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Flood monitoring and community based flash flood warning system for flood prone region

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Abstract. Flooding is one of the major disasters occurring in various parts of the world. Due to the high density of buildings, flash floods are prevalent in cities. Floods in India is a huge obstacle to achieving economic growth in the country. Monsoon induced Flash floods hit the Southern Coast of India every year. The flood destroyed thousands of houses and swept some of them down into the sea killing hundreds of peoples, injured many, along with causing several landslides. Southern Coast of India Flood marked in a row of severe monsoon flooding. As a solution to this problem, this proposed work an approach to develop a hypothetical flood alarming system. This research work discusses a proposed solution for the problem by alerting the residents to move to safety before water level rises and also to take necessary precautions to reduce the local risk of flooding via mobile phone which is sent through Short Message Service (SMS) using GSM module. The rainfall and discharge values (flow rate) of the flood affected area are collected and sorted on the daily values. From the rainfall values, flow rate is calculated. It has been observed and estimated discharges were compared analytically and graphically using IoT (Arduino UNO) system.

1 Introduction

Flood occurs when water overflow from the rivers, lakes, tanks are due to heavy rainfall or failure of some dams with a sudden release of huge amount of water and it can happen at any time of the year. Flooding can be very dangerous, when floods happen in an area that people live, the water carries along objects like houses, cars, furniture and even people. It can wipe away property, trees and many more heavy items. Floods can completely disturb the human life and the economy, which depends upon the agriculture. Therefore, proper alert forecasting makes the farmer to protect the crop from flooding.

Floods can cause widespread devastation, resulting in loss of life and damages to personal property and critical public health infrastructure. As per the study by World Health Organization, between 1998-2017, floods affected more than 2 billion people worldwide. People, who live in floodplains or non-resistant buildings, or lack warning systems and awareness of flooding hazard, are most vulnerable to floods. Between 80-90% of all documented disasters from natural hazards during the past 10 years have resulted from floods, droughts, tropical cyclones, heat waves and severe storms. Floods are also increasing in frequency and intensity, and the frequency and intensity of extreme precipitation is expected to continue to increase due to climate change. There are 3 common types of floods. Flash floods are caused by rapid and excessive rainfall that raises water heights quickly, and rivers, streams, channels or roads may be overtaken. River floods are caused when consistent rain or snow melt forces a river to exceed capacity. Coastal floods are caused by storm surges associated with tropical cyclones and tsunami.

As climate change increasing the frequency and severity of floods around the world is also intensifying. Therefore, adaptation is becoming extremely important. Besides structural measures to mitigate flood risk, non-structural measures are known to be highly effective and low-cost.

1.1 Case Study

Kerala is situated between the Arabian Sea to the west and the Western Ghats to the east. The topography consists of a hot and wet coastal plain gradually rising in elevation to the high hills and mountains of the Western Ghats. Kerala climate is mainly wet and maritime tropical, heavily influenced by the seasonal heavy rains brought up by the monsoon. There are 44 rivers in Kerala, all but three originating in the Western Ghats. 41 of them flow westward and 3 eastward. The rivers of Kerala are small, in terms of lengths, breadth and water discharge. The rivers flow faster, owing to the hilly terrain and as the short distance between the Western Ghats and the sea. All the rivers are entirely monsoonfed and many of them shrink into rivulets or dry up completely during summer.

1.2 Floods in Kerala

The disaster of South-west monsoon has wreaked havoc in Kerala. Heavy flooding in the past decades has

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drowned many districts in Kerala and caused the deaths of many people. About a million people were evacuated, mainly from Wayanad, Malappuram, Kannur, Kuttanad, Chengannur, Idukki, Pathanamthitta, Thrissur, Palakkad, Aluva, Chalakudy, Eraviperoor, Ayiroor, Thiruvalla, North Paravur. All 15 districts of the state were placed on red alert during the floods in last few years.

The intense monsoon rain from the south-west causes rivers in Kerala to swell their banks, which in turn floods the adjacent areas. Rainfall of high intensity with long duration and its frequency are the main causes of flood. In addition, maintenance and management of dams, deforestation of hill areas causes sudden rising of water as cutting of trees reduces the water carrying/storing capacity of ground and can lead to flooding in Kerala. The heavy rain in the early part of monsoon-filled dams of its capacity and due to release of excess water made the situation worse that lead to the devastating flood in Kerala. The effects of these floods have damaged property and the disaster took the lives of people living near the coastal areas and the lives of the people during the rescue operation. Problems like this can be prevented by warning directly to the public especially those living near the coastal areas. The problem of flood is one of the main concerns now a day. Therefore, its need of much quicker and advance system to let the people know before the destruction occurs.

Fig. 1. An aerial view of flood in Kerala.

2 Early flood warning system

The aim of this project work is to give the society an early alert to move before the water rises and also to reduce the risk of flooding via mobile phone which is sent through Short Message Service (SMS) using GSM module. The rainfall and discharge values (flow rate) of the flood-affected areas is collected and sorted all the daily values. From the rainfall values, flow rate is calculated. Observed and estimated discharges were compared analytically and graphically. Using observed flow rate, inflow and outflow the IoT (Arduino UNO) has developed. The Ultrasonic sensor, Arduino UNO, GSM modem and LCD display are the hardware's used in the system. Arduino UNO collects the data from the ultrasonic sensor and these are displayed on LCD and transmit the data to send the alert using GSM modem through SMS via mobile phone to the recognized residents. Since majority of the people in Kerala uses mobile phones, it is a good strategy to give an early warning to the society through SMS as it is the most effective way to this point of view [1]. Therefore, the society will be alerted and better prepared to face the disaster nearest to their home.

3 Methodology

3.1 Discharge calculation

With the available data that were collected, estimated discharge was calculated using Curve number method. The curve number method is a simple, widely used and efficient method for determining the approximate amount of runoff from a rainfall even in a particular area. Although the method is designed for a single storm event, it can be scaled to find average annual runoff values. The stat requirements for this method are very low, rainfall amount and curve number. The runoff curve number is based on the area's hydrologic soil group, land use, treatment and hydrologic condition. The CN runoff equation is as follows:

$$Q=((P-0.2S)^2)/(P+0.8S) \text{ for } P>0.2S \quad (1)$$

Where, Q=Runoff in mm P=Rainfall in mm; Ia=Initial abstraction; S=Potential maximum retention after runoff begins.

$$CN=25400/(254+S) \quad (2)$$

Where, CN is Curve Number Curve Number (CN) is dimensionless number ranging from 0 to 100. The value of CN number was taken as 65.

Initial Abstraction (Ia) Ia is the amount of water before runoff, such as infiltration, or rainfall interception by vegetation. Historically it has generally been assumed that Ia=0.2S.

Antecedent Moisture Condition (AMC): The soil moisture condition in the drainage basin before runoff occurs is another important factor influencing the final CN value. In the Curve Number Method, the soil moisture condition is classified in three Antecedent Moisture Condition (AMC) classes: AMC I : The soils in the drainage basin are practically dry. AMC II : Average condition AMC III : The soils in the drainage basins are practically saturated from antecedent rainfalls. Table 1 gives a summary of all classes based on the 5-day antecedent rainfall (i.e. the accumulated total rainfall preceding runoff under consideration.

Table 1. Classification of Antecedent Moisture Condition (AMC).

AMC Class	Total five day antecedent rainfall(mm)	CN value
AMC I	<27.5	CN dry
AMC II	27.5-53	CN
AMC III	>53	CN wet

3.2 Calculation for flood frequency

India Basic to all frequency analyses is the concept that there is a collection of data, called the ‘population’. For flood frequency studies, this population are taken as the annual maximum flood, occurring at a location on a river (called the site). Since the river has flooded during the past years and is likely to go on flooding over the coming years (unless something exceptional like drying up of the river happens!), the recorded flood peak values which have been observed for a finite number of years are only a sample of the total population. Here, ‘flood peak’ means the highest recorded discharge value for the river at any year.

Flood frequency analysis starts by checking the consistency of the data and finding the presence of features such as trend, jump, etc. Trend is the gradual shift in the sample data, either in the increasing or decreasing directions [2]. This may occurs due to human interference, like afforestation or deforestation of the watershed. Jump means that one or a few of the data have exceptional values – high or low, due to certain factors, like forest fire, earthquake, landslide, etc which may change the river’s flow characteristics temporarily.

The next step is to apply a convenient probability distribution curve to fit the data set. Here, it is assumed that yearly observed peak flow values are random numbers and which are also representative of the population, which includes all flood peak values, even these which have not been recorded or such floods which are likely to happen in future. Each data of the set is termed as a variate, usually represented by ‘x’ and is a particular value of the entire data range ‘X’. The probability of a variable is defined as the number of occurrences of a variate divided by the total number of occurrences, and is usually designated by ‘P’. The total probability for all variates should be equal to unity, that is, $\sum p=1$.

Distribution of probabilities of all variants is called Probability Distribution, and is usually denoted F(x) as shown in Figure 2 and the cumulative probability curve; F(x) is of the type as shown in Figure 3.

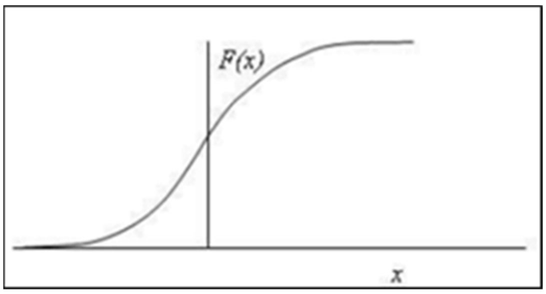

Fig. 2. A typical probability distribution.

The cumulative probability, designated as $P(x \leq x)$, represents the probability that the random variable has a value equal to or less than certain assigned value x is equal to $1 - P(x \leq x)$, or $P(x \geq x)$. In the context of flood frequency analysis, we may use the above concepts by assuming the recorded yearly flood peaks as the variate ‘x’. Then, if the functions f(x) or F(x) becomes known, then it is possible to find out the probability with which certain high flood peak is likely to occur. This idea may be used to recalculate the high flood peak that is likely to be equaled or exceeded corresponding to a given frequency. Which one of these fits a given data set has to be checked using certain standard statistical tests. Once a particular distribution is found best, it is adopted for calculation of floods likely to occur corresponding to specific return periods.

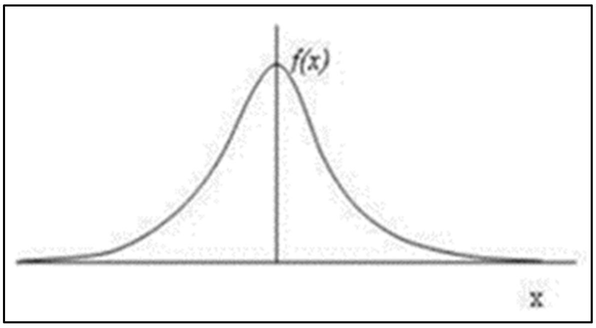

Fig. 3. Cumulative probability curve.

4 Design and development of flood warning system

4.1 Hardware used

The hardware’s used for the development of Hypothetical flood warning system [3], are shown in Figure 4.

1. The Arduino UNO: it UNO is a microcontroller board. It has 14 digital input/output pins. The Arduino Uno can be powered via the USB connection or with an external power supply. External (non-USB) power can come either from an AC-to-DC adapter or battery.
2. The ultrasonic sensor will give the accurate distance with minimum error possible. It consists of four pins; those are VCC, GND, TRIG, ECHO pins. Ultrasonic sensor includes ultrasonic transmitters, receiver and control circuit. It uses power supply from the adaptor used by Arduino UNO. It produces sound waves in each 20 microseconds. The emitted sound waves are at high frequencies that a human can’t hear. When the sound waves are emitted and when they hit any object or obstacle (water) then the sound waves get reflected back to the ultra-sonic sensor [3]. (Labo et al ,2016) The ultra-sonic sensor will calculate the time duration between emitted and reflected sound waves and with that time it can tell at what distance the object or obstacle is located (water level).
3. LCD Display: LCD Modules can present textual information to user. It is like a cheap “monitor”. They come in various types. The one we used is 16x2 LCD Module. It has 2 rows and 16 columns.
4. GSM Modem: SIM800L Module is a small GSM/GPRS Module and ideal for small ideal projects. The module sup-ports quad-band GSM/GPRS network, available for SMS. The SIM800L can work up to 2Amps current at peak

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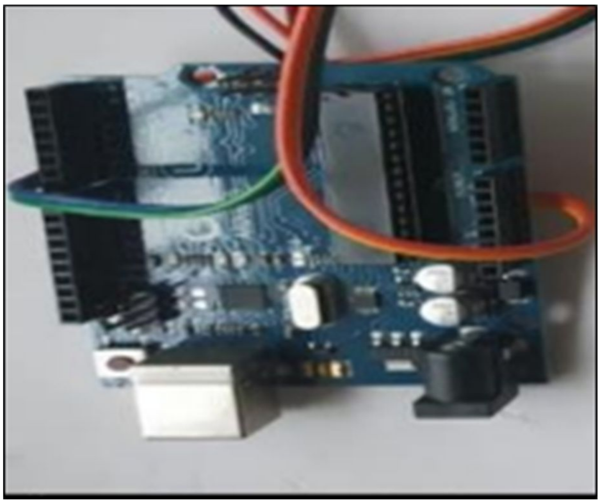
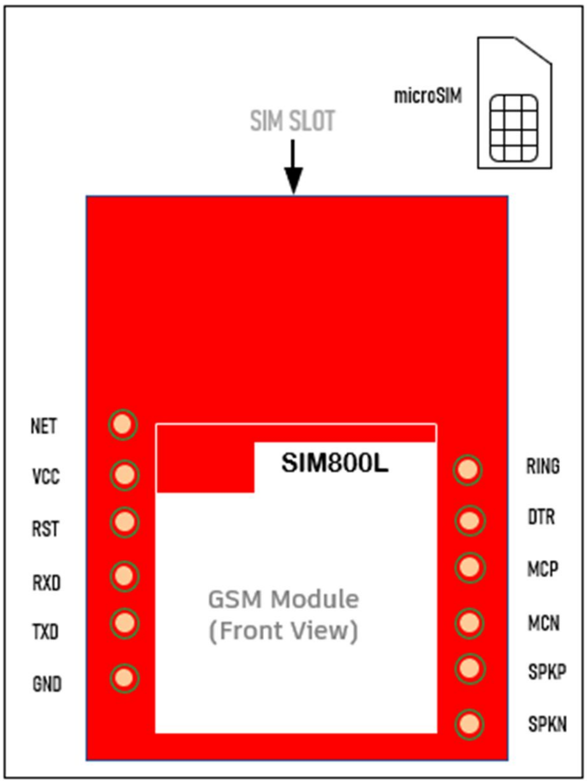


(a)

(b)

(c)



(d)

Fig. 4: Arduino UNO; Ultrasonic Sensor; LCD Display; GSM modem.

4.2 Working of flood warning system

The hypothetical flood warning system alerts the resident nearby the river area through SMS. The Arduino UNO micro-controller is used to control the whole system [4]. Once the power supply is given, the ultrasonic sensor determines the water level and the values would be displayed on the LCD display. The water level would be compared with the hypothetical threshold value which is set and if the current water level crosses the set threshold value, the microcontroller would enable SMS to be sent to residents to alert them via GSM modem [5].

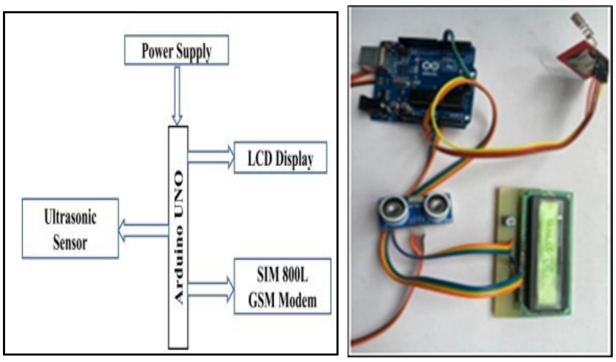


Fig. 5. Block diagram of flood warning system & connection setup of hardware's.

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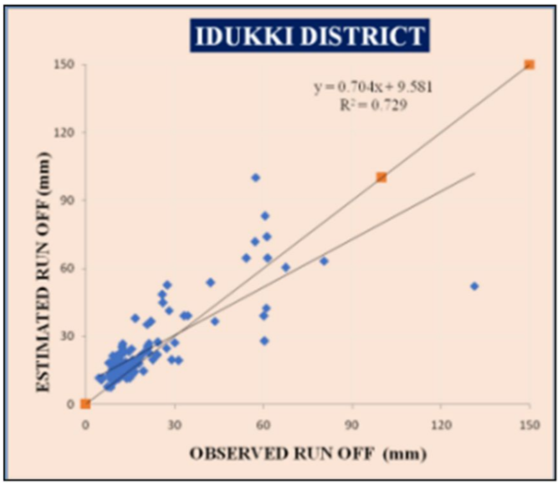
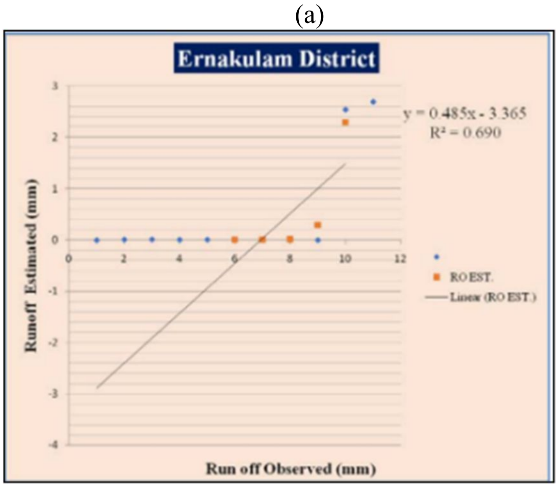
5 Design and development of flood warning system

The graph for the estimated and observed run off was plotted for three districts; Idukki, Ernakulam and Wayanad.



(a)



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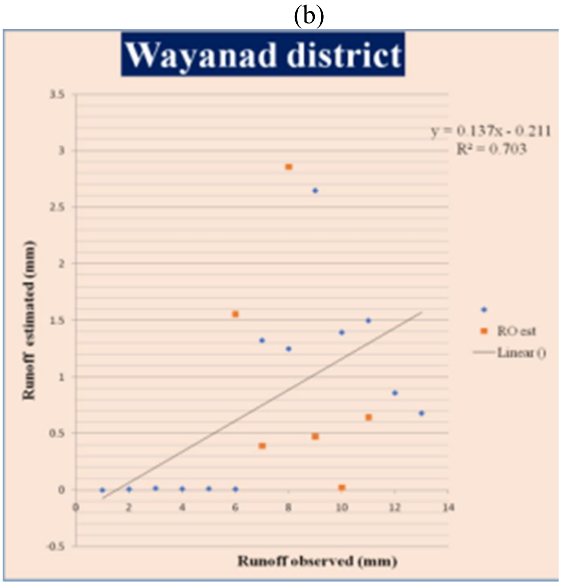

(c)

Fig. 6. Scatter plots of estimated runoff versus Observed runoff for Idukki, Ernakulam and Wayanad.

From the Figure 6, it was observed the value of *R*2 was less than 0.8. This inferred that there is no co-relation between the estimated runoff and observed runoff values that were compared due to the missing values in data. Based on the analysed data, a hypothetical threshold level was set (7 inches) for the functioning of hypothetical flood warning system. For real implementation, considering river geometry and reservoir geometry and the accurate rainfall data for at least past 20 years and flood discharge data, threshold value would be set as 50%, 75%, and 100%. Once the water level in the reservoir crosses the threshold level, flood alert would be sent.

(a)

(b)

(c)

Fig. 7. Testing of the developed flood monitoring system.

After the analysis of the data was done, a model was developed to check the suitability of the system. (Chanderki et al, 2018). The ultrasonic sensor is placed at the top of the bucket. Here, the bucket is considered as the reservoir. Once the water is poured into the bucket the sensor senses the water level and values are displayed on the LCD display. In the Figure the distance i.e. water level is displayed in cm and inches. A hypothetical threshold level was set as 7 inches. Again, the water is poured into the bucket. When the water level crosses the threshold level, it will be displayed on the LCD display. Finally, the SMS alert is sent to the Smartphone using GSM modem. (Shah et al, 2018). For real implementation, the contact numbers of all the residents living in the flood prone areas can be collected and hence the flood-warning alert can be sent to all the residents of that area.

6 Conclusion

For a sub-tropical monsoonal state like Kerala characterized by heavy rainfall, it is important monitor and receive timely emergency alerts about the flow of water and water level situation based of the riverbed. Development of flood warning system enlightens the confidence to provide an alert system through SMS to overcome the flood risk. It acts as a precautionary action for the victims in preventing loss of lives, trauma from disaster and property from damage using Flood warning system. Flood warning system is the promising technique in flood prone areas where lack an alert system to alert people to save their lives.

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