

Forecasting and communication key elements for low-cost fluvial flooding early warning system in urban areas

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ABSTRACT

Fluvial flooding occurs when a river overflows its banks due to excessive rainfall, and it is the most common flood event. In urban areas, the increment of urbanization makes communities more susceptible to fluvial flooding since the excess of impervious surfaces reduced the natural permeable areas. As flood prevention strategies, early warning systems (EWS) are used to reduce damage and protect people, but key elements need to be selected. This manuscript proposes the monitoring instruments, communication protocols, and media to forecast and disseminate EWS alerts efficiently during fluvial floods in urban areas. First, we conducted a systematic review of different EWS architectures for fluvial floods in urban areas and identified that not all projects monitor the most important variables related to the formation of fluvial floods and most use communication protocols with high-energy consumption. ZigBee and LoRaWAN are the communication protocols with lower power consumption from the review, and to determine which technology has better performance in urban areas, two wireless sensor networks were deployed and simulated in two urban areas susceptible to fluvial floods using Radio Mobile software. The results showed that although Zigbee technology has better-received signal strength, the difference with LoRaWAN is lower than 2dBm, but LoRaWAN has a better signal-to-noise ratio, power consumption, coverage, and deployment cost.

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1. INTRODUCTION

In the 21st century, floods have affected most people in the world and it represents approximately 47% of all climate-related disasters since 1995 [1], [2]. The period 2008-2017 recorded 348 natural disasters with 153 flood events; however, 2018 was a standout year with 127 flood events recorded. Figure 1 compares the recorded natural disasters from 2008-2017 and those reported in 2018.

The most common flood event is fluvial floods and triggering severe economic and human losses. Fluvial (river flood) or riverine flooding occurs when a river overflows its banks due to excessive rainfall [3], [4]. The World Resources Institute (WRI), with four Dutch research organizations, developed the Aqueduct Global Flood Analyzer tool that estimates current and future potential exposed to urban populations in most countries and major river basin in the world [5]. They studied and ranked 164 countries that are affected by river floods every year. They selected the 15 most-affected countries and they are all considered developed or developing countries. The Asian continent is the most affected by river floods, and India is the country with

the highest percentage of people exposed to these disasters. Figure 2 illustrates the 15 countries most exposed to river floods worldwide according to WRI.

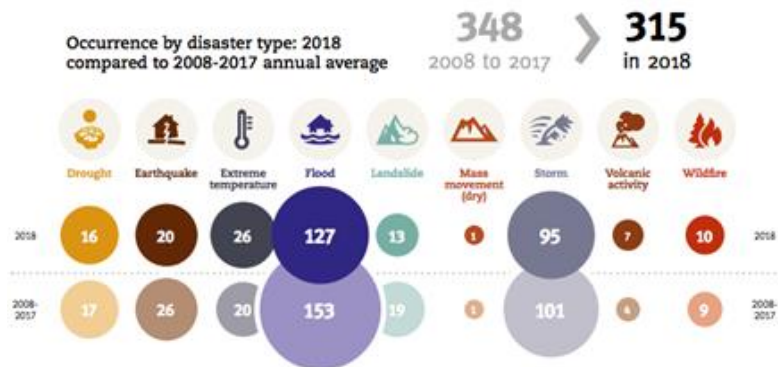


Figure 1. Numbers of natural disasters from 2008 to 2018 [6]

In urban areas, the rapid and unplanned urbanization is the primary cause of fluvial floods frequency increment during massive rainfall events [7], [8]. The excess of impervious surfaces reduced the natural permeable areas and changed the hydrologic and hydraulic watershed’s response to precipitation that leads to the increment of runoff volumes and peak discharges [9]. Floods in urban areas represent one of the most significant challenges to human security and sustained economic growth, as the population during the period 2017–2050 is expected to increase by around 20%-30% and two-thirds of the population that live in the cities [10].

15 Countries Account for 80% of Population Exposed to River Flood Risk Worldwide

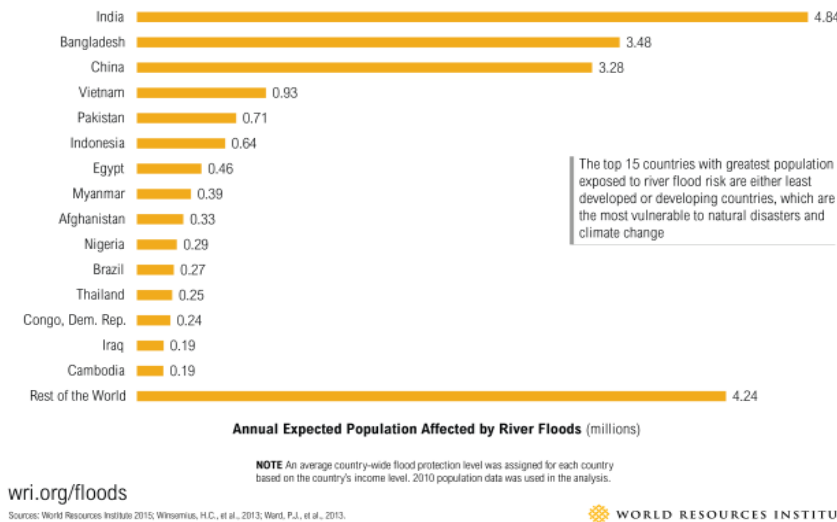


Figure 2. Most affected countries by fluvial floods [6]

There is a difference in urbanization impact between developing countries and developed countries. In developing countries, urban growth often occurs rapidly in large spaces such as entire cities; on the contrary, in developed countries, urban growth is done on a small scale and controlled. They also use technology for dynamic control within the urban environment [11]. To mitigate the risk of human losses and economic damages caused by river floods in urban areas, the International strategy for disaster reduction (ISDR) considered EWS a non-structural measure suitable for populations without enough resources to minimize the risk of flooding or implement structural solutions [2].

According to the World Meteorological Organization (WMO) and ISDR, an effective EWS has four main processes: Disaster risk knowledge, forecasting, dissemination–communication and preparedness–response [2], [12]. Disaster risk knowledge identifies hazards, the exposure, vulnerabilities, and risks of a population; the forecasting process involves the monitoring and information process [13]. This process defines and implements the technology to measure meteorological and hydraulic variables, and analysis of acquired data. Dissemination–communication guarantees the sending of alerts and that they are received and understood. Finally, preparedness–response involves the activities and policies implemented in a community that allows them to react timely in a disaster event [14].

This manuscript proposes the monitoring instruments and communication protocols that guarantee the process of forecasting and disseminating alerts from an EWS efficiently during fluvial floods in urban areas. Different EWS for fluvial floods in urban areas worldwide were reviewed and compared to the variables, sensors, and communication protocols classifying into main and complementary instruments. It was identified that not all projects monitor the most important variables related to the formation of fluvial floods and the most used communication protocols with high-energy consumption. Likewise, ZigBee and LoRaWAN are the communication protocols with lower power consumption from the review, therefore, to determine which technology has better performance in terms of communication (link profile, low power consumption, and lower cost), two wireless sensor networks (WSN) were deployed and simulated in two urban areas susceptible to fluvial floods using radio mobile software. The results showed that that Zigbee technology has better-received signal strength (RSS), but LoRaWAN is the most suitable for both cases due to has better signal-to-noise ratio, power consumption, and deployment cost.

2. METHOD

As a first step, this research conducted a literature review to identify the primary and complementary instruments to measure the variables related to fluvial floods, the methods for information processing and the most used means for the dissemination of alerts. IEEE, ACM and Science Direct digital libraries were consulted to select data ranging from 2010 to 2020. Table 1 shows the search string limiting the information found, inclusion and exclusion criteria.

Table 1. Search string, criteria for inclusion and exclusion

Search String	Inclusion Criteria	Exclusion Criteria
Flood Warning OR Early Flood Warning System Fluvial Floods Warning System AND River Flood Early Warning Urban Fluvial Floods OR Urban Flooding	Research articles, books, conference papers, reports from government agencies, articles in English and Spanish	Results that are not related to the topic, articles other than in English and Spanish

Ten architectures developed in different locations worldwide were selected to alert the community about the risk of fluvial flooding in urban areas. Each architecture describes the methods and instruments used to monitor and analyze in real-time the meteorological and hydraulic variables related to river floods, as well as the methods to send the alert. A comparative analysis was carried out and identified the key elements, main and complementary, for the forecasting and dissemination process.

Since the reviewed projects used different communication protocols, as a second step, we selected the technologies with the lowest power consumption to send the acquired data to a data processing center and compared them in terms of transmission parameters, coverage, performance, energy consumption, and costs using radio mobile software. This software uses the irregular terrain model (ITM) or the Longley-Rice model to predict radio signals'attenuation in the frequency range of 20 MHz to 20 GHz [15].

From the review, Zigbee and LoRaWAN are the communication protocols with the lowest power consumption. To identify which of the two technologies is more suitable for fluvial floods early warnings in urban areas, we performed a simulation of two different systems for two riverside municipalities (Malambo and Palmar de Varela) in Colombia affected annually by fluvial floods of Magdalena River [16]. For both areas, a network with Zigbee and another with LoRaWAN were designed; each network has three nodes and a central station to cover the affected study area. Figure 3(a) and 3(b) presents a map with the sensor networks, nodes location, and the distance to the central stations.

The nodes and base stations are at 15 m above ground level and use vertical supports of different sizes to allow data transmission between the monitoring nodes and their respective network gateway. Table 2 shows each of the points and the distance between the monitoring nodes and the base station of each municipality.

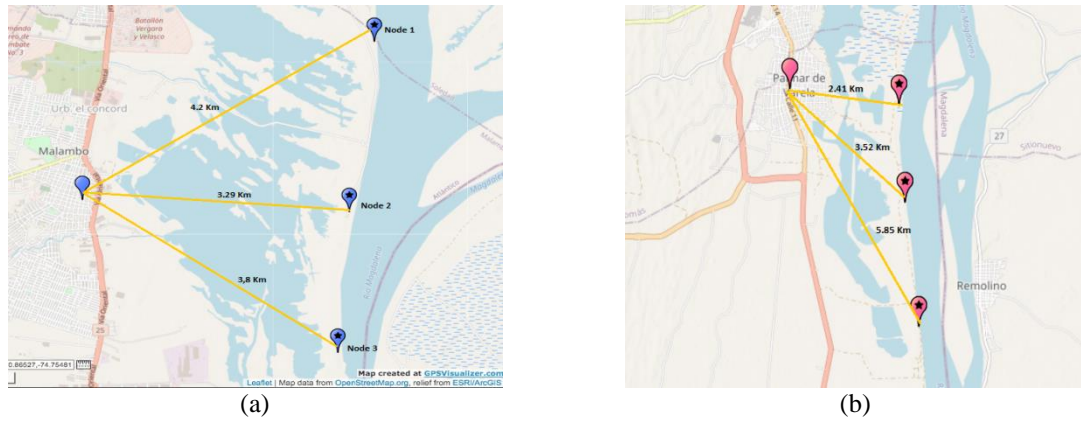


Figure 3. A map with the sensor networks, nodes location, and the distance to the central stations, (a) Malambo WSN, (b) Palmar de Varela WSN

Table 2. Location and distance of from nodes to gateway

Point	Location	Distance from node to gateway (Km)
Gateway Malambo	10°51'33.49"N, 74°46'21.07"O	N/A
Node 1 - Malambo	10°52'44.61"N, 74°44'22.35"O	4,22
Node 2 - Malambo	10°51'27.97"N, 74°44'32.70"O	3,29
Node 3 - Malambo	10°50'24.36"N, 74°44'37.29"O	3,8
Gateway Palmar	10°44'25.58"N, 74°45'18.98"O	N/A
Node 1 - Palmar	10°44'13.98"N, 74°44'0.42"O	2,41
Node 2 - Palmar	10°43'5.67"N, 74°43'56.27"O	3,52
Node 3 - Palmar	10°41'39.18"N, 74°43'46.41"O	5,85

2.1. Architecture network

The wireless sensor networks have a star topology with three monitoring nodes and a central node. The monitoring nodes have a photovoltaic system, an Arduino ONE, a rain gauge, and the selected wireless technology that sends the data to the central node. Since both WSN works in a star topology, each of the three monitoring nodes is configured as slaves and the central nodes as masters. Table 3 shows the specifications of the communication modules used in radio mobile software. Based on the review and Radio Mobile simulation results, we proposed the key elements, main and complementary, for the forecasting and dissemination process of a real-time effective early warning system for fluvial floods in urban areas.

Table 3. LoRa and zigbee devices specifications

Wireless specifications	Dragino LoRa Shield v1.2	Digi XBee-PRO 900HP
Frequency band	915 MHz	902 a 928 MHz
Data rate	until 300 kbps	Until 200 Kbps
Line of sight	15 km	6,5 Km
Transmission power	+20 dBm - 100 mW	+24 dBm - 250 mW
Receiver sensitivity	-148 dBm	-101 dBm
Antenna	Omnidireccional 3dBi	Dipole 2,1 dBi
Voltage	3,3 a 5 VDC	2,4 a 3,6 VDC
Tx current	120 mA	229 mA
Rx current	10,8 mA	44 mA
Stand by current	0,2 uA	3 uA

3. RESULTS AND DISCUSSION

Below, ten architectures of EWS are described from some of the most affected countries by fluvial floods in their urban areas.

3.1. Fluvial floods early warning system architectures

3.1.1. Cagayan river basin, Philippines

The government of the Philippines deployed more than 1,500 hydro-meteorological stations nationwide to provide real-time data for rain and flood event monitoring using two primary sensors, an

automated rain gauge (ARG) and water level monitoring stations (WLMS) installed on bridges near the local communities [17]. For the Cagayan river basin, the Department of Science and Technology (DOST) and the Advanced Science and Technology Institute (DOST-ASTI) developed a predictive model based on the random forest algorithm to provide timely warnings of water level and flood hazard and it becomes in a decision support tool for the local communities.

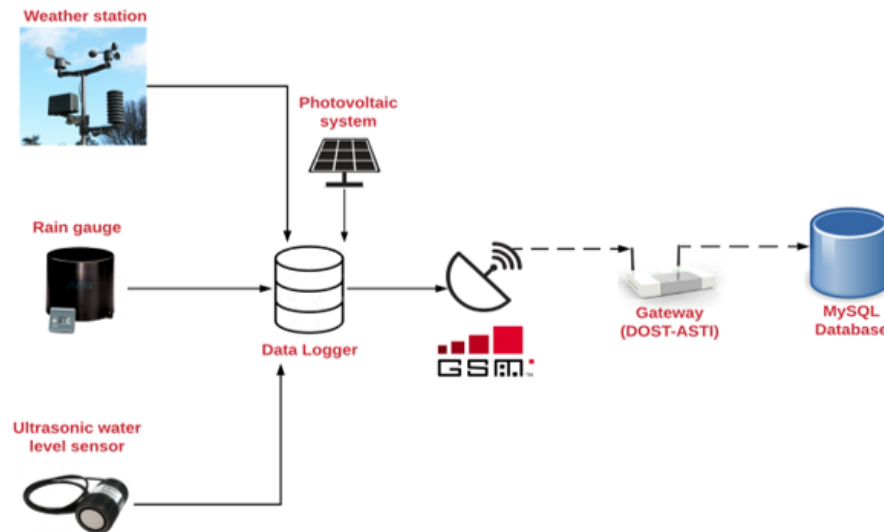


Figure 4. Cagayan river basin EWS

Besides the ARG, this predictive model integrated an ultrasonic sensor to measure water level changes in the river and a weather sensor to monitor wind speed, wind direction, air temperature, air pressure, and air humidity. The sensor data was collected by a solar-powered data logger and sent it via GSM to a GSM gateway of DOST-ASTI. Figure 4 illustrates the EWS structure.

3.1.2. Chennai, India

In Chennai, a city in southern India, [18] implemented a ZigBee based wireless sensor network for early flood monitoring and warning system. Each node has a water level sensor and flow level sensor and sends the acquired data to a server via a wireless ZigBee communication protocol. When the water at the dam reaches a high level, the people receive a warning message by an android application, even without network connectivity. Likewise, the application warns people to evacuate to safer zones through stored images. A significant advantage of the system is that the application can be used offline. Figure 5 illustrates the EWS structure.

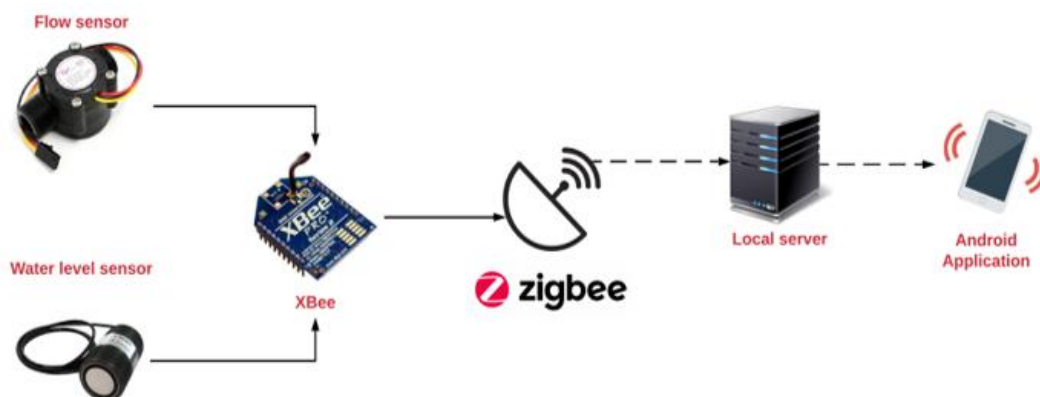


Figure 5. Chennai EWS

3.1.3. Tuy loan river basin, Vietnam

The Ho Chi Minh City International University developed an early flood warning system using a mobile network. The system consists of a station powered by solar energy, a monitoring center, and a notification system. The flood warning station has a water level sensor and a rain gauge sensor that monitors water level changes in the river and rainfall. The sensors data are stored in a memory card and transmitted to the monitoring center via GPRS protocol [19].

The monitoring center receives, analyze data from the stations, and sends results to the notification system where the alarm can be generated to the considered areas. The warning message has the warning level, the measured data, and the predicted occurrence time of flooding. Likewise, a website indicates the river water level, rainfall, and the predicted information for the next few hours. Figure 6 illustrates the EWS structure.

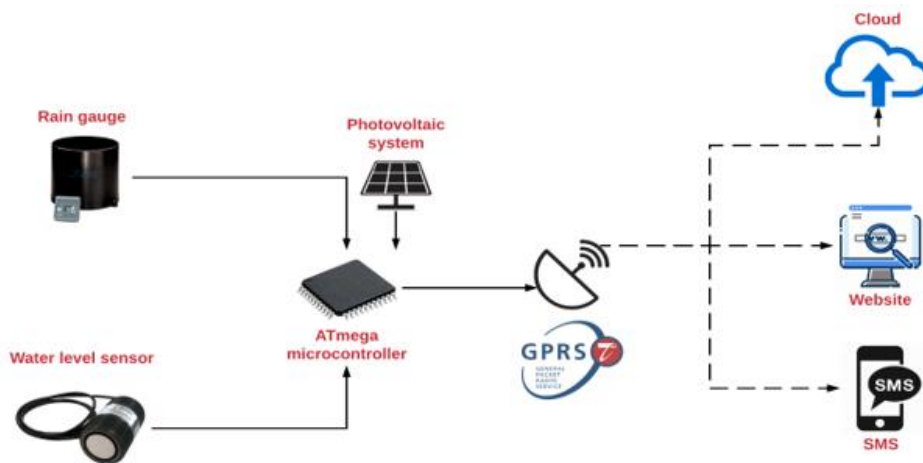


Figure 6. Tuy loan river basin EWS

3.1.4. Bangkok, Thailand

Dersingh presented the design and development of a flood warning system via mobile and computer networks. The system integrated a tipping bucket (rain gauge), an ultrasonic sensor, and a camera that measure the amount of rainfall, water level, and image of the surrounding area periodically. The collected data are sent to a server over the Internet via GSM/3G air card, stored on a database, and processed to determine early warning of flood in the zone [20]. After getting sensors data, the system analyzes and compares it with historical data including data of the year 2011, where the significant flood in Thailand happened. The data are used for two principal threshold criteria: the amount of rainfall in twenty-four hours and water level. If these values are equal or higher than the major flood, the system generates a warning message to the web and mobile application. Figure 7 shows the EWS structure.

3.1.5. Northern and Western Provinces, Rwanda

Floods commonly affect Rubavu, Nyabihu, and Musanze districts. Therefore, Vunabandi et al. proposed an innovative and inexpensive framework designed to provide early warning for natural disasters via a siren. The system has a water level detector (sensor) to monitor water level changes. It works by recording and transmitting sensor data to the server computer via ZigBee protocol [21]. The server processes the data and then gives the warning to advice vulnerable citizens before the floods come around their houses. The Arduino Uno board captures data and sends signals when the water level sensor detects the presence of a boost of water compared to the average river flow level. Lastly, an alert warning sound will be sent through siren only when the detected water level exceeds the average expectation to a hazardous water flow level on the river. It should be noted that a Wi-Fi protocol also assists real-time data transmission. The system works with solar panels. Figure 8 illustrates the EWS structure.

3.1.6. Bangladesh

Islam *et al.* designed and implemented an early warning system that provides a way to remotely supervising water levels of river stations [22]. The system has a Honeywell LL103101 water sensor, which produces a digital output that determines the presence or absence of liquid. The obtained data are sent to the

Apache web server via Zigbee. River level data and alerts are sent through a website and SMS. To send SMS messages from the website, they used Ozeki NG SMS Gateway. The proposed system aims to register the water level every hour, show it to the supervisor, and caution the relevant authorities when the level of water exceeds a user-defined threshold. The early warning system works with a battery. Figure 9 illustrates the EWS structure.

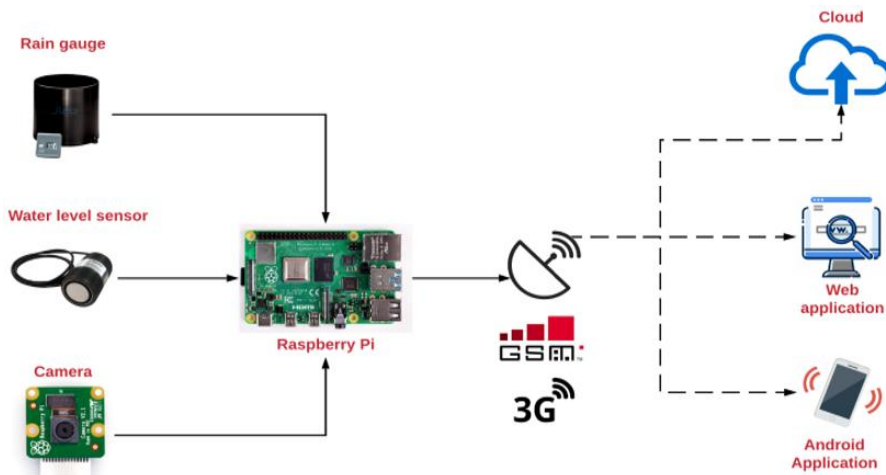


Figure 7. Bangkok EWS

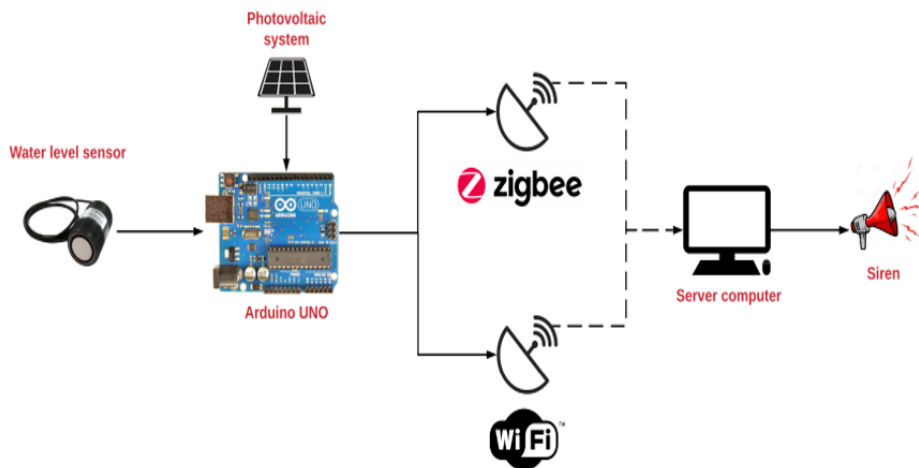


Figure 8. Rwanda EWS



Figure 9. Bangladesh EWS

3.1.7. Jamshoro, Pakistan

The Mehran University of Engineering and Technology developed a flood/drought forecasting system (FDFS) using WSN to help the Pakistani government obtain early information about flooding and drought possibilities to take timely measures [23]. The system covers 19 barrages of 27 mainstream rivers in Pakistan and comprise a mechanical buoy equipped with water level sensors in the river and weather stations to monitor wind, pressure, humidity, and water pressure. Furthermore, the system uses ZigBee between the sensor and the coordinator and then uses worldwide interoperability for microwave access (WiMAX) to send the data to the internet. Figure 10 shows the EWS architecture.

3.1.8. Tabasco, México

Leon *et al.* proposed an early warning system for river overflow. The network consists of an ultrasonic water level sensor that measures the distance between the sensor and the water mass. The TTGO microcontroller processes the sensors data. The collected data are sent to a Raspberry Pi 3B + via LoRa [24]. The raspberry pi keeps the data on a database and in the same way, the data will be published in a Twitter account. Figure 11 illustrates the EWS structure.

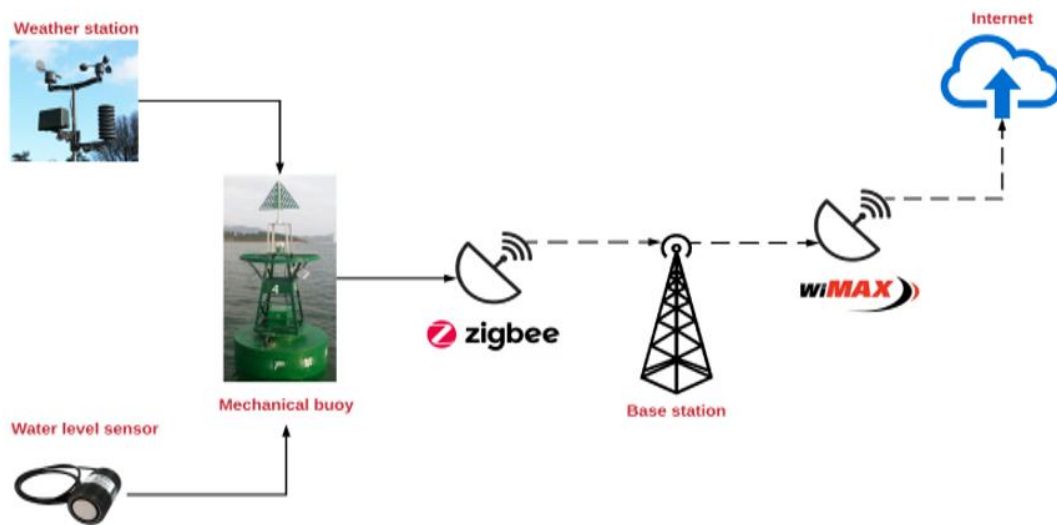


Figure 10. Jamshoro EWS

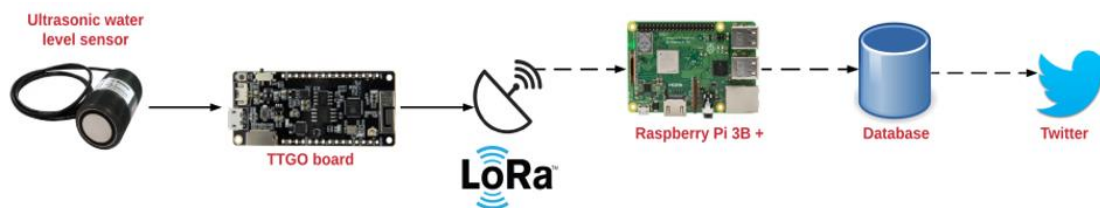


Figure 11. Tabasco EWS

3.1.9. Manzanares River basin, Colombia

Guillot *et al.* developed an early warning system that predicts possible floods in the Manzanares River basin in Santa Marta, Magdalena [25]. The system incorporates a rain gauge, a radar level sensor, soil moisture, and an Arduino MEGA 2560 that processes the data. A data logger collects the acquired data and sends it to a local server via GPRS. If the mobile network fails, the backup protocol (Zigbee) will transmit the acquired environmental measurements. The information on a possible flood is sent to a mobile application, which employs a prediction model to issue three types of alerts: yellow, orange, and red. These alerts are visible to the community members and entities belonging to the emergency operations center of the Santa Marta District. Furthermore, the system sends river levels via SMS. Figure 12 illustrates the EWS structure.

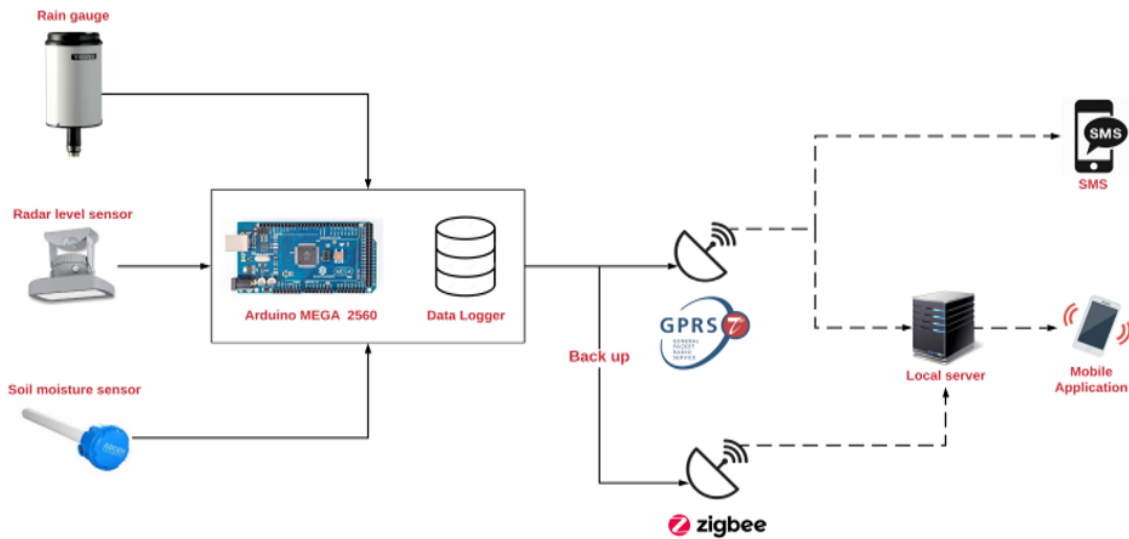


Figure 12. Manzanares river basin EWS

3.1.10. Negro and Tobia river basins, Colombia

An EWS integrated with a weather station and an ultrasonic water level sensor powered by solar panels monitors the Negro and Tobia rivers in Colombia [26]. The system uses a microcontroller to process the data and a LoRa communication module to send it to a web server. The alert will reach Tobia's fire station and the information will be available in the cloud through an application that generates another alert to the population. Figure 13 shows the EWS.

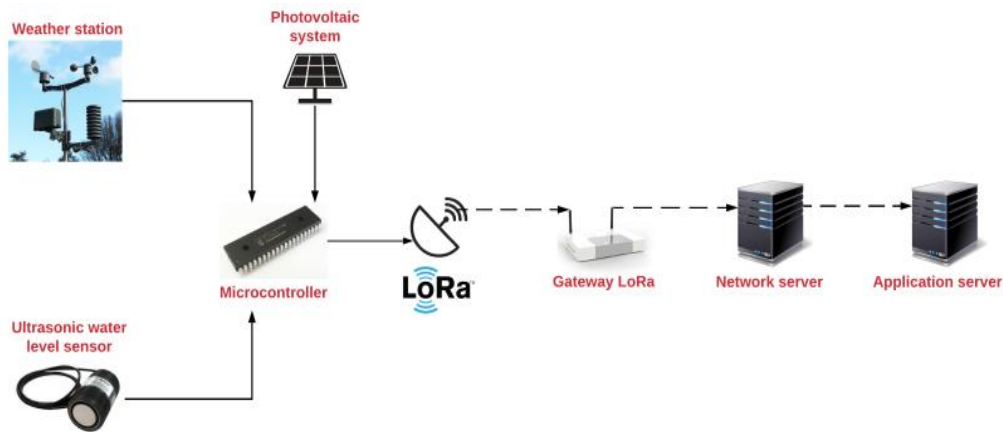


Figure 13. Negro and Tobia river basins EWS

Table 4 summarizes the monitoring instruments implemented in the projects mentioned above to measure the variables related to the formation of fluvial floods in urban areas. Likewise, Table 4 shows the communication protocols to send sensors' data, where do they process the data, the alert dissemination methods, if the information is available online, and the power supply system. All the reviewed projects focused their early warning system design on the forecasting and alert dissemination processes.

From the reviewed projects, all of them considered the water level as the primary variable to monitor and can be classified into submergible and ultrasonic sensors. The submergible sensors are pressure sensors that measure the uniform weight of a column and translate it to level measurement. Conversely, ultrasonic sensors are non-submergible sensors that send a sound wave to the water and measure the water level by calculating the sound wave's sending and receiving time.

Besides the water level sensor, three of the reviewed projects used a rain gauge to measure the precipitation, and the others used other complementary instruments such as flow meter, weather stations, and

an anemometer. Only one project implemented a camera to record the river conditions. Considering the communication protocol, most of the reviewed projects used one protocol to send the acquired data and the most used are Zigbee and GPRS. Only two projects have a backup protocol in case the main protocol fails. Table 5 compares the project protocols in terms of nominal range and transmitted power.

Table 4. Review summary

Location	Sensors	Sensors Variables To Measure	Communication System	Information Processing	Alert Dissemination	Power Supply
Cagayan River Basin, Philippines	Ultrasonic sensor	Water level	GSM	Local and web server	SMS Web application	Solar panel
Chennai, India	Flow meter Water level sensor	Flow Water level	ZigBee	Server	Mobile application	-
Río Tuy Loan, Vietnam	Rain Gauge Water level sensor	Precipitation Water level	GPRS	Server	SMS Web application	Solar panel
Tailandia	Rain Gauge Water level sensor Camera	Precipitation Water level Image	GSM/3G	Web server	Mobile and Web application	-
Rwanda	Water level sensor	Water level	ZigBee	Server	Siren	Solar panel
Bangladesh	Water level sensor	Water level	ZigBee	Local and web server	Web application SMS	Battery
Pakistan	Water level sensor Weather sensor	Water level Air humidity Atmospheric pressure	Zigbee Worldwide Interoperability for Microwave Access (WIMAX)	Web raw data	-	-
Tabasco, México	Ultrasonic sensor	Water level	LoRaWAN	Data based	Twitter	Battery
Colombia	Ultrasonic sensor	Water level	GPRS Zigbee	-	SMS	Solar panel
Tobia, Cundinamarca, Colombia	Rain Gauge Ultrasonic sensor Anemometer	Precipitation Water level Wind speed and direction	LoRaWAN	Local and web server	-	Solar panel

Table 5. Communication protocols comparison

Protocols	ZigBee/IP	Wi-Fi	Wi-Max	GSM/GPRS	LoRaWAN
Nominal range (km)	0.01–1	0.01–0.1	0.3–49	2–35	2-5 km (urban) 5-15 km (rural) > 15 km (LOS)
Transmitted Power (W)	0.1	0.8-1	0.25	2-may	0.020

According to Table 5, Zigbee and LoRaWAN have lower transmitted power and GPRS is the protocol with higher power consumption. However, GPRS has a better nominal range, therefore better coverage. This is the main reason for which LoRa has been widely used in IoT applications [27]. About power supply, most of the projects use a photovoltaic system; others are connected to the grid and have batteries in case of power supply failure. All the reviewed EWS sends the acquired data to a local or web server for processing the measurements and create the alerts. The preferred means to communicate the alerts to the risk population are web applications and SMS; only one project used a social network like Twitter and one project used a sound alert.

3.2. RF propagation simulation

From Table 5, Zigbee and LoRaWAN are the communication protocols with lower power consumption; for this reason, they are being widely used to deploy sensor networks. To identify the most suitable protocol to send timely alerts for fluvial floods in urban areas, these technologies were compared using radio mobile software, simulating two WSN in two riverside municipalities affected by fluvial floods in Colombia, Malambo and Palmar de Varela. Following, Tables 6 and 7 present the radio link profile of Malambo WSN and Palmar de Varela WSN with the path loss and RSSI measurements for each radio link.

Table 6. Malambo WSN radio link profile

Radio Link	Distance (Km)	PathLoss (dB)		Received Signal Strength Indicator (RSSI) (dBm)	
		LoRaWAN	Zigbee	LoRaWAN	Zigbee
Node 1 - Gateway	4,22	104,1	104,1	-78,4	-76,3
Node 2 - Gateway	3,29	101,9	102	-78	-76
Node 3 - Gateway	3,8	103,2	103,2	-85,9	-84,3

Table 7. Palmar de varela WSN radio link profile

Radio Link	Distance (Km)	PathLoss (dB)		Received Signal Strength Indicator (RSSI) (dBm)	
		LoRaWAN	Zigbee	LoRaWAN	Zigbee
Node 1 - Gateway	2,41	99,2	99,3	-75,4	-73,4
Node 2 - Gateway	3,52	102,5	102,6	-77,5	-75,4
Node 3 - Gateway	5,85	106,9	107	-82,9	-80,8

In Malambo, the radio links between the monitoring nodes and the gateway showed a path loss for both technologies between 102-104 dB and for Palmar de Varela between 99-107 dB. The above is because the municipality of Palmar de Varela has a lower population density rate and more cleared areas. Considering the RSSI, Zigbee technology presented a better performance than LoRaWAN. This is because Zigbee modules transmit up to +24 dBm compared to the maximum transmit power of LoRaWAN devices, which is +20 dBm. However, the measurement difference between both technologies is not as significant in each radio link.

3.3. Devices costs

An important parameter to consider when implementing a WSN is cost. Table 8 shows the costs per device for Zigbee and LoRa technology used for the simulation. From Table 8, Zigbee technology devices are more expensive than LoRa devices; therefore, the implementation of LoRaWAN communication protocol to send timely alerts is more suitable for a low-cost EWS. Considering the simulation results, although Zigbee technology obtained a better RSSI than LoRaWAN, there is a low difference between each node's reception power levels, which is between 1-2.1 dBm. Likewise, considering other parameters, LoRaWAN has a low sensitivity to the noise of its equipment, it has a higher coverage range, the energy consumption is lower than Zigbee, and the cost per device. Therefore, LoRAWAN is the most suitable communication protocol for fluvial floods in urban areas.

Table 8. Cost per device for zigbee and LoRa

Component	LoRa		Zigbee	
	Device	Cost	Device	Cost
Tx module	Dragino LoRa Shield v1.2 915MHz	\$23,92	Digi XBee-PRO 900HP	\$42,90
Antenna	Omnidirectional3dBi 915MHz	\$9,89	Dipolo 2,1 dBi 900MHZ	\$20
Gateway	Dragino LPS8	\$124,18	Modem XBee-PRO 900HP	\$154,06
	Total	\$157,99	Total	\$216,96

Figure 14 shows the proposed primary and secondary elements of the forecasting and dissemination process for an effective fluvial flood early warning system in urban areas. It also shows the communication protocol selected from the RF simulation. From Figure 14, the central monitoring instruments for the forecasting process are the water level sensor and the rain gauge. Although the rain gauge was not the main instrument in all the reviewed projects, it is included in the proposed forecasting process since precipitation measurement is one of the main inputs for flood modeling in urban areas [28]. The weather station, flow meter, and video recording are considered complementary monitoring instruments.

The review showed that GPRS and Zigbee are the most used communication protocols; however, GPRS has a higher power consumption, it needs a more complex photovoltaic system that will increase the deployment cost; likewise, it depends on the mobile services costs. Since Zigbee and LoRaWAN have the lowest power consumption, we compared them in terms of RSSI, coverage, S/N ratio, power consumption, and costs to determine which technology has better performance. From the results, Zigbee has better RSSI than LoRaWAN, but the difference is low. Due to LoRa has lower consumption, the devices are cheap, have higher coverage, and better S/N ratio, it was selected as the primary communication protocol and it is suggested to use Zigbee as a backup protocol in case of failures. The acquired data is sent to a web or local server to process the information and create the alerts to send them to the risk population.

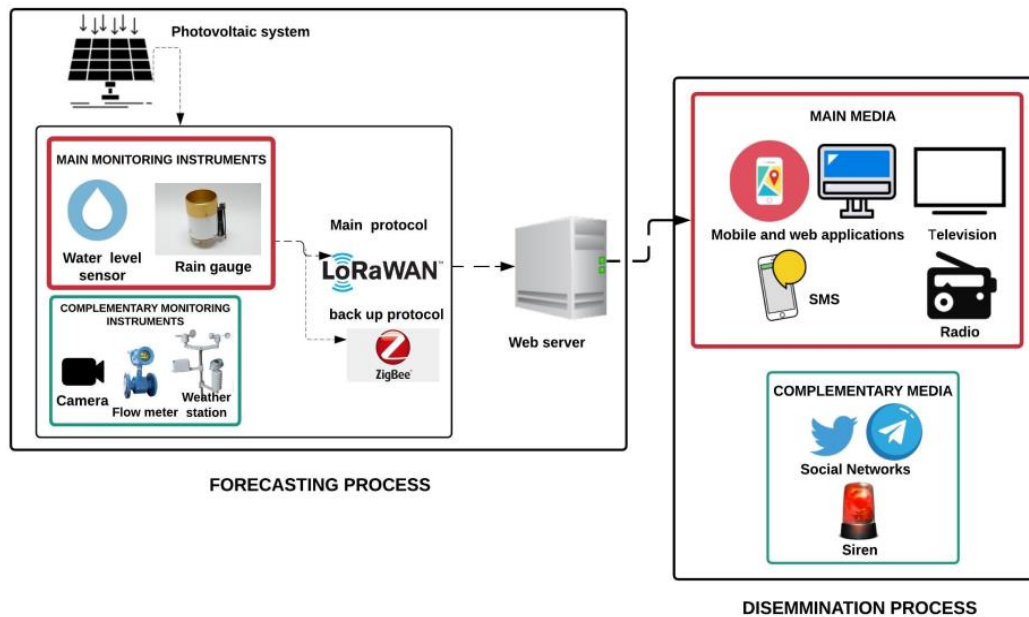


Figure 14. Proposed key elements for forecasting and dissemination process

About the dissemination process, from the review, the most used media were mobile and web applications, as well as short message service (SMS). However, a survey carried out to Hong Kong residents which are considered to be one of the safest cities in the world today, showed that the preferred media for disaster alert dissemination are television (52%), Facebook (18,9%), WhatsApp (9,6), radio (8,2%), news agency websites (6,1%) and government websites (2,9%) [29], thus, television and radio were included as main media for alert dissemination. Social networks and sound alerts like sirens are complementary media. It is suggested to use Twitter and telegram since allow easy and free linking with different platforms.

4. CONCLUSION

This research performed a systematic review and a Radio Frequency simulation to determine the key elements of the forecasting and dissemination process for an effective early warning system (EWS) for fluvial floods in urban areas. For the forecasting process, the systematic review showed that the most used instrument for monitoring is the water level sensor, that we can find them of two types, ultrasonic and pressure. However, there are radar water level sensors, which external agents less affect their signal, but they are more expensive. On the other hand, in addition to the level sensor, some reviewed projects used rain gauge for precipitation measurement that is a vital input for flood modeling in urban areas; therefore, it is considered central monitoring. Other monitoring instruments such as weather stations, flow meter, and camera for video recording are considered as complementary monitoring instruments.

Likewise, the review showed that Zigbee and GPRS are the preferred communication protocol to send the acquired data to the data center for information processing; however, GPRS has high power consumption and the cost is high over time. The protocol with lower power consumption is LoRaWAN and to determine which technology has better performance, we compared LoRaWAN and Zigbee in terms of RSSI, coverage, S/N ratio, power consumption, and costs by an RF simulation.

Using Radio Mobile software, two WSN for two urban municipalities in Colombia affected by Magdalena River floods were deployed. In each municipality, it was simulated a WSN Zigbee and another with LoRaWAN, with three monitoring nodes and a gateway for each one. The simulation results showed that Zigbee has better RSSI than LoRaWAN, but the difference is low. Since LoRaWAN has lower power consumption, higher coverage, better S/N ratio, and the cost per device is cheaper than Zigbee; it was selected as the primary communication protocol and Zigbee a backup protocol in case of failures.

For the dissemination process, from the review, the leading media used to send the alerts to the risk population are web and mobile application and SMS and the complementary media are social networks and sound alerts. However, television and radio were included since they are massive; they are useful mass media for disseminating alerts. It should be noted that the channels for sending alerts must be multiple to guarantee communication with the community.

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