International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 08 | Aug 2021 www.irjet.net p-ISSN: 2395-0072

Fuzzy Based Flood Warning Expert System using IoT and LoRa Technology

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Abstract - *Flood is a very destructive and it becomes cause of harm for everything that is society, land, different infrastructures like bridges, farms and many more things. In recent decade western Maharashtra had three flood incidences, in year 2005,2019 and recently in 2021. So flood avoidance is necessary or at least detection of flood in advance is necessary to save human lives, animal lives and infrastructure. It is necessary to find out what are the basic things which helps flood to occur. And if we carefully find the basic cause or root cause then we find rainfall, soil moisture capacity of land, speed of water flow, water level, temperature and humidity these are the basic things which help the flood situation to arises. As we know that all these parameters like rainfall, water speeds etc are continuously changing entities. So while collecting data from such changing entities and execute this continuously changing data to produce fruitful results is a big deal. So to resolve this issue we may think of one of the good algorithm known as Fuzzy logic. It deals with uncertain or continuously changing data and produce fine results which have resemblance with human produced results. In this paper we mentioned use of different sensors for above mentioned parameters and apply the data collected from these sensors to fuzzy logic and fuzzy logic produce chances of flood in percentage form. Sensors like ultrasonic sensor, water flow sensor, soil moisture sensor, rain fall sensor etc. are used. For soil moisture sensors LoRa(Long range) technology is used which is a wireless, open source technology. It collects data from different soil moisture sensors which are placed at different places in the bed and outside the bed of river. All the data collected from sensors is accumulated on raspberry Pi unit which acts as a computing unit and on which fuzzy logic is present as a source of computation. The produced result is also send on cloud platform for display. We produce flood occurrence chances in percentage form as well as in graphical form using concept of membership function available in fuzzy logic. Triangular member functions are used.*

***Key Words*: LoRa, flood detection system, fuzzy logic, IoT, membership function**

1. INTRODUCTION

In year 2005, 2019 and recently in year 2021 western Maharashtra including Sangli and Kolhapur district had experience of flood situation. It actually affect human as well as animal life, farming land and eco-system in this region, in short it affects everything of society. It changes the economic status of these two districts very badly. So it becomes necessary to have pre-intimation about occurrence of flood to save whichever is possible. Keeping this in mind we have tried to develop an expert flood detection system using IoT and LoRa technology. As LoRa(Long Range) technology is a low power consumable, open source, pretty long range wireless technology which is used in this project to acquire the data from soil moisture sensors in continuous form. Different sensors like ultrasonic sensor (used for water level), rainfall sensor, and water flow speed sensor are used to acquire data from surrounding. All this data is collected at the Raspberry Pi unit which is used as computing device and using python this computing unit decides the percentage of flood occurrence. This data is further transmitted to cloud platform. Though all sensors perform well to collect data correctly and send it to the computing unit but all this data is continuously changing data and so we use Fuzzy algorithm to determine whether a flood situation arises or not? Why fuzzy algorithm is used? Because this is a very robust algorithm that works on uncertain data with quite good results.Most commonly used triangular member function is used to represent the calculated data in graphical format also. Use of fuzzy logic algorithm is appropriate as we have to deal with uncertain data. As simple logic produce output in the form of yes and no format, but fuzzy logic produces output in terms of degree of membership function. It produces output in the range of 0 to 1 like 0.2, 0.6 or 0.8 etc. It also includes or support linguistic rules so as to make it more easy and familiar to human behavior. In this paper we are collecting data from different sensors and using that collected data we are able to produce results about the

occurrence of the flood is possible or not? So in this case use of IoT is appropriate.

After producing the result that is whether flood occurs or not? This system also sends the data to the cloud system for further analysis or observation. For this aspect, we use a 4G wireless dongle for communication between Raspberry Pi and the cloud.

1.1 Overview of Fuzzy logic system

Dictionary meaning of fuzzy is not clear that is vague. In this century while the study of science one thing is arises that is the study of uncertainty. Lotfi A. Zadeh in 1965 first introduces this concept and he gave the name fuzzy set. This is a set which does not have precise boundaries. In case of non fuzzy set if we say that suppose A is asset and m is an object of this set then the statement "m is member of A" must be either true or false. But this is not the case in the fuzzy set here the statement "m is member of A", maybe true to some extent. This is called the degree of membership. In case of non fuzzy set which is also called as crisp set every element has value either 1 or 0 which decides whether the element under consideration is member or non member of set. But in the case of fuzzy set value assigned to every element is falls within a specified range and it indicates the membership range of elements in the set. If this value is higher at that time then, it shows a higher degree of membership. This concept is called a membership function and that set is called a fuzzy set.Commonly used values for membership function are [0, 1]. Fuzzy set supports linguistic concepts and they are used to define states of variables. These variables are called fuzzy variables. The difference between crisp variable and fuzzy variable is that fuzzy variable have capability to response gradual transitions between states and they have natural capability to express and deal with uncertainties. Fuzzy sets have tremendous expressive power and its usefulness depends on us how we construct appropriate member function for given context. As mentioned in introduction section flood detection system works on the input like water level, water flow speed, rain fall and soil moisture capacity of soil and all these factors are changing factors. To deal with such uncertain and changing entities we need an algorithm which is able to handle uncertain data exactly like a human brain. Fuzzy logic is one of the algorithms which produce results that have human resemblance. Fuzzy logic uses different member functions like triangular member function, trapezoid member function, etc. The triangular member function is used mostly. In this paper, we have also used the triangular member function. Fuzzy logic always produces result in between 0 and 1 only. 1 means extremely high value. For given universal set X, we may have fuzzy set of type set A is defined by function in the following form

A : X -> [0, 1]

Fuzzy Logic Systems (FLS) produce acceptable but definite output in response to incomplete, ambiguous, distorted, or inaccurate (fuzzy) input.

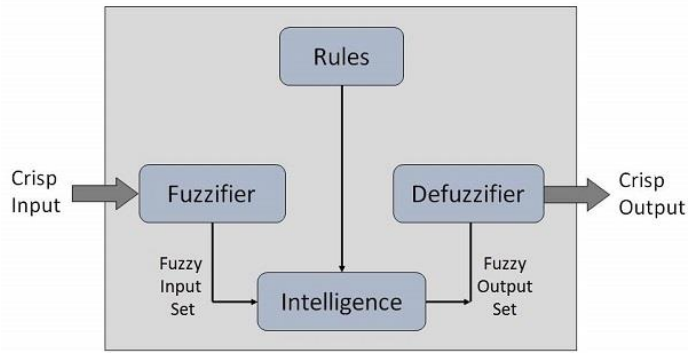

Fig-1.1: Fuzzy Logic system**.**

Membership function is a function that specifies the degree to which a given input belongs to set. The membership functions (MFs) play vital role in the overall performance of fuzzy representation. The shapes of MFs are important for a particular problem since they effect on a fuzzy inference system. The only condition a MF must really satisfy is that it must vary between 0 and 1. The choice of which of the MF to use depends entirely on the problem size and problem type. It is really important to know how many MFs are needed (e.g., low, med, and high MF) and also choosing the intervals of MFs. These two factors also have a great impact on the outcome of a fuzzy logic system. Triangular MF is one of the most encountered MF in practice. The triangular MFs are formed using straight lines. These straight line membership functions have the advantage of simplicity.

Triangular function: defined by a lower limit a, an upper limit b, and a value m, where a < m < b.

$$\mu_A(x) = \begin{cases} 0, & x \le a \\ \frac{x-a}{m-a}, & a < x \le m \\ \frac{b-x}{b-m}, & m < x < b \\ 0, & x \ge b \end{cases}$$

Fig-1.2: Membership Function

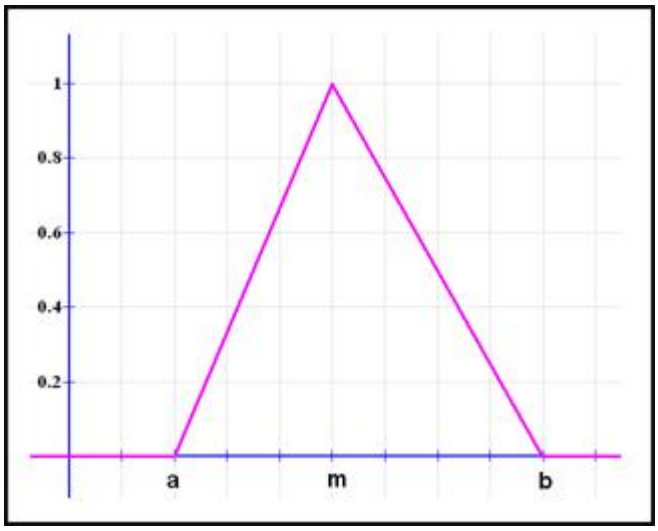

Fig-1.3: Membership Diagram**.**

2. RELATED WORK

Much research has been done on early flood detection system in past years. If we consider the example along with IoT, LoRa is used to detect flood situation[1]. Hydrology is one of the big examples of uncertain data. Fuzzy logic is one of the great solutions to deal with uncertain data. For the water resource management, water resource assessment, ground water hydrology analysis, this fuzzy logic based model is useful. When combined with other models it may show greater performance [2]. As fuzzy logic is able to produce output in between true and false (i.e. between 0 and 1) it is most useful in the field of Artificial Intelligence (AI). For rainfall prediction it uses five rule fuzzy system and triangular membership function and ultimately it predicts rainfall [3]. Frequent changes in water level may be detected using ultrasonic sensors then data is analyzed and send to flood management system using SMS. Using four machine learning algorithms prediction of flood situation is possible [4]. Water surface flow and water altitude are measured using sensors and using fuzzy logic system with linguistic rules flood detection is made using embedded system[5]. Data is collected from water level sensor and provided to decision tree algorithm for prediction of flood situation. Data and result is transmitted to cloud system using wi-fi module [6].

3. ROLE OF IoT

Proper placement of sensors - This point includes the proper location and altitude of sensors. For flood detection different parameters like water flow speed, soil moisture, humidity, rainfall, surface run flow of water are responsible. For more accuracy soil moisture sensors are placed at multiple points in the river bed as well as outside the river bed. If river water comes out from river bed and spread in nearby places then using multiple soil moisture sensors we can collect data using LoRasystem(LORA RA-01 long range wireless transceiver sx1278 (433mhz) with spring antenna) which is a wireless technology. From weather station setup we receive information about rainfall, humidity and temperature. This weather station has wired connection with processing unit. For detecting surface run flow we use ultrasonic sensor(hc-sr04 Ultrasonic sensor for altitude detection with 5v , 40 Hz with maximum sensing range of 450 cm) and for sensing running water flow speed we use water flow speed sensor() both of which are also having wired connection with processing unit.

Computing unit – In this paper raspberry Pi(3 B+) unit is used as computing unit. All sensors send data to this raspberry pi unit where all data is collected and fuzzy logic algorithm is applied on this data so as to produce result. Python 3.5 version is used to write code which process sensor data and produce result. This processing unit is not only acting as a computing device but also act as primary storage unit. In critical situation processing unit send alert to alarm station using LoRa technology.

System Integration - All data from sensors including wireless sensors and wired sensors is collected into computing unit. In computing unit Fuzzy logic with Membership Functions and rules developed for fuzzy logic will be applied on sensor data and result is produced.

Sensor data and result produced is stored on computing unit as primary storage. In critical condition alert is send to alarm system. Using 4G connectivity sensor data and result produced is sending to cloud system.

4. SYSTEM ARCHITECTURE

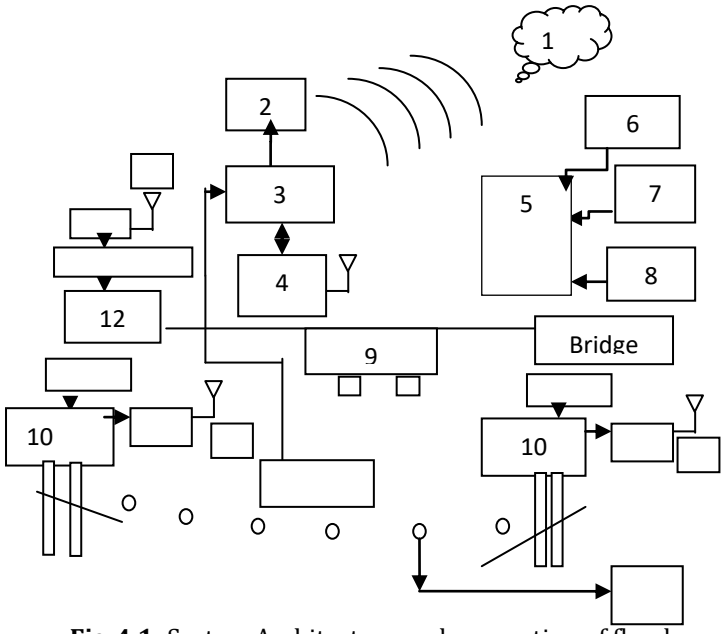

Fig-4.1: System Architecture and connection of flood detection system with cloud system**.**

Sr. No.	Description
1	Cloud System
2	4G unit
3	Processing Unit
4	LoRa unit
5	Weather Station
6	Humidity Sensor
7	Rainfall Sensor
8	Temperature Sensor
9	Ultrasonic Sensor
10	LoRa Transmission unit
11	Water Flow Sensor
12	Alarm Unit LoRa receiver unit
13	Soil Moisture Sensor

In this system architecture ultrasonic sensor, water flow sensor and weather station these have wired connection with computing unit that is raspberry Pi unit. But soil moisture sensors have wireless connection with computing unit. If you see carefully soil moisture sensors have a term named as Tx it means it transmits the data to computing unit. While one LoRa unit is used with an alarm system you notice that it uses Rx unit it means it receives signals from the computing system. Soil moisture sensor and water flow sensors are actually placed in river bed, soil moisture sensors are also placed outside the river bed. LoRa unit is operated on Lipo battery which is operated on 3.7v with 1200mah.This unit continuously sends the data to computing unit with interval of milliseconds. All the data collected from different sensors is firstly collected in different files and with 5 second delay computing unit access this data for its calculation. We have also prepared log file for rainfall unit so we may access data later also.

The computing unit is nothing but raspberry Pi 3B+. Using python 3.5 and sensor data we apply fuzzy logic rules on sensor data to calculate flood chances. Here basically we use four inputs namely water level, water flow, rainfall and soil moisture and our fuzzy logic system generates output that is flood chances in percentage form. This calculated data is continuously sent to cloud system using wi-fi 4G unit. We are able to plot graph of flood chance. Also we are able to produce tabular data in terms of sensor collected data and flood calculation. In critical condition we are able to send alarm for indicating flood occurrence.

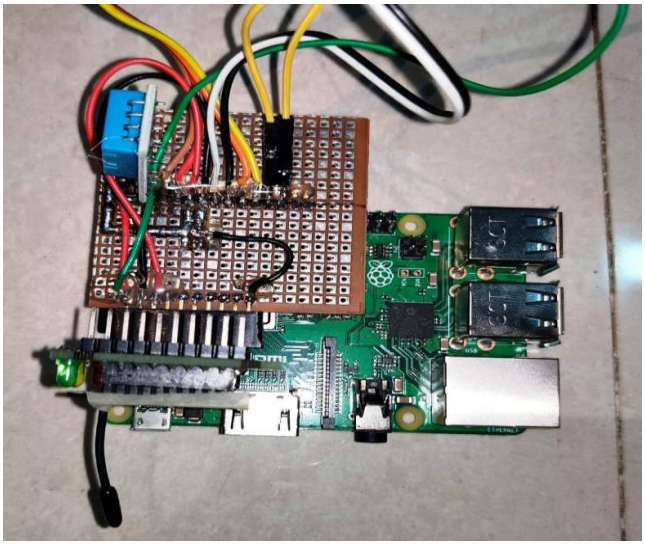

Fig-4.2: Raspberry Pi 3B+system with LoRa

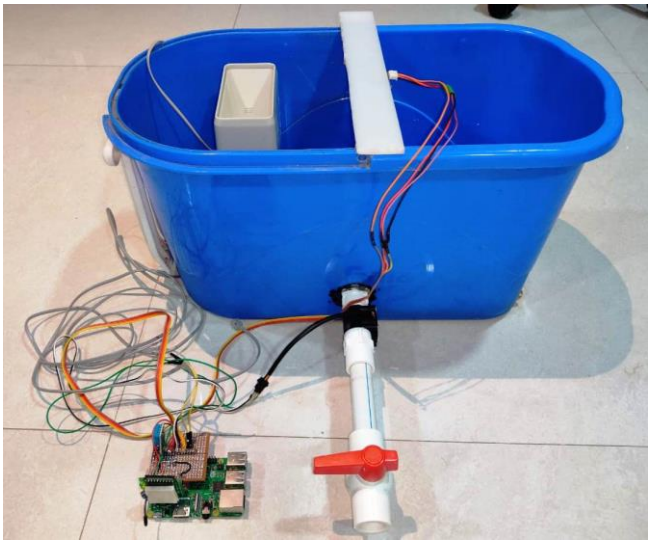

Fig-4.3: Lora Based Flood Detection Model

Fig-4.4: LoRa Node

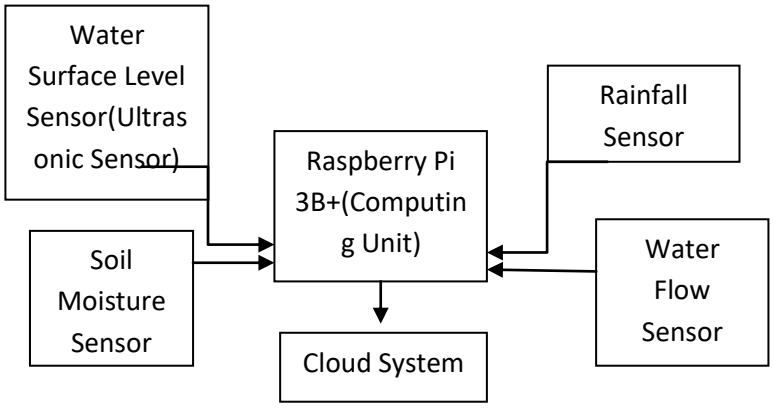

Fig-4.5: System flow diagram.

5. IMPLEMENTATION OF THE SYSTEM

Selection of sensors to sense the data from the environment. Here presently we are using four sensors namely ultrasonic sensor for measuring the height of surface water level, water flow sensor to check the velocity of flowing water, soil moisture sensor for checking water holding capacity of the soil, and rainfall sensor for measuring the average rainfall. Ultrasonic sensor HC SR-04 with maximum range of 450 cm is used. For scaling purpose we may assume that 1cm = 1 Feet in actual. Pin number 23 and 24 were used for trigger and echo purpose. The following formula is used to find the height of surface water level height = ((Trigger time – echo time)/2)/speed of ultrasonic speed. At the same time we are using rainfall sensor to measure the rain fall. This sensor has two buckets of 0.2794mm. When one bucket gets totally filled it gets tilted and second part of bucket is now ready to fill. On this tilting of bucket in one hour we will able to find average rainfall per hour. We use this information to predict the result. Pin number 25 is used to connect rainfall sensor to Raspberry Pi. For soil a moisture sensor that is for LoRaunit we use pin number 23 on computing unit. With 8 bit size and with 9600 baud rate it transmits signal to computing unit. To connect water flow sensor we use pin number 18 is used. Just like rain fall sensor this sensor also has one tilting unit which tilts when water flow through it. Data is collected after every five seconds.

The screen shots of ultrasonic sensor (as an example) which is used to determine height of water level is given below

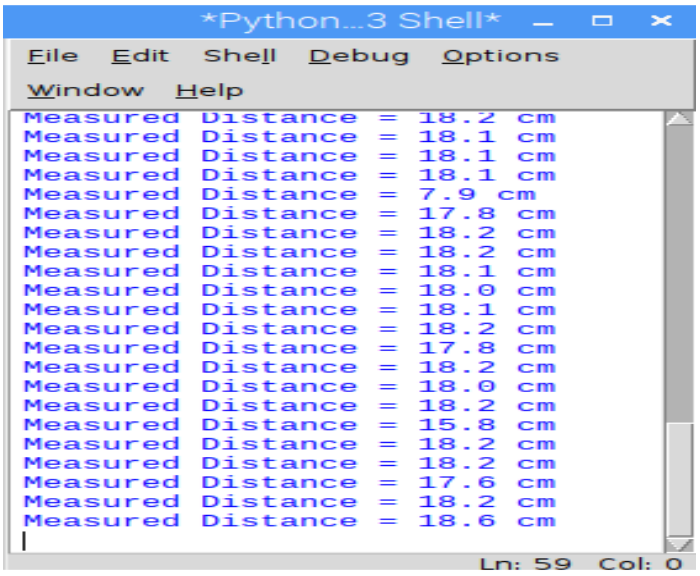

Fig-5.1: Output of Ultrasonic Sensor

After selection of sensors we need a device which can perform three activities like hardware interface between different sensors, computational ability and network interface for transmitting data or result to desired destination(that is cloud system). For this reason we are using Raspberry Pi 3B+ unit as main computing device. This Raspberry Pi have debian based light weight Operating System with clock speed of 1.4 GHz, four core and RAM of 1 GB. This device can receive the data from sensors, process it

using fuzzy logic which is written using python 3.5 and able to send this data to cloud server.

Below is the screen shot of fuzzy logic output.

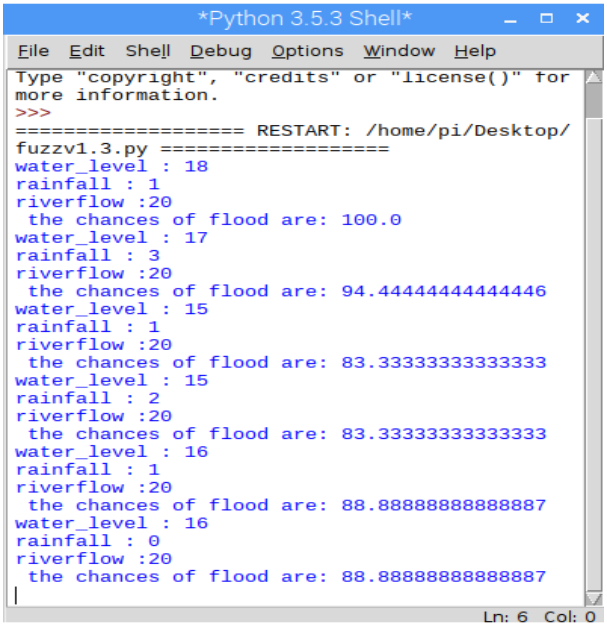

Fig-5.2: Output of Computing Unit

The idea of a fuzzy set is basically an extension of the classical set theory. In the determining set (crisp), the value of an item x in A on set. Membership function (MF) is a curve that shows the drawing points of inclusion in membership numbers with an interval between 0 and 1.

Fuzzy inference system method of Takagi-Sugeno-Kang (TSK) is a method for the fuzzy inference rules are represented in the form of IF - THEN, where output (consequent) system does not form fuzzy set, but in the form of a constant or linear equations

5.1 Fuzzy Logic

In this section how fuzzy logic is applied on this system is discussed. The first thing is to make membership function of each input that is membership function for surface water level and rainfall. These are the two inputs we are applying to get the result.

Method of investigation – In this section how input data for computing unit is collected, how that input get processed and output how output is developed all these things are discussed. Basically computing unit collects data from four sensors and this data is provided as input to the fuzzy system and only one output is generated that is flood chances in percentage form.

5.2 Simulation Technique

Computing unit means Raspberry pi unit is already having operating system on it. It also equipped with fuzzy logic system which is written using Python 3.5. This computing system accepts data from four sensors as input and produce output as flood occurrence chances in percentage form. By using matpotlib library of python it is possible to plot graphical representation of all the sensor data as well as graph of output that is flood situation. Also we use scikit-fuzzy package which is quite helpful to deal with problems which includes fuzzy logic system. After output is generated our computing unit is able to send this output to cloud system for further investigation.

5.3 Fuzzy Logic System and Rules

Rainfall	Water flow	Soil moisture	Water level	Flood Chances
Poor	Good		Poor	***Low***
Average	Average		Average	***Medium***
Good	Poor		Good	***High***
Poor		Poor	Poor	***Low***
Good		Good	Good	***High***

Table-5.3.1: Linguistic rules for fuzzy logic .

5.4 Output from Fuzzy Logic System

When the sensor data like ultrasonic sensor, rainfall sensor etc is available to fuzzy logic then it compute the result to predict the chances of flood in percentage form also we are able to map this output in graphical form.

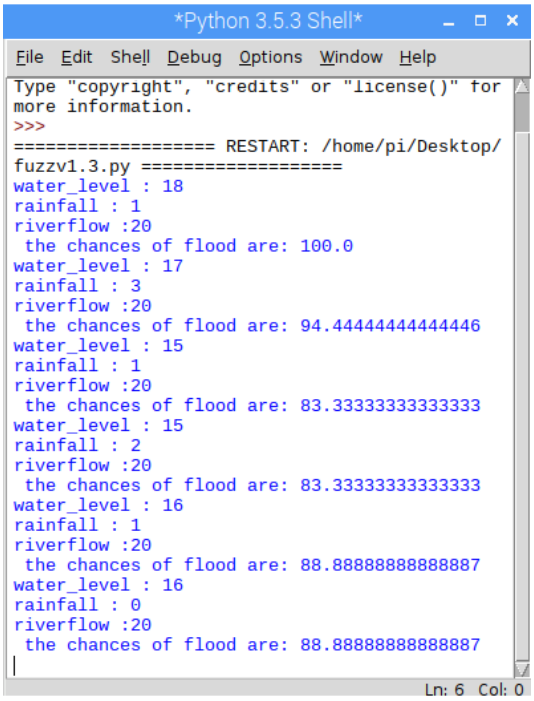

Fig-5.3: Output of Computing Unit

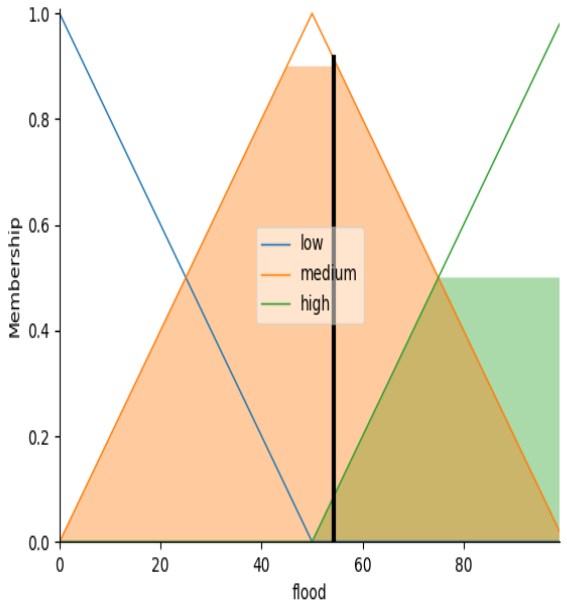

Fig-5.4: Output of Computing Unit in Graphical Form

6. CONCLUSION

This paper includes two distinct hardware parts namely computing unit (Raspberry Pi unit) and various sensors namely rainfall sensor, soil moisture sensor, water flow sensor, water level sensor. Data sensed by all these sensors is gathered in the computing unit where the result is produced using Fuzzy Logic System that is how much is the probability of flood consequences are there? In this system excluding LoRa based soil moisture sensor is only the wireless sensor and rests of the sensors have wired connection with computing unit. The output of this system can be used to alert the needy people when there is probability of flood situation.

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