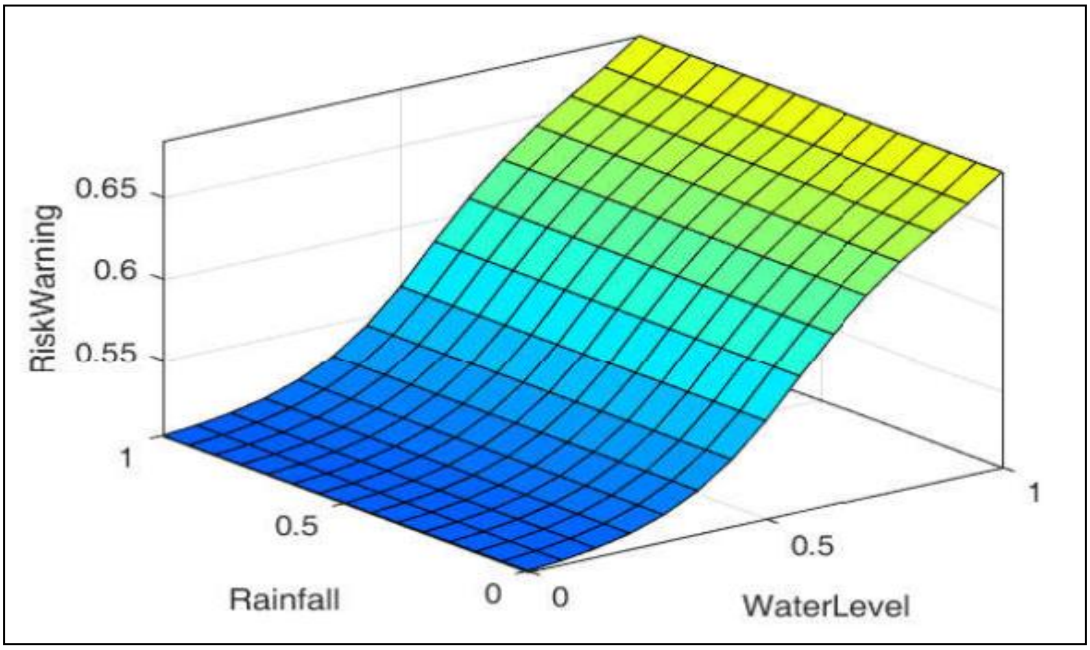


Figure 6.4.2 (b): Surface Viewer to show the dependency of outputs on input in FES

6.5 A Prototype of IoT based FES

Urban flood is a problem of Indian metro cities that can be avoided by preparation at the initial stage of urbanization. We know expert systems have acquired information, generally from history or experts via interview or questionnaire. Here, it acquires knowledge from historical data and researches. Fuzzy expert systems (FESs) are the systems designed using the principle of fuzzy logic and expert systems. Here, both parts of FES, fuzzy logic, and expert system are included in the component rule base and inference engine.

Using the discussed design, the researcher has developed a prototype of ES. This is an IoT based FES designed with the help of rules discussed. But before, the installation of devices properly, the researcher designed it for manual data entry. However, after deployment of IoT mechanism, it will be able to collect data and to make a decision about a flood, automatically. It will work with the threshold, but threshold values will be different for each city. To find a threshold to decide flood risk table 3 indicates maximum rainfall and maximum monthly mean rainfall of the most flooded urban areas of India.

Table 6.5(a): Rainfall data of flood prone cities

State	Max. RF in a day (mm)	Max. Monthly Mean Rainfall from 1901-2000 [28]	No. of the severe flood [29] in past decades
Jammu, Srinagar	200 [178]	349	3
Delhi NCR	295 [179]	247	3
Ahmedabad, Surat, Baroda	459 [180]	440	15
Guwahati	150 [181]	351	5
Kolkata	289 [182]	333	5
Mumbai, Kolhapur	944 [177]	819	11
Bangalore	860 [183]	185	4
Hyderabad	240 [177]	178	5
Chennai	550 [184]	353	7

This table shows the variation of maximum daily rainfall and maximum monthly rainfall city by city. Thus, to choose threshold few values have been chosen using the equation 6.2. Equation 6.2 provides us threshold as indicated in table 6.5 (b).

$$\text{Min of } \left[\frac{Maximum\ monthly\ Mean\ rain}{2} \,\|\, \frac{\text{Maximum rain in a day}}{2}\right] = \text{Threshold} \quad \ldots\ 6.2$$

Table 6.5 (b): Threshold decision for flood prone cities

State	Max. RF in a day / 2	Max. monthly Mean / 2	Threshold
Jammu, Srinagar	100	175	100
Delhi NCR	147	124	124
Ahmedabad Surat & Baroda	230	220	220
Guwahati	75	175	75
Kolkata	145	165	145
Mumbai, Kolhapur	472	410	410
Bangalore	430	92	92
Hyderabad	120	89	89
Chennai	275	176	176

Now, from table 6.5 (b) we can see threshold is variable that can’t use in the form a fixed value. Thus, three cases, including below average, average and High and values are assigned to decide risk as per equations:

if Level < = (W_{th}-10%(W_{th})) = Below average

if Level=>(W_{th}+10%(W_{th})) = More than average / High

Else Level = Average

For easiness, the decimal values are assigned to all them just as per table 6.5 (c).

Table 6.5 (c): Assignment of values in rules (Fuzzyfication)

Water Level	Rainfall Situation
Below Average = 0	No Rain = 0
Average = 0.5	Rain =1
More than Average = 1	

Using these conditions to the threshold, a prototype of an ES has been developed that is working appropriately. Figure 6.5 (a) indicates a page where the user can manage all the locations where sensors have been deployed. After login figure 6.5 (a) comes as per this system, it is secure. Figure 6.5 (b) represents a screenshot of the page showing risk type at a different location.

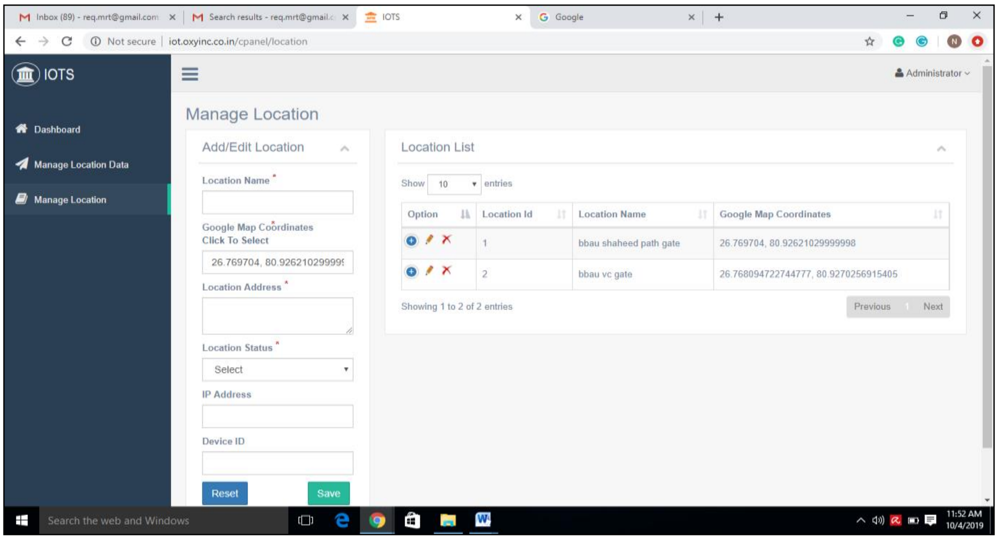


Figure 6.5 (a): Location entry for deployed IoT devices

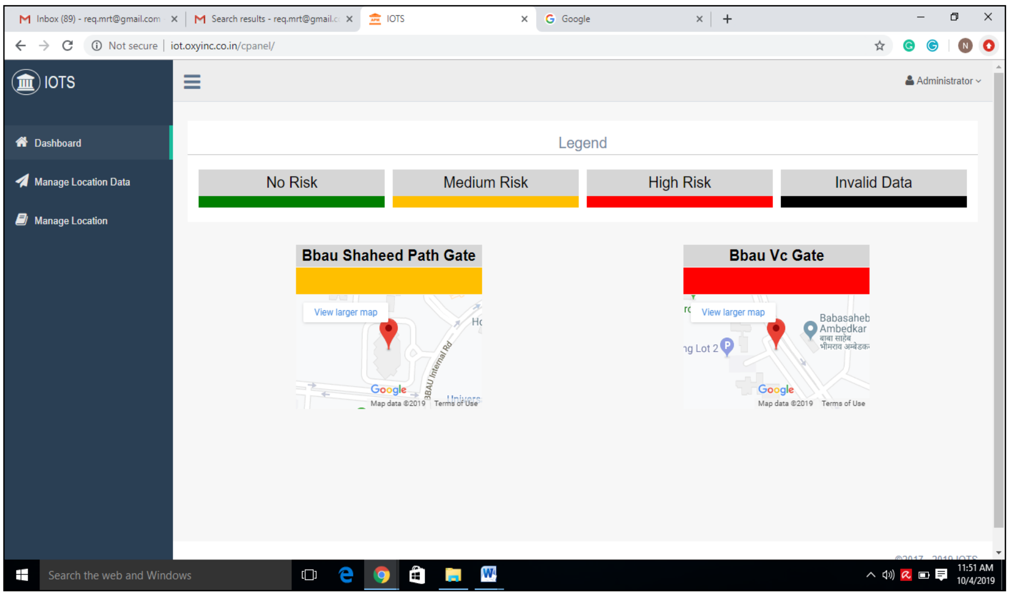


Figure 6.5(b): Risk of flood at different places

6.5.1 Comparison of IoT based FES with other ES

Before our fuzzy-based system, few other expert systems were studied including Pinto et al. [185] and Krol et al. [176]. The researcher found other systems similar to our work. Out of all those, the few that got popular are CAFFG, SIATA, and ELDEWAS. Table 6.5.1 (a), and (b) shows a comparison between the features of existing systems with our proposed ES.

Table 6.5.1 (a): Comparison in the communication link used

Protocol	CAFFG	SIATA	ELDEWAS	IoT based FES
Telemetry	Yes	No	Yes	Yes
GPRS	No	Yes	No	No

Table 6.5.1 (b): Comparison of IoT based FES with others

Sensor / Data Collection Method	CAFFG	SIATA	ELDEWAS	IoT based FES
Precipitation sensor	Yes	Yes	Yes	No
Water level sensor	No	Yes	No	Yes
Moisture sensor	No	Yes	No	No
Rainfall Sensor	No	No	No	Yes
Temperature sensor	Yes	Yes	Yes	No
Wind sensor	No	Yes	Yes	No
Historical rainfall data	No	No	No	Yes
Historical flood data	No	No	No	Yes
Other secondary data	No	No	No	Yes

6.5.2 Hypothesis and Validation

A hypothesis is based on the relationship of water level and presence of rainfall to calculate the risk of flood. Here, a number of variables are three in which two are independent variables while one single dependent variable.

(a) Hypothesis

Hypothesis concerns relationships between input variables and the output variable as:

- **Null Hypothesis (H_0):** There is no relationship between the water level and the presence of rainfall with the flood risk.

- **Alternative Hypothesis (H_a):** There is a relationship between the water level and the presence of rainfall with the flood risk.

(a) Validation

To test the relationship between different kinds of variables regression is an efficient tool. In the case of a designed expert system based on multiple inputs and output variables. The test required multiple linear regressions to check the hypothesis, So multiple linear regression has been performed.

Multiple Linear Regression: Two independent variable case

$$y = b_0 + b_1x_1 + b_2x_2 \quad \text{…. 6.3}$$

Table 6.5.2 (a): Data calculation for MLR

Risk (Y)	Water level (x1)	Rainfall (x2)	$(X_1)^2$	$(X_2)^2$	X_1Y	X_2Y	X_1X_2
0	0	0	0	0	0	0	0
0	0	1	0	1	0	0	0
0	0.5	0	0.25	0	0	0	0
0	1	0	1	0	0	0	0
0.5	.5	1	0.25	1	0.25	0.5	0.5
1	1	1	1	1	1	1	1
$\sum Y =$ **1.5**	$\sum x_1$ =3	$\sum x_2$ =3	$\sum X_1^2$ = 2.5	$\sum X_2^2$ = 3	$\sum X_1Y$ = 1.25	$\sum X_1Y$ = 1.5	$\sum X_1X_2$ =1.5

$$b_0 = \bar{y} - b_1\,\overline{x1} - b2\,\overline{x2} \quad \text{…. 6.4}$$

$$b1 = \frac{(\sum x_2^2)(\sum x_1y) - (\sum x_1x_2)(\sum x_2y)}{(\sum x_1^2)(\sum x_2^2) - (\sum x_1x_2)^2} \quad \text{…. 6.5}$$

$$b2 = \frac{(\sum x_1^2)(\sum x_2y) - (\sum x_1x_2)(\sum x_1y)}{(\sum x_1^2)(\sum x_2^2) - (\sum x_1x_2)^2} \quad \text{. …6.6}$$

$$\sum x_i^2 = \sum X_i^2 - \frac{(\sum X_i)^2}{N} \quad \text{…. 6.7}$$

For i=1, $\sum x_1^2 = \sum X_1^2 - \frac{(\sum X_1)^2}{N}$

For i= 2, $\sum x_2^2 = \sum X_2^2 - \frac{(\sum X_2)^2}{N}$

$$\sum x_iy = \sum X_iy - \frac{(\sum X_i)(\sum y)}{N} \quad \text{…. 6.8}$$

For i =1, $\sum x_1 y = \sum X_1 y - \frac{(\sum X_1)(\sum y)}{N}$

For i=2, $\sum x_2 y = \sum X_2 y - \frac{(\sum X_2)(\sum y)}{N}$

$$\sum x_1 x_2 = \sum X_1 X_2 - \frac{(\sum X_1)(\sum X_2)}{N} \qquad \text{.... } 6.9$$

$\sum x_1^2 = 2.5 - 9/6 = 2.5\text{-}1.5 = 1$

$\sum x_2^2 = 3 - 9/6 = 3\text{-}1.5 = 1.5$

$\sum x_1 y = 1.25 - \frac{4.5}{6} = 1.25 - .75 = .5$

$\sum x_2 y = 1.5 - \frac{4.5}{6} = 1.5 - .75 = .75$

$\sum x_1 x_2 = 1.5 - 9 / 6 = 1.5 - 1.5 = 0$

b1 = $\frac{(\sum x_2^2)(\sum x_1 y) - (\sum x_1 x_2)(\sum x_2 y)}{(\sum x_1^2)(\sum x_2^2) - (\sum x_1 x_2)^2} = \frac{(1.5).(.5)-0}{1.5-0} = \frac{0.75}{1.5} = 0.5$

b2 = $\frac{(\sum x_1^2)(\sum x_2 y) - (\sum x_1 x_2)(\sum x_1 y)}{(\sum x_1^2)(\sum x_2^2) - (\sum x_1 x_2)^2} = \frac{0.75-0}{1.5-0} = 0.5$

b0 = $\bar{y} - b_1 \overline{x1} - b2\, \overline{x2}$ = 1.5- 0.5*3-0.5*3 = -1.5

y = $b_0 + b_1 x_1 + b_2 x_2$ = -1.5 +0.5X1+0.5X2

$$y = 0.5x_1 + 0.5x_2 - 1.5 \qquad \text{.... } 6.10$$

Here, a linear relationship was established between input and output variables as shown by an equation. So, we can reject the null hypothesis and accepts the alternative hypothesis.

CHAPTER 7 | CONCLUSION

In literature and in life we ultimately pursue,
not conclusions, but beginnings.

—Sam Tanenhaus

7.1 Background

As a social responsibility of the researcher towards the nation and society, the deliverables presented in the thesis try to contribute a little. This thesis has been written to represent the efforts of the researcher to save living beings, and assets from flood disasters. A flood may cause loss of assets and human lives as indicated by many reports and researches discussed in the literature review. The thesis is all about the flood disasters in India. It helps to solve the issues arising due to flood, the possible method for flood avoidance, possible sensing methods for flood detection, deployment of detection devices and then the development of flood risk finding mechanisms. Research has been performed to find out the risk of flood based on real-time data. An Expert System (ES) has been developed using a MATLAB Logic Designer to find risk and it would be highly beneficial for society and the real estate industry to save all kinds of assets from a flood. All the steps of designing an expert system to find out flood risks have been discussed. Here, the Flood risk finding mechanism is nothing but an expert system. However, it is not a full-fledged expert system with rich features, but it will be able to lead to a path to develop a feature-rich expert system. The researcher suggested at least two kinds of data required to find out the risk of flood, including water level and status of rainfall.

In addition, the research has proposed a method to drain and store water systematically by proposing a cellular architecture to develop flood-free plain for newly developing cities and their drainage mechanism. It has also been conducted to acquire data for detection using detection devices. In the task of designing a low-cost network, the researcher gained success in device development. These devices were designed to generate data to be used by the expert system for finding the risk of a possible flood. The contributions made by this research have been included in the next section.

7.2 Major Research Contributions

The conducted research presents the methodology to develop a CA-based drainage system for flood avoidance. Second, it performs a comparative study on the working of flood detection devices. After it, a transmitting device that is capable to sense two kinds of data has been proposed. The research presents a comparative study for the deployment of wired and wireless devices. Apart from analyzing different flood detection devices, it presents a framework to use sensory data gathered by IoT in an intelligent way in the fuzzy-based expert system. Let us see the list of contributions as:

7.2.1 Flood Avoidance Strategy

The researcher has tried to avoid flood at least for newly developing cities. This thesis presents a pattern to design the structure of the drainage system to avoid flood in a newly developing city. This structure of the drainage system is based on the concept of computer science called Cellular Automata (CA). The researcher has focused on the structure of the drainage mechanism to drain water in many directions and to store rainwater intelligently. The researcher has focused on studying the structure to maximize the number of exits and the following is the result of the study:

Number of Exits in Various Patterns: In the figures 7.2.1, we can see there is no difference in the way of exit for water discharge in rectangular structure and octagonal structure, but the hexagonal shape has more exits for different layers of CA from layer 1 to 4. In this figure, the number 4 indicates the top layer on CA and leveled it down to 1 which is just above where the reservoir is situated.

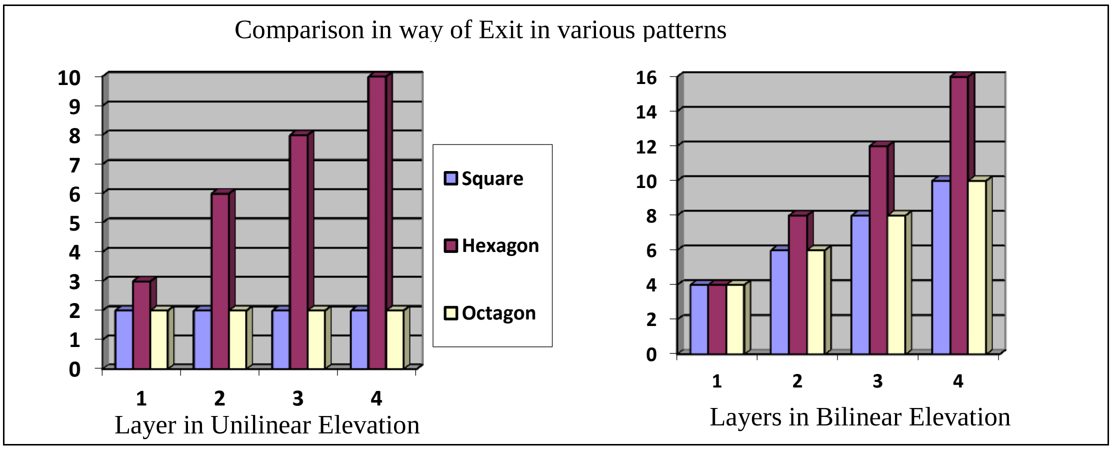


Figure 7.2.1: Number of exits in unilinear and bilinear elevation

7.2.2 Comparison between Devices for Flood Detection

To make a comparison between devices for flood detection, the following steps have been taken:

- Design and development of existing water level detection devices;
- Design and development of existing rainfall detection devices;
- Performance and cost evaluation of devices of both modes for raindrop detection and water level;
- Comparison between proposed and existing wireless detection devices.

Initially, all the developed devices were designed using Fritzing software and then breadboards based embedded single board computers and other components. All the important dimensions were considered to compare the suitability of the devices for the requirement of the application. The researcher has developed the devices at low-cost using the concept discussed in the literature. Various samples were taken to check the accuracy of the devices. Researchers have implemented both kinds of devices using breadboard, components and Arduino Uno board. The researcher acquired data from all kinds of devices to check the accurate working of these devices. In this row, to find the impact of the costs in the budget for the deployment of the project of such devices on campus, real-time prices from the Amazon site have been considered. After all this exercise, a comparison is shown in chapter 4, between the cost of wired and wireless devices to detect rainfall and to measure water level and there was a clear impact on the budget. This impact has been shown in figure 7.2.2 (a). The cost comparison of individual devices performed in the chapter shows that the proposed transmitting device was costly, but it was useful to acquire two kinds of data. Thus, the cost of the proposed device was very much less than the cost of others. The cost comparison between the cost of the proposed transmitting/detection device and existing transmitting devices for the same kind of data acquisition has been shown by figure 7.2.2 (b).

At the end of chapter 4, the equivalence of the proposed transmitting and detection device with the devices developed using the existing concept has been validated using a statistical test. It means, it can be concluded that the proposed transmitting/detection device is equivalent to two kinds of existing devices and it is able to replace two different transmitting devices. Both figures 7.2.2 (a) and 7.2.2 (b) are derived from the data indicated in the tables of Appendix B.

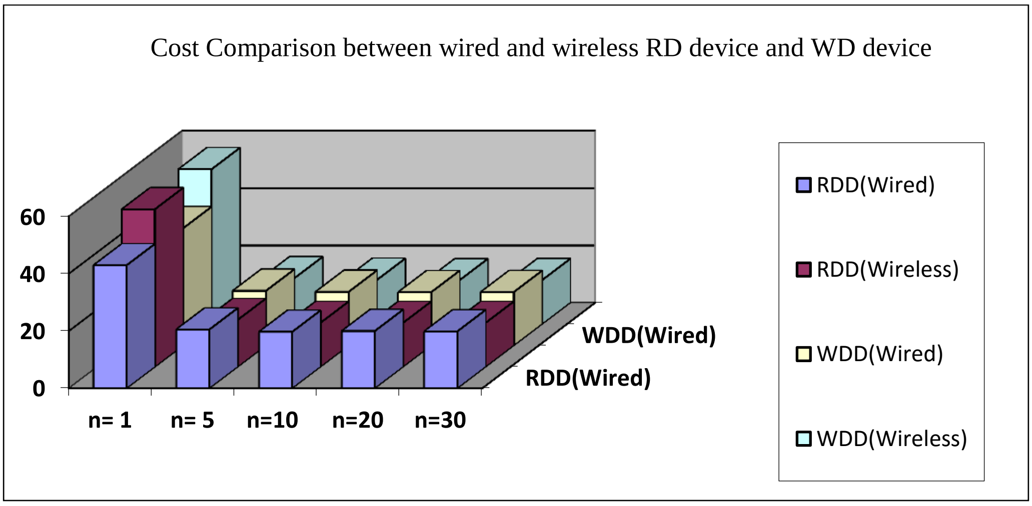


Figure 7.2.2 (a): Impact of quantity of developed devices on the Costs

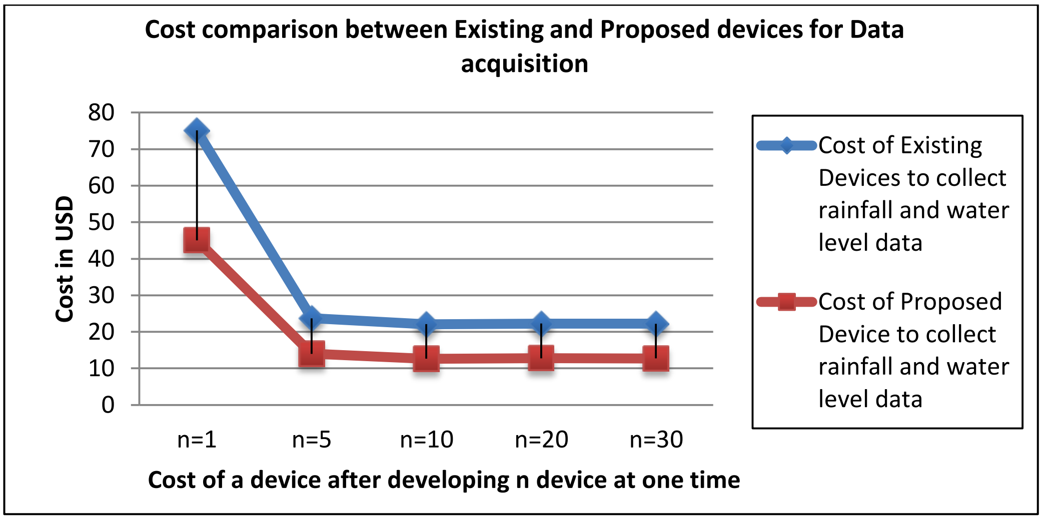


Figure 7.2.2 (b): Cost comparison between existing and proposed devices

7.2.3 Deployment Strategies

Finding the correct location to deploy the device is an important task because the location of the deployment of devices affects the performance and cost of the project. Therefore, the researcher has attempted to find out locations to deploy devices in different cases of an urban flood. Here, an idea to deploy IoT mechanism with minimum cost to get maximum benefit has been proposed. This method of finding a location to deploy devices may be referred to as the Deployment strategies based on Cellular Automata (CA), which are divided into two kinds of mechanisms as:

(a) The deployment strategy for existing cities, and

(b) The deployment strategy for newly developing cities.

For existing cities, device deployment is suggested on the path of water flow. So, to find the path of water flow a Cell Elimination Algorithm (CEA) is presented. On the other hand, device deployments on the corner of cells are suggested for the newly developing cities if the city developed by CA-based planning. In this case, the requirement of devices varies due to the shape and layers involved in the CA-based drainage system as indicated in figure 7.2.3. This figure is based on the data indicated by table 5.3.3.

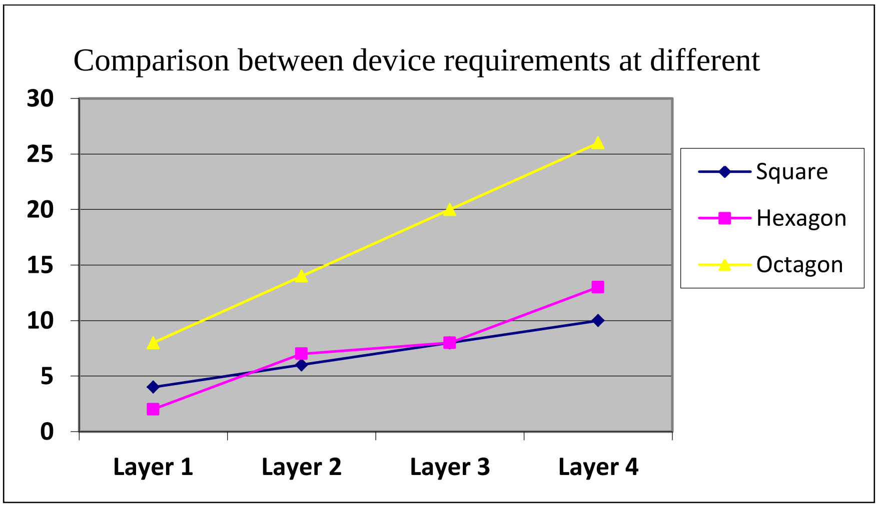


Figure 7.2.3: Comparative of layerwise requirement of the detection device

The figure indicates that deployment is based on the hexagonal grid pattern and is economically efficient due to the requirement of devices.

7.2.4 Expert System

After getting data from things, the question was to utilize this data intelligently, so the researcher attempted to develop an expert system to predict the risk of the possibility of the flood by utilizing sensory data. Risk calculation is performed based on a threshold that may vary from city to city because of the difference in peak rainfall of different cities.

Chapter 6 throws light on the expert systems involved in decision making using popular way of soft computing including NN based ES and Fuzzy Logic based ES. An ES to use the sensory data in the form of a Fuzzy Expert system after a comparative study between both kinds of expert systems has been proposed. This ES will be able to help authorities to take appropriate action for the survival of the public. Few tasks have been performed in the development of this Fuzzy based Expert System to find risk for the alert about the flood. These tasks are:

- Fuzzification and defuzzification performed to design an ES;
- The framework of a Fuzzy based ES to use the data;
- Design and development of the flood risk Finder ES using Mamdani Systems;
- Find out the dependency of one of the outputs on inputs;
- Development of ES prototype.

A Web-based risk finder system is developed using the concept simulated in chapter 6. Though the developed expert system is not an automatic mechanism to show the risk, it is an attempt to develop a feature-rich expert system in the future. The performance of the proposed expert system will depend on the suitability of rules and on the dependency of output on input rules. So, the dependency of rules has been checked using MATLAB Fuzzy Tool Box and shown in chapter 6. The concept of the proposed ES has been validated using multiple linear regressions. GUI for ES is developed that is capable to show a different kind of risk as indicated by screenshot in figure 7.2.4.

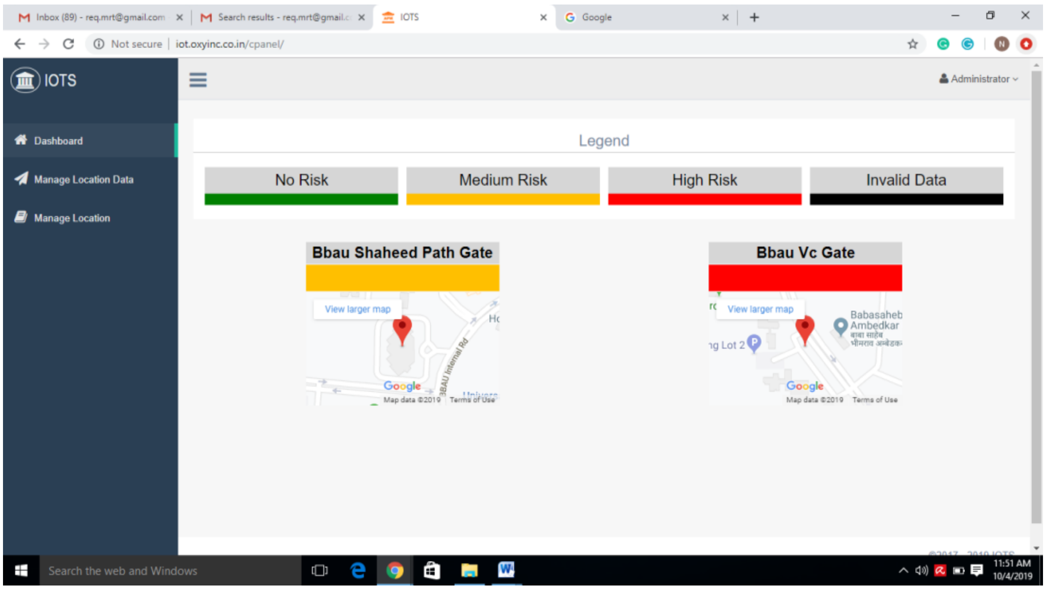


Figure 7.2.4: Page showing risk at various locations

7.3 Other Findings

Apart from the main contribution, few findings achieved in the duration of research have been mentioned below:

- **Development of a way to SLR:** From the literature survey, the researcher found a few strong outcomes to start research. The challenges in implementing

IoET are discovered from a literature survey. The study suggests using ORK to get research papers of the same kind in the form of samples to perform a systematic literature review. In research, the WORK algorithm proposed has been utilized in METHWORK. This ORK based search provided SLR that is able to provide better results and findings such as the selection of components to develop the device, selection of methods to use raw data detected by devices, etc. The outcomes of SLR were utilized to find the objectives of the research. The outcomes of SLR are:

- Selection of technology suitable to detect flood;
- Selection of Reference Model and layer to work for flood detection;
- Selection of controller board and sensors to develop devices.

- **Development of METHWORK:** The researcher spent a long time to perform an SLR to find a suitable reference model, layer to which the solution belongs. After studying the literature, the IoT reference model of CISCO was chosen. This reference model had benefits of clear abstraction between its layers based on functionality and utilized by the METHWORK approach. This METHWORK approach is developed to find out the most popular research trends by ranking. The METHWORK provides a better ranking than the other ranking approaches used to make comparisons with METHWORK was Dense ranking, Ordinal ranking, Standard competition; and Modified competition.

  In comparison, METHWORK was found better and efficient. This approach is applicable to finding ranks in research trends in every research domain while indicated well performed for IoET (i.e. By ranking in research trends, and suitable components to develop devices). The work performed due to the results shown in this technique will be correct because this technique has been validated using the χ^2 –Test that proved the statement of hypothesis in favor.

7.4 Significance of the Work

A series of tragedies caused by the failure of flood management, Decision-making mechanism, and drainage networks proves that the absence of a proper approach in handling may be a matter of life and death. There is reportedly no good understanding of the nature of the technologies involved in the Flood Management System (FMS). The absence of flood avoidance mechanisms, absence of measurement, and absence of perfection in the FMS remain a difficult problem. To find a suitable way to measure flood is difficult. This study was carried on improving safety by minimizing loss by the prior finding risk of a flood using an accurate risk finder system. To develop an IoT based mechanism to find out the flood risk, the work of finding out a suitable layer of reference model having a trend of flood detection was done. After successfully finding the suitable components to develop low-cost detection devices, research was conducted to perform different tasks to accomplish phases of a flood management system. These phases include preparation, avoidance, detection, and recovery. The significance of the work in the thesis can be understood with its usefulness in the flood management system. Tasks performed in the phases of the flood management system have been indicated in the checklist shown in table 7.4.

Table 7.4: Work performed in terms of Flood Management System for any City (A checklist)

Phase	Checks	Tried in the Thesis	Yes/ No
Response & Recovery	All assets important to humans are identified.		
	Municipality knows the path of water flow in the city.		
	A plan of fast recovery/ response is ready for a flood disaster.		
Alert Generation	City radio, TV channel is ready to alert in the city.		
	A web-based alert generation mechanism is available.	X	
	Mobile apps with a map of a city ready to alert each individual.		
	Volunteers in each colony are ready to provide the alerts.		
Flood Detection	Sensors are deployed in the city to provide real-time data.	X	
	A flood detection network developed for the city.	X	
	Any flood detection mechanism deployed in the city.	X	
	Public flood detection networks deployed in the City.		
Flood Avoidance	Is any reservoir available to collect excess water in the city?		
	A drainage mechanism to exit excess water is available and working properly.		
	Structure to develop a reservoir within the city is available.	X	
	To ensure maximum water exit, a perfect structure of drainage mechanism available.	X	

Conducted research will be definitely significant, directly in terms of the following:

- It will help to avoid flooding by helping a drainage designer to develop designs with suitable cellular shapes.
- It will help to determine the impact of design for the construction of the drainage mechanism.
- Evaluation of existing detection devices indicates the applicability of detection devices developed for different modes. It determines a place of proposed transmitting/ detection device among all the flood detection devices.
- It will help to evaluate the cost of detection devices and cost estimation for deployment. This help may facilitate estimation, and planning of new projects.
- It will help to better understand the deployment approaches for flood detection mechanism, and design of flood risk finder expert system, which in turn may enable to comprehend the process of a feature-rich Expert System development.
- The proposed approach encourages developers to come out with good flood detection and flood avoidance models.
- The proposed approach will enable a path to design a good Expert System for various kinds of disasters.

7.5 Answers to Research Questions

The various research questions posed in the chapter-1 are one by one answered by the Research Findings. The questions and finding to solve query are given below:

Research Question: Which design is better for a quick exit of water to avoid flood?
Finding: A CA-based design is better for flood avoidance.
Research Question: In case of failure in avoidance, how is flood pre-detection possible?
Finding: Flood prediction is possible using the water level and status of the raindrop.
Research Question: What will be the method of finding the symptoms of a flood?
Finding: IoT based devices are able to detect symptoms of a flood.
Research Question: What kinds of technologies are in use to sense data of symptoms of the flood?

Finding: Sensor-based technologies are able to sense symptoms of flood including WSN and IoT.

Research Question: Which sensors will be able to sense the parameters of a flood?

Finding: Ultrasonic and raindrop sensors will be able to sense the parameters of a flood?

Research Question: How the development of flood detection devices is possible on a low budget?

Finding: Using the bulk purchase of all the components of devices, the development of devices at low-cost is possible.

Research Question: How can we use detection data to decide flood risk?

Finding: We can use detection data to decide flood risk using a decision-making system or expert system.

Research Question: If the arrangement of devices is possible in wired and wireless modes, then what will be the difference in the cost?

Finding: Cost of the wired mechanism is cheaper than the wireless mechanism but in the case of bulk purchase, no big difference is found between them.

Research Question: What will be the device deployment strategy for effective flood detection? Will it affect the minimum number of devices to be deployed?

Finding: Water flows in the downward direction and cellular automata provide a layer-wise drainage mechanism in which all the layers may be placed at different heights, so device deployment on the path of water flows is suggested. This strategy is utilized in both the deployment algorithm presented, including the Cell Elimination algorithm and Cellularly Deployment Algorithm. Yes, device deployment strategy affects the minimum number of devices to be deployed.

Research Question: What will be the intelligent method to find out the chances of a flood?

Finding: Fuzzy based expert system will be an intelligent method to find out the chances of a flood.

Research Question: How can we develop an Expert system to provide flood risk?

Finding: Using MATLAB or dot NET framework, we can develop an ES to find a risk.

7.6 Limitations

The researcher performed research to accomplish the task to develop an intelligent risk finding system, effort to flood avoidance and detection of symptoms. In this work, few tasks were considered in limitations as:

- **In drainage mechanism:** A drainage mechanism is suggested for avoiding the flood disaster. The proposed drainage mechanism is just an effort to provide input for flood avoidance. This mechanism is based on plain modeling. So, the testing and validation of design just depend on real-time development of the design that was not possible in our IT lab. So, in the absence of real-life practical, results may be affected.
- **In the detection mechanism:** IoT based detection mechanisms are based on developed devices that collect accurate and timely data. The working and performance of the devices based on existing concepts have been compared with the proposed detection device. The mechanisms of devices discussed by other researchers are compared. In this comparison, the researcher was unable to check the performance and working of the existing wireless rainfall detection device and that is still a challenging task.
- **An expert system development:** An expert system designed and developed is based on fuzzy logic that consumes data sent from IoT based water level and rainfall detection devices. Statistically, it provides correct results as per the desired objective, but it is unable to work automatically without human intervention.
- **In METHWORK:** Algorithms proposed in METHWORKS may be implemented with other ranking methods or to find other kinds of trends. The ranking of these trends may vary due to the samples.

7.7 Future Directions

Research is a continuous process and reaching one outcome encourages other researchers to perform the next steps. In the future, there are few main tasks to be accomplished by the researcher as:

- Researchers can plan to conduct more experiments to find new designs of IoT based detection devices for acquiring other kinds of data.

- Different implementations of the Expert System are possible. Researchers may implement the same by choosing another set of parameters and soft computing techniques.
- Automation of the Expert system is very important and it will be our next step to be performed.
- The real-time mechanism of the drainage system can provide the surety of successful research and avoidance of flood, so the real-time implementation may avoid the urban flood permanently.
- The METHWORKS can be implemented to find out the ranking in other applications also.

In a nutshell, we can say, the conducted research will be helpful to develop an IoT mechanism to detect a flood event by sensing some environmental symptoms. Other than detection, this research will also guide people to develop a drainage system to make the cities flood-free.

Appendix A: METHWORK

In the MATHWORK, there are *n* topics to be ranked in *m* researches that provide instructions on the topics assumed for ranking. IoT reference model of Cisco adopted to opt the topics to choose the trends of IoET. So, N= {1. . . ., n} and M= {1. . . , m} denotes the set of topics and sets of research, respectively. A research's instruction assigns with nonnegative valuation to each topic; $\lambda_{i.j}$ indicates j's valuation to i. The instruction matrix assumed as the n× m matrix λ = (λ i j): j's instruction indicated in column j (i.e. The value of all research on the topic), the authors indicated it by the value of j to all topics and row i. Here, the value of λ_{ij} assumed as a 0 or 1, and 1 indicated by √ while for 0 positions left blank. Let us see the procedure of METHWORK indicated in the figure given below:

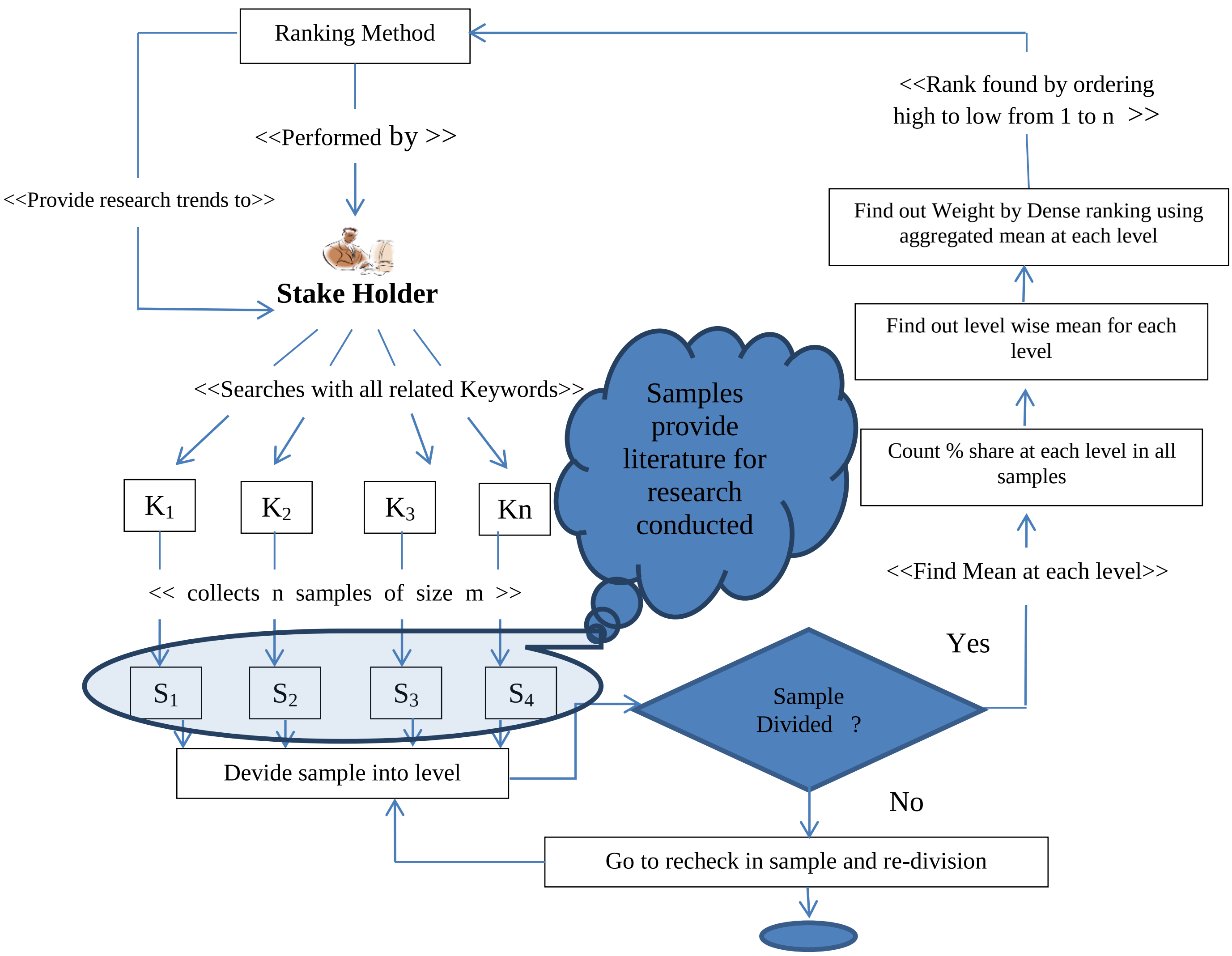


Figure A1(a): Mechanism of METHWORK

A1. Description

In METHWORK researcher searches the samples based on ORK suggested by experts, as shown in figure A1(b). Each keyword finds a sample containing research papers and documents. Then, in the next step, all the samples will be subdivided into phases of the research area in order from the preparation of data generation to the final utilization of data. Here, each sample contains a different number of papers, thus, the consideration of percentage at each level in every sample suggested to be calculated. This percentage calculation is suggested to make homogeneity at each level. The fourth step calculates the mean of each phase in the summarized data of all the samples. The next step is to assign ranks from highest to lowest order using a dense ranking that assigned weightage of each level. The highest weighted trends assigned rank 1, then the second-highest is 2 and so on. WORK algorithm used in METHWORK are:

With Opted Related Keyword (WORK) Algorithm

```
Start
      Step 1          Choose n ORK
                      Find n sample using n ORK
      Step 2          For (i=1; i<=n; i++)
                      {
                        Bifurcate sample in R standard subparts
                        If (sample == bifurcated successfully)
                         {
      Step 3              Count %age share at each subpart
                         }
      Step 4              Find out Mean at every Level
      Step 5             For (i=1; i<=R; i++)
                            {
                              Assign 1 to R in order from  Higher to lower % age by
                              Dense Raking;
                              Display the rank;
                             }
                          }
                          else
                          bifurcate again;
      Step 6          Goto Step 2;
End.
```

Figure A1 (b): Work algorithm

METHWORK is based on the popularity of trends in which researchers involved while other approaches are based on citation counts [186] to find out Journal ranking.

A2. Case study: Application of METHWORK

Data collection in METHWORK starts by choosing keywords that depends on requirement. So, the researcher considered queries to find out trends under IoET and the ranking of these trends.

Method of Paper collection: Now, ORK 1 and 2 are chosen for finding a solution, i.e. rank; while ORK 3 is used to test the correctness of the solution. ORKs are:

- ORK 1: Monitoring using IoT;
- ORK 2: Environmental monitoring using IoT;
- ORK 3: Limitations of environmental monitoring in IoT.

Each ORK collects a set of researches from Google in a sample. Out of all these researches, only Scopus and IEEE papers have considered being studied. Here, papers representing reviews of other's work and papers providing approaches to security were skipped because both categories are applicable at multiple phases of the reference model and not helpful to decide interest. In tables A2 (a), (b), and (c), "All related Articles" field shows related papers as indicated below:

Table A2 (a): Status of papers in sample 1

Papers for Keyword 1= 137				
	Found	**All related Articles**	**Reviewed**	**Added**
Scopus / IEEE	8	51	23	07
Others	117	73	02	00
Books	12	12	09	01

Table A2 (b): Status of papers in sample 2

Papers for the Keyword 2=140				
	Found	**All related Articles**	**Reviewed**	**Added**
Scopus / IEEE	7	48	29	11
Others	130	64	21	01
Books	03	00	01	00

Table A2 (c): Status of papers in sample 3

Papers for Keyword 3= 88				
	Found	**All related Articles**	**Reviewed**	**Added**
Scopus / IEEE	04	31	22	16
Others	80	31	03	00
Books	04	01	01	00

A3. Implementation of METHWORK

To find a ranking of research trend within IoET, METHWORK applied is as follows:

Step 1: (Keywords Selection):

No. of ORK = 2;

Collect data in samples using ORK.

Step 2: (Division in Samples): Table A3 (a) represents two samples found by two ORKs. It is structured by distributing papers in various levels of the IoT reference model according to their contributions. Here, note that research may be considered at more than one level if it contributes to more than one level.

Table A3 (a): Layer wise division in sample

	Sample 1	**Sample 2**
Thing	26	19
Connectivity	26	18
Edge / Fog	23	15
Storage	7	5
Aggregation	9	3
Application	15	6
Processing	8	1
Sample size	32	22

- **Divisions of Researches found in the samples:** Papers of each sample classified into subgroups based on the levels of the IoT reference model as per table A3 (b).

Table A3 (b): Issues considered at various levels

Considered Issues	**Research area**	**Levels**	**Level**
Issues with device design	Embedded System and design	Thing	1
Issues with connectivity, Networks, and protocols	Network Protocol	Connectivity	2
Issues of data reduction and generation	Edge / Fog Computing	Edge / Fog	3
Issues of data handling, management.	Database Management and big data handling	Storage	4
Issue of Data analysis	Data aggregation & analysis	Aggregation	5
Issues of applications and software	Software Application design	Application	6
Issues of service, models.	Cloud service models	Processing	7

Step 3 (Percentage Calculation): Table A3 (c) indicates the percentage of research papers at a particular level in samples; it has been counted by research contribution.

Table A 3 (c): Layer wise percentage of research papers

	Sample 1		Sample 2	
	No. of papers	% in sample	No. of papers	% in sample
Thing	26	81	19	86
Connectivity	26	81	18	81
Edge / Fog	23	71	15	68
Storage	7	21	5	22
Aggregation	9	28	3	13
Application	15	46	6	27
Processing	8	25	1	4
Sample size	32		22	

Step 4 (Mean Calculation): Table A3 (d) represents the layerwise mean of all the samples that indicate the aggregated percentage of popularity found in both samples.

Table A3 (d): Mean of the percentage of research in layers

	% in sample (A)	% in sample (B)	Mean
Thing	81	86	83.5
Connectivity	81	81	81
Edge / Fog	71	68	69.5
Storage	21	22	21.5
Aggregation	28	13	20.5
Application	46	27	36.5
Processing	25	4	14.5

Step 5 (Ranking): Table A3 (e) represents the ranking assigned to the layers based on popularity in order of high to low by applying Dense ranking [187]. Here, high weight considered as a top rank and so on.

Table A3 (e): Ranking of layers from Mean

Level of IoT	Mean	Ranks by Dense	Equivalent Rank
Thing	83.5	7	1
Connectivity	81	6	2
Edge / Fog	69.5	5	3
Storage	21.5	3	5
Aggregation	20.5	2	6
Application	36.5	4	4
Processing	14.5	1	7

Its validation has been discussed by Neeraj et al.[121].

Appendix B: Cost of devices used in experiments

B1. Cost Comparison between the wired and wireless devices

Cost estimation is performed in this chapter in two steps including:

(1) The development cost of devices to deploy(wired);

(2) The development cost of devices to deploy (wireless).

- **The development cost of devices to deploy (Wired)**

The budget to deploy devices in wired mode is different from the wireless mode. Here, the total cost of the components involved in the device has been considered. Let us see the cost of components purchased in different quantities to find out the budget.

1) **Water level Detection Device:** The cost of components is adapted from amazon.com.

Table B1 (a): Cost of wired water level detection device

Component	**1**	**5**	**10**	**20**	**30**
Ultrasonic sensor	6.99 [192]	9.78 [191]	15.99 [190]	29.50 [189]	45.49 [190,189]
Arduino board	16.99[194]	21.94 [195]	43.80 [196]	87.60 [196]	131.40 [196]
Connecting wire	8.99 [193]	44.95 [193]	89.90 [193]	179.80 [193]	269.70 [193]
LCD	7.99 [197]	18.99 [198]	37.98 [198]	75.96 [198]	113.94 [198]
Total cost of WD	40.96	95.66	187.67	372.86	560.53
Cost of a device	40.96	19.13	18.76	18.64	18.68

2) **Raindrop Detection Device:** Let us consider the cost of components involved.

Table B1 (b): Cost of wired raindrop detection device

Component	**1**	**5**	**10**	**20**	**30**
Raindrop sensor	7.99 [199]	11.90 [200]	15.50 [202]	36.80 [201]	52.30 [201,202]
Arduino board	16.99 [194]	21.94 [195]	43.80 [196]	87.60 [196]	131.40 [196]
Connecting wire	8.99 [193]	44.95 [193]	89.90 [193]	179.80 [193]	269.70 [193]
LCD	7.99 [197]	18.99 [198]	37.98 [198]	75.96 [198]	113.94 [198]
Total cost of RD	42.96	102.78	197.18	400.16	597.34
Cost of a device	42.96	20.55	19.71	20.05	19.91

B2. The development cost of devices to deploy (Wireless)

To calculate the budget to deploy wireless detection devices for flood-prone areas, the researcher has considered the budget of developed devices. In this, raindrop detection and water level detection devices have been considered.

1) **Water level Detection Device:** Cost of components for this device with the cost have indicated in table B2 (a) for its purchase in different quantities.

Table B2 (a): Cost of wireless water level detection device (transmitting device)

	n=1	n=5	n=10	n=20	n=30
Ultrasonic sensor	6.99 [192]	9.78 [191]	15.99 [190]	29.50 [189]	45.49[190,189]
Arduino Uno	16.99[194]	21.94 [195]	43.80 [196]	87.60 [196]	131.40 [196]
Transmitter	5.09[203]	7.49[204]	12.99[205]	25.98[205]	38.97[205]
LCD	7.99 [197]	18.99 [198]	37.98 [198]	75.96 [198]	113.94 [198]
Total cost of WD	37.06	58.2	110.76	219.04	329.8
Cost of a device	37.06	11.64	11.07	10.95	10.9933333

2) **Raindrop level Detection Device:** To develop a raindrop detection device, a raindrop detection sensor along with Arduino UNO, transmitting and receiving components, and LCD unit has been considered, that is why the cost of these components is considered in budgeting as per the table B2 (b).

Table B2 (b): Cost of wireless raindrop detection device (transmitting devices)

	n=1	n=5	n=10	n=20	n=30
Raindrop Sensor	7.99 [199]	11.90 [200]	15.50 [202]	36.80 [201]	52.30 [201,202]
Arduino Uno	16.99[194]	21.94 [195]	43.80 [196]	87.60 [196]	131.40 [196]
Transmitter	5.09[203]	7.49[204]	12.99[205]	25.98[205]	38.97[205]
LCD	7.99 [197]	18.99 [198]	37.98 [198]	75.96 [198]	113.94 [198]
Total cost of RD	38.06	60.32	110.27	226.34	336.61
Cost of one device	38.06	12.064	11.02	11.315	11.22

3) **Cost of Proposed Flood Sign Detection Device:** It will be useful to detect both signs of a flood, including water level and raindrop using a device of low cost.

Table B2 (c): Costs of proposed wireless flood detection device (transmitting devices)

	n=1	n=5	n=10	n=20	n=30
Ultrasonic sensor	6.99 [192]	9.78 [191]	15.99 [190]	29.50 [189]	45.49[190,189]
Raindrop Sensor	7.99 [199]	11.90[200]	15.50 [202]	36.80 [201]	52.3[201,202]
Arduino board	16.99[194]	21.94[195]	43.80 [196]	87.60 [196]	131.40 [196]
Transmitter	5.09[203]	7.49[204]	12.99[188]	25.98[188]	38.97[188]
LCD	7.99 [197]	18.99[198]	37.98 [198]	75.96 [198]	113.94 [198]
Total cost of FSD	45.05	70.1	126.26	255.84	382.1
Cost of one device	45.05	14.02	12.626	12.792	12.736

PUBLICATIONS:

Patents:

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