

**DESIGN OF AN EARLY WARNING SYSTEM FOR RIVERINE FLOODS
A CASE STUDY OF RIVER NYAMWAMBA**

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ABSTRACT

Climate change is widely acknowledged to be one of the key problems affecting mankind this century, and as a worldwide challenge, it necessitates global solutions, in which every stakeholder must participate in the battle to mitigate the effects of this global crisis. Climate change is already affecting every inhabited area on the planet, with anthropogenic interference contributing to many reported changes in weather and climate extremes. Climate change happens when changes in the Earth's climate system result in new and unpredictable weather patterns. This change carries with it risks such as famine, drought, heat waves, landslides, and floods.

Since 2013, river Nyamwamba in Kasese district has been bursting its banks, flooding many areas within its catchment, destroying important infrastructure, property and even human lives. Despite the existence of structural flood control structures like gabion walls that aim to prevent the flood from invading inhabited areas, no mechanism has been used in this region to notify locals of the possibility of flooding when such structures are overpowered by the flood waters.

This research project aims to provide an innovative approach to alert people living within the Nyamwamba river catchment on the possibility of flood occurrence using best available technology and the Internet of Things (IOT). Basing on a model on flood risk assessment of the river Nyamwamba, high-risk areas were visualized and reliable river stage parameters obtained that were used threshold values for the FEWS design. An Arduino Uno-programmed microcontroller controlled all input values for the modelled river section. An ultrasonic sensor was used to monitor the safe, medium, and high/peak water levels. As a result, the river stage is constantly

displayed on an LCD screen, an SMS is sent to registered phone numbers at medium and high-water levels, and a buzzer alarm is only sounded at high water level.

Key words: River floods, Climate Change, Climate Extremes, IOT, Arduino, and Early Warning.

Background of the study

It is universally accepted that climate change is one of the greatest challenges facing humanity this century, and as a global challenge it requires global solutions (MWE, 2015) where every stakeholder has to take part in the fight to reduce the impacts of this global problem. Through scientific research and observation of the day-to-day happenings, it can be deduced that climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes (IPCC, 2021). Uganda as a country has already experienced the effects of climate change in form of climate-induced disasters such as floods, drought, landslides, and many others. Kasese district in western Uganda is naturally endowed with many rivers that flow from the slopes of Mount Rwenzori and river Nyamwamba is one of them. In May 2013, Kasese district was hit by a disastrous flood that caused a lot of damage to people's property, infrastructure, and even lives (United Nations Development program, 2013). These floods have continued to occur annually from April to May. A flood of nearly the same magnitude as that of May 2013 occurred again in Kasese district in May 2020 and led to the destruction of both public and private property and loss of lives. Physical Structures such as gabion walls aimed at reducing the impacts of flooding collapsed and hence the flood waters found their way into the areas that had been protected by these flood walls (KDLG, 2020). Early warning systems in form of Community radios were put in place in the sub-counties of Karusandara, Maliba, and Nyakiyumbu to alert the community members on the occurrence of a flood event (KDLG, 2020). However, these warning systems cannot effectively alert the community members on the occurrence of a flood event because they entirely rely on

their operator(s) hence the suggestion of an unmanned early warning system that is based on signal relays controlled remotely and can provide real-time information on river flow with no human intervention. Since the major aim of disaster management is to integrate interrelated processes to provide efficient means of analysing, monitoring, and predicting disasters and this integration should result in measures that are both preventive and reactive such that the possibilities of causalities and environmental destruction can be kept minimal (Shah et al., 2019). As a result, this study will focus on the use of cutting-edge technologies such as the Internet of Things, which will improve system performance by providing reliable, accurate, and timely data or information that will be used in making life-saving decisions. The Internet of Things (IoT) refers to physical things equipped with sensors, processing power, software, and other technologies that connect to and exchange data with other devices and systems over the internet or another communication network (Gillis, 2021).

Problem Statement

Floods causing loss of life, property, and damage to infrastructure such as roads, power lines, and water supply systems are an annual phenomenon in Uganda. Kasese district is one of Uganda's districts that has occasionally been hit by disasters, especially floods. Kasese's natural endowment with many rivers and snow on the peaks of mount Rwenzori and other factors such as steep mountain topography and highly concentrated relief rainfall make her susceptible to floods. These floods have hit this region severally leading to the loss of lives, property, animals, houses, power lines, roads, bridges, and most recently a hospital. As a result, the development of the district and the whole country in turn has been slowed down by this repeated flooding. Due to the changing climatic conditions, extreme weather events such as droughts and floods will still be experienced throughout the whole world and hence these floods are still a great threat to human lives, property, and livelihoods. According to the Sendai framework (2015-2030), the risk of natural hazards and

associated disasters is on an increase due to increasing exposure and vulnerabilities (UNISDR, 2015). Floods are a meteorological event that develops over time (Parker, 2017), an alert or a warning can be sounded to help people evacuate the high-risk areas. As a result, the focus of this study is on the design and building of a Flood Early Warning System (FEWS) for River Nyamwamba plain which is prone to floods of greater magnitude. This idea of the early warning system in the Nyamwamba river catchment has been a recommendation in many scientific studies within the catchment such as the one conducted by Tibara et al., (2021). This system will help reduce the vulnerability of the communities within the river Nyamwamba catchment and enhance their resilience toward the world's greatest water-related hazard.

General Objective

To design and construct a flood early warning system with enhanced capability of disaster warning information dissemination.

Specific objectives

- 1. To install an ultrasonic sensor for real-time monitoring of river water depth.*
- 2. To develop a system for sending alerts and warnings to the community members within the Nyamwamba river catchment.*
- 3. To test the performance of the FEWS*

Methodology

STUDY AREA

The Nya Mwamba River Catchment Area

The Nyamwamba River on which this project was carried out is found in the Kasese district of Uganda. This river was chosen because it has been discovered that 80% of its catchment area is prone to flooding (Ocen, 2022), and these floods occur on an annual basis, bringing a great deal of pain, property and infrastructure damage, economic losses, and death.

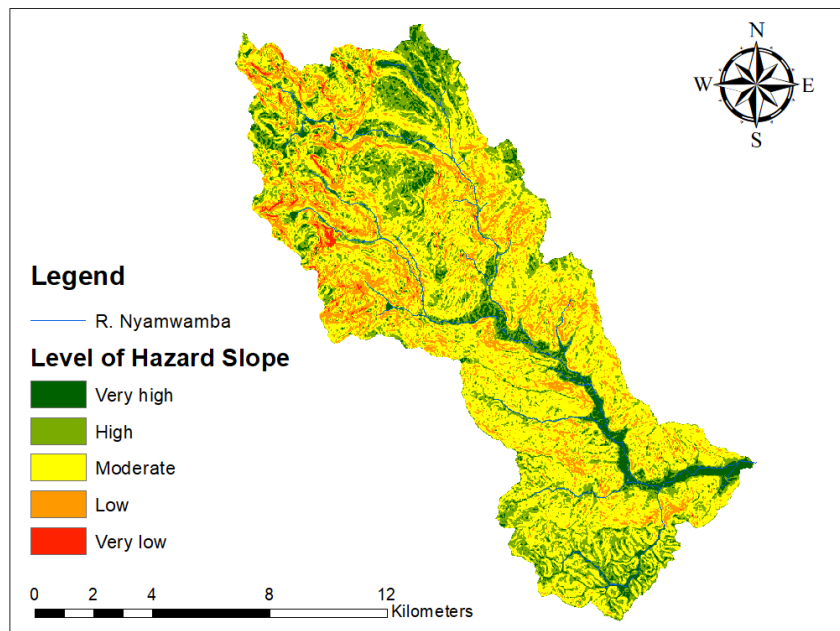


Figure 1: Delineated River Nya Mwamba basin showing areas vulnerable to flooding (Ocen, 2022).

General Methods for achieving all objectives

Gathering of Requirements

Various approaches and methods were used to obtain information that will help in the achievement of all the objectives of this research study. The research focal areas were how water level sensing can be performed, the influence of floods on the sensing system, how alerts are distributed to target communities, and how quickly people will respond favourably to the warning information. The primary methods were as follows:

Document analysis

This method entailed using the internet to read key publications such as textbooks, articles, journals, magazines, newspapers, and websites. This provided a wide understanding of international designs, design requirements, and considerations for hazard warning systems. The research report about 'Flood Risk Assessment of River Nyamwamba' (Ocen, 2022) has been a very instrumental source for obtaining data

and information about the behaviour of river Nyamwamba. Different documents were critically read in order for the three objectives of this study to be achieved.

Interview

This method involved primarily interviewing some technical people who work with Kilembe mines and Nyamwamba hydropower dam. The interviews were online via phone. The key issues discussed during the interviews included flooding challenges faced by people in the area, the extent of flooding, methods of warning dissemination, and why the warning system (originally installed on the Kilembe mines bridge) is no longer operational.

Methods for Specific Objective 1

Ultrasonic Sensor Testing and Experiment Data Analysis

The Ultrasonic sensor which was used for measuring the water level was tested for accuracy and the following procedure was followed to get data that was later analysed using MS Excel.

- 1. Provided an indoor environment for execution of the test.*
- 2. A graduated meter rule of length was used to provide the actual distance to be measured.*
- 3. The ultrasonic sensor HC-SR04 was positioned at the zero mark, and connected to an Arduino Uno Microcontroller on which a program for measuring distance has been uploaded (program is shown in the appendix section)*
- 4. An object was placed at different positions of known length along the ruler to act as an obstacle to the waves emitted by the sensor.*
- 5. The distance measured by the sensor is displayed on the serial monitor in the Arduino IDE.*

Also, based on this study's objectives, the other data obtained about the previous flood levels, challenges faced by people during floods, and the mechanism of operation of the previous flood warning system were cross-checked for consistency.

The data was then examined in conformity with the objectives to determine the actual system needs and provide suitable solutions and recommendations.

Water Level Measurement.

The ultrasonic sensor was utilized in measuring water level data that was then sent to the microcontroller for processing. The ultrasonic sensor will be installed at a riverbank to measure water levels in a real-world project. The location will be upstream of the Nyamwamba River basin, immediately after the confluence of two important tributaries. During days of no flooding (safe water levels), the flow should be largely uniform over the whole width of the river, and a location with no substantial backwater-flow impacts should be chosen. Water level values in the prototype are calculated using a scaling factor from actual river stage data.

$$PWL (cm) = \frac{\text{Actual River Stage (m)}}{\text{Scale Factor}}$$

Flood Depth

Analysis of the flood depths for different return periods at three areas within the Nyamwamba river catchment that is Kilembe Mines Hospital, Chanjojo, and Kyiriba Kithumba Hotel had been done by Ocen, (2022) and the threshold values for the prototype will be calculated using his results. It was observed that the flood depth increases with increase in the return period for all the observation stations.

Table 1: Depth of flood at different marked areas generated from a model on “Flood Risk Assessment of the Nyamwamba River” Adopted from (Ocen, 2022).

		Flood Depth (m)		
SITE		Kilembe Mines Hospital	Chanjojo	Kyiriba Kithumba Hotel
RETURN PERIODS	10	10.97	9.19	5.35
	25	14.29	11.29	7.06
	50	17.84	12.52	8.25
	100	20.33	16.13	10.19

Water Level Data processing

Several tools and programming languages were used to customize the Microcontroller's functionality to the project's requirements and scope. The Arduino Uno microcontroller was used to handle the input data from the ultrasonic sensor before passing it as output data to the output devices. Arduino was chosen because it runs on the ATmega328, which provides direct access and control over the microcontroller's programming (Arduino®, 2022b). It can be powered by a USB cable, an AC-to-DC adapter, or a battery. On the Arduino board, the Arduino IDE (Integrated Development Environment) was used to build microcontroller programs. The IDE is built on the C++ programming language and is linked to the Arduino hardware components to upload and communicate with them. The microcontroller analyses the water level data obtained from the ultrasonic sensor and compares the current water levels (Safe, Medium, and High) with the pre-determined threshold values.

Methods for specific objective 2

Sending alerts and warnings

The SIM800L GSM module and the buzzer are the primary output devices used to disseminate disaster information. The GSM module is utilized to send catastrophe information to the target populations via SMS. Two kinds of messages are sent depending on the water levels. The first SMS alert is to inform the people about the increasing water levels and it is **“Flood Danger Status: MEDIUM. Please Prepare for Evacuation and Stay Alert”**. The second SMS alert is to inform the people to quickly vacate the flood zones and it is **“Flood Danger Status: HIGH. Please Evacuate the area immediately!-Ghuthibithe”**.

The GSM module is powered using a 2A-rated DC-DC buck converter (LM2596) which is connected to a 7-12V solar battery.

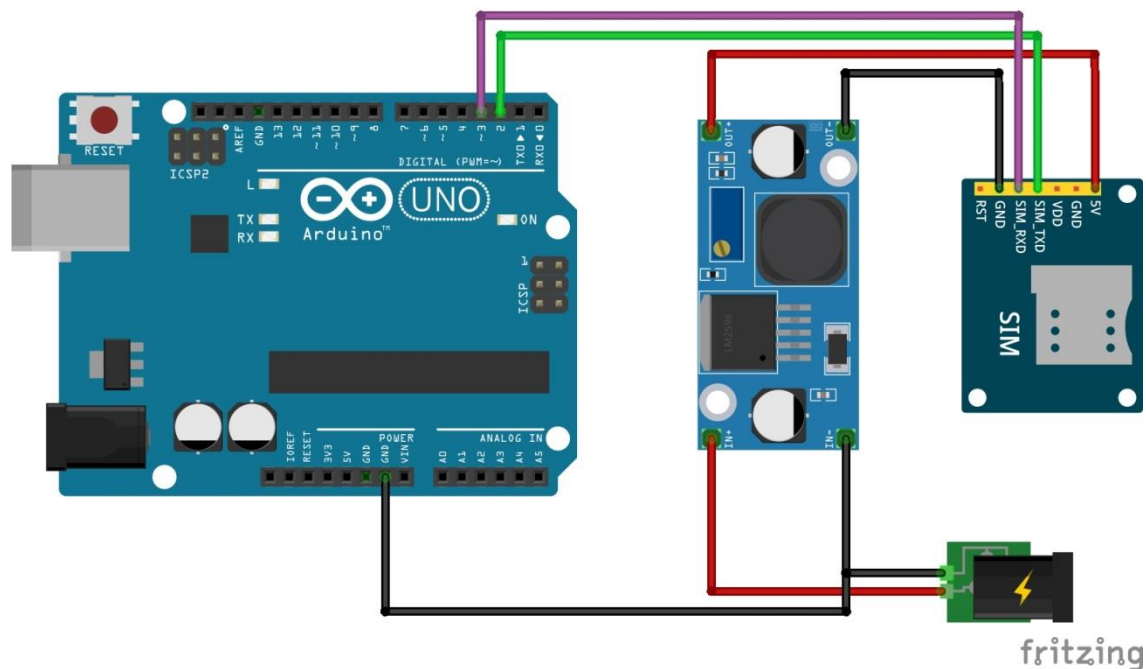


Figure 1: Powering the GSM Module and its connection to Arduino Uno Microcontroller.

The buzzer alarm is used to disseminate disaster information by making a very loud noise and is sounded as an emergency call to take additional measures during high water levels.

Methods for Specific objective 3

Design and construction of the flood early warning system prototype

The scope of this research was limited to developing a prototype for a flood early warning system. An Arduino Uno Microcontroller (ATMEGA 328P model), an ultrasonic sensor, an LCD screen (16X2), a GSM module (SIM800L model) and a SIM card, a DC-DC buck converter, a buzzer alarm, a breadboard, jumper wires, resistors were used to build the prototype. The system circuit diagram was created with Fritzing Software (refer to Appendix C), while the system logical flow diagram was created with MS Word (Refer to Appendix D). The prototype's design and construction were divided into three major systems: input, data processing, and output as seen in figure 6 below. The input system comprises of the ultrasonic sensor, the data processing is made up of the Arduino Uno microcontroller and the output system has the LCD, buzzer and the SIM 800L GSM module. The output devices are operationally based on the microcontroller's command, which is also based on the current water level, as indicated in Table below.

Table 2: Output devices working at certain water levels

<i>Pre-set levels</i>	<i>Precaution</i>	<i>Output device(s)</i>
<i>Level 1</i>	<i>Safe Level</i>	<i>LCD</i>
<i>Level 2</i>	<i>Medium level</i>	<i>LCD, and SIM800L GSM module</i>
<i>Level 3</i>	<i>Flood Level</i>	<i>LCD, SIM800L GSM module, and Buzzer</i>

Figure 2 below also shows the interaction and interrelation between input, Data processing and output systems.

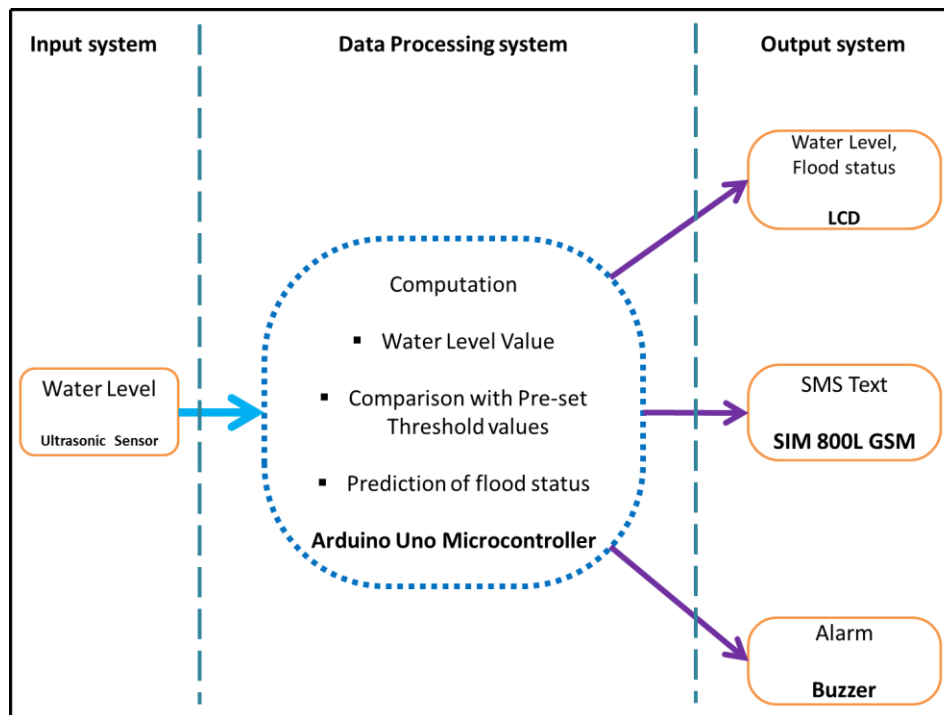


Figure 6: The Three major systems of the Flood Early Warning System

Housing the system components

With exception of the buzzer and ultrasonic sensor, the other components of the system that is the entire electrical system is in the control box which is made of mild steel housing, this housing is weather proof and was painted to make it resistant rusting. The control box is fitted with a locking system to ensure safety and easy maintenance of its components.

Testing and validation

The system was tested shortly after implementation to confirm that the overall functionality of the system met the study's goals. Validation was required in the event of system misbehaviour to guarantee that the study's principal purpose was clearly expressed and attained.

System Block Diagram

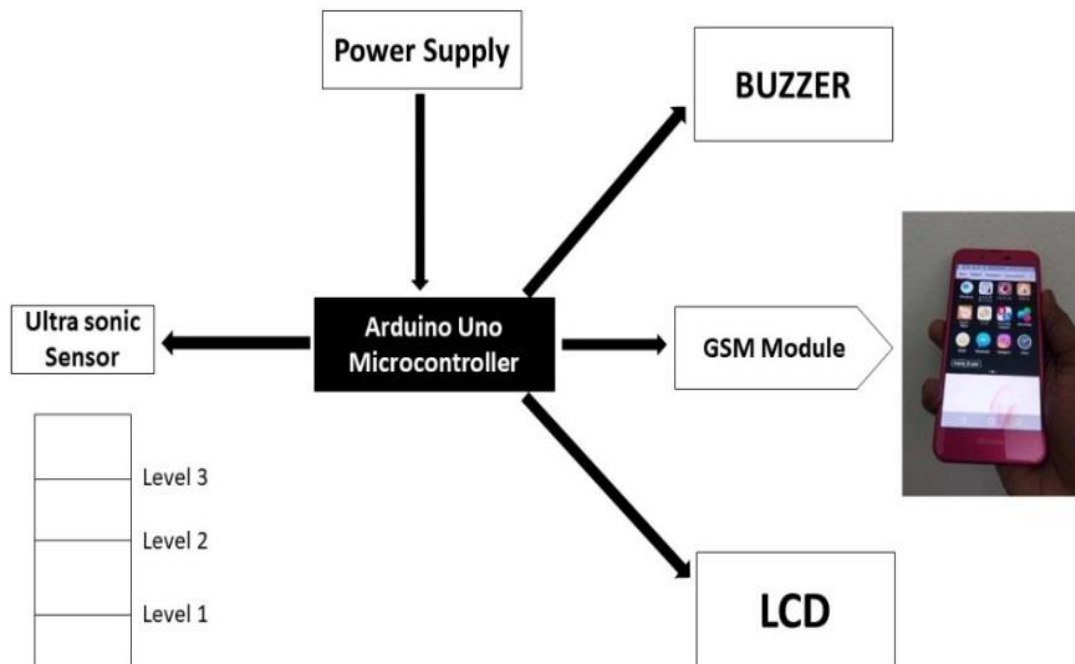


Figure 3: System Block Diagram for the components

RESULTS

Measurement of the water level

The HC-SR04 ultrasonic sensor was mounted on top of a bucket to represent a stretch of the river and was used to monitor and measure the water level. Each water level measurement is sent to the Arduino Uno microcontroller, which compares it to the pre-set threshold values to decide if it is a high, medium, or low level. However, the Ultrasonic sensor (input system component), was tested for accuracy and the results are as shown in the section below.

Accuracy testing of the input system

*The purpose of conducting this test was to determine the accuracy of data collected from the ultrasonic sensor and ensure the system can perform well in measuring water level. The results of the experiment of using ultrasonic sensor HC-SR04 to measure distance can be seen in **Appendix B**. Figures 8 and 9 below show a comparison between the distance measured by the sensor and that indicated on the graduated metre rule.*

The line graph in Figure 9 below shows not much gap between the reading recorded by the ultrasonic sensor and the ruler. However, it can be seen that the gap increased gradually at greater distances though the error remained minimal. Nevertheless, this shows that the ultrasonic sensor is accurate conforming to the findings of Mastor et al., (2015) who found out that the average accuracy of the HC-SR04 ultrasonic sensor is over 93% and all the results were within an acceptable precision range.

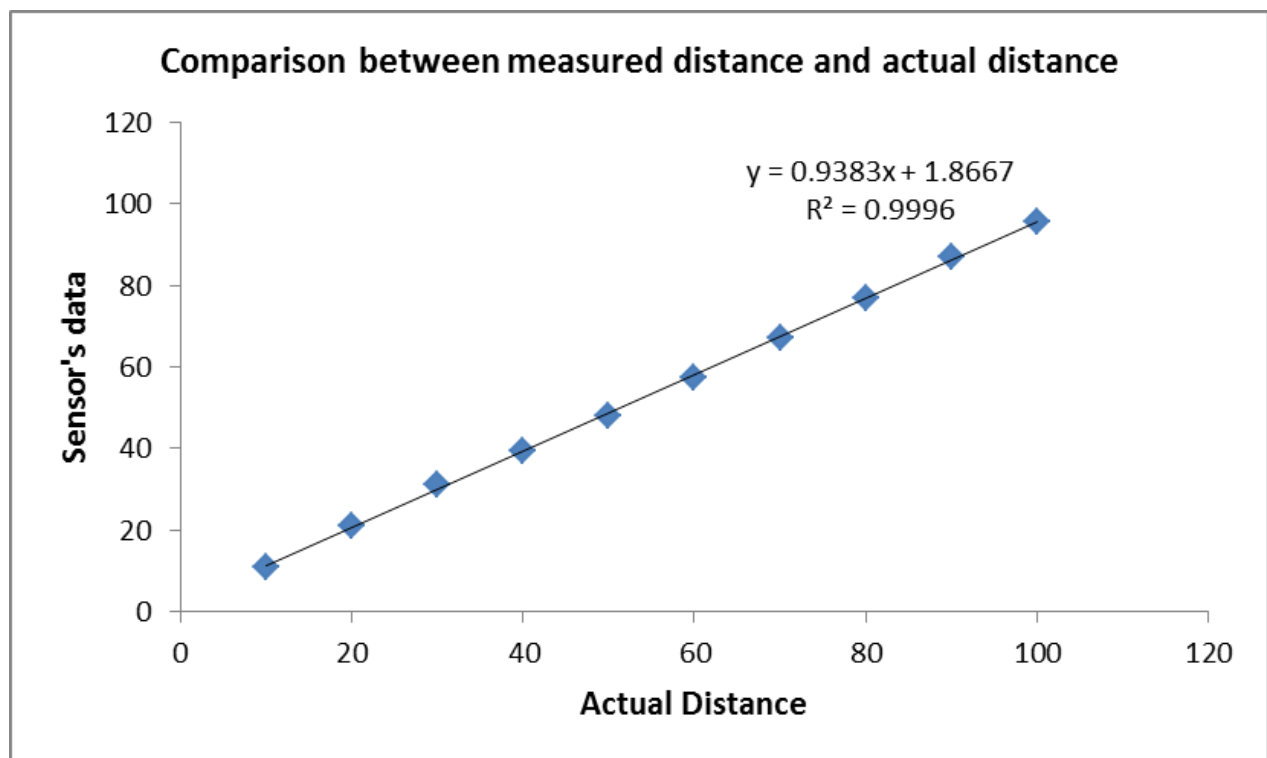


Figure 4: Comparison of distance measured by Ultrasonic sensor and that indicated on the ruler



Figure 5: Variation between Ultrasonic sensor's measured distance and that on the ruler

Threshold Water Level Values

Based on the flood depth data in table 2 and the 10-year return period results, it can be shown that the peak flood will have varied heights at different stations within the river catchment region. The 10-year return period data was chosen such that after the ten years, an update of the flood risk assessment model of the Nyamwamba river catchment can be performed in line with the prevailing conditions at that time. Kilembe Mines Hospital station was chosen because it is closer to the catchment's upstream region than the other two. The flood peak of 10.97m was approximated to 10 m in the prototype. The 10m depth was related to the 15cm of the prototype peak flood to obtain a design scale factor of 2/3.

$$\text{Scale Factor} = \frac{\text{Flood Peak Stage (m)}}{\text{PWL(cm)}} = \frac{10}{15} = \frac{2}{3}$$

Taking $3\frac{2}{3}$ m as the maximum safe level, and $6\frac{2}{3}$ m as the maximum medium level, these will translate into the following design parameters.

Table 3: Design parameters for FEWS

<i>Precaution</i>	<i>Actual River Stage (m)</i>	<i>Prototype Water Level (cm)</i>
<i>High/Flood</i>	10	15
<i>Medium</i>	$6\frac{2}{3}$	10
<i>Low/Safe</i>	$3\frac{2}{3}$	5

To protect the sensor from rising water levels in the prototype, it was located 5cm from the high flood mark. Warnings and alerts were not issued at the exact maximum levels shown in the table above, but rather between one and the other.

The table below indicates the distance between the water's surface and the ultrasonic sensor, as well as the related precaution that will be displayed on the LCD or communicated over GSM if the water level rises within that range. A range of values was chosen to be more reliable than just taking a single value as determined in the flood risk assessment model.

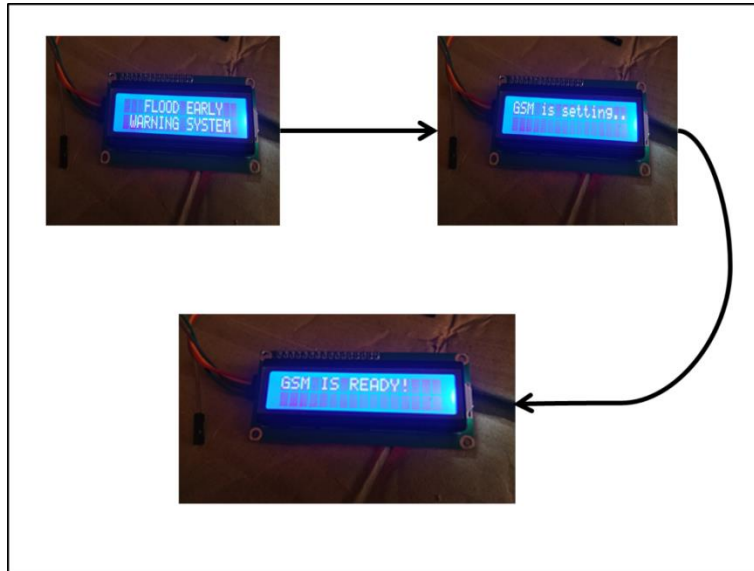
Table 4: Threshold Values for Water Levels

<i>Water Level</i>	<i>Distance between the water surface and ultrasonic sensor</i>
<i>High/Flood</i>	2cm-9cm
<i>Medium</i>	10cm-14cm
<i>Low/Safe</i>	15cm-19cm

System Testing

After connecting the different elements of the flood warning system together, the set up was powered up and tested for correctness and functionality.

The system will run an initial process showing that the GSM is ready to disseminate information about the likelihood of flood occurrence.



*Figure 6: LCD showing the initial phase of the River Flood Early Warning system
The LCD screen shows the measured water level. The LCD will indicate "Safe Level" if the water level is deemed to be low (less than or equal to 5cm as per the prototype).*

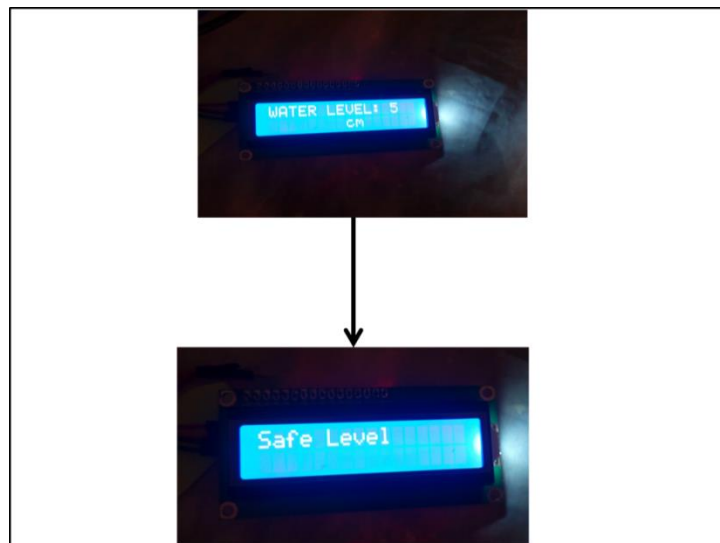


Figure 7: LCD displays Safe level during times of low water level

Dissemination of Disaster alerts and Warnings

Depending on the water level data from the input system, warnings and alerts have been sent. It relies on GSM network; however, it only uses the SMS component which has been proven to work in remote and far off places as well (Randhawa et al., 2018). Since incoming SMS are free in Uganda, the message alerts will be disseminated free of cost to the registered user numbers.

The reliability of the system was measured by comparing the number of LCD displaying SMS status ‘SMS Text Sent’ with the number of SMS that is actually received by the recipients. During the test, two numbers were registered in the system and all warning SMS reached the recipients with an exception if the phone with the registered number is off although the status on LCD is ‘SMS Text Sent’.

Firstly, the SIM800L GSM module sends an SMS to the registered mobile telephone numbers alerting them of the rising water levels and asking them to be ready to evacuate and remain vigilant if the current water level falls under the medium level.



Figure 8: SMS delivered to phone during Intermediate rising water levels

Secondly, if the water level determined goes into the high/flood level category, the GSM module sends text messages through SMS instructing people to evacuate and leave the region, and a loud buzzer sounds an alarm as an indicator to take any other means necessary and exit the area. During the test process, the buzzer was audible in a radius of 40m.

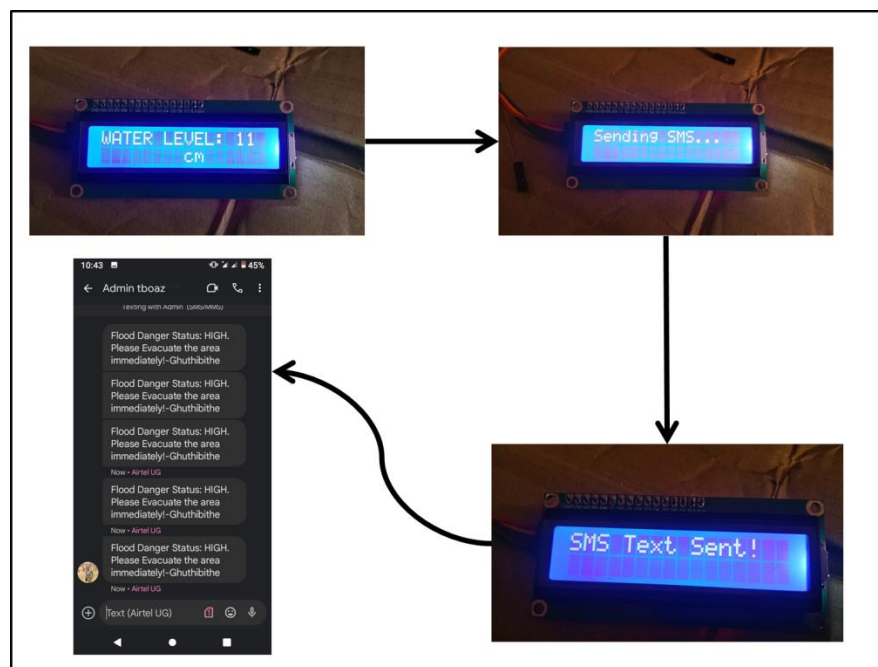


Figure 9: SMS delivered during times of high water levels

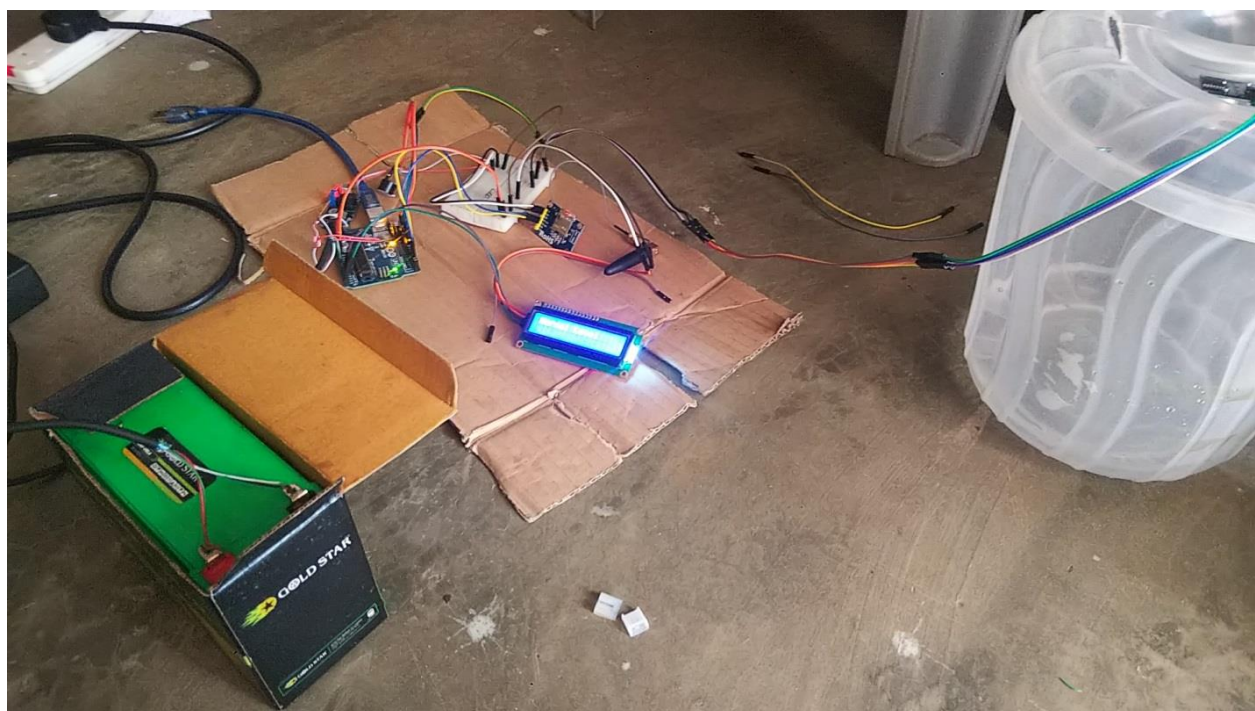


Figure 10: Flood Early Warning System set-up

Challenges

- *Information on the **field/real/actual** river stage was difficult to find.*
- *The utilization of GSM communication is impacted by variations in the weather patterns, topography, and proximity to service provider communication towers.*
- *Only cell phone numbers that have already been registered in the system received disaster information. As a result, services are not provided for refugees and other individuals who may have recently arrived from locations beyond the flood-prone area.*



Figure 11: Flood Early Warning System final prototype

Conclusion

The study ultimately led to the design and construction of a FEWS that is affordable to install and trustable to use in any community affected by flooding.

Warning alerts and messages were sent to all the saved phone numbers and received in due time. This gives the technical staff and the general public plenty of time to evacuate, saving many lives and valuable property, hence the achievement of the first objective of this study.

A non-contact water level monitoring system was put in place and it was able to keep track of the changes in water levels and the data sent to the microcontroller for comparison with the pre-set threshold values. The water level values were displayed on the LCD and this means that they can easily be recorded in a book for future use. As a result, the second goal of this study was met.

The success achieved in monitoring the water levels and dissemination of alerts and warning messages at levels that have been categorised as disastrous, is an indication for meeting the third objective of this research study.

Recommendations

Further research in not only monitoring river water levels, but also discharge flow rates, precipitation data, and catchment run-offs can be done to create a more dependable FEWS that provides better preparedness in times of crisis.

Research can be carried out to determine how sensor readings can be archived online for future use and made freely available to researchers and system designers.

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