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# IoT-based system for automated floodwater detection and early warning in the East African region; a case study of Arusha and Dar es Salaam, Tanzania

**Ange Josiane Uwayisenga*, Neema Mduma and Mussa Ally**
School of Computation and Communication Science and Engineering at Nelson Mandela African Institution of Science and Technology (NM-AIST), P.O. Box 447, Arusha, Tanzania

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## Abstract
***Climate change is a major cause of the increase of natural disasters like floods, droughts, and storms. Although several countries have been affected by such natural disasters, the East African region is one of the most affected. This work focuses on floods as the most frequent disaster in the East African region where 280 died and about 2.8 million people were affected by the floods that occurred in 2019 alone. During the floods, people not only lost their lives and got displaced, but property and infrastructure were also damaged. Different techniques have since been developed to mitigate the effects of floods. However, the methodologies used have not responded to the identified problems that include lack of community awareness, information inadequacy, and low-cost systems. To solve these problems, the present study aims at developing a low-cost system that detects and alerts the community on upcoming flood incidents. The proposed floodwater detection and early warning system comprise of three units. The sensing unit continuously monitors environmental parameters using ultrasonic, temperature and humidity sensors. The processing unit processes and analyses the collected data from the sensors. Then, the alerting unit alerts the community and local authorities using a buzzer and a Short Message Service (SMS) notification. The system uses the global system for mobile communication to provide internet connectivity which enables data to be collected, stored, and monitored in the cloud. The system was implemented at Themi river as one of the case study areas. The results showed that floods can be detected and the community near the flood-prone area alerted early. Therefore, the use of the developed system in flood-prone areas can contribute to environmental disaster risk mitigation, and subsequently, the death rates due to environmental natural disasters.***

## Keywords
***East Africa region, Floodwater detection, GSM module, Internet of things, Early warning systems.***

## 1.Introduction
Climate change is currently one of the most serious and extreme issues worldwide. Besides the contribution of human activities to climate change, the planet's climate is changing now much more than ever [1]. Due to climate-related and geophysical disasters, a total of 1.3 million people have died between 1988 and 2017, and a further 4.4 billion injured, homeless, and displaced [2]. Although a greater number of these disasters were due to geophysical events like earthquakes and tsunamis, 91% of all documented disasters due to natural hazards resulted from floods, droughts, tropical cyclones, heat waves, and other excessive weather events [3]. The effects of climate change are anticipated to further increase due to the general change and variability of climate.

Among the natural disasters, floods are the most frequent and dangerous with adverse effects on the society [4].

According to the report of the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) of 2019, the East Africa region continues to suffer from flooding more than any other region. In the 2019 flood incidents alone, an estimated 2.8 million people were affected and over 280 people died in the region. Like other countries in the region, Tanzania continues to face the impacts of exorbitant incidents like floods and unusually heavy rainfall, particularly in its Central and Northern regions. These frequent incidents have impacted people's lives resulting in deaths, damage of property, infrastructure, disruption of agricultural activities, and damage to human health and general well-being [5]. Dar es Salaam is one of the cities in Tanzania that has faced the worst negative impacts of

*Author for correspondence

flooding, including inaccessibility and unavailability of quality water [6]. Among the factors that have been identified as the primary contributing factors to these flood events are heavy rainfalls and human activities such as inappropriate land use, desertification, and aggravation of drainage systems.

Disaster risk reduction and management are among the currently existing programs in the East African Community [7]. However, the lack of a system to enhance community awareness of upcoming flood incidents remains a challenge.

The main objective of this project was to develop an Internet of Things (IoT)-based system for timely flood detection and early alerts to the community living in or close to flood-prone areas. To attain the main objective, the following were performed:

1. Analyzation of the requirements for developing an automated floodwater detection and early warning system.
2. Design and development of an automated floodwater detection and early warning system.
3. Validation and implementation of the developed system at a particular targeted flood-prone area.

## 2.Related works

Flood events are a challenging natural disaster which impacts on the sustainable environmental, social and economic development of a country [8]. Several studies were conducted to assess and analyze flood risks. Taking advantage of technological advancements, various mechanisms were developed to detect and monitor floods at different flood-prone areas.

Flood risk assessment was used to find out the statistical analysis on the risks that floods can cause at a flood-prone area and how these can be mitigated. Several studies on flood risk analysis and assessment were conducted to identify possible flood risks in the society [9]. Approaches including Geographical Information System (GIS) were used to collect and analyze many types of integrated data from flood-prone areas for the identification of flood risks [10]. In Malaysia, a flood-risk map was also used to assess flood damage and vulnerability and the identification of high-risk flooded areas contributed to the mitigation of flooding effects [11]. However, there is a need to design new approaches to increase awareness of flood events through early warnings while taking advantage of the new technological advancements at the same time.

Flood monitoring is one of the key factors which contributes to the mitigation of flood effects by controlling flooding in flood-prone areas. Flood monitoring systems that use the Global System for Mobile Communication (GSM) module to generate Short Message Service (SMS) notifications to respective users were also developed [12]. Data was collected and sent through SMS notifications as a way of storing data. However, this method proved not to be suitable for live data visualization to support decision-making. Device's interconnection and data exchange were also used to monitor flood through the IoT as a network of physical objects. In a study by Chamim et al. [13], a web-based approach was used for flood monitoring and early warning. The access of warning alarms and monitoring of water levels was via the web that requires the internet. This means that communities living in flood-prone areas could be unaware of upcoming floods since only those with internet connectivity could benefit from the system. Some of the existing approaches used Wi-Fi to enable data monitoring from connected devices over the internet [14, 15]. However, wireless network technology is limited to a certain range. To solve this challenge, this project used a mobile network that operates over an unlimited range.

A study conducted in the districts of Uttar Pradesh in India aimed to develop a mechanism that can locate water infrastructure and monitor the deluged areas [16]. The study used the Synthetic Aperture Radar (SAR) technology with images being remotely collected using an antenna attached to a satellite to find the flooded areas. The images taken were analyzed to determine the intensity of flood-affected areas. Similarly, another approach was developed to identify flood-affected regions [17]. Remotely sensed images were analysed and classified using Contiguous Deep Convolutional Neural Network (CDCNN). Another study used the image segmentation technique to monitor floods [18]. Images were captured using a surveillance camera fixed close to the river. The identified flood-prone areas gave a point of view on the statistical analysis of affected areas and the effects on society. Nevertheless, community awareness of the imminent flood was not addressed in the aforementioned studies.

The study conducted by Natividad and Mendez developed a system that uses SMS notifications to give daily alerts and updates on flood status to local authorities and other concerned people [19]. A similar study was also conducted to develop a flood-detection system using the ThingSpeak platform for data monitoring [20]. The system alerts the community near flood-prone areas using SMS notifications. Another study also used SMS notification as an approach to avoid flood destruction [21]. However, many people in rural areas, despite the current technological advancements, do not possess mobile phones. Therefore, the developed alerting methods were not suitable as an early warning for prompt evacuation during flooding.

Furthermore, Sekuła et al. [22] developed a system that uses fiber optic technology to carry information to a central terminal where transmitters and repeaters are required. Another study developed a system that uses remote sensing satellite imagery to collect data from different flood-affected areas [23]. However, the developed systems were not cost-effective, making it hard to implement in certain flood-prone areas. Besides their high-priced designs, the systems were not purposely developed to provide awareness of the possible imminent flood incidents.

Recent studies have revealed that the speed of sound in air changes with changes in ambient atmospheric parameters like temperature and humidity [24, 25]. This can influence the distance measurements of the ultrasonic sensor. Besides, some of the developed flood-detection systems used ultrasonic sensors to detect floods without considering the ambient environmental factors [19, 26]. This can affect the sensed data, thus providing inaccurate results in terms of the detected distance.

Although some early-warning operational systems have been deployed at transboundary rivers in some East African Partner States, their development was achieved with the assistance of international donors [7], making them inadequate.

To address the various challenges presented by the existing systems, the present study demonstrates the need to develop an IoT-based system for automated floodwater detection and early warning in the East African region. The developed low-cost system can be used in any flood-prone area to detect floods and provide accurate information. The system will continuously monitor information on the flood status and provide updates in real-time, hence, significantly contribute to alleviating the impacts of losses due to floods in the region.

## 3.Material and methods

### 3.1Case study

The study was carried out in Msimbazi and Themi rivers in Dar es Salaam and Arusha respectively. These rivers were selected as the most affected by floods during heavy rainfall seasons. River depth was measured to know the water levels and maximum river depths. This helped during the system installation process in the field. *Table 1* shows the river depth measurements towards the community settlements.

**Table1** River depth measurements

| S.No | River | River depth |
|---|---|---|
| 1 | Msimbazi river | Maximum river depth: 2 m 20 cm<br>Minimum river depth: 75 cm |
| 2 | Themi river | Maximum river depth: 37 cm<br>Minimum river depth: 25 cm |

### 3.2 System design and specification

The developed system was designed into three units, namely the sensing, processing, and alerting units.

#### 3.2.1 Sensing unit

This unit comprises of ultrasonic HC-SR04, temperature and humidity sensors for the determination of distance, environmental temperature and humidity respectively. The ultrasonic sensor is used to detect the distance between the sensor and the object in its proximity. In the present study, the ultrasonic sensor was used to detect the rise in water levels while measuring the distance detected between the water surface and the sensor. The sensor operates at a frequency of 40 Hz and a range of 0.02 to 4 m. The working voltage and current are 5 V and 15 mA respectively. The purpose of using temperature and humidity sensors was to ensure the monitoring of temperature and humidity changes in a given flood-prone area. The Digital Humidity and Temperature (DHT22) sensor type was the better selection with a sampling rate of 0.5 Hz every 2 seconds. The sensor has an inbuilt basic chip that performs analog to digital conversion and outputs a digital signal with the humidity and temperature. The working voltage ranges between 3 - 5 V while a maximum of 2.5 mA was employed in the current conversion. The DHT22 sensor operates in a temperature range of -40 to +125$^0$C, with an accuracy of ± 0.5$^0$C and a humidity range of 0 to 100 %, with an accuracy of ± 2 to 5%.

### 3.2.2 Processing and monitoring unit

In this unit, Arduino UNO R3 was used as an open-source microcontroller board. It operates at 5 V and 16 MHz of voltage and clock speed respectively. The microcontroller receives data from sensors for further processing and analysis. The GSM module SIM808 is a hardware device used to establish communication between the cellular network and the mobile phone user. The device operates at a voltage of 3.4 to 4.4 V harvested from an external power supply with an operating temperature of -40 to 85$^{0}$C. In this unit, the module was used to provide internet connectivity for real-time data monitoring in the cloud.

### 3.2.3 Alerting unit

The alerting unit consisted of a buzzer and a GSM module. An alarm and SMS notification methods were used to alert the concerned authorities. The buzzer was used to produce an alarm for alerting the community near the flood-prone area. The device operates at a voltage of 4V-8V and 2300 Hz of the resonant frequency. With the use of a GSM module, SMS notifications will be sent to local authorities. Furthermore, a Liquid Crystal Display (LCD) which operates at a voltage of 4.7 - 5.3 V with a current consumption of 1 mA was used to display the water level condition. *Figure 1* shows the block diagram of the developed system.

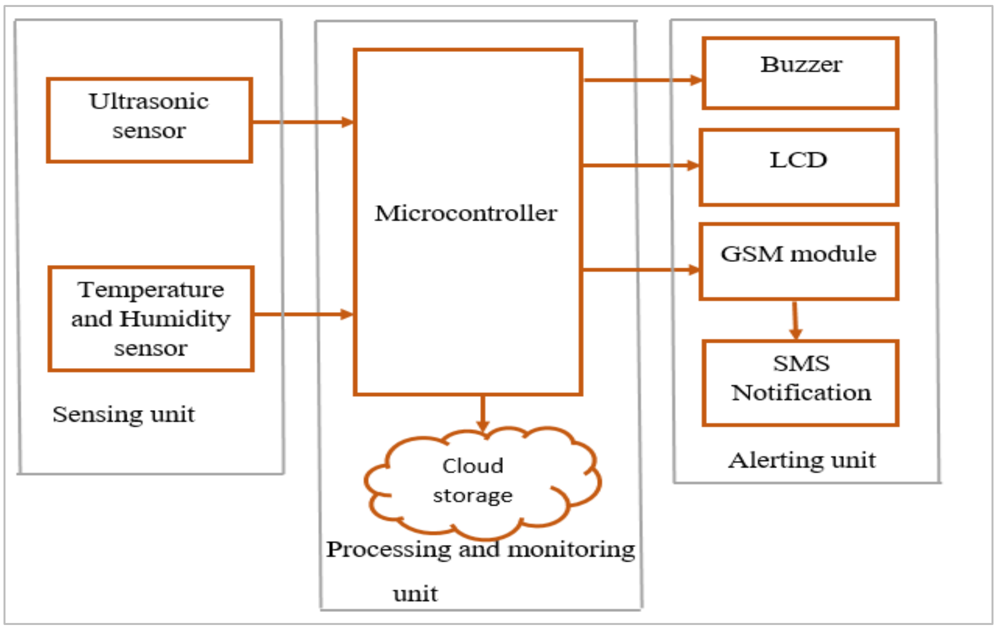


**Figure 1** Block diagram of the developed system

## 3.3 System implementation

During the implementation process, the following steps 3.3.1 to 3.3.5 were performed for the completion of the project module.

### 3.3.1 Configuration and integration of the system components

The components of the system were configured on the Arduino board before their integration. Arduino UNO consists of a single-board microcontroller that reads input from various sensors and other devices connected to it and turns them into an output. The board comprises 14 digital input and output pins, and 6 analog pins that use an analog to digital converter. The ultrasonic sensor trig and echo pins were connected to pins 10 and 13 of the Arduino respectively. The trig pin was set as output while the echo pin was set as an input. The DHT22 temperature and humidity sensor data pin was connected to the analog pin A0 of the Arduino. The GSM module transmitter (Tx) and receiver (Rx) pins were connected to pins 2 and 3 of the Arduino respectively. The supply wire of the buzzer was connected to pin 9 of the Arduino and set to output. Light Emitting Diode (LED) long leg pin was connected to pin 8 of the Arduino and set to output. Pins (RS, E, D4, D5, D6, and D7) of the LCD were set up on the Arduino digital pins 12, 11, 7, 6, 5, 4 respectively. Leaving out the GSM module, other components were supplied with an energy of 5 V from the Arduino.

During the system integration process, all units were linked together. Their interaction proved the effective system functionality and its compliance with the requirements. *Figure 2* shows the circuit diagram.

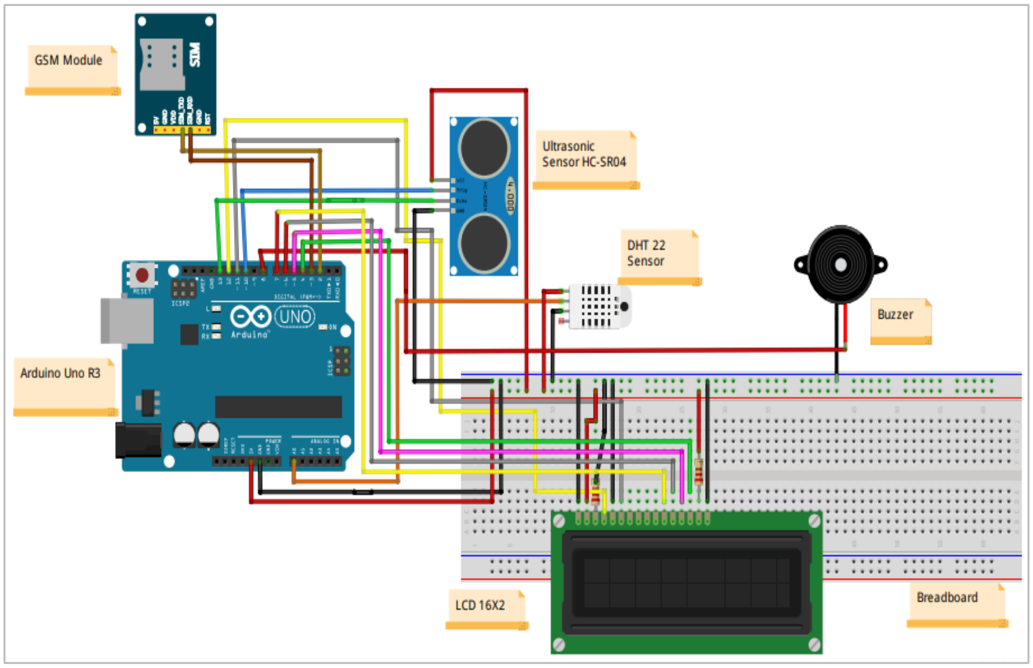


**Figure 2** Circuit diagram

### 3.3.2 Programming language and software used

With the help of the Arduino Integrated Development Environment (IDE), the system was developed using the C programming language, a general-purpose, procedural, and high-level computer programming language. Arduino IDE is an open-source software tool that consists of a text editor written in functions from C++ and C programming languages. The software provides access for users to create their modules and use them in the program. The text editor from Arduino IDE was used to write the program code. The libraries needed for sensors and other components were imported. The program output was seen in a serial monitor window in the Arduino IDE.

The ThingSpeak platform was used to continuously monitor the collected data from the sensors. ThingSpeak is an IoT open source and analytics platform designed for aggregation, analysis, and visualization of data live streams in the cloud. The platform plays a key role in the storage and retrieval of data from the sensing unit over the internet using the Hypertext Transfer Protocol.

### 3.3.3 Functionality of the developed system

The system was powered on and continued to run iteratively for the sensors and other components to operate and start the initialization of parameters. In this project, the ultrasonic sensor was used to detect the distance between the water surface and the sensor position. The sensor continuously monitored the rise in water level while measuring the detected distance. The temperature and humidity sensors monitored the changes in the ambient temperature and humidity respectively. The data collected from the sensors were forwarded to the microcontroller to be processed and analyzed. After data analysis, each single output data were compared to the required threshold. A rise in the water level greater than the threshold signified the reduction of the distance between the water surface and the sensor. In this case, the community was alerted through an alarm generated by the buzzer and an SMS notification sent to the local authorities. Furthermore, the data were continuously monitored in the cloud storage through the ThingSpeak platform.

*Figure 3* shows the flow chart of the developed system.

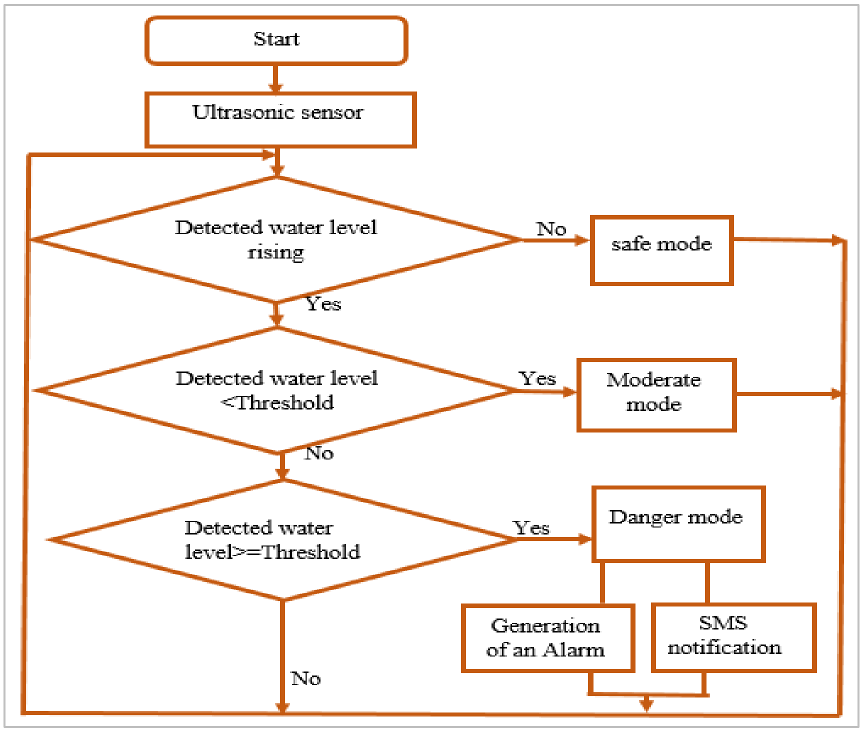


**Figure 3** Flowchart of the developed system

### 3.3.4 Distance detected calculation

The speed of sound in air changes with temperature and humidity. To accurately calculate the detected distance, the ambient temperature and humidity should be considered when calculating the speed of sound. The ultrasonic sensor detects the distance between the sensor and the targeted object (water surface) using the two transducers. The trig transducer emits acoustic sound waves which hit (the transmitter of the sensor) the water surface and reflect towards the echo transducer (the receiver of the sensor). The distance was calculated basing on the speed of sound in air and the time of flight of the sound waves between the sending and receiving transducers. However, only the time taken for the sound waves to travel to the object was considered, thus the time was divided by 2.

The speed of sound in air is 331.4 m/s (at $0^0$C of temperature and 0% of humidity). In this project, the speed of sound in a target environment area was calculated by considering the ambient temperature and humidity. The monitored parameters; distance, temperature, and humidity were measured in cm, °C, and % units respectively. Equations 1 and 2 show the formula of the speed of sound and distance calculated respectively.

$$S = 331.4 + (0.606\times T) + (0.0124\times H) \quad (1)$$

Where *S*: Speed of sound for a targeted area, *T*: Temperature, and *H*: Humidity

$$D = (T/2)\times S \quad (2)$$

Where *D*: Distance and *T*: Time flight

### 3.3.5 System testing

The testing process was conducted using lab and field-testing approaches. During the lab testing, two water containers were used. Water from the second container was flowing into the first container through an attached faucet. The ultrasonic sensor was mounted on the first container to continuously detect the rise in water level.

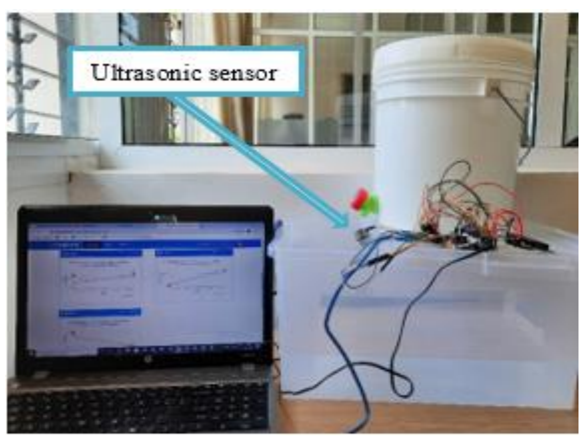


**Figure 4** Connection of hardware components used for the lab testing approach

The field-testing approach was conducted using a prototype from an assembled circuit built on a designed Printed Circuit Board (PCB). *Figure 5* shows the various steps in the prototype preparation process starting from the placement of the system parts on PCB. After soldering, a complete prototype was provided.

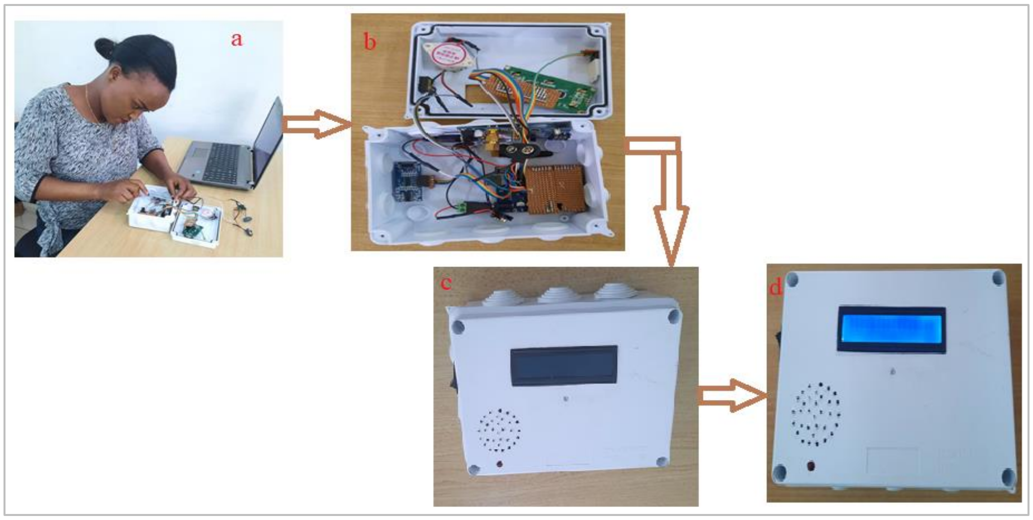


**Figure 5** Prototype development

The purpose of the field-testing process was to ensure that the system could effectively be deployed to a certain flood-prone area and operate as expected. The system was installed at Themi river as one of the case studies at a maximum river depth of 37 cm. The ultrasonic sensor was positioned facing the water surface to continuously monitor the rise in water level. The temperature and humidity sensors were unceasingly monitoring the changes in the ambient temperature and humidity respectively.

*Figure 6* shows the system installed at Themi river with a switch used to power the system on and off.


**Figure 6** System installed in the field

## 4.Results

The results presented in this section show the outputs obtained during both lab and field-testing approaches.

### 4.1 Lab testing approach

Based on the water level in the first container, the initial distance measured between the sensor and the water surface was 10 cm. The ultrasonic sensor continuously monitored the rise in water level. As the water from the second container flowed into the first one, an increase in water level was detected. The distance measured between the water surface and sensor was less than 5 cm, indicating a dangerous condition (*Table 2*). In that case, an alarm was produced reaching a frequency of approximately 2300 Hz. An SMS notification was also sent to a subscribed mobile phone number. The alarm and SMS notification were triggered when the water level was in a dangerous condition. Besides, LED was switched on to indicate the dangerous condition of the distance detected. The sensed distance, temperature, and humidity data were updated after every 15 seconds both in cloud storage and on the serial monitor. It was also observed that an increase in water level in the container led to the reduction of the distance between the water surface and the sensor, and vice-versa. Three comparison statements were used to control the rise in water level. The comparison was done for the detected distance between the current water surface, sensor and threshold. The results obtained from the lab testing approach were effectively evaluated and met the requirements. As presented in *Figures 7, 8, 9*, an instant visualization of the live data was enabled for the detected distance, temperature, and humidity data from DHT22 sensor.

**Table 2** Comparison statements used for the lab testing approach

| S. No | Water level measurement | Mode Description |
|---|---|---|
| 1 | The detected distance between sensor and water surface in a container >/=10 cm | Safe mode: no rise in water level has been detected. |
| 2 | The detected distance between sensor and water surface in a container < 10 cm and the detected distance between the sensor and the water surface in a container = 5 cm | Moderate mode: there is a rise in water level, but the condition can be maintained. |
| 3 | The detected distance between the sensor and the water surface in a container < 5 cm | Danger mode: there is a rise in water level with a high probability of flood occurrence. |

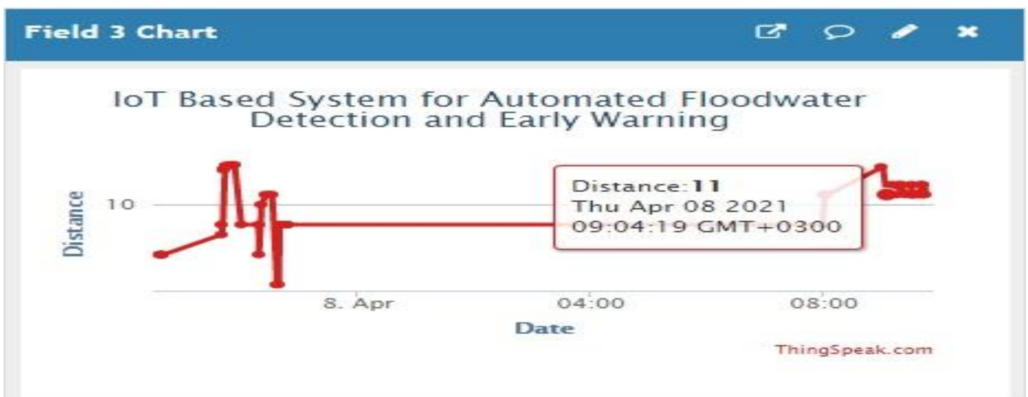


**Figure 7** Visualization of distance data from DHT22 sensor

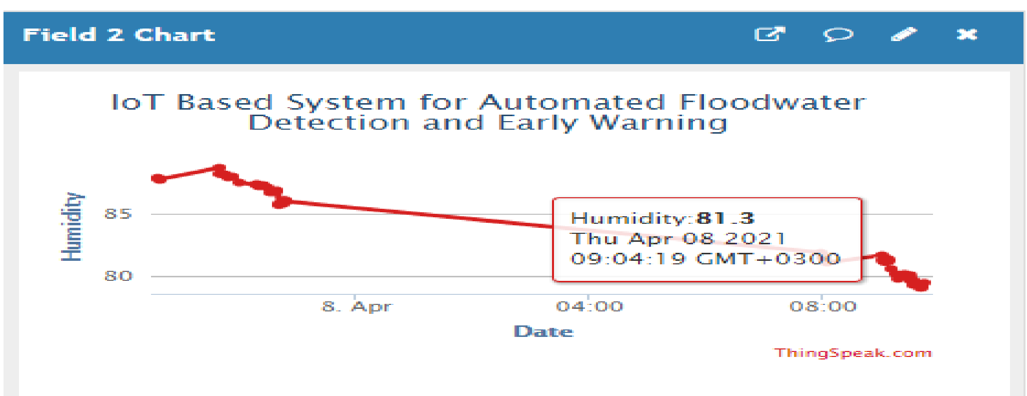


**Figure 8** Visualization of humidity data from DHT22 sensor

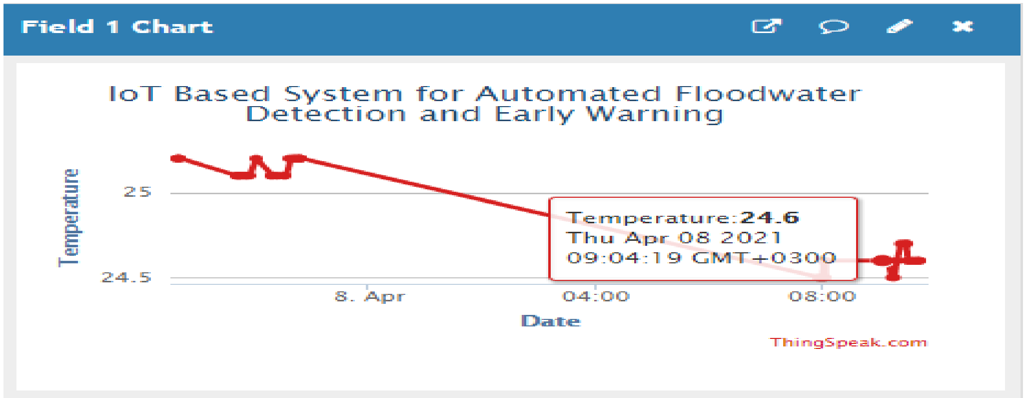


**Figure 9** Visualization of temperature data from DHT22 sensor

### 4.2 Field testing approach

During the field-testing process, the system was installed at a maximum river depth of 37 cm. From the system evaluation process, it was observed that the rise in water level, which can cause a flood incident occurred when there was heavy rainfall. As the water flowed into the river, a certain change in the water level was detected. However, this did not indicate any negative effects because the distance detected between the sensor and the water surface was much less than the required threshold. Data from the sensors were continuously sent to the cloud and monitored in real-time. Figure 10 shows the SMS notification. Furthermore, the water level, condition was displayed using the LCD device. *Figure 11* depicts water level conditions in the field. Complete list of abbreviations is shown in Appendix I.

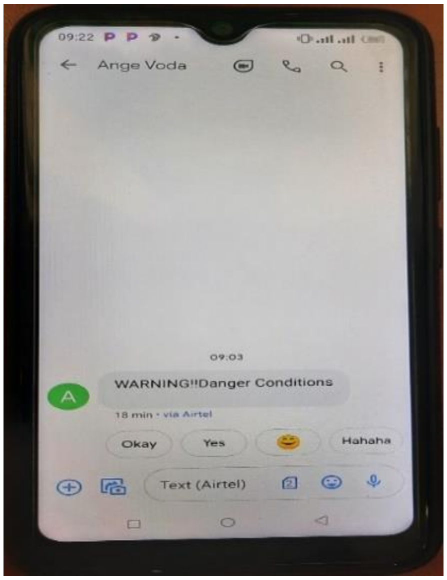


**Figure 10** SMS notification


**Figure 11** Display of water level condition

## 5.Discussion

The experiments conducted in the lab and the field proved that floods can be automatically detected and their effects on the community reduced. *Figure 4* depicts the instant flood-detection process from the lab approach. The distance, temperature, and humidity parameters were monitored using ultrasonic, and temperature and humidity sensors respectively. Updates of data from the sensors were provided every 15 minutes in the cloud. *Figures 7*, *8*, and *9* represent the visualization of the livestream data of distance, temperature, and humidity. The rise in water level which exceeds the required threshold leads to the generation of an alert. *Figure 10* shows the text message that was sent to the local authorities to inform them of a dangerous condition. In such a case, rescue can be provided to the flood victims without delay. The alarm alert method generated by the buzzer proved to be a fast way to alert the community of danger. Thus, the vulnerable can be alerted early and evacuated to save their lives. The testing process in the field proved that the system can effectively be installed in a particularly flood-prone area. *Figure 11* shows the developed prototype installed at Themi river.

Based on the observations, results, and evaluations carried out during the project implementation, the system's affordability, accuracy, efficiency, and effectiveness are assured. From the gaps presented in the existing systems, the followings were addressed in this project:

- The developed system could detect the rise in water level and continuously sent real-time updates to the cloud.
- The equipment used for system development was quite affordable as compared to those used in the already existing systems.
- The community awareness of imminent flood incidents was increased by providing alerts through an alarm as the fastest way.

### Limitations

The development of an IoT-based system for automated floodwater detection and early warning is limited to the following aspects:

1. The energy power supply harvested from an external battery.
2. River depth parameter in detecting the rise in water level.
3. Monitored data from one system installed in one particular flood-prone area.

## 6.Conclusion and future work

Flood incidents are very hard to manage during heavy rainfalls and affect people living close to flood-prone areas. This study aims to contribute to disaster risk reduction by alleviating the effects of floods on society. This can be achieved by detecting floods and alerting the community in flood-prone areas. The developed system proved that the information on flood status can be provided within 15 seconds. The results from the system's functionality showed that the effects of flood incidents can be mitigated through an early-warning system that is user-friendly and does not require complex maintenance. Flood incidents can occur in different water bodies and other flood-prone areas. Thus, a deep understanding of flood management is required. The following directions should be taken into consideration for future work:

- The integration and monitoring of floodwater detection systems from different flood-prone areas at a central unit
- The detection of rising water levels can be improved by considering other river parameters besides river depth
- The system powering method can be improved to add more value to this work

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### Conflicts of interest

The authors have no conflicts of interest to declare.

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**Ange Josiane Uwayisenga** obtained her Bachelor of Science in Computer Engineering from the University of Rwanda (College of Science and Technology), Rwanda. Currently, She is taking her Master's studies in Embedded and Mobile Systems (EMoS) program at Nelson Mandela African Institution of Science and Technology (NM-AIST). Her objective is to utilize her skills and knowledge to improve the quality of society's life and businesses' application through digital transformation. She is experienced in Embedded projects development and software integration projects related. Her research interest lies in ICT for addressing agriculture, climate change, and natural disasters.
Email: uwayisengaa@nm-aist.ac.tz

**Neema Mduma** is a lecturer at the Nelson Mandela African Institution of Science and Technology (NM-AIST) in Tanzania. She has PhD and MSc in Information and Communication Sciences and Engineering from NM-AIST in 2020 and 2016 respectively. Neema is passionate about education particularly girls, and during her PhD, she developed a Machine Learning model called BakiShule which aimed at preventing students from dropping out of school. Neema's efforts towards women in science have been recognized through an award from L'Oréal UNESCO as 20 young talents in Sub-Saharan Africa for the year 2020. Her research interests are Artificial Intelligence, Machine Learning, and Data Science.
Email: neema.mduma@nm-aist.ac.tz

**Dr. Mussa Ally Dida** is a Senior Lecturer at NM-AIST School of Computational and Communication Sciences and Engineering (CoCSE), Deputy Centre Leader of the Centre of Excellence in ICT in East Africa (CENIT@EA). He has a PhD in Information and Communication Engineering from Beijing Institute of Technology (BIT), China attained in June 2017. He has supervised/ co-supervised 14 Masters and 2 PhD students to graduation and he is currently supervising more than 10 masters and PhD students. He has published more than 40 papers in highly reputable journals. His research interests are in the areas of Wireless Communication Systems, Embedded Systems, and IT Systems Development.
Email: mussa.ally@nm-aist.ac.tz

**Appendix I**

| S.No. | Abbreviation | Description |
|---|---|---|
| 1 | CDCNN | Contiguous Deep Convolutional Neural Network |
| 2 | DFHT | Digital Humidity and Temperature |
| 3 | GIS | Geographical Information System |
| 4 | GSM | Global System for Mobile Communication |
| 5 | IDE | Integrated Development Environment |
| 6 | IoT | Internet of Things |
| 7 | LCD | Liquid Crystal Display |
| 8 | LED | Light Emitting Diode |
| 9 | OCHA | Office for the Coordination of Humanitarian Affairs |
| 10 | PCB | Printed Circuit Board |
| 11 | Rx | Receiver |
| 12 | SMS | Short Message Service |
| 13 | SAR | Synthetic Aperture Radar |
| 14 | Tx | Transmitter |