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Development of flash flood warning system for Nkpolu road, Rumuigbo in Port Harcourt Metropolis

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Abstract
The most hazardous type of floods are flash floods, which combine the devastating force of a flood with extremely high speeds. This project entails creating a flash flood warning system that can identify floods and instantly notify drivers plying Nkpolu Road in Rumuigbo, Port Harcourt, using a mobile device. Soil samples collected from Nkpolu Road were transferred to the laboratory and examined, along with rainfall data collected from the Nigeria Meteorological Agency (NIMET). On the basis of the examination of the soil samples and rainfall data, the measurement apparatus was constructed. The HC-SR04 ultrasonic sensor, the SIM900L data transmission module, the DFRobot gravity pH sensor, the SHT20 soil temperature/humidity sensor, and the Arduino microcontroller are all integrated into the system. According to the analysis, the soil types on Nkpolu Road are sandy loam and loamy sand, and the intensity of the rainfall is often highest between July and September.The system on Nkpolu Road was designed to send out warning messages via a mobile device every six minutes and to identify flash floods when it rained. When the rain started to come down, the alerts would progress from saying "no flooding" to "minor flooding," "moderate flooding," and eventually "severe flooding." They would then send out warnings in real time as soon as each degree of flooding was determined. The warning that day that it rained was "no flooding". When it didn't rain at all, no warning signal was sent. When the Nkpolu Road floods, this technology helps drivers avoid the area and instantly switch to another route that is open.

Keywords: Flood, flooding, flash flooding, river state Nigeria, flash flooding warning system, mobile device, rainfall

Introduction

Generally speaking, one of the most hazardous natural disasters that the world has to contend with is floods. Numerous factors influence the extent of damage caused by flooding as well as an area's susceptibility to it. Because flash flooding has such severe environmental consequences on a community, it is critical to determine the flooding status and come up with a plan for alerting the relevant parties ahead of time so they can make necessary preparations and not be caught off guard.

Flash floods, as defined by the National Weather Service (2017), occur when low-lying areas such as washes, rivers, dry lakes, and depressions rapidly fill with water. A hurricane, tropical storm, or strong thunderstorm may produce a lot of rain, and ice sheets and snowfields may be covered in a cascade of melted snow. Both natural ice or debris dam collapses and man-made structures like dams can result in flash floods. Flash floods vary from typical floods in that the period of time between the beginning of the rain and the beginning of the flooding is less than six hours. Rainfall is more and more intense in West African parts of Africa than it is in snowy ones.Many changes in land use can lead to modifications in hydrological systems, which are one of the causes of the danger of floods. Deforestation caused by the logging industry, urbanisation brought on by development, and the elimination of wetlands all contribute to the basin's increased runoff and decreased water accumulation. Urbanisation raises the risk of flash floods and increases the amount of impermeable surfaces (like parking lots, sidewalks, and roadways). Flash floods have a detrimental effect on both the built area and the natural ecology. In addition to having a wide range of detrimental side effects on plants, human and animal life, and livestock, flash floods have the potential to wreak catastrophic damage to structures and infrastructure. Consequences in urban environments are particularly difficult (Diakakis *et al*., 2020).

Flash floods have killed a great number of humans and animals. More individuals are getting hurt, and some of them lose their homes. The disruptions to the electricity and water supplies cause stress and suffering for people. Flu, dysentery, dermatographia, and pneumonic plague are just a few of the illnesses and infections that may spread by floods. Insects and snakes will occasionally wander into the area and wreak devastation.

Lately, several scholars have developed a range of methods to decrease the harmful consequences of flash floods in different regions. Most of the suggested fixes focus on alerting locals in advance of the possibility of flash flooding at a specific time so that suitable precautions may be taken. Only a non-linear approach may be used to address the non-linear flash flood monitoring and detection scenario. Modern methods are based on linear control systems, including proportional integral (PI), proportional integral derivative (PID), and others. Evidently, real-time detection and monitoring necessitates the deployment of a non-linear controller, such as a system constructed using predictive modelling, as the object being detected and monitored is non-linear in nature.

Frankenfield (2022) defines artificial intelligence (AI) as the imitation of human intellect in computers designed to think and behave like people. The capacity of a machine to simulate brain activities, such as learning and problem-solving, is known as artificial intelligence.

The capacity to think and perform actions that maximise the likelihood of accomplishing a given objective is the ideal quality of artificial intelligence. The idea that computer programmes can automatically learn from and adapt to new data without the assistance of humans is known as machine learning (ML), a subset of artificial intelligence (Frankenfield, 2022).

A statistical method called predictive modelling makes use of data mining and machine learning to forecast and predict possible future events. It uses both current and historical data to do this. It works by comparing data from the past and the present and extending what it learns to a model designed to forecast future events (Rami, 2020).

This paper suggests using predictive modelling to create a warning system for flash floods.

The globe is in danger due to numerous environmental issues (Christopherson, 1997; Oyegbile, O., 2008). Kolafe *et al*. (2015) state that flooding is thought to be the most catastrophic natural disaster on Earth. Flooding happens when an excessive amount of water rushes over normally dry terrain (Djimesah *et al*., 2018). This can happen when rainfall exceeds the soil's capacity to hold it down (Nwachukwu *et al*., 2018). As stated by Peduzzi *et al*. (2009), "the rate of flood occurrence in recent times has been unprecedented," with over 800 million people living in flood-prone areas and 70 million people annually exposed to floods. According to Rentschler and Salhab, flood disasters happen once every 100 years, and at those times, 14.7 billion people, or 19% of the world's population, are directly exposed to serious risks. Destructive floods have been a major calamity ever since the dawn of humanity. Usually located along to waterways, they have towns that are in danger of being destroyed. Since floods are a natural event, they happen frequently. Despite all attempts at flood management, the threat of flooding has not been totally eliminated, and it is unlikely that it ever will be, as flood defenses sometimes fall short of offering comprehensive protection. The average annual damage due to flooding has risen to several billion US dollars worldwide. Certain recent floods have shattered records for both total material losses (social and economic qualities) and absolute record stages (geophysical aspects) when compared to floods during the period of observational data. Each year, floods claim thousands of lives. There are several kinds of floods, each with special traits and a long history of precautionary actions taken by people. There are river floods that reach a continental scale (produced by rainfall, snowmelt, or a combination of the two), debris flows, floods in deltas threatened by storm surges, ice jam floods, and dam breach floods. The world's expanding urbanization, the expansion of settlements into flood-prone areas, and our over-reliance on the protection offered by flood control projects like levees and reservoirs are all contributing factors to the potential for flood damage. Small and medium-sized floods are often protected from by dikes; that is, the frequency of floods in this range is declining. However, the losses in a levee-protected landscape surpass those in a natural one when a disastrously large flood occurs and the dikes fail. Due to their flatness, fertile soil, and close proximity to water, flood plains—which are also prone to development—are areas where anthropopressure produces a desire to consume more land. Other factors contributing to an increased danger of flooding include a rise in the percentage of impermeable land, deforestation, and improvements made to channels, such as straightening water courses. Overall, there is an increase in the runoff coefficient, a quicker and higher hydrograph peak (the system's reaction to heavy precipitation), and a faster rate of water, sediment, and other material erosion and movement. Development has spread to steep slopes in mountainous areas that are vulnerable to debris flows and landslides. The issue is getting worse in steep places as a result of road construction, residential area development, and deforestation. Numerous catastrophic floods have occurred recently throughout the world are discussed in further detail in this contribution.

There are five different types of floods, according to the National Severe Storms Laboratory. These consist of:

1. River Flood
2. Coastal Flood
3. Storm Surge
4. Inland Flooding
5. Flash Flood

The foregoing list should have made it clear that flooding can occur anywhere, both inland and along the coast.

River Flooding

A river flood occurs when water levels exceed the tops of the riverbanks. Any river or stream channel has the potential to flood. This includes all bodies of water, from little streams to the largest rivers on the planet.

Causes of River Flooding

River flooding has four primary causes. These are the following:

1. Heavy rains brought on by tropical storm systems that fall on land
2. Extended periods of time when the same area is consistently covered in thunderstorms
3. Rainfall and snowmelt combined
4. Jam made with ice

River floods can happen suddenly or gradually. Sudden river flooding events are more likely to occur in smaller rivers, steeply valleymed rivers, rivers that flow across impermeable terrain for a considerable amount of their course, and usually dry channels. Low-rising river floods, on the other hand, usually happen in big rivers with big catchment basins. Any area of land where precipitation gathers and flows off into a shared outlet is known as a catchment area.

Coastal Flood

Coastal flooding is the inundation of typically dry land areas near the coast with seawater.

Coastal Flooding's Causes

Coastal flooding is often caused by a combination of high winds, barometric pressure, and sea tidal surges. Typically, storms at sea result in certain circumstances, like:

1. Hurricanes in tropical areas
2. The Great Wave
3. Higher than normal tides

Storm Surge

Another type of flooding that is commonly linked to coastal flooding is storm surge flooding.

Storm surge is the term for an atypical rise in the water level in coastal areas that is higher than the average astronomical tide.

Causes of Storm Surge

Storm surge is usually caused by weather-related storms that bring higher-than-normal tides along the shore. There are three components to this surge. They are as follows:

1. The Air
2. Waves in the Ocean
3. A decrease in air pressure

Storm surge-related flooding is quite risky. Large coastal regions can be simultaneously flooded by it.

Moreover, flooding can occur shortly as a result of it. High tides combined with storm surges cause very serious flooding. This may cause storm seas to rise as high as twenty feet! The most dangerous aspect of any tropical cyclone is storm surge, meteorologists stress once more. It poses the greatest risk to people's lives and property.

Inland Flooding

Inland flooding is referred to as urban flooding by certain organizations. Another kind of inland flood is a flash flood. Any flooding that happens inland, away from the shore, is referred to as an inland flood. Storm surge and coastal flooding are therefore not considered inland floods.

Causes of Inland Flooding

Inland floods are nearly invariably caused by rainfall. Inland flooding is caused by rain in two ways. It might occur as a result of a brief but heavy downpour or as a result of consistent rain over several days. Inland floods are also caused by snowmelt, however rainfall is a more frequent culprit. Inland flooding can also occur when dams, ice, or debris obstruct waterways. Urban areas are frequently more vulnerable to inland floods due to the lack of outlets for the water to escape. The following urban characteristics have the potential to either cause or worsen inland flooding:

1. Paved streets and roads
2. Low-volume drainage apparatus
3. Dense structures
4. Insufficient green space

Flash Flood

One of the most catastrophic kinds of flooding is called a flash flood, and it usually results from very heavy rain falling quickly (NWS, 1995). Water released from the rain in six hours could not be absorbed by the soil due to the little duration and high intensity of the rain. The inability of the canals to drain this runoff, depending on the condition and size of the basin, could result in flooding that could be disastrous (Grunfest, 1998; Messner and Meyer, 2015). Scholars define flash floods in a number of ways, such as storm-driven phenomena or hydro-meteorological events. When everything is taken into account, a flash flood is defined as an exceptionally strong downpour that is followed by six hours of abrupt, catastrophic, and destruction (Lóczy, 2010). River flooding has historically caused the most damage from floods, but in recent years, it appears that attention has shifted to flash flooding due to its clear destructiveness, abruptness, unpredictability, and frequency. Given the aforementioned, it is imperative that flash flood hazard assessment be approached differently with respect to method, data, and processes because of topographic and general factors (Czigány *et al*., 2010; Zhang *et al*., 2001). Flash floods are always associated with other forms of flooding; they never happen in isolation. It's possible for one to trigger the other, in which case both might work together. Flash floods may cause landslides, river flooding, and other related but unanticipated phenomena (Iverson, 1997). Rainfall that triggers a flash flood is typically fairly strong, able to swiftly wet the surrounding ground, and able to carry the majority of objects with it as it flows off (Kofo, 2012). The short duration of a storm occurrence causes the water released from the heavy rain to cover the land so quickly that the channels and basins cannot accommodate the large volume of water within the brief period of time. Furthermore, it might raise the stream's level to the point where the rushing water back upstream floods the surrounding area (Creutin and Borga, 2003; Collier, 2007). Flash floods are characterized by the destruction of highways, bridges, culverts, and other physical structures due to their quick movement and the weight of their load. Farmlands are submerged in water and debris during floods, which kills crops and other vegetation. It also releases hazardous chemicals from flooded chemical industries and sewage from vulnerable septic tanks. Given that the discharged water may contain animal excrement, chemical emissions, and faeces, public health issues could develop in addition to the spread of several diseases caused by the release of different pathogens (Kofo, 2012; Cutter, 1996). A flash flood is the most frequent and damaging type of flood. Flash floods can happen anywhere from a few minutes to several hours following a period of intense rain or an unplanned dam breakdown (NOAA, 1992). Experts say that after a significant downpour, flash floods usually occur six hours later. It happens in urban areas, along water channels, and in steep terrain and is linked to little warning (USDA, 2010). Furthermore, metropolitan centers were severely harmed by flash floods that happened in dry areas without stream courses. The extent of damage depends on how close the area is to the river channel. Stated differently, the effects of flash floods diminish with greater distance. The flash flood disaster was made worse by impervious surfaces and an inadequate drainage infrastructure (Menne and Murray, 2013; Mohammed, Worku, and Sterk, 2012). Urbanization results in impermeable surfaces because of the construction of roads, buildings, bridges, and recreational areas, all of which hasten runoff.

Causes of Flash Floods

Numerous factors can lead to flash floods. The majority of flash floods occur during brief but intense thunderstorms that produce a lot of rain in as little as six hours. Two essential components are needed to assess the likelihood of flash flooding:

1. Rate of rainfall
2. Duration of rainfall

Flash floods can also occur as a result of levee failure, dam failure, or the large-scale discharge of water from an ice jam.

Dangers of Flash Floods

The force of flash floods is immense. They are capable of uprooting trees, toppling boulders, demolishing bridges, and scouring new paths. Violent floods that rip through city streets, riverbeds, and canyons, destroying everything in their path, are the hallmark of this type of flooding. Waves as high as thirty feet can submerge entire communities during flash floods. Another reason why flash flooding is so deadly is that it can happen suddenly and without warning. This is particularly true in cases where dams or levees break. The US National Weather Service suggests being aware of the flood hazard in your neighbourhood before a flash flooding storm happens. In addition, they recommend creating an emergency plan for your family or company in case of a flash flood.

Materials and methods

The flash flood warning system proposed in this chapter consists of an Arduino MEGA 2560 microcontroller, a SIM900L module for data transmission to a mobile device for receiving alerts, and an HC-SR04 ultrasonic sensor, DFRobot Gravity pH sensor, and SHT20 soil temperature/humidity sensor. The system is designed to measure water levels in real time and provide early warning alerts to people using flash flood-prone roads.

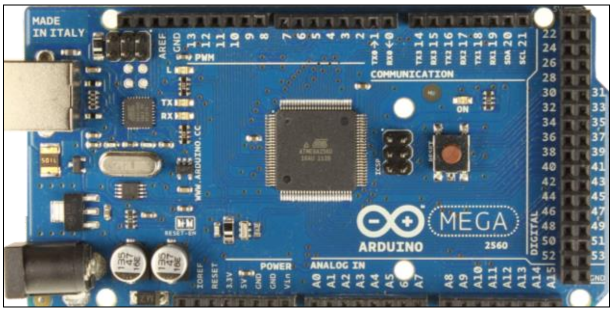

Fig 1: Arduino Mega 2560 (Arduino.cc)

The Arduino MEGA 2560 microcontroller is used to read the distance measured by the sensor, convert it to water-level measurements, and check if the water level exceeds a predefined threshold, which indicates a potential flash flood risk. If the water level exceeds the threshold, an alert is triggered, and the SMI900L module transmits the alert to a mobile device.

Fig 2: HC-SR04 ultrasonic sensor (Sheldon, 2022)

The HC-SR04 ultrasonic sensor is mounted on a pole above the water surface, and its position is calibrated so that the sensor faces the water at a perpendicular angle. The sensor sends out an ultrasonic wave, which travels toward the water's surface and reflects back to the sensor. The time taken for the wave to travel to the water surface and back to the sensor is measured and used to calculate the distance between the sensor and the water surface.

SIM900A GSM Module

The SIM900A GSM module was integrated into our system to enable real-time communication and SMS notifications. This module is responsible for sending alerts to relevant parties in case of flooding.

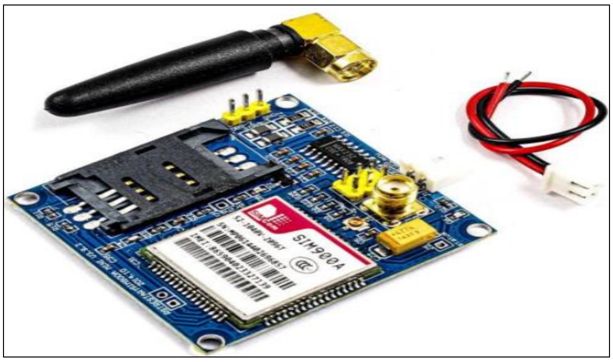

Fig 3: SIM900A GSM Module (Sheldon, 2022)

The following materials were used in the flash flood warning system:

1. **Arduino Mega 2560 Board:** The Arduino Mega 2560 is a microcontroller board with an ATmega2560 microcontroller at its core. It offers a large number of digital and analogue input/output pins, making it suitable for complex projects. It also offers the required computing power and interfaces to connect and control various sensors. The Arduino Mega will act as the system's brain.

2. **HC-SR04 Ultrasonic Sensor:** The HC-SR04 is an affordable and widely used ultrasonic sensor that measures distances by emitting ultrasonic waves and calculating the time it takes for the waves to bounce back. In our system, the HC-SR04 will be used to measure the water level in a particular area susceptible to flash floods.

3. **SIM900L GSM Module:** The SIM900L GSM module will be in charge of communicating the water level data obtained by the HC-SR04 sensor to a mobile device over the Global System for Mobile communication (GSM) network.

4. **DFRobot Gravity pH Sensor:** The DFRobot Gravity pH sensor, which measures a solution's acidity or alkalinity, can be used to analyze the pH levels of soil, revealing important details about the soil type.

SHT20 Soil Temperature/Humidity Sensor: The SHT20 sensor provides precise readings of soil temperature and humidity, which are essential for comprehending soil moisture content and the likelihood of flash floods.

System Architecture

The flash flood warning system architecture involves the following steps:

1. **Sensor Connections:** Connect the DFRobot Gravity pH sensor, HC-SR04 ultrasonic sensor, SMI900L and SHT20 soil temperature/humidity sensor to the Arduino Mega 2560 board. Ensure that the sensor pins are correctly connected to the appropriate digital or analog input pins on the Arduino board.

2. **Sensor Data Acquisition:** Use the appropriate libraries and code to read data from the HC-SR04 ultrasonic sensor, pH sensor and SHT20 sensor. The libraries provide functions to interface with the sensors and retrieve accurate measurements of water level, pH, temperature, and humidity.

3. **Power Supply:** 2000mAh Battery A reliable power supply is essential for the continuous operation of our flash flood warning system, especially in remote or flood-prone areas where the electrical grid may be unreliable. We employ a 2000mAh rechargeable battery to power the system. This high-capacity battery provides extended runtime, ensuring that the system remains operational even in the absence of grid power. Additionally, the system incorporates power-saving mechanisms to optimize battery life, such as sleep modes and low-power sensor operation.

4. **Data Processing and Analysis:** Process the sensor data obtained from the Arduino board. Use algorithms and calculations to analyze the collected data. Calculate soil moisture levels, pH values, and interpret them to determine soil types and assess the risk of flash floods.

5. **Visualization and Reporting:** Present the analyzed data in a user-friendly format for effective decision-making. Visualize the data using graphs, charts, or maps to highlight soil characteristics, flood risk levels, and soil type distributions. Generate reports or alerts for relevant stakeholders to take appropriate actions.

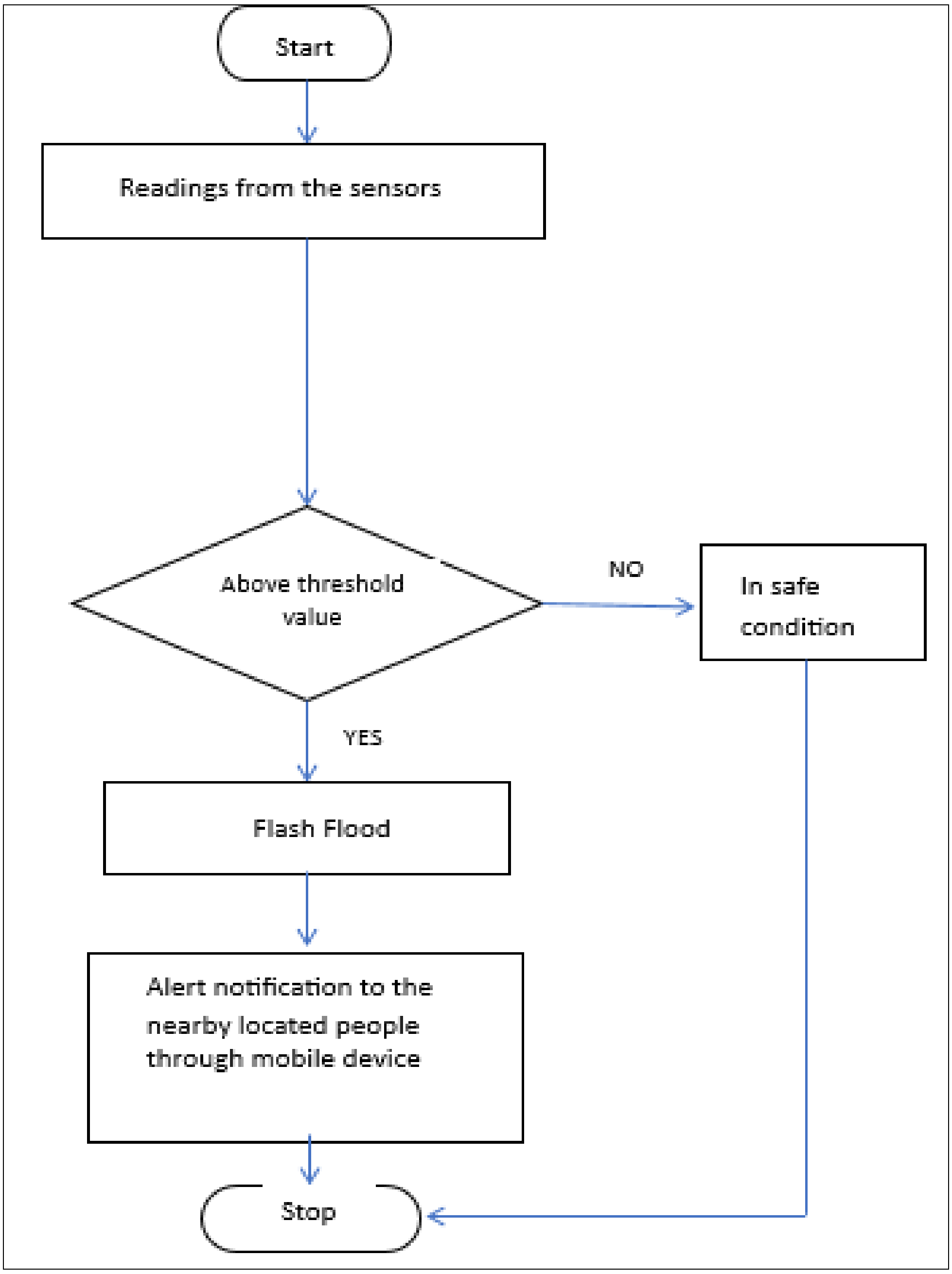

Fig 4: System Flow chat

System Algorithm

Here is an algorithm for the flash flood warning system using the HC-SR04 sensor for water level measurement, SIM900L module for data transmission and DFRobot Gravity pH sensor and SHT20 Soil temperature/humidity sensor connected to the Arduino Mega 2560 board for soil measurement and analysis:

1. Initialize the System:
   - Set up the Arduino Mega 2560 board and ensure all necessary libraries and dependencies are installed.
   - Connect the HC-SR04 sensor, SIM900L module, DFRobot Gravity pH sensor, and SHT20 Soil temperature/humidity sensor to the appropriate pins of the Arduino Mega 2560 board.

2. Establish Communication with SIM900L Module:
   - Initialize the SIM900L module and establish a communication link between the Arduino Mega 2560 board and the SIM900L module.
   - Set up the necessary parameters for network connectivity (e.g., APN, username, password).
   - Ensure the SIM card is inserted correctly and has an active data plan.

3. Measure Water Level Using HC-SR04 Sensor:
   - Configure the HC-SR04 sensor by setting the appropriate digital input and output pins on the Arduino.
   - Trigger the sensor by sending a short pulse from the Trig pin and measure the time it takes for the ultrasonic wave to return to the Echo pin.
   - Convert the measured time to distance using the speed of sound in air.
   - Calculate and store the water level based on the distance measurement.

4. Measure Soil pH Using DFRobot Gravity pH Sensor:
   - Read the analog input from the DFRobot Gravity pH sensor using the Arduino's analog input pin.
   - Convert the analog reading to the corresponding pH value using calibration data.
   - Store the pH value in a variable for further analysis and transmission.

5. Measure Soil Temperature and Humidity Using SHT20 Sensor:
   - Retrieve temperature and humidity data from the SHT20 sensor using the appropriate libraries and functions.
   - Store the temperature and humidity values in separate variables for further analysis and transmission.

6. Synchronize Data using SIM900L Module:
   - Format the collected sensor data (water level, pH, temperature, humidity) into a suitable data structure or format for transmission.

7. Repeat Monitoring and Analysis Process:
   - Set a suitable time interval for continuous monitoring and data collection.
   - Repeat steps 3-6 at regular intervals to update the water level, pH, temperature, and humidity measurements.

8. Handle Exceptional Cases:
   - Implement error handling mechanisms for scenarios such as network connection failures, sensor malfunctions, or data transmission errors.
   - Include appropriate error messages or notifications to indicate any issues encountered during the monitoring process.

9. Implement Power Management:
   - Optimize power consumption by employing sleep modes or power-saving techniques when the system is idle or not actively monitoring.
   - Consider using external power sources or batteries to ensure continuous operation in remote locations.

Conclusion

Monitor the system's performance and make necessary adjustments or improvements based on real-world observations and user feedback.

Design Concept

The first step in implementing the flash flood warning system is to assemble the hardware components:

1. The HC-SR04 sensor's VCC pin is connected to the 5V pin on the Arduino board. Its GND pin is connected to the ground (GND) pin on the Arduino. Its Echo pin is connected to a digital input pin on the Arduino, and the Trig pin is connected to a digital output pin on the Arduino. The sensor requires two digital pins (trigger and echo) to communicate with the Arduino. The trigger pin sends the ultrasonic pulse, and the echo pin receives the reflected pulse. By measuring the time it takes for the pulse to return, the water level can be calculated.
2. The SIM900L module's VCC pin is connected to the 5V pin on the Arduino board. Its GND pin is connected to the ground (GND) pin on the Arduino. A serial communication connection between the Arduino and the SIM900L module is established using the appropriate serial communication pins. The module requires power connections and communication via AT commands to transmit data to the cloud. The Arduino will send commands to the SIM900L module to establish a GPRS connection and upload the sensor data.
3. The DFRobot Gravity pH sensor's VCC pin is connected to the 5V pin on the Arduino board. Its GND pin is connected to the ground (GND) pin on the Arduino. The SIG pin is connected to an analog input pin on the Arduino.
4. The SHT20 Soil Temperature/Humidity sensor's VCC pinis connected to the 5V pin on the Arduino board. Its GND pin is connected to the ground (GND) pin on the Arduino. The SDA pin is connected to the Arduino's SDA pin (for I2C communication), and the SCL pin to the Arduino's SCL pin.

The second step is programming the Arduino

Write a code in the Arduino programming language (based on C/C++) to read the sensor data from the HC-SR04, format it appropriately, and send it to the cloud via the SIM900L module. The code should include logic to handle communication with the SIM900L module, establish a GPRS connection, and upload the data to a mobile device.

After the HC-SR04 sensor is connected to the Arduino MEGA 2560 microcontroller, and the SIM900L module is connected to the microcontroller's serial port. The software program for the microcontroller is then uploaded using the Arduino Integrated Development Environment (IDE).

The software program for the microcontroller consists of two main parts: the code for reading the distance measured by the sensor and the code for triggering alerts based on predefined thresholds. The code for reading the distance is implemented using the *pulseIn() function,* which measures the time taken for the ultrasonic wave to travel to the water surface and back to the sensor. The distance is then calculated using the speed of sound in the air and the time measured by the sensor.

The code for triggering alerts is implemented using an 'if statement' that checks if the water level exceeds the predefined threshold. If the water level is above the threshold, an alert message is sent through the SIM900L module to a mobile device.

Once the software program is uploaded to the microcontroller, the system is ready for testing. The HC-SR04 sensor is mounted at a suitable location above the water surface, and the system is powered on. The water level measurements are then monitored using a mobile device connected to the SIM900L module.

The third step is System Operation:

Once the system is set up and running, it will operate as follows:

1. The HC-SR04 sensor continuously measures the water level and sends the data to the Arduino Mega 2560.
2. The Arduino Mega 2560 receives the sensor data, processes it, and sends it to the SIM900L GSM module.
3. The SIM900L module establishes a GPRS connection with the mobile device using the GSM network.
4. The Arduino sends the formatted data to the SIM900L module, which in turn transmits it to the mobile device.

Finally, the integration of Arduino Mega 2560, HC-SR04 ultrasonic sensor, and SIM900L GSM module provides a robust solution for flash flood warning system. This system allows real-time monitoring of water levels in vulnerable areas and enables timely response to potential flash floods. By uploading the sensor data to the mobile device, stakeholders can have a comprehensive view of the flood situation, aiding in disaster preparedness and response efforts.

Implementation Considerations

During the implementation of the flash flood warning system, several factors need to be considered:

1. **Calibration:** Calibrate the sensors before deployment to ensure accurate readings. Follow the calibration procedures provided by the sensor manufacturers to achieve reliable and precise measurements.

2. **Power Supply:** Ensure a reliable and continuous power supply for the system. This can be achieved through a combination of battery power depending on the deployment location and requirements.

3. **Sensor Placement:** Place the sensors strategically to ensure representative measurements. Consider the soil depth at which the sensors are inserted, as it can affect the accuracy of the collected data. Install the sensors in locations that reflect the characteristics of the area under study.

Applications and Benefits

The flash flood warning system offer several applications and benefits:

1. **Early Warning System:** By monitoring soil moisture levels and analyzing temperature and humidity data, the system can provide early warnings for flash floods. This allows authorities and communities to take timely actions and implement preventive measures, potentially saving lives and reducing property damage.

2. **Water Management and Agriculture:** Understanding soil types and their characteristics is vital for effective water management and agricultural practices. The system can assist in optimizing irrigation strategies, identifying suitable crops for specific soil types, and managing soil erosion.

3. **Environmental Planning and Land Use:** The data collected by the system can contribute to environmental planning and land use management. It provides valuable insights into soil properties and their spatial distribution, assisting in making informed decisions about infrastructure development, urban planning, and ecological preservation.

In a nutshell, flash flood warning system plays a crucial role in mitigating the impacts of extreme weather events. The implementation of this system using the DFRobot Gravity pH sensor, SHT20 soil temperature/humidity sensor, HC-SR04 ultrasonic sensor and Arduino Mega 2560 board provides a powerful tool for assessing water level, soil conditions, understanding flood risks, and optimizing water management strategies. By continuously monitoring soil parameters, early warnings can be issued, and informed decisions can be made to prevent and mitigate the devastating effects of flash floods.

Methods of Data Collection

The following steps outline the data acquisition and processing procedures:

1. Program the Arduino to trigger the HC-SR04 sensor by sending a short pulse from the Trig pin. Measure the time it takes for the ultrasonic wave to return to the Echo pin. Convert this time to distance using the speed of sound in air. Repeat this process for multiple sensors at different heights to monitor water levels accurately.
2. Read the analog input from the DFRobot Gravity pH sensor using the Arduino's analog input pin. Convert the analog reading to the corresponding pH value using calibration data. Store the pH values along with the timestamp for further analysis and transmission.
3. Retrieve temperature and humidity data from the SHT20 sensor using the appropriate libraries and functions. Store the acquired data along with the timestamp for subsequent analysis and transmission.

Rainfall Data

Data on rainfall in Port Harcourt was made available by the Nigerian Meteorological Agency at the Port Harcourt International Airport for the 36-year period spanning from 1981 to 2016 and from 2014 to 2022. Data analysis was conducted to investigate variations in rainfall for varying intensities on a daily, monthly, and annual scale. The analysis focused on examining patterns, changes, and/or occurrences over the specified period and their correlation with the fast spreading flash floods that affected the entire city.

Methods of Data Analysis

Rainfall Analysis

Rainfall data analysis is required to comprehend an area's trend, volume, potential for discharge, and planning needs. The primary purposes of the analysis are to design and develop the best flood water control policy as well as to supply input data for a flood management system. The analysis of rainfall data aids civil engineers in designing dams, bridges, and other structures depending on the area's best, worst, and predicted rainfall situations. When designing, constructing, and maintaining buildings connected to flooding, it is important to understand both complex and basic concepts such as moving averages, return periods, probabilities, mean annual rainfall, range, standard deviation, skewness, and intensities (Herath and Ratnayake, 2004). Rainfall Amount Surface runoff, often known as flash flooding, happens quickly when rainfall intensity is so strong that it surpasses both the rate of evaporation and the rate of penetration into the soil. An increase in rainfall at a certain place raises the likelihood of a flood (Nyarko, 2002). Since the earth cannot absorb all of the water falling as rain so quickly, higher rainfall rates lead to more runoff. The Center for Hydrometeorology and Remote Sensing (CHRS) at the University of California provided rainfall intensity data for 2016. Elkhrachy (2015) notes that the CHRS uses neural network function classification/approximation processes to compute a rainfall estimate rate at each 0.25° x 0.25° pixel of the infrared brightness temperature image provided by geostationary satellites.

Topography Analysis

This study will incorporate topography information into the analysis by obtaining accurate elevation and slope data. This can be obtained from the Shuttle Radar Topographic Mission (STRM) website and processed through the use of geoinformation techniques which involve remote sensing and Geographic Information System techniques. Analyze the topographic data to identify potential drainage patterns, flood-prone areas, and other relevant features that influence soil conditions and water movement.

Performance Evaluation

The flash flood warning system proposed in this chapter uses an HC-SR04 ultrasonic sensor and an Arduino MEGA 2560 microcontroller to measure water levels in real-time and trigger alerts when the water level exceeds a predefined threshold. In this chapter, the performance of the system in terms of accuracy, reliability, and response time are evaluated. Also, prediction capability of the system was also evaluated.

Accuracy

To evaluate the accuracy of the flash flood warning system, we compared the water level measurements obtained from the system with the water level measurements obtained from a manual water level gauge. The manual gauge was used as a reference to validate the accuracy of the system. The tests were conducted over a period of time, during which the water level on the road varied.

Reliability

The reliability of the system was evaluated by testing the system's ability to operate continuously over an extended period. The tests were conducted for a period of time, during which the system was left to operate continuously without any intervention.

Response Time

The response time of the system was evaluated by measuring the time taken for the system to detect a change in the water level and trigger an alert. The tests were conducted by manually raising the water level on the road and measuring the time taken for the system to trigger an alert.

Results

The study conducted in 2011 by Chiadikobi *et al*. states that rainfall in Port Harcourt peaks in July, August, and September, with August serving as a brief interlude. According to the study, Port Harcourt floods in reaction to rainfall, with the biggest floods occurring during periods of peak rainfall. The City always faces flooding between July and September of each year, mostly due to rains.

General information on the type, composition, moisture content, and permeability of the soil was revealed by two soil samples that were taken for analysis at Nkpolu Road in Port Harcourt. After both samples were analyzed, it was determined that one was sandy loam (SL) and the other was loamy sand (LS). The high percentage of sand (average over 80%), silt component (average 6%), and clay component (average over 13%), characterize loamy sand (LS). The majority of the time, loamy sand has a moderate moisture content of over 15% and an average permeability of 2.0 cm/sec x 10-3. Loamy soil permits water to pass through sometimes until the moisture content reaches its maximum and is no longer able to do so, resulting in flash floods. During the sampling phase, a single location for sandy loam (SL) soil samples was taken. The average percentage of sand in the soil is between 74% and 79%, the average percentage of silt is 4%, and the average percentage of clay is more than 19%. The sandy loam soil typically has an average moisture content of more than 12% and a permeability of roughly 1.7 cm/sec x 10-3. Floods are possible because the sandy loam soil fills in quickly and lets little water through. The findings of the soil analysis revealed that all of the sand fractions were medium and fine in size. The percentage of soil that was retained on a sieve with a 2.00 mm mesh size ranged from 87.73 to 97.89%, and the particle size diameter was between 0.84 and 1.92 mm. The samples' average moisture content was medium, and their permeability values were typically very low in one and too low in the other. These characteristics contributed to the flash flood that was seen during the rainy season. This was in line with a 2011 study by Chiadikobi *et al*. that found that the aforementioned characteristics of soils make them more prone to floods. The primary causes of flash floods are heavy rains that come primarily between May and September each year. Because of the city's highly moist soil, which is less porous and readily filled to capacity, runoff from heavy rainfall occurs frequently, leading to flash floods. Because of the city of Port Harcourt's rugged terrain, the drainage system is extremely intricate. Because most of the city is constructed on average low to somewhat sloppy terrain, flash floods can be quite destructive in certain places while remaining mild and low in others. Residents of the city are at risk of flash floods during the rainy months due to the city's high precipitation rates, sloppy terrain in some areas, less permeable soil with a moderate to high moisture content, poor land use and land cover, and high drainage density.

From the result gotten from rainfall analysis and soil analysis, it was decided that the flash flood warning system be deployed on Nkpolu road in Port Harcourt metropolis in September. In other to avoid false alarm the system would first monitor the moisture content of the soil, once it detects moisture it would start sending out warning alert.

Result of Analysis of Soil

Particle size distribution (PSD), moisture content, permeability, and texture class were examined in the laboratory for two soil samples from Nkpolu Road in the Port Harcourt Metropolis, designated S1 to S2. The analysis's conclusion is as follows:

Sample S1: East West Road, Nkpolu Junction. The results of the analysis of Sample S1 revealed that it contained 74.00% sand, 5.56% silt, and 20.44% clay, with a moisture content of 14.93% and a permeability of 2.4 x 10-3 cm/sec. Sandy loam (SL) was identified as the texture class.

Sample S2: East West Road, Nkpolu Junction. The results of the analysis of Sample S2 revealed that it contained 78.96% sand, 9.60% silt, and 11.44% clay, with a moisture content of 23.22% and a permeability of 2.8 x 10-3 cm/sec. It was concluded that the textural class was loamy sand (LS).

Rainfall Data

The study conducted in 2011 by Chiadikobi *et al*. states that rainfall in Port Harcourt peaks in July, August, and September, with August serving as a brief interlude. According to the study, Port Harcourt floods in reaction to rainfall, with the biggest floods occurring during periods of peak rainfall. The City always faces flooding between July and September of each year, mostly due to rains.

Soil Analysis

General information on the type, composition, moisture content, and permeability of the soil was revealed by two soil samples that were taken for analysis at Nkpolu Road in Port Harcourt. After both samples were analyzed, it was determined that one was sandy loam (SL) and the other was loamy sand (LS). The high percentage of sand (average over 80%), silt component (average 6%), and clay component (average over 13%), characterize loamy sand (LS). The majority of the time, loamy sand has a moderate moisture content of over 15% and an average permeability of 2.0 cm/sec x 10-3. Loamy soil permits water to pass through sometimes until the moisture content reaches its maximum and is no longer able to do so, resulting in flash floods. During the sampling phase, a single location for sandy loam (SL) soil samples was taken. The average percentage of sand in the soil is between 74% and 79%, the average percentage of silt is 4%, and the average percentage of clay is more than 19%. The sandy loam soil typically has an average moisture content of more than 12% and a permeability of roughly 1.7 cm/sec x 10-3. Floods are possible because the sandy loam soil fills in quickly and lets little water through. The findings of the soil analysis revealed that all of the sand fractions were medium and fine in size. The percentage of soil that was retained on a sieve with a 2.00 mm mesh size ranged from 87.73 to 97.89%, and the particle size diameter was between 0.84 and 1.92 mm. The samples' average moisture content was medium, and their permeability values were typically very low in one and too low in the other. These characteristics contributed to the flash flood that was seen during the rainy season. This was in line with a 2011 study by Chiadikobi *et al*. that found that the aforementioned characteristics of soils make them more prone to floods. The primary causes of flash floods are heavy rains that come primarily between May and September each year. Because of the city's highly moist soil, which is less porous and readily filled to capacity, runoff from heavy rainfall occurs frequently, leading to flash floods. Because of the city of Port Harcourt's rugged terrain, the drainage system is extremely intricate. Because most of the city is constructed on average low to somewhat sloppy terrain, flash floods can be quite destructive in certain places while remaining mild and low in others. Residents of the city are at risk of flash floods during the rainy months due to the city's high precipitation rates, sloppy terrain in some areas, less permeable soil with a moderate to high moisture content, poor land use and land cover, and high drainage density.

Conclusion

According to Pratatomo (2016), flash floods can be triggered either alone or in combination by intense rainfall, abrupt lake breaches, check dam collapses, and extremely steep terrain. Due to a number of issues with forecasting and the speed at which they inflict havoc, flash floods are particularly destructive and devastating floods that slow down and minimize emergency responses (Smith and Petley, 2009). Due to climate change variability, which produces rainstorms, snowmelt, glacial lake outbursts, and high intensity rainfall, flash floods are affecting people, wildlife, homes, and populations all over the world. These events lower living standards and result in significant economic loss as well as infrastructure damage (Ali *et al*., 2016). Floods are the most frequent and well-known natural disaster, with virtually no chance of prevention or mitigation. Therefore, efforts to lessen their influence or impact on the human population are crucial (Ali *et al*., 2016).

Protection, readiness, and prevention are the main objectives of flash flood warning systems in order to drastically reduce future flood-related expenses.

A warning system for flash floods is primarily designed to advise cars to stay off flooded roads in an effort to prevent or reduce casualties, property damage, and social disturbance. Their objective is also to promote deliberate planning for effective use of water and land.

Due to the speed and suddenness of flash floods, their brief duration, and the interaction of several natural variables, it is nearly impossible to prevent them; however, we must take action to lessen their negative effects on people and property. By gathering dependable data with enhanced technology and developing forecasting techniques based on modeling and risk assessment expertise, significant efforts are currently being undertaken to raise public knowledge and awareness of flash floods. Every time there is a flash flood, an assessment is required to determine what went wrong and what can be done better. Similar to how a thorough understanding of the causes that contribute to flash floods as they relate to Port Harcourt would help to mitigate the damage, accurate data on regions of risk will help to tame the danger. The study yielded the following results:

1. The average monthly rainfall in Port Harcourt varied from 136.0 mm to 232.58 mm.
2. The largest monthly rainfall totals were typically seen in July or September; these two months together account for 16% of the annual rainfall totals in each of those years.
3. Rainfall in Port Harcourt is responsible for almost half of the city's flooding.
4. 88% of the time that a study on rainfall was carried out, the total amount of rainfall exceeded 2000 mm.
5. Low permeability causes excessive surface runoff in most of the loamy sand and sandy loam soil samples collected along Nkpolu Road in the Port Harcourt metropolitan area.
6. Ultimately, the Port Harcourt metropolis's Nkpolu Road flood conditions could be instantly communicated to road users via the development of a flash flood warning system.

Summary

Due to the high impact of flash flooding in a locality's ecosystem, it is important to analyze the flooding situation and develop a way of warning the stakeholders so that they will not be caught off guard and as well as precautions to be taken on time.

Flash flood warning systems are essential for reducing the effects of such catastrophes because they provide timely and accurate information about water levels on roads that are vulnerable to flash floods. They also monitor soil moisture levels and provide temperature and humidity data of the soil and transmit the information to mobile phones via the SIM900L module.

Finally, a flash flood warning system was created that could inform drivers in real time about the flooding circumstances or states on Nkpolu Road in the Port Harcourt metropolis.

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