International Journal of Advanced Multidisciplinary Research
ISSN: 2393-8870
www.ijarm.com
(A Peer Reviewed, Referred, Indexed and Open Access Journal)
DOI: 10.22192/ijamr Volume 12, Issue 2 -2025

Research Article

DOI: http://dx.doi.org/10.22192/ijamr.2025.12.02.008

Proposed Early- Warning System for Floods of Al-Hawad Valley, Northern Sudan

Samir Muhammad Ali Hassan Alredaisy[1] ; Hatem Al-Obaid Ibrahim Nouh[2]; Naji Obaid Naeem Khalafala [3]; Ahmed Suleiman Mustafa Al-Siddiq[3]; Wijdan Dirar Omar Ahmed[4] ; Al-Tayeb Ibrahim Ahmed Wadi[1]

[1]University of Khartoum, Dept. of Geography;
[2]National Centre for Research; University of Bahri,
[3]Faculty of Humanities, Department of geography;
[4]University of El- Quran El-Kareem and Islamic Sciences, Dept. of Geography,
Corresponding author: Samir Muhammad Ali Hassan Alredaisy,
E-mail: *samiralredaisy1@gmail.com*

Keywords

torrential floods,
disaster,
early warning system,
damage reduction

Abstract

This research aims to develop an automatically early warning system of floods to alert resident population in Kaboshia area prior to onsets of Al-Hawad valley floods. This early warning system was developed on remote sensing method by using self-operated surface runoff monitoring devices “SOSRMD” where the data is sent to the early warning system server, which in turn processes the data and enters it into modeling software of sudden floods to produce maps showing the extent, depth, and speed of the flood, and finally processing them with population maps. The device sends text messages to the residents who are exclusively at risk of flooding, via phone, of the time and danger of the flood, with refuge areas defined for the population in advance. Data was collected by installing the device at the entrance of Al-Hawad valley to the study area with main goal of sending water discharge data to a remote server where MySQL database and Map-Box open web mapping system were preinstalled. The station’s was tested in January 2020 where five scenarios were proposed at 357.0; 358.0; 359.0; 360.0; and 360.5 meters of water rise against area coverage by flood. The impacts were consecutively; there is no water coverage; little water coverage; remarkable water coverage; obvious water coverage; and entire water coverage and the waters got out of control. The main result is that, there is an increase of water coverage with increased water level. The five proposed scenarios of area coverage by Al-Hawad flood were also tested for size of damage on property “homes”. The result is that, damage increases with increased coverage by floods. This device “SOSRMD” was further tested for verification at a private farm in Khartoum State where it proved its validity and reliability. The device “SOSRMD” is expected to provide decision support through websites and smart phone applications that help the decision maker to immediately access and assess the disaster, and also it estimates self-relief requirements

1. Introduction

Torrential floods are a worldwide problem as they cause devastating disasters. This is documented by applied research such as that in Kedarnath area of the Mandakini River (Rao et al. (2014); in the Gard region in southern France (Ruin et al. (2008); and in China (He et al. 2018); and in Sudan which, as a part of the eastern Nile region, is characterized by highly variable river flows, making it prone to floods with devastating effects on lives and property (World Bank, ?; Nile Basin Initiative, 2020), and at a micro-geographic level such as the severe effects of torrential rains and floods in the East Nile locality in Khartoum state (The International University of Africa-Disaster Institute 2015). This requires proper national planning and public participation where early warning systems “EWS” of floods are essential to manage and curb the impacts of floods and to make their water a sustainable value. This research aims to develop an automatically early warning system of floods “SOSRMD” to alert resident population in Kaboshia area prior to onsets of Al-Hawad valley floods.

2. Theoretical background

The flood index is an indicator to the amount of rain that is needed to cause the minimum flood in the basin. The torrent flood index is the amount of rainwater in a certain period over a small basin that needs to be used to create secondary flood conditions (full bank) at the outlet of the basin. The main question of this research is: How much rainwater is needed in a small basin to create floods in small valleys? This research works to design an early warning system to reduce the risk of floods by Al-Hawad valley.

The pluvial flooding occurs when intense rainfall overflows the limits of urban drainage and water accumulation causes hazardous flash floods, where they are becoming increasingly frequent due to climate change and human actions (Acosta et al. 2018).

An early warning system is defined as a socio-technical system designed to create and distribute useful warning information in a timely manner to enable the target system to take a practical response to the dangerous threat in order to avoid the disaster or reduce its impact or impact (Abdullah et al. 2020). Effective early warning systems are characterized by continuous scientific development, increased driving time, use of technology, and good dissemination of participation of partners and beneficiaries through a good understanding of their needs - increasing ownership - building capabilities. It relies on science-based solutions to close the gap between prevention and preparedness measures (Pappenberger et al. 2015). A flood early warning and response system (FEWRS) is essential to ensure that all stakeholders receive the right information and are provided with necessary actions and response information to avoid loss of lives and property (Abdullah et al. 2020).

An early warning system consists of a group of interconnected elements of knowledge of risks by identifying the existing or expected danger, causes, and the extent of the possibility of it occurring; monitoring the movement of risks is the turn here to monitor the movements of these risks; ability to respond that there must be a quick response to deal with the danger; and availability of communications through which communication can be made to deliver the warning to everyone to achieve efficiency and effectiveness (Abdullah et al. 2020). An effective early warning system must include not only the technologies for accurately detecting an emerging floods, but also a civil communication system through which the population can be timely warned by the local government and other sources (Jin et al. 2011). The establishment of a comprehensive early flood warning broadcasting equipped with IVR by the government is crucial to reach flood victim community (Kamrul, 2013).

Real-time dynamic warning systems can be applied to the early-warning platform at central, provincial, municipal, and county levels (Liu et al. 2018), and all monitoring systems constituted fully integrated early warning systems EWSs have working EWSs, and advances in sensor technologies have resulted in more reliable, high frequency and automated samplers for data collection in water quality studies (Joseph et al. 2010).

Provision of the warning and communicating requires accuracy, understandability, and action - precise and reliable - and must provide the final beneficiaries with risk and advice when reacting. Here, age, gender, and public awareness of the respondents have significant relationship with early warning system on disaster management (Wabanhu, 2017). Negative correlation found between public plans to move from their residence and dissemination of information with early warning system to the community (Wabanhu, 2017).

3. Relevant research

Castillo et al. (2004), referred to the efforts of the Andean region in Venezuela to provide them with a flood risk warning system by taking advantage of air communications and information technology. The National Weather Service (NWS) in USA worked to improve flood forecasting and warning and work to improve community response to its risks (Mogil 1978); while the use of an indicator Operation Efficiency Index as a quantitative method to distinguish between a flood event and a torrent flood was suggested (Kobiyama et al., 2007); and Gaume et al. (2009) identified the first step in creating an atlas of severe torrent floods by collecting data on about 550 documented flood events according to a scientific strategy in Europe. YAN (2009) also worked on building and legitimizing an early warning model for thaw floods in northern Xinjiang – China which greatly benefited in reducing the scale of the disaster and helping in making a warning decision. Ruin et al. (2007), indicated that torrential floods are difficult to predict accurately and the use of "cognitive" mental maps combined with GIS data processing to assess motorists' perception of torrent flood risks.

The rainfall forecast from WRF weather model was used in the Configured Hydrologic Modeling System (NAM) to produce runoff forecasts (Nile Basin Initiative. 2020). The National Early Warning and Monitoring Centre of Natural Disasters in Brazil allowed the analysis of the EWS, identifying behaviors, as reinforcement and balancing loops, not always intuitive, to support better management and planning decisions to improve the system effectiveness (Pegetti et al. 2020). This platform consists of eight fixed riverside hydrological monitoring stations, eight meteorological stations, nomadic mobile monitoring stations called "drifters" used in the flow, and a sniffer with data muling capability (Ibarreche et al. 2019).

The Emergency Water Information Network (EWIN) in Colima, Mexico effectively compiles and forwards information to decision-makers, government officials, and the general public, potentially providing valuable minutes for people to evacuate dangerous areas (Ibarreche et al. 2019). The system includes hardware, software, plans and procedures, and personnel that work in an integrated manner to increase the mitigation time available prior to the onset of flooding. This mitigation time increase is a consequence of a reduction in the time required to collect data, to evaluate and identify the flood threat, to notify emergency personnel and the public, and to make decisions about the appropriate response (Kim et al. 2004).The proposed methodology for the third stage could support flash flood prevention measures in the 13th 5-Year Plan for Economic and Social Development of the People's Republic of China, 2016–2020 (Liu et al. 2018). The approach is designed to work in situations of limited data availability with an emphasis on sustainability and appropriate technology in flood-prone Karnali River basin in western Nepal (Smith et al. 2017). The DeLone and McLean (D&M) model is the most widely employed model, and recorded in 28 studies by 39% (Abdullah et al. 2020). The combination of reliability and avoided damages leads to the warning expectation as an indicator for the optimal alert. EWS as a non-structural protection measure induce very low detrimental effects on the natural environment and can be quickly implemented (Nachtnebel. 2014).

Ibrahim (1997) recommended establishing an early warning system and coordination between relevant authorities in Khartoum State to reduce flood disasters. Jupp (1998) used remote sensing to provide decision support for declaring areas of exceptional drought in Australia, while the GAO (2004) designated a model and method to evaluate regional flood fragility. LIU's (1999) presented a general idea of how to create an evaluation system based on the relationship between urban disaster reduction, disaster environment, and socio-economic development. Similarly, Zhou (2010) used the statistical frequency method to prevent and reduce the capacity of urban disasters in China, and YAN (2009) also worked on building and legitimizing an early warning model for thaw floods in northern Xinjiang – China which greatly benefited in reducing the scale of the disaster and helping in making a warning decision, Castillo et al. (2004), referred to the efforts of the Andean region in Venezuela to provide them with a flood risk warning system by taking advantage of air communications and information technology. National Weather Service (NWS) in USA worked to improve flood forecasting and warning and work to improve community response to its risks (Mogil 1978). (Kobiyama et al., 2007) suggested the use of an indicator Operation Efficiency Index as a quantitative method to distinguish between a flood event and a torrent flood, while Gaume et al. (2009) identified the first step in creating an atlas of severe torrent floods by collecting data on about 550 documented flood events according to a scientific strategy in Europe. Ruin et al. (2007), indicated that torrential floods are difficult to predict accurately and the use of "cognitive" mental maps combined with GIS data processing to assess motorists' perception of torrent flood risks.

The strengthening of the community-based Flood and drought preparedness and early warning system in Sudan using operational and innovative models in addition to Satellite-based transmission technology for real-time automatic water level telemetry system (CTCN. 2024). The components of Early Warning System of Sudan Flood Resilience and Water Resources Management Project enhancing forecasting and early warning; improving the maintenance of small-scale water storage structures; and institutional capacity building and project management (World Bank,2 ?). The Taya system is a community-led indigenous system. It is a network of tents that are built in the proximity of informal settlements that are highly vulnerable to flooding; primarily they operate as lookout points situated in strategic locations to monitor the river water level and other factors that have been identified as signs of potential flooding (UNNDR.2022). The Taya system is an incredible display of community collaboration and empowerment, and an excellent case study on community-led adaption which incorporates indigenous knowledge. Capacity-building of Taya members involves an informal training process using oral transmission of knowledge (UNNDR.2022).

4. The study area, material, and Methods

The Al-Hawad Valley is located in north-central Sudan between 00"20' 15˚-00" 50'16˚ N, and 00" 40' 33˚-00" 50' 34˚ E, and flows across three administrative States of Gedarief, Khartoum, and River Nile (Figure 1). This is important since it passes through many villages, urban centers, and archaeological sites, where agriculture and grazing are based.

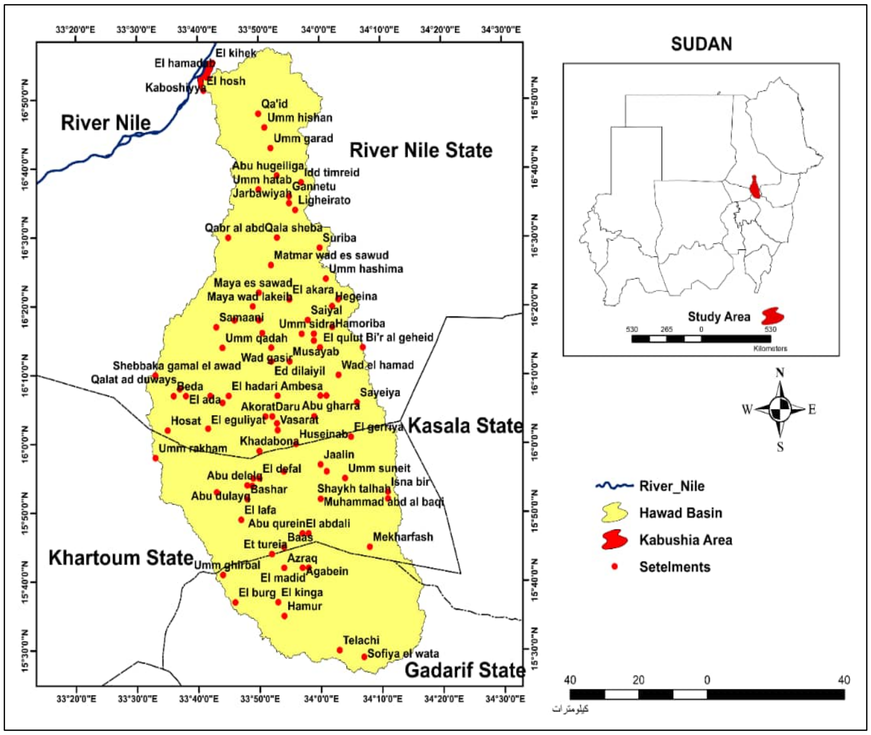

Figure 1: Location of AL-Hawad Valley Basin
Data sources and methodology, and analysis

4.1. Material

The self-operated surface runoff monitoring device "SOSRMD" was designed with local parts that proved its effectiveness. It consists of many related different parts, these are Arduino Uno Controller; Ultras Sonic distance Sensor; Water Flow Sensor; Sd Card Module; GSM Module; Wires; and Connectors; Solar Cell and 7-volt Battery; Hosted windows-based Server; Mobile phone; ArcGIS Software; Mab-Box open web mapping system; and MySQL Database and Wires and Connectors (Figure 2), where their assemblage produced the device (Figure 3) which also contains a solar energy device and a direct transmitter to the Internet.

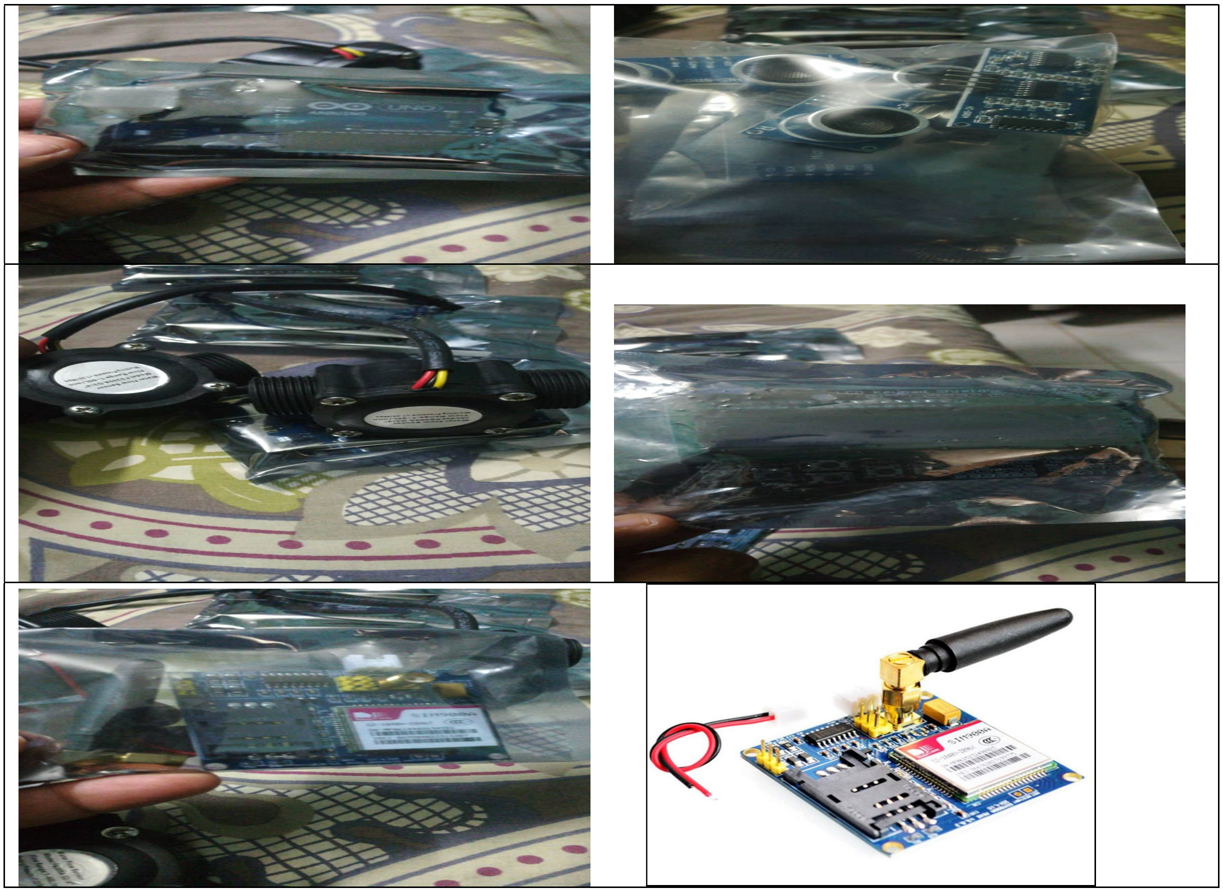

Figure 2: Parts of self-operated surface runoff monitoring device “SOSRMD”

Figure 3: The self-operated surface runoff monitoring device “SOSRMD”

The Arduino UNO Controller:

Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the microcontroller on the board. To do so you use the Arduino programming language (based on Wiring), and the Arduino Software (IDE), based on Processing. The specification of the Arduino is shown in table 1. The number of pulses using an Arduino is used and then the flow rate in liters per hour (L/hr) was calculated using a simple conversion formula.
Arduino has been used in thousands of different projects and applications. The Arduino software is easy-to-use for beginners, yet flexible enough for advanced users. It runs on Mac, Windows, and Linux. Teachers and students use it to build low cost scientific instruments, to prove chemistry and physics principles.

The Ultra-sonic sensor:

The role of ultra-sonic sensor (Figure 4) is to measure the distances to water surface, as the water level changes the reading will follow these changes, when the water flow stop the sensor will keep reading the depth of the water stream bottom (see the figure ….), however, the accuracy of the sensor is high enough to make it a useful tool. Once the ultra-sonic sensor takes the reading through the controller, the reading normally transferred to the GSM Module and from this module to the remote server via SIM Card GPRS technology.

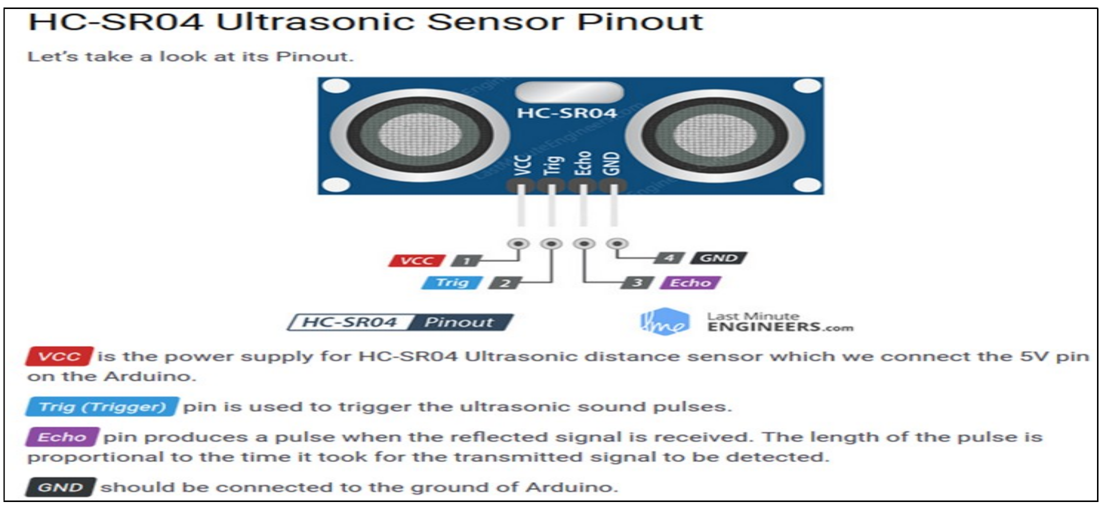

Figure 4: Ultra-sonic sensor

The water flow meter:

The water flow meter generically measures the water flow through principle of Hall Effect (Figure 5).The water pushes against the fins of the rotor, causing it to rotate. The shaft of the rotor is connected to a Hall Effect sensor. In this flow meter, for every liter of liquid passing through it per minute, it outputs about 4.5 pulses.

A correction factors were applied to make the sensor able to measure the discharge based on water stream cross-section and the final reading in form of cubic meter. All these corrections done within the code (uploaded to Arduino), the second steps normally the reading from the sensor moved to the GSM Module (see section of GSM module) and send to remote server at real-time

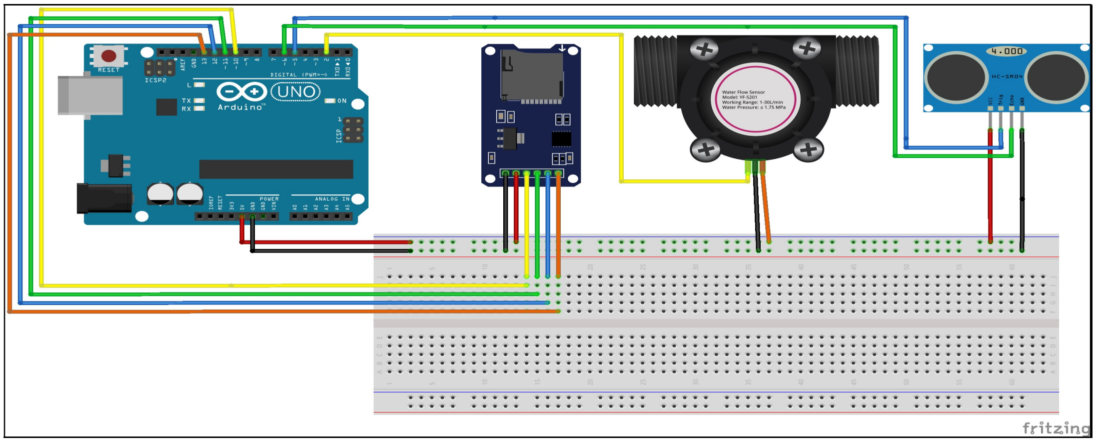

Figure 5: The water flow meter

Windows-based server:

A windows-based server was hosted from Quantum hosting Company on (date…..) for the purpose OF building a real time flood early warning system which consuming the real-time readings from Web Mapping for flood early warning system. This system utilized the MapBox open sources to housing all web mapping efforts, which include inundations layers and integration with MySQL database

The MapBox:

MapBox is the location data platform for mobile and web applications. It provides building blocks to add location features like maps, search, and navigation into any experience you create. Since 2010, it has rapidly expanded the niche of custom maps, as a response to the limited choice offered by map providers such as Google Maps. MapBox is the creator of, or a significant contributor to, some open source mapping libraries and applications, including the Mapbox GL-JS JavaScript library, the MB Tiles specification, the Tile Mill cartography IDE, the Leaflet JavaScript library, and the CartoCSS map styling language and parser (https://en.wikipedia.org/wiki/Mapbox last access 1/26/2020).

The Flow Rate Sensor:

The Arduino flow meter works on the principle of the Hall Effect (Figure 6). According to the Hall Effect, a voltage difference is induced in a conductor transverse to the electric current and the magnetic field perpendicular to it. Here, the Hall Effect is utilized in the flow meter using a small fan/propeller-shaped rotor, which is placed in the path of the liquid flowing. The liquid pushes against the fins of the rotor, causing it to rotate. The shaft of the rotor is connected to a Hall Effect sensor. It is an arrangement of a current flowing coil and a magnet connected to the shaft of the rotor, thus a voltage/pulse is induced as this rotor rotates. In this flow meter, for every liter of liquid passing through it per minute, it outputs about 4.5 pulses. This is due to the changing magnetic field caused by the magnet attached to the rotor shaft as seen in the picture below.

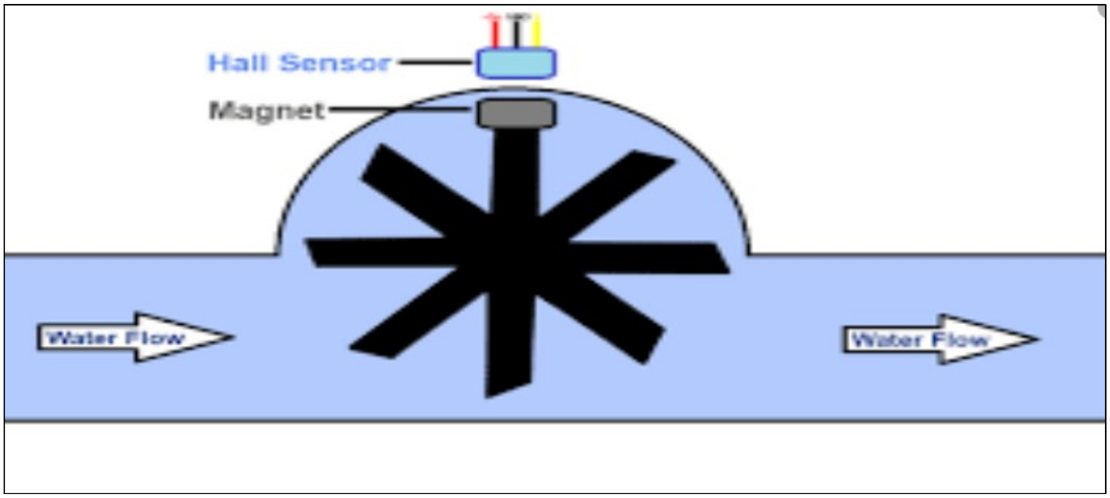

Figure 6: Flow Rate Sensor

The GSM Module:

SIM900A is an ultra compact and reliable wireless module. This is a complete GSM/GPRS module in a SMT type and designed with a very powerful single-chip processor integrating AMR926EJ-S core, allowing you to benefit from small dimensions and cost-effective solutions.

The SIM900A Modem is built with Dual Band GSM/GPRS based SIM900A modem from SIMCOM. It works on frequencies 900/ 1800 MHz. SIM900A can search these two bands automatically. The frequency bands can also be set by AT Commands. The baud rate is configurable from 1200-115200 through AT command. The GSM/GPRS Modem is having internal TCP/IP stack to enable you to connect with internet via GPRS.

The Device operation code

The Device “SOSRMD” operation code is shown by table 2.

Table 2: Device “SOSRMD” operation code

```
#include <SoftwareSerial.h>
#include <SPI.h>
#include <SD.h>
//#include <TimeLib.h>
//******************
********************
*****************
// Sim900A GSM Modem
//******************
********************
*****************
SoftwareSerial Sim900A(7, 8);
//#include <NeoSWSerial.h>
// The Hall-effect sensor is connected to pin 2 which uses interrupt 0. Configured to trigger
//on a FALLING state change (transition from state to LOW state)
attachInterrupt(sensorInterrupt, pulseCounter, FALLING);
//*****************
******************
******************
// SD Card Setup
// Because this loop may not complete in exactly 1 second intervals we calculate
// the number of milliseconds that have passed since the last execution and use
// that to scale the output. We also apply the calibrationFactor to scale the output
// based on the number of pulses per second per units of measure (litres/minute in
// this case) coming
toSerial();
// Sim900A.println("AT+HTTPPARA=\"CONTENT\",\"application/x-www-form-urlencoded\""); /* Set CONTENT Type */
delay(3000);
toSerial();
//
//float Flow = 44.444; //analogRead(A0);
//float Level = 555.555; // analogRead(A1);
```

```
//NeoSWSerial
Sim900A(7, 8);
//******************
********************
*****************
// Ultrasonic sensor
Pins
//******************
********************
*****************
//VCC: +5VDC/Trig :
Trigger (INPUT) -
Pin10/ Echo: Echo
(OUTPUT) - Pin 13
/GND: GND
int trigPin = 5; //
Trigger //was pin 10
int echoPin = 6; //
Echo //was pin 10
long duration, cm,
inches;
//******************
********************
*****************
// Liquid flow rate
sensor
//******************
********************
*****************
//Measure the
liquid/water flow rate
using this code. Connect
Vcc and Gnd of sensor
to arduino, and the
signal line to arduino
digital pin 2.
byte statusLed = 13;
byte sensorInterrupt =
0; // 0 = digital pin 2
byte sensorPin = 2;
// The hall-effect flow
sensor outputs
approximately 4.5
pulses per second per
litre/minute of flow.
float calibrationFactor =
4.5;
volatile byte
pulseCount;
//*****************
******************
******************
Serial.print("Initializi
ng SD card...");
if (!SD.begin()) {
Serial.println("initiali
zation failed!");
// return; }
Serial.println("initiali
zation done.");
// myFile =
SD.open("Level_Flow.
txt", FILE_WRITE);
//*****************
******************
******************
// GPRS GSM Modem
setup
//*****************
******************
******************
//Attach GPRS or
deAttach
Sim900A.println("AT
+CGATT?");
delay(200);
toSerial();
//bearar Setting
Sim900A.println("AT
+SAPBR=3,1,\"CONT
YPE\",\"GPRS\"");
delay(500);
toSerial();
//
Sim900A.println("AT
+SAPBR=3,1,\"APN\"
,\"sudaninet\"");
delay(500);
toSerial();
//bearar Setting
Sim900A.println("AT
+SAPBR=1,1");
delay(6000);
toSerial(); }
//*****************
******************
******************
**
from the sensor.
flowRate = ((1000.0 /
(millis() - oldTime)) *
pulseCount) /
calibrationFactor;
// Note the time this
processing pass was
executed. Note that
because we've
// disabled interrupts
the millis() function
won't actually be
incrementing right
// at this point, but it
will still return the
value it was set to just
before
// interrupts went away
oldTime = millis();
// Divide the flow rate
in litres/minute by 60 to
determine how many
litres have
// passed through the
sensor in this 1 second
interval, then multiply
by 1000 to
// convert to millilitres.
flowMilliLitres =
(flowRate / 60) * 1000;
// Add the millilitres
passed in this second to
the cumulative total
totalMilliLitres +=
flowMilliLitres;
unsigned int frac;
// Print the flow rate
for this second in litres
/ minute
Serial.print("Flow
rate: ");
Serial.print(int(flowRat
e)); // Print the integer
part of the variable
Serial.print("L/min");
Serial.print("\t"); //
Print tab space
// Print the cumulative
total of litres flowed
String Flowmeter =
"f=";
String WaterLevel =
"l=";
String ambersand=
"&";
String DateTime
="dt=";
String SendData =
Flowmeter + Flow +
ambersand+
WaterLevel + Level ;
// String SendData =
Flowmeter + Flow +
ambersand+
WaterLevel + Level +
ambersand +
DateTime + now() ;

//$sql="INSERT into
level_and_flow(
Station_Name,Sensor
_Name,Channel_Nu
mber,Reading_Date,
Reading_Time,Readi
ng_Value,Reading_U
nit,Date_Time)
//values(
'".$_POST["ST"]."','
".$_POST["SN"]."','
".$_POST["C"]."','".
$_POST["D"]."','".$
_POST["T"]."','".$_
POST["V"]."','".$_P
OST["U"]."',now())"
;
/*String SendData =
"" // Needs to insert
each sensor seprately,
which is take time !!!
SendData +=
String("ST=");
SendData +=
String("Station 1");
SendData += "&";
SendData +=
String("SN=");
SendData +=
String("Flow
```

```
float flowRate;
unsigned int flowMilliLitres;
unsigned long totalMilliLitres;
unsigned long oldTime;
//*******************************************************
// SD CARD
//*******************************************************
File myFile;
// change this to match your SD shield or module;
const int chipSelect = 10;
//*******************************************************
//
//*******************************************************
void setup() {
Sim900A.begin(38400);
Serial.begin(9600);
//while (!Serial) continue;
Serial.println(" Config SIM900A");
delay(200);
Serial.println("Done..");
Sim900A.flush();
Serial.flush();
//*******************************************************
// Ultrasonic sensor setup
//*******************************************************
//Define inputs and outputs
pinMode(trigPin,
//
//*******************************************************
void loop() {
//*******************************************************
// Ultrasonic sensor loop
//*******************************************************
// The sensor is triggered by a HIGH pulse of 10 or more microseconds.
// Give a short LOW pulse beforehand to ensure a clean HIGH pulse:
digitalWrite(trigPin, LOW);
delayMicroseconds(5);
digitalWrite(trigPin, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin, LOW);
// Read the signal from the sensor: a HIGH pulse whose duration is the time
//(in microseconds) from the sendingof the ping to the reception of its echo off of an object.
pinMode(echoPin, INPUT);
duration = pulseIn(echoPin, HIGH);
// Convert the time into a distance
since starting
Serial.print("Output Liquid Quantity: ");
Serial.print(totalMilliLitres);
Serial.println("mL");
Serial.print("\t"); // Print tab space
Serial.print(totalMilliLitres/1000);
Serial.print("L");
// Reset the pulse counter so we can start incrementing again
pulseCount = 0;
// Enable the interrupt again now that we've finished sending output
attachInterrupt(sensorInterrupt, pulseCounter, FALLING);
float Flow = flowRate;
//*******************************************************
String dataString = "";
// if the file opened okay, write to it:
dataString += String(Flow);
dataString += ",";
dataString += String(Level);
myFile = SD.open("Level_Flow.txt", FILE_WRITE);
if (myFile) {
Serial.print("Writing to Level_and_Flow.txt...");
myFile.println(dataString);
// close the file:
myFile.close();
Serial.println(dataString);
} else {
Meter");
SendData += "&";
*/
Serial.println(SendData);
delay(5000);
//
String AT = "AT+HTTPDATA=";
int sLength =SendData.length();
String comma = ",";
int delay1 = 10000;
String Command = AT + sLength + comma + delay1 ;
Sim900A.println(Command);
delay(2000);
toSerial();
// Sim900A.println(SendData);
//Serial.println(data);
delay(5000);
toSerial();
// set HTTP action type 0 = GET , 1 = POST , 2 = HEAD
Sim900A.println("AT+HTTPACTION=1");
delay(3000);
toSerial();
// Sim900A.println("");
Sim900A.println("AT+HTTPTERM");
delay(300);
toSerial();} }
//*****************************************************
//
//*****************************************************
```

```
OUTPUT);
pinMode(echoPin, INPUT);
//*********************************************************
// Flow Meter setup
//*********************************************************
// Set up the status LED line as an output
pinMode(statusLed, OUTPUT);
digitalWrite(statusLed, HIGH); // We have an active-low LED attached
pinMode(sensorPin, INPUT);
digitalWrite(sensorPin, HIGH);
pulseCount       = 0;
flowRate         = 0.0;
flowMilliLitres  = 0;
totalMilliLitres = 0;
oldTime          = 0;
cm = (duration/2) / 29.1;     // Divide by 29.1 or multiply by 0.0343
//inches = (duration/2) / 74;   // Divide by 74 or multiply by 0.0135
Serial.print("cm=" + cm );
Serial.print(cm);
long Level = cm;
delay(1000);
//******************************************************
// Flow rate sensor loop
//******************************************************
if((millis() - oldTime) > 1000)    // Only process
. counters once per second {
// Disable the interrupt while calculating flow rate and sending the value to the host
detachInterrupt(sensorInterrupt);
// if the file didn't open, print an error:
Serial.println("error opening Level_and_Flow.txt");
}
//*******************************************************
// GSM Modem loop
//*******************************************************
// INIT HTTP
Sim900A.println("AT+HTTPINIT");
delay(3000);
toSerial();
// Sim900A.println("AT+HTTPPARA=\"CID\",1\"");
delay(300);
toSerial();
// set HTTP para value
Sim900A.println("AT+HTTPPARA=\"URL\",\"http://197.254.205.16/wl/wd.php\"");
delay(3000);
*****
void toSerial() {
while (Sim900A.available() != 0) {
Serial.write(Sim900A.read()); } }
//******************************************************
*****
// Insterrupt Service Routine - FLow Meter
//******************************************************
*****
void pulseCounter()
{
// Increment the pulse counter
pulseCount++;
```

The Device "SOSRMD" specification:

The Device specification is shown by table 1.

Table 1: The Device "SOSRMD" specification

1	Dual-Band 900/ 1800 MHz
2	GPRS multi-slot class 10/8GPRS mobile station class B
3	Compliant to GSM phase 2/2+
4	Dimensions: 24*24*3 mm
5	Weight: 3.4g
6	Control via AT commands (GSM 07.07 ,07.05 and SIMCOM enhanced AT Commands)
7	Supply voltage range : 5V
8	Low power consumption: 1.5mA (sleep mode)
9	Operation temperature: -40°C to +85 °

4.2. Methods

The sequences of methods that have been followed throughout the course of research are shown by figure (7). The early warning system “SOSRMD” for Wadi Al-Hawad floods depends on the innovation of a sensor station with the Discharge Measurements at Gagging Stations device. It relies on remote sensing to measure the flow of torrent water in the valley in terms of the quantity of water, its speed, and the water level, and linking these measurements with a direct link to the Internet that monitors the flow of water in the valley around the clock and sending the measurement data over the network to the means of reception from computers or mobile devices with main goal of sending water discharge data to a remote server where MySQL database and Map-Box open web mapping system were preinstalled.

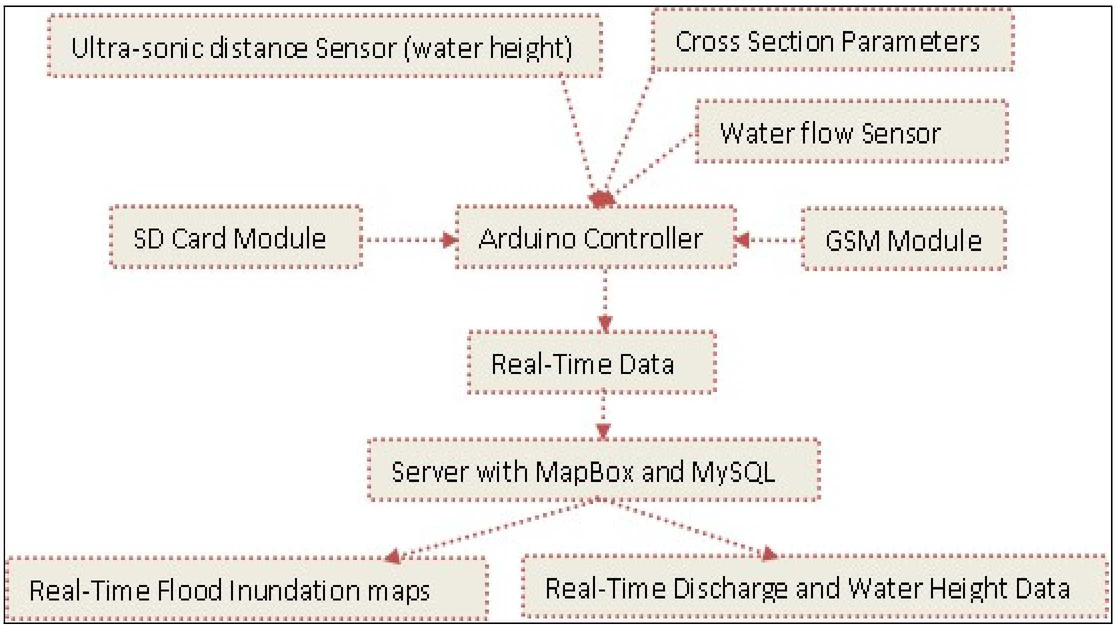

Figure 7: sequences of methods followed throughout the course of research

The water discharge measurement device was installed at one the bridges at the entrance of Al-Hawad valley at Tahadi National Road crossing point (Figure 8), The device was installed at the bottom of Wadi Al-Hawad at a point beyond which there is no supply to the valley from any other tributary, on the outskirts of the urban area in the Kaboshia area, where it was installed under a bridge on the Challenge Road at the position 33°41'32.355"E _ 16°52'23.599"N (Figure 5) at a height of 358 meters above sea level. The height of the device is 4 meters, including 2 meters from the ground with the height of the bridge and 2 meters for the top of the bridge.

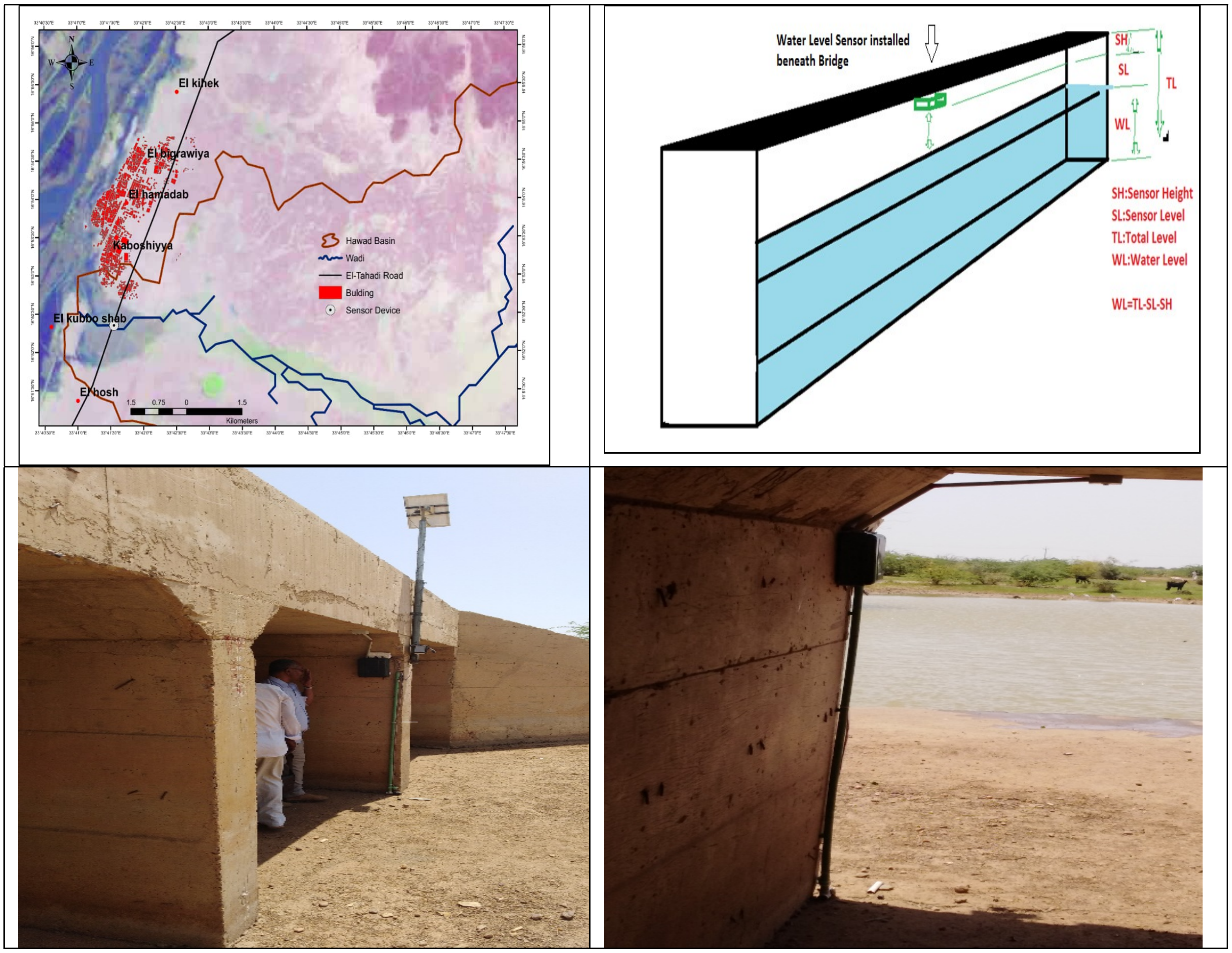

Figure 8: location and installation of Al-Hawad Valley Water level sensor

5. Results

5.1. The expected scenarios of area coverage by Al-Hawad flood

The installed station's data was linked to the Internet at the link (197.254.205.16).The station's was tested on that link in January 2020 by proposing five scenarios for a rise in the water level at the station and its impact on the size of the area covered by torrent water in the Kaboshia area. There were five proposed scenarios, including:-

1- The first scenario is when the water is at 357.0 meters above sea level. This shows no water coverage on the residential area, and the water is confined to a very narrow area along the valley course (Figure 9).

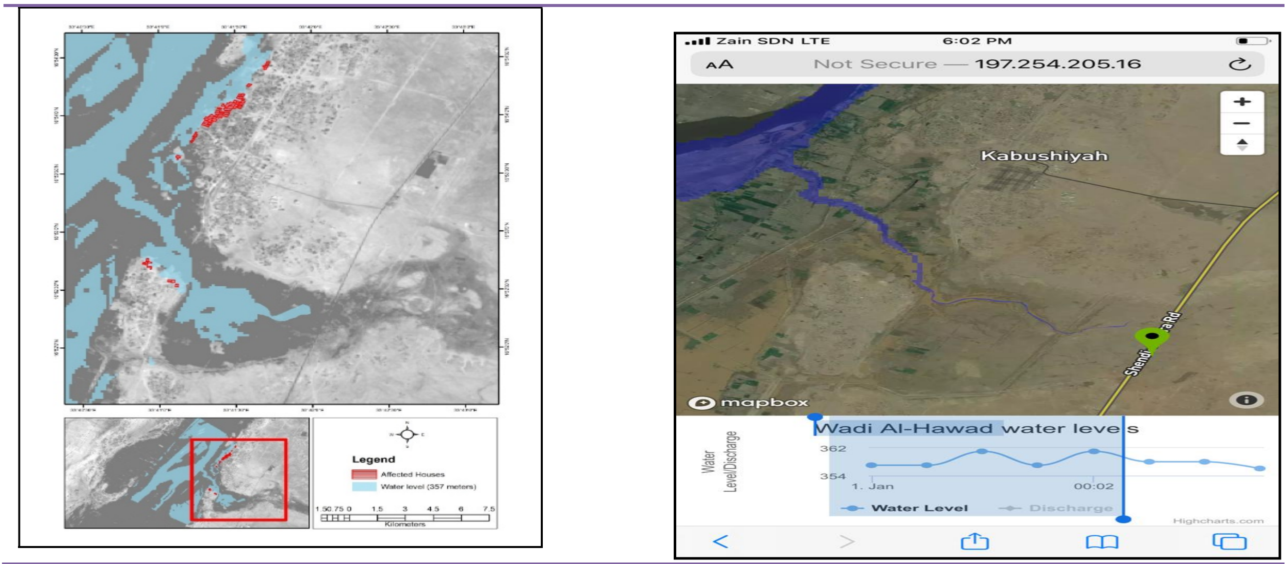

Figure 9: The first Scenario

2- The second scenario is when the water is at 358.0 meters above sea level. This shows a little water coverage (Figure 10).

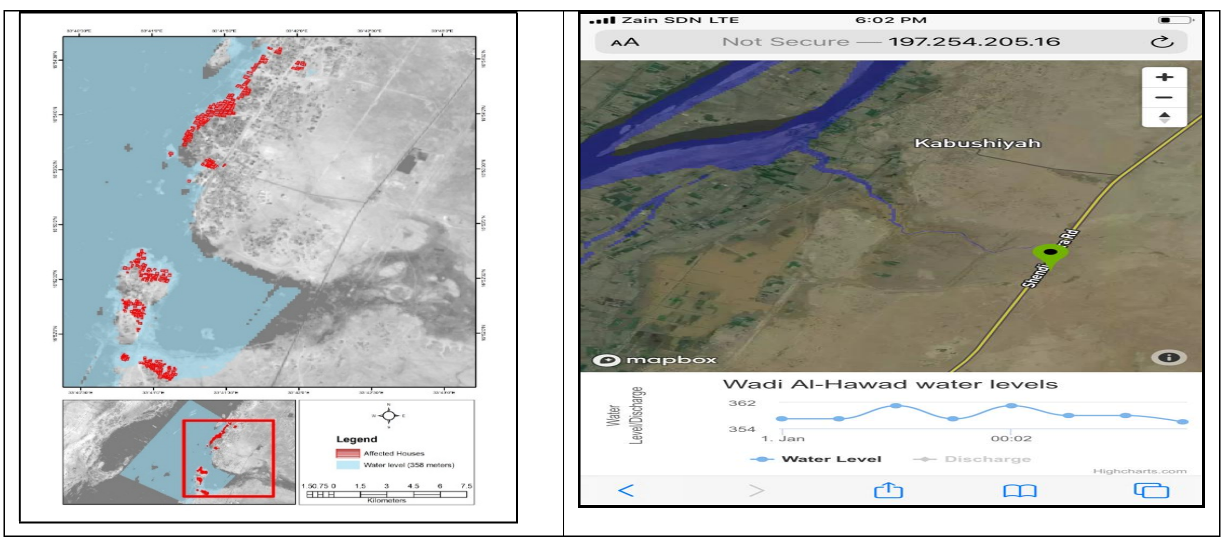

Figure 10: The second scenario

3- The third scenario is when the water is at 359.0 meters above sea level. This shows that, there is remarkable water coverage (Figure 11).

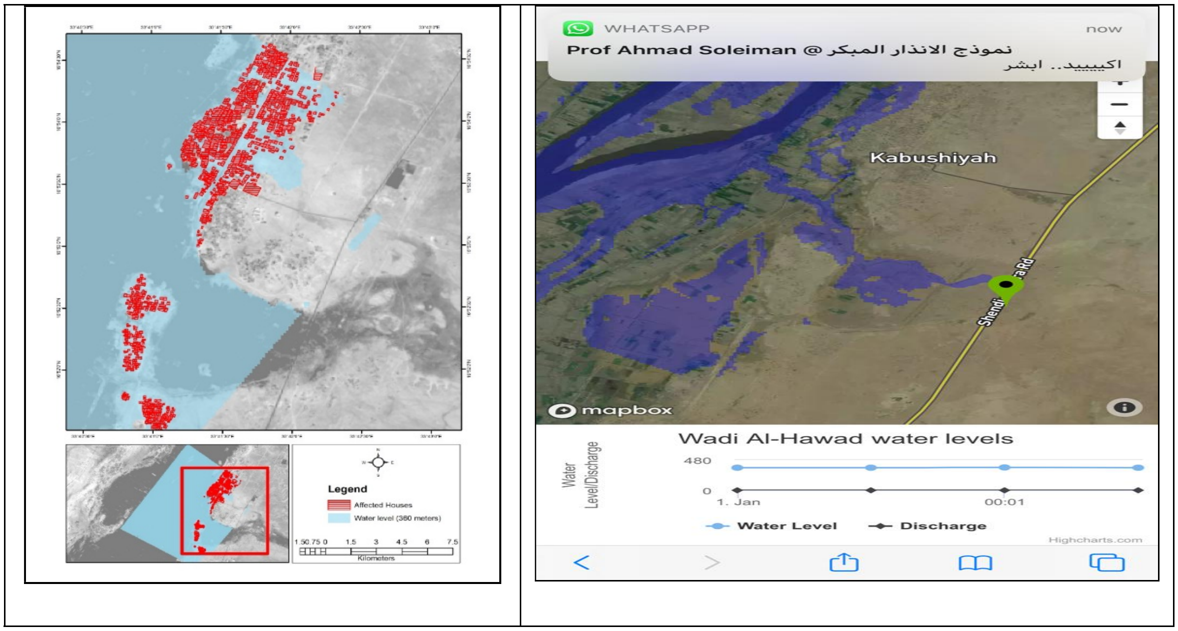

Figure 11: The third scenario

4.-The fourth scenario is when the water is at a 360.0 meters above the sea level. This shows obvious water coverage on the residential area (Figure 12).

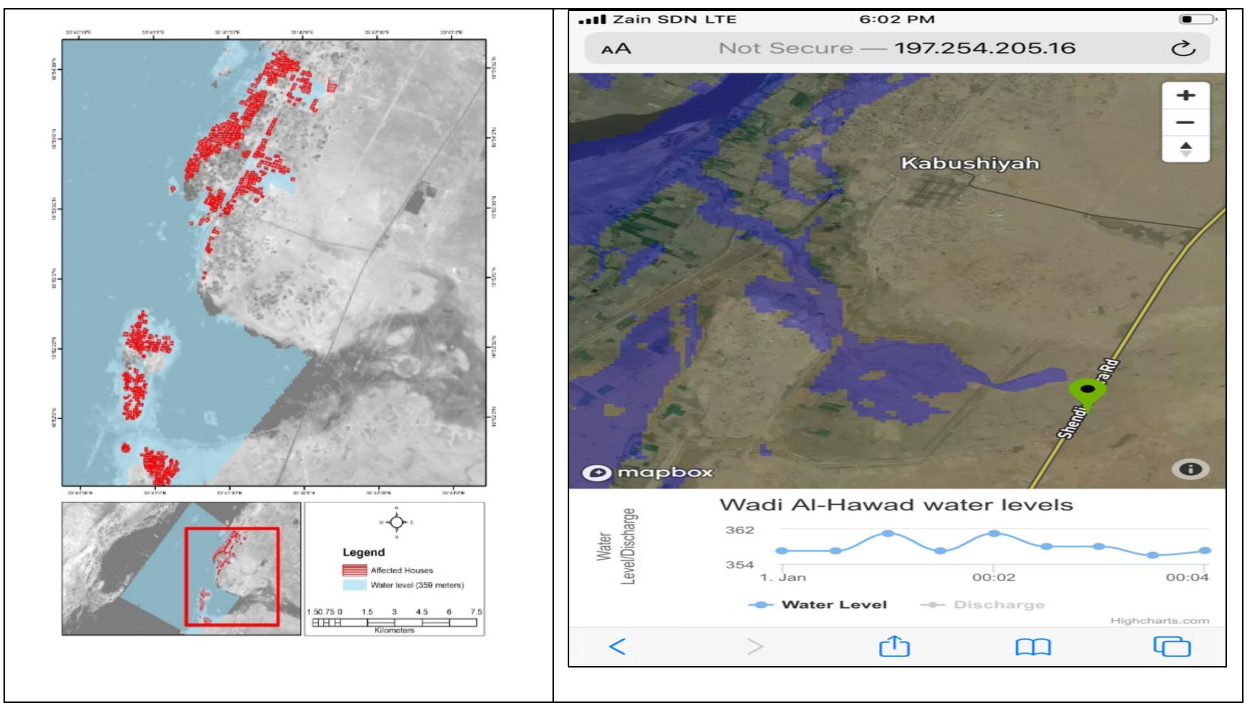

Figure 12: The fourth scenario

4- The fifth scenario is when the water is at 360.5 meters above sea level. Here, the water reached the height of the bridge where the device was installed. The water covers the entire residential area and completely got out of control (Figure 13).

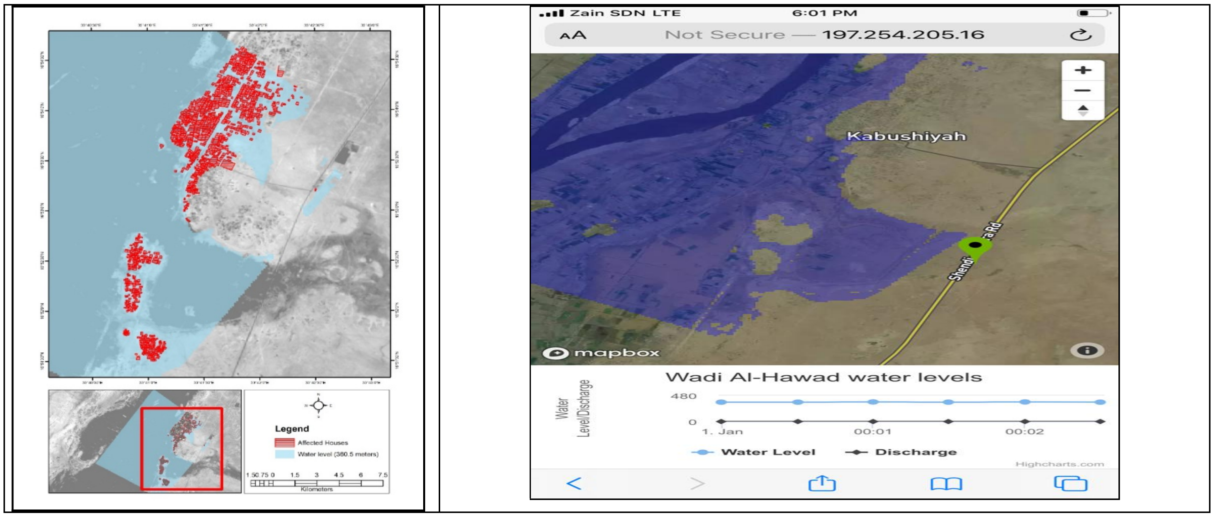

Figure 13: The fifth scenario

The general result is that, there is an increase of water coverage with increased water level.

5.2. The expected size of damages by the tested scenarios of Al-Hawad floods

The five proposed scenarios of area coverage by Al-Hawad flood were also tested for size of damage on property "homes" according to the tested level of torrent water at heights of 357 - 358 - 359 - 360 - 360.5 meters above sea level Figure (14). The obvious comprehensive result is that there is a direct relationship between size of damage and area coverage by floods (Figure 15).

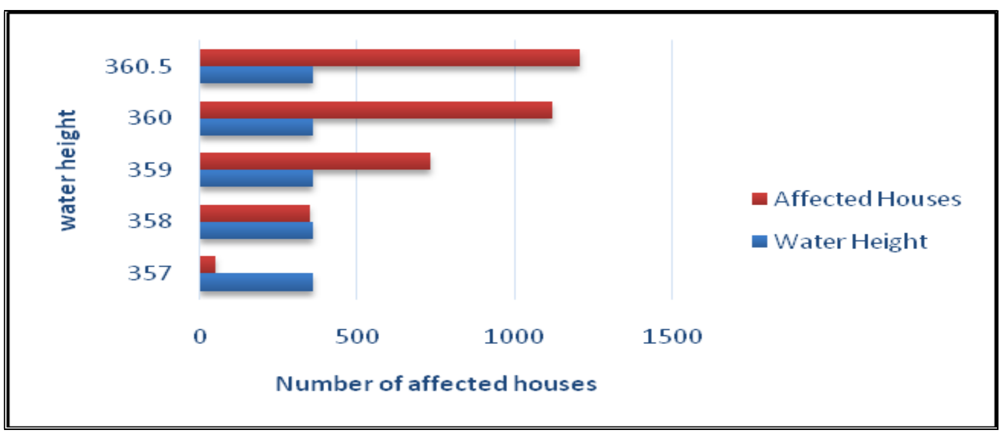

Figure 14: The expected size of damages by the proposed scenarios of area coverage by Al-Hawad flood

Figure 15: Flood in residential areas

6. Discussion

The discussion of the results will be within the expected benefits of the proposed early warning system of Al-Hawad valley “SOSRMD” based on others’ experiences. Early Warning Systems (EWS) are used to minimize casualties (Acosta et al. 2018), and they gradually change behaviors of communities over time as they start to trust the system and lead times are increased, resulting in more social capital and a wider range of early actions that reduce avoidable loss and damage in the Karnali River Basin of Nepal (Rajesh et al. 2020). They are also, a useful tool to save lives, prevent damage and enhance the resilience of a society (Cools et al. 2016), where the potential benefits of an improved early warning in terms of avoided human impacts are particularly relevant in case of a major flood event in urban flood (Balbi et al. 2016), and there will be a perceived increase in the understanding of the potential impacts by the public, added awareness of antecedent conditions by forecasters, a possible reduction in “false alarms,” and increased interagency communication in emergency management personnel (Potter et al. 2020), as well as the inundation damage reduction (Kim et al. 2004); and reliable in helping reduce some of the negative impacts of environmental degradation, pollution and disasters (Joseph et al. 2010); and are an effective and essential tool to minimize damages caused by natural disasters (Pegetti et al. 2020); and not only reduce flood losses but also potential spinoff in a Swedish local risk management context (Persson et al. 2015); and yields direct and indirect, tangible and intangible benefits (Kim et al. 2004).

Flood early warning systems FEWS have been implemented in many parts of the world to reduce flood risk and impacts, where their direct benefits in the period of 2000-2017 is the declining global trend in flood disaster damages and causalities are evident (UNU-INWEH, 2019). Continental and global scale flood forecasting systems provide vital early flood warning information to national and international civil protection authorities, to make decisions on how to prepare for upcoming floods in Europe (Pappenberger et al. 2015), they are likely have a substantial monetary benefit in this cross-border continental-scale flood early warning system in Europe (Pappenberger et al. 2015). The potential benefits from early warning capacity in all developing countries include: avoided asset losses due to natural disasters; an average of 23,000 saved lives per year, and between 3 and 30 billion USD per year of additional economic benefits in developing countries (Hallegatte, 2012).

The National Early Warning and Monitoring Centre of Natural Disasters in Brazil generated cognitive maps that translated the perceptions of the experts and were used to structure the problem and to support the construction of a system model of early warning system for natural disasters (Pegetti et al. 2020). Setting up a functional pathway for ensuring consistency in message development and dissemination is also an issue of critical importance Kamrul, 2013).

The Emergency Water Information Network (EWIN) offers a solution that integrates an early warning system, notifications, and real-time monitoring of flash flood risks has been implemented in Colima, Mexico covering the Colima and Villa de Alvarez metropolitan area. The European "Floods Directive" 2007/60/EU has produced an important shift from a traditional approach to flood risk management centered only on hazard analysis and forecast to a newer one which encompasses other aspects relevant to decision-making and which reflect recent research advances in both hydraulic engineering and social studies on disaster risk on Sondrio, Italy (Molinari et al. 2013). The new framework is developed for flood risks using examples from selected Nordic and other European countries The study shows how social media and digitalization initiatives in the Nordic countries can support web-based access to historical data, real-time forecasts, and climate projections which can provide a coherent and integrated platform for stakeholder interaction and co-production for planning and decision-making that integrate hazard and risk knowledge. This can increase societal resilience and flood risk assessment across community and sector boundaries with proper analysis of risk areas, trade-off in costs and benefits of different solutions for a Nordic framework for web-based flood risk management (Henriksen et al. 2018). Through the comparative analysis of submergence depth early warning and flood loss early warning, it is found that there were differences in the direct loss of building property types under the same submergence depth, in which the residential areas were most affected by floods urban flood (Zang et al. 2022). The "IT System for the Country's Protection Against Extreme Hazards," which is currently being developed in Poland, with particular emphasis on reducing the risks related to natural disasters and minimizing the problems of crisis management in Poland (Krzysztof et al. 2019).

In the lower part of the Sihl valley (Switzerland), the proposed approach can improve flood cost estimation by extending its scope beyond direct and tangible damages; quantitative and semi-quantitative data with subjective and local knowledge, improving the use of commonly available information; and produce estimates of model uncertainty by providing probability distributions for all its outputs (Balbi et al. 2014). Community-based flood early warning system implemented in the Ratu River—a small tributary of the Koshi River was instrumental in the dissemination of flood early warning information and in building local capacities to understand the risks and take timely action. The flood early warning resulted in awareness-raising, strengthened upstream–downstream linkages, and resulted in a greater willingness among communities to help each other prepare for flood disasters in the Ratu watershed (Bajracharya et al. 2015). The South Pacific region suggests that investments in a tsunami warning system in the region may lead to significant economic benefits (Jin et al. 2011). Sudan's flood early warnings can only be effective with information from the Ethiopian highlands. The Nile Basin Iintiative has already achieved significant success with its flood preparedness and early warning systems include improved risk mapping for local communities; developed a flood embankment design and maintenance manual. The FPEW model has been replicated in the Awash River basin in Ethiopia and Sudan, and is being replicated in other Nile sub-basins (World Bank, ?).

Conclusion

This research aims to develop an automatically early warning system of floods "SOSRMD" to alert resident population in Kaboshia area prior to onsets of Al-Hawad valley floods. The main results are that:-

1- Area coverage by flood increases with increased water level, and
2- Size of material damage increases with increased area coverage by floods.

The device "SOSRMD" is expected to provide decision support through websites and smart phone applications that help the decision maker to immediately access and assess the disaster, and also it estimates self-relief requirements. The proposed device "SOSRMD" might be faced by many obstacles as was the case in many other experiences, such as lack of resources to keep EWS equipment operational; community trust; and proper guidelines to communicate warnings in three urban communities in Pakistan (Rana et al. 2021); and functional and community feedback in Narayani Basin in Nepal (Lal, 2022); as well as autonomous, dependent, linkage, and independent failure factors (Samansiri et al. 2023)

References

Abdullah A. R., Mohamad, A. S., Al Halbusi, H., Al Abri, S. (2020). A Systematic Review on Flood Early Warning and Response System (FEWRS): A Deep Review and Analysis. Sustainability, 13(1), 440. https://doi.org/10.3390/su13010440

Acosta, M. C; Francisco, B.M.; Marcos, M. P.; Emiro D. H.-F.. 2018. Real-Time Early Warning System Design for Pluvial Flash Floods—A Review. Sensors 2018, 18(7), 2255; https://doi.org/10.3390/s18072255.

Bajracharya, S. R., Khanal, N. R., Nepal, P., Rai, S. K., Ghimire, P. K., & Pradhan, N. S. (2020). Community Assessment of Flood Risks and Early Warning System in Ratu Watershed, Koshi Basin, Nepal. Sustainability, 13(6), 3577. https://doi.org/10.3390/su13063577

Balbi, S., Balbi, S., Villa, F., Mojtahed, V., Giupponi, C. 2014. Estimating the Benefits of Early Warning Systems in Reducing Urban Flood Risk to People: A Spatially Explicit Bayesian Model. Proceedings of the 7th Intl. Congress on Env. Modelling and Software, San Diego, CA, USA, (May 26, 2014). https://ssrn.com/abstract=2441909).

Balbi, S., Villa, F., Mojtahed, V., Hegetschweiler, K. T., and Giupponi, C. 2016. A spatial Bayesian network model to assess the benefits of early warning for urban flood risk to people, Nat. Hazards Earth Syst. Sci., 16, 1323–1337, https://doi.org/10.5194/nhess-16-1323.

Castillo, E. M., Quintela, D. H., Ramiro M. 2004.Wireless sensor networks for flash-flood altering. Proceedings of the fifth international Caracas conference on devices, circuits and systems, 1, 142-146.

Cools J., Demetrio I. , Sarah O. .2016. Lessons from flood early warning systems. Environmental Science & Policy. Volume 58, April 2016, Pages 117-122.

CTCN. 2024. Technical Assistance. https://www.ctc-n.org/technical-assistance. The Climate Technology Centre and Network (CTCN), UN City, Marmorvej 51, 2100 Copenhagen, Denmark.

Gauma E, Bain V, et al. 2009. A compilation of data on European flash floods. Journal of Hydrology, 367 (12):70-78.

Hallegatte, S. 2012. A Cost Effective Solution to Reduce Disaster Losses in Developing Countries: Hydro-Meteorological Services, Early Warning, and Evacuation (May 1, 2012). World Bank Policy Research Working Paper No. 6058, Available at SSRN: https://ssrn.com/abstract=2051341

He. B., Huang X, et al. 2018. Analysis of flash flood disaster characteristics in China from 2011-2015. Natural hazards 90 (1):407-420.

Henriksen, H. J., Roberts, M. J., Van der Keur, P., Harjanne, A., Egilson, D., & Alfonso, L. (2018). Participatory early warning and monitoring systems: A Nordic framework for web-based flood risk management.

International Journal of Disaster Risk Reduction, 31, 1295-1306. https://doi.org/10.1016/j.ijdrr.2018.01.038.

Ibarreche, J., Aquino, R., Edwards, R. M., Rangel, V., Pérez, I., Martínez, M., Castellanos, E., Álvarez, E., Jimenez, S., Rentería, R., Edwards, A., & Álvarez, O. (2019). Flash Flood Early Warning System in Colima, Mexico. Sensors, 20(18), 5231. https://doi.org/10.3390/s20185231

Jin, D., & Lin, J. (2011). Managing tsunamis through early warning systems: A multidisciplinary approach. Ocean & Coastal Management, 54(2), 189-199. https://doi.org/10.1016/j.ocecoaman.2010.10.025

Joseph E. Q., Bernard E., Gilbert, L. R. 2010. Early Warning Systems: A Review. Journal of Terrestrial Observation. Volume 2, Issue 2: 24-44.

Kamrul, H. M. 2013. Flood warning system: a cost- benefit analysis of the northern Bangladesh. BRAC Univeristy. http://hdl.handle.net/10361/10213

Kim, M. Cl, Nathan, D. Pingel, P. E., David T., Ford, P. E. 2004. Quantifying the Benefit of a Flood Warning System Natural Hazards Review Volume 5, Issue 3. https://doi.org/10.1061/(ASCE)1527-6988(2004)5:3(131)

Kobiyama M, Goerl R F.2007. Quantitative method to distinguish flood and flash flood as disasters. SUISUI Hydrological Research Letters, 1 11-14.

Krzysztof G., Frederick M., B. 2019. Analysis of the Potential of IT System Support in Early Warning Systems: Mitigating Flood Risk in Poland. Prehospital and Disaster Medicine Volume 34 Issue 5. https://www.cambridge.org/core/journals/prehospital.

Lal. P.C. 2023. Challenges and Prospects of Flood Early Warning Systems: A Study of Narayani Basin. A sian journal of water, environment and pollution 20(1): 17-24.

Liu, C., Guo, L., Ye, L. et al. A review of advances in China's flash flood early-warning system. Nat Hazards **92**, 619–634 (2018). https://doi.org/10.1007/s11069-018-3173-7

Mogil, H. M., Monro, J. C., Groper, H. S. 1978. NWS's falsh flood warning and disaster preparedness programs. Bulletin of American Meteorological Society, 59 (6): 690-699.

Molinari, D., Ballio, F., and Menoni, S. 2013. Modelling the benefits of flood emergency management measures in reducing damages: a case study on Sondrio, Italy, Nat. Hazards Earth Syst. Sci., 13, 1913–1927, https://doi.org/10.5194/nhess-13-1913-2013, 2013.

Nachtnebel, H.P. 2014. HOW TO ASSESS THE BENEFITS FROM EARLY FLOOD WARNING SYSTEMS? https://files.abrhidro.org.br/Eventos/Trabalhos/7/PAP014732.pdf 6th conference on flood management Sao Paulo Brazil

Nile Basin Initiative. 2020. EN forecast and early warning system. Seasonal report. https://ikp.nilebasin.org/sites/default/files/Flood_IKP_Reports/Reports/2020%20Flood%20Forecast%20and%20Early%20Warning%20Activity%20Report.pdf

Pappenberger,F., Hannah,L., Cloke , D.J.P. , Fred rik Wetterhall , et al. 2015. The monetary benefit of early flood warnings in Europe Environmental Science & Policy Volume 51, August 2015, Pages 278-291.

Pegetti, A. L., Piacesi, M. T., Neyra Belderrain, M. C., & Rosa Bergiante, N. C. (2020). Dynamic modeling of an early warning system for natural disasters. Systems Research and Behavioral Science, 37(2), 292-314. https://doi.org/10.1002/sres.2628

Pegetti, A. L., Piacesi, M. T., Neyra Belderrain, M. C., & Rosa Bergiante, N. C. (2020). Dynamic modeling of an early warning system for natural disasters. Systems Research and Behavioral Science, 37(2), 292-314. https://doi.org/10.1002/sres.2628.

Persson, E.S., Nyberg, L., Svedung, I. (2015), "Flood warning in a Swedish local risk management context", Disaster Prevention and Management, Vol. 24 No. 3, pp. 383-396. https://doi.org/10.1108/DPM-07-2014-0140.

Potter S.; Sara H; Peter K. 2021.The Benefits and Challenges of Implementing Impact-Based Severe Weather Warning Systems: Perspectives of Weather, Flood, and Emergency Management Personnel. Weather, climate, and society 13 (2): 303–314.

Rajesh, K., Rai , M., J.C. Van, D., H. et al. Warning system in the Karnali River Basin of Nepal. International Journal of Disaster Risk Reduction Volume 47, August 2020, 101534.

Rana, I., Ahmad , S., S., Ali, J. 2021. Effectiveness of flood early warning system from the perspective of experts and three affected communities in urban areas of Pakistan, Environmental Hazards, 20:3, 209-228, DOI: 10.1080/17477891.2020.1751031

Rao, K.H., Dadhwal. V.K., Diwakar, P.G. 2014. Kedarnath flash floods: A hydrological and hydraulic simulation study. Current Science, 106 (4): 598-603

Ruin, I., Gaillard, J. C., Lutoff, C. 2007. How to get there? Assessing motorists' flash risk perception on daily itineraries. Environmental hazards 7 (3):235-244.

Samansiri, S., Fernando, T., & Ingirige, B. (2023). Critical Failure Factors of Flood Early Warning and Response Systems (FEWRS): A Structured Literature Review and Interpretive Structural Modelling (ISM) Analysis. Geosciences, 13(5), 137. https://doi.org/10.3390/geosciences13050137

Smith, P. J., Brown, S., Dugar, S. 2017. Community-based early warning systems for flood risk mitigation in Nepal, Nat. Hazards Earth Syst. Sci., 17, 423–437, https://doi.org/10.5194/nhess-17-423-2017, 2017.

UNNDR. 2022. A network of tents in Khartoum's urban island: community flood management in action. https://www.preventionweb.net/news/network-tents-khartoums-urban-island-community-flood-management-action.

UU-INWEH Report Series, Issue 08.2019. Flood Early Warning Systems: A Review Of Benefits, Challenges And Prospects. United Nations University Institute for Water, Environment and Health, Hamilton, Canada.

Wabanhu, G. R. 2017. Examining the Effectiveness of Early Warning System for Disaster Management in Tanzania: A Case Study of Management of Floods in Kinondoni Municipality. Masters thesis, The Open University of Tanzania.

World Bank.?. THE NILE STORY BRIEFING NOTE 7 Reducing flood devastation in the Nile Basin https://documents1.worldbank.org/curated/en/371061468178188641/pdf/102253-BRI-P092334-PUBLIC-ADD-SERIES-Box394828B-Brief-7-Flood-Forecasting.pdf

World-Bank.2?. WB-P175911 https://ewsdata.rightsindevelopment.org/temp/tmp974q5O/WB-P175911.

Yan Y., Liu, Z.,Y.E., Zhao, X. 2009. Establishment and validation of early-warning model for snowmelt flood in North Xinjiang Arid Land Geography, 2009-04 http://en.cnki.com.cn/Article_en/CJFDTOTAL-GHDL200904011.htm

Zang, Y., Meng, Y., Guan, X., Lv, H., & Yan, D. 2022. Study on urban flood early warning system considering flood loss. International Journal of Disaster Risk Reduction, 77, 103042. https://doi.org/10.1016/j.ijdrr.2022.103042

Access this Article in Online	
Quick Response Code	Website: www.ijarm.com
	Subject: Disaster Management
DOI:10.22192/ijamr.2025.12.02.008	

How to cite this article:
Samir Muhammad Ali Hassan Alredaisy ; Hatem Al-Obaid Ibrahim Nouh; Naji Obaid Naeem Khalafala; Ahmed Suleiman Mustafa Al-Siddiq; Wijdan Dirar Omar Ahmed ; Al-Tayeb Ibrahim Ahmed Wadi. (2025). Proposed Early- Warning System for Floods of Al-Hawad Valley, Northern Sudan. Int. J. Adv. Multidiscip. Res. 12(2): 65-87.
DOI: http://dx.doi.org/10.22192/ijamr.2025.12.02.008