Experiments of an IoT-based wireless sensor network for flood monitoring in Colima, Mexico

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ABSTRACT

Urban flooding is one of the major issues in many parts of the world, and its management is often challenging. One of the challenges highlighted by the hydrology and related communities is the need for more open data and monitoring of floods in space and time. In this paper, we present the development phases and experiments of an Internet of Things (IoT)-based wireless sensor network for hydrometeorological data collection and flood monitoring for the urban area of Colima-Villa de Álvarez in Mexico. The network is designed to collect fluvial water level, soil moisture and weather parameters that are transferred to the server and to a web application in real-time using IoT Message Queuing Telemetry Transport protocol over 3G and Wi-Fi networks. The network is tested during three different events of tropical storms that occurred over the area of Colima during the 2019 tropical cyclones season. The results show the ability of the smart water network to collect real-time hydrometeorological information during extreme events associated with tropical storms. The technology used for data transmission and acquisition made it possible to collect information at critical times for the city. Additionally, the data collected provided essential information for implementing and calibrating hydrological models and hydraulic models to generate flood inundation maps and identify critical infrastructure.

Key words | digital water network, early warning systems, flooding, tropical storms

HIGHLIGHTS

- IoT-based wireless sensor network for hydrometeorological data collection and flood monitoring has been developed for Colima-Villa de Álvarez in Mexico.
- Real-time data is transferred over 3G cellular network and Wi-Fi.
- Tests of the network on three separate tropical storm events showed robustness of the network during extreme events.

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INTRODUCTION

Recent developments of digital cities as the exploration of cyberspace to smart cities as the exploitation of the physical space resulted in proposing that the next stage is a networked society based on cyber-physical systems (Ishida 2017). This conceptualisation advocated in recent decade such as digital twins for a range of infrastructures is currently being implemented in water systems (Lee 2008). The coupling between the physical and cybernetic layers of water systems and related infrastructure can provide new opportunities to increase the efficiency of water infrastructure and can increase resilience in water planning and services (Makropoulos & Sávic 2019). For example, using multiple sensors, water systems and related infrastructure can be controlled in real-time and data can be continuously integrated into models. Such pairing of the virtual and physical components of the water systems will also be an important tool in applications such as urban flood management, which is one of the main challenges facing urban areas (Bachmann *et al.* 2016; Lund *et al.* 2018).

Water in cities is a critical resource, and its management is associated with many challenges; for example, monitoring freshwater quality and quantity is a local and global concern (Artiola 2004; Camara *et al.* 2020). Water can also present a threat to the population when flooding occurs (Olya & Alipour 2015; Plümper *et al.* 2017; Ryan 2018). Tackling flooding disasters in urban areas is a primary concern in many cities around the globe (Davidsson 2020). Therefore, smart digital infrastructure to monitor and forecast flood events is critical for improving the resilience of urban areas to hazards such as those related to flooding.

Climate change is set to increase the frequency and severity of floods in many parts of the world (Miller & Hutchins 2017). Extreme hydroclimatic events will continue to disproportionately affect vulnerable populations and low-income countries (Enenkel *et al.* 2020). In past years, the number of reported flood events has increased substantially (Tanoue *et al.* 2016), affecting people and causing significant economic loss and damage to affected environments over time, including Mexico (López-Marrero & Tschakert 2011; Kundzewicz *et al.* 2014; Khouakhi *et al.* 2019). On a global scale, records show that between 1900 and 2010, floods have a more significant and increasing number in comparison with other disasters both in terms of recorded events and people affected (EM-DAT 2020).

Floods in Mexico are a major challenge for managers as flood events are increasing in regularity and severity (De *et al.* 2012). Climate-related disaster management in Mexico has been focussing more on the actions of repairing, emergency assistance than on the prevention (Constantino *et al.* 2011). However, this form of intervention does not reduce the possibility of disasters with the corresponding negative effect on the social functioning of the geographical areas that usually face such events. In the light of current knowledge, it is important to develop a preventive approach to mitigating the risk of flooding in Mexico. One effective way to reduce the risk of floods lies in developing and implementing an early warning system. This early warning system is one of the main tools in the preventive approach; unfortunately, many developing countries have poor flood monitoring infrastructure (Matthews *et al.* 2011). The density of the river and climate monitoring network in Mexico is severely deficient now. Urban areas are particularly unmonitored currently, and only the cities of Tuxtla Gutierrez, Tijuana, Monterrey, Acapulco, Chalco, and Mexico City have a hydrometeorological alert system.

The state of Colima (west-central Mexico) is often affected by the cyclonic activity from the Pacific basin. Colima-Villa de Alvarez is the most urbanised area of the state. Its proximity to the coastline makes it exposed to tropical cyclones and their associated hazards. In the last decade, flooding is becoming more frequent in Colima and in the context of climate change; it is likely that this increasing trend will continue in the coming decades.

Different flood forecasting systems and hydrological models have been developed worldwide (e.g. Noymanee & Theeramunkong 2019; Uteuov *et al.* 2019; Cheval *et al.* 2020). Some of them use real-time data for their assessments and predictions (Alfieri *et al.* 2019; Echeverribar *et al.* 2019; Lindenschmidt *et al.* 2019; Zhang *et al.* 2019; Deng *et al.* 2020; Khalid & Ferreira 2020; Ritter *et al.* 2020). To develop a real-time flood forecasting system, several areas of research are needed. These include expertise in data sensing at the appropriate location and time, wireless transmission of flood data, sensor data fusion, model generation, prediction at the remote weather station, and flood resilience expertise. This project combined different groups and expertise to design a cost-effective flood monitoring and forecasting system (Mendoza-Cano *et al.* 2019). Resilience to floods in the study area has been evaluated by Mendoza-Cano *et al.* (2019) in 10 critical areas of Colima-Villa de Álvarez. Resilience is an indicator of a system's ability to withstand disruption within acceptable degradation parameters and their recovery time (Nguyen & James 2018). The study was performed on public knowledge of the existing security protocols for floods. It evaluated the public perception of critical services' availability, such as freshwater, electricity, food, drainage, communications and public transport during flash flood events. This research identified populated low resilience zones that can be considered a priority for resources and effort to mitigate floods and their impacts. These results demonstrated the need to implement strategies that strengthen the community capacity to cope with the effects of extreme hydrometeorological phenomena in Colima-Villa de Álvarez.

In this paper, we show how expertise in water engineering, embedded electronics, radio communications and web development have come together to develop and test an Internet of Things (IoT)-based digital water solution (1) allowing collection of high-resolution hydrometeorological data, (2) monitoring of urban fluvial water level, and (3) issuing potential flood level alerts for the public in Colima. Section 2 describes the study area, field survey, sensor network structure, types of nodes implemented and their specifications, the acquisition and transmission of data and the graphical user interface. Tests and Result section show some early results of the network monitoring of three main storm events which occurred during the tropical cyclone season of 2019.

METHODS

Study area

The Colima River catchment is located in the north of the Colima state (west-central Mexico). It is a sub-catchment of the Armeria's river basin (Figure 1). The catchment area is about 150 km^2, and the main Colima River originates from the slopes of the Colima volcano and has a dynamic river bank vegetation. The state of Colima is often affected by the Eastern Pacific cyclonic activity during the tropical cyclones season. Colima-Villa de Alvarez is the most urbanised area of the state, and its proximity to the Pacific coastline makes it exposed to tropical storms that frequently cause damage and disruptions. Some of the most destructive storms that made landfall near Colima and created significant damage to infrastructure, include *Jova* in 2011 and *Patricia* in 2015 (category 4 hurricane).

Figure 2 shows the monthly temperature and precipitation in the municipality of Colima for the period 1950–2017. A unimodal precipitation regime can be observed, with a significant wet period from June to October and a marked dry period from November to May. Most storms occur in September with about 17 storm events; some of them are of cyclonic origin. The percentage of days with a storm in the municipality of Colima is 18%.

Network design and sensor locations

Several field campaigns were conducted across the catchment area to select suitable sites for data collection and sensor deployment. First, rivers and their tributaries in the Colima river basin was mapped and analysed before the survey. The main goal was to assess the optimal sites needed for flood monitoring and prediction and assess the representativeness of the selected locations following the previous historical floods. Other objectives of the survey included (1) assessment of the security of the data loggers and base stations (fixed nodes), (2) measurement of the strength of the 3G network, and (3) assessment of the accessibility to sites for deploying and maintaining the sensors. The tributary interactions and critical locations for the data collections needed for the monitoring and modelling from the hydrological perspective were also considered. Sixteen locations have been defined hereafter represented as static nodes. These nodes are composed of eight nodes of water level and soil moisture and eight weather station nodes. Each node has a data logger, communication module, power module, local backup storage and corresponding sensors.

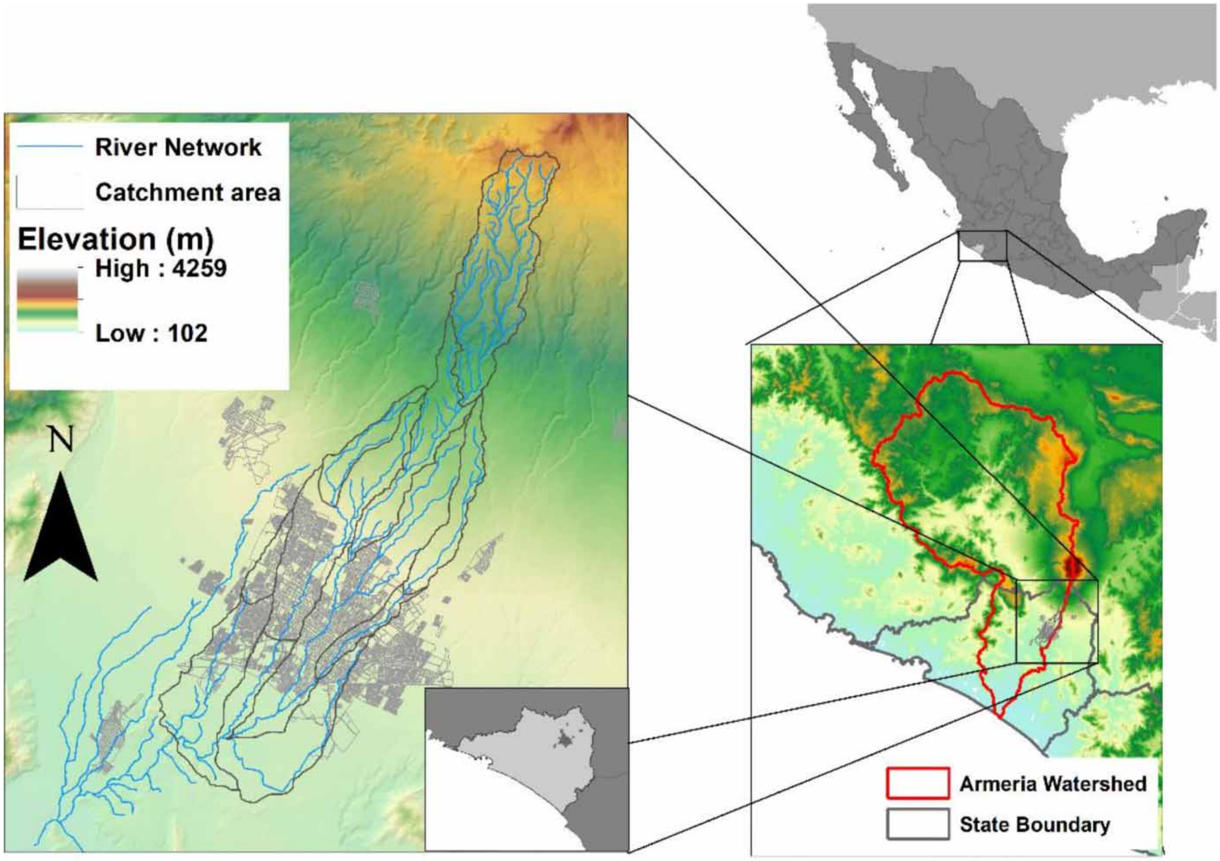

Figure 1 | Study area of Colima-Villa de Álvarez, Mexico. Left panel shows the city of Colima, the catchment area and its elevation and Colima river network.

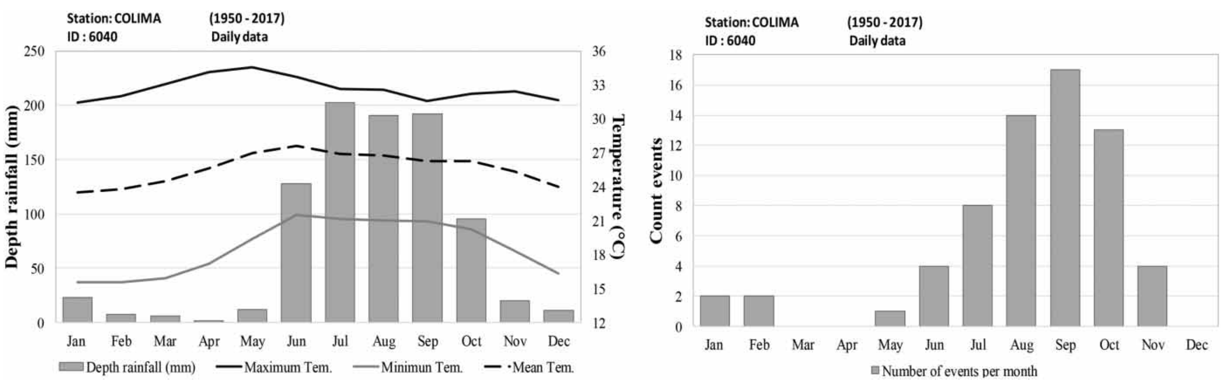

Figure 2 | Distribution of rainfall and temperature (left panel) and storm events (right panel) from 1950 to 2017.

We worked with different stakeholders during the site selection process, the most significant being the local water authority (CONAGUA-Colima) in addition to the public schools, universities and other public institutions. Several meetings with the above stakeholders were held to establish the most suitable and secure locations for the sensors. These collaborations provided valuable information on the suitability and security of the final selected locations. For example, public schools and universities across Colima city provided their support to deploy the weather stations on their building roofs where the weather station is exposed, safe and easy to maintain. For the water level nodes, non-contact ultrasonic sensors were placed under bridges with data loggers and solar panels placed on towers of 6 m high. Figure 3 shows the locations of the selected nodes along with the signal strength of the 3G/4G network in the study area.

Hardware and network development

The network is based on four building blocks (Figure 4):

- The weather station nodes use Ethernet technology for their communication with the server; the nodes are also equipped with local storage.
- Water level nodes (hereafter RiverCore) encompassing ultrasonic water level sensors (Toughsonic). RiverCore communicates with the server using 3G cellular communication technology, and it is also equipped with a local data storage.
- The Drifters which are floater designed to map water velocity for specific events, have a GPS and local storage; they use 900 MHz Long-Range RF Module (XBEE XSC PRO) technology to communicate with RiverDrones.
- RiverDrone is a drone used to locate the drifters along the rivers. RiverDrone uses 900 MHz Long-Range technology to communicate with the Drifters and 3G to connect to the central server.

Each of the components has its respective embedded system based on the energy and communication requirements. Regarding the software design, all the devices were programmed in C ++ for microcontrollers using serial interrupts and time control tasks. All communication with the central server uses the IoT publish-subscribe-based messaging protocol (MQTT) that includes messages in JSON format that allows the standardisation of information. This

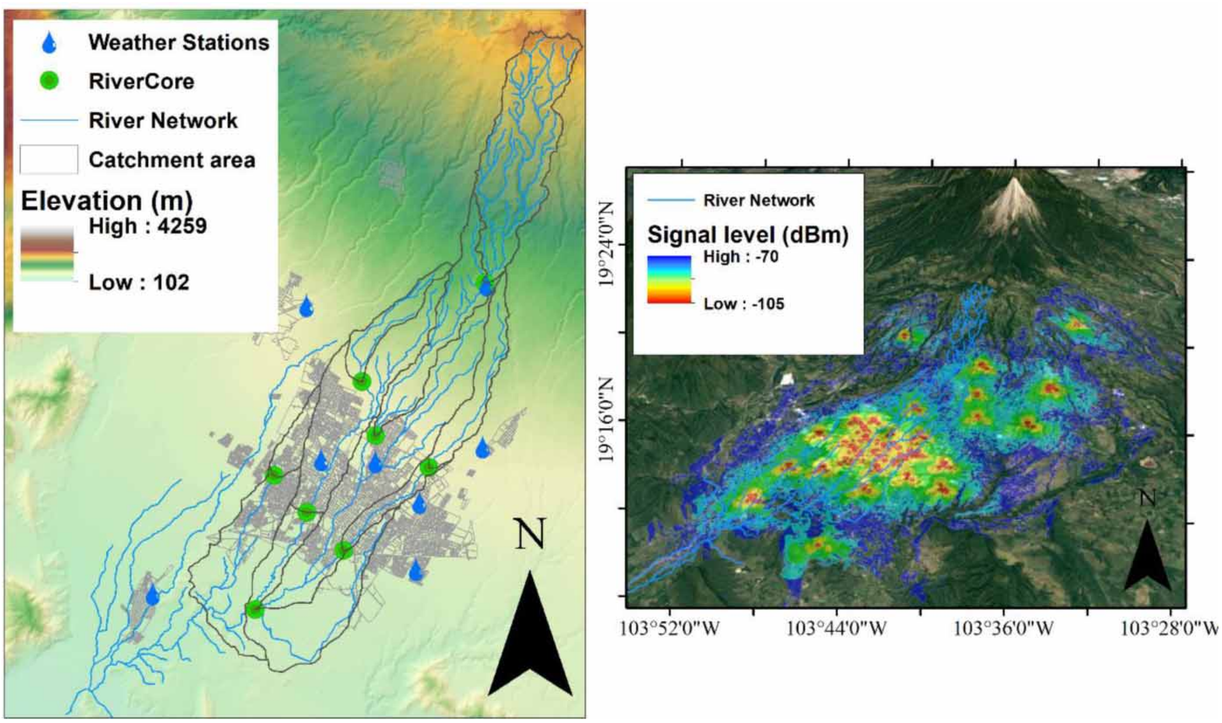

Figure 3 | Location of the fixed nodes in Colima-Villa de Álvarez, Mexico (left). The right panel map shows the 3G/4G signal strength in the study area.

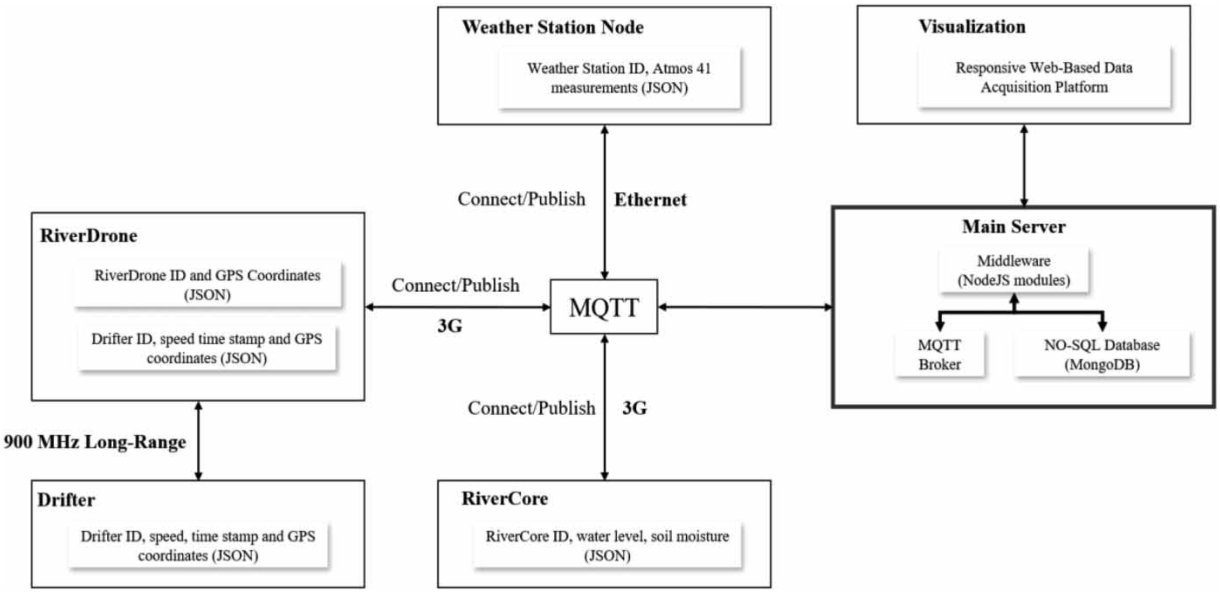

Figure 4 | General diagram of the implemented network.

allows the website to display the data in near-real-time and store the data in a database.

Static nodes

Weather station nodes. The weather station node retrieves information from the commercial multisensory Atmos 41, which includes 12 weather sensors (solar radiation, precipitation, vapour pressure, relative humidity, air temperature, humidity sensor temperature, barometric pressure, horizontal wind speed, wind gust, wind direction, tilt, lighting and lighting average distance). Atmos 41 is a three-wire interface following the SDI-12 protocol for communicating sensor measurements (Table 1). We designed a shield/daughterboard for Arduino MEGA with an Ethernet communication (ENC28J60), a local storage unit with a capacity of 32G allowing data backup during potential breaks of communication with the central server and a real-time clock to timestamp mark.

RiverCore nodes. The RiverCore node is composed of an ultrasonic water level (Toughsonic) and soil moisture (Teros10) used for water level monitoring, high water level warnings and for hydrological modelling a shield/daughterboard with own design using Arduino DUE with a 3G cellular communication (SIM5320A), RS-485 transceiver and a data logger; details are shown in Table 2.

Table 1 | Weather station node specifications

Devices	Manufacturer name	Description
Ethernet breakout	Microchip	ENC28J60
MicroSD card breakout board	Adafruit	microSDHC
Case	Steren	IP65
Weather station	METER Group	ATMOS41
PCB	Tres Ríos	Own design
Microcontroller	Microchip	ATMEGA2560
RTC breakout	Adafruit	DS1302

Dynamic nodes

The fixed static hydrometeorological nodes are supported by dynamic sensors (*Drifters and RiverDrones*) that can collect data during specific events to understand how the catchment behaves during floods in terms of tributary relative timing and interaction (Pattison *et al.* 2014). Drifters and RiverDrone are both designed to work together, where RiverDrone is used to locate the Drifters.

Table 2 | *RiverCore* specifications

Devices	Manufacturer name	Description
3G Radio	SIMCom	SIM5320A
MicroSD card breakout board	Adafruit	microSDHC
Case	ABB	IP65
Battery	LTH	12v 80Ah
Water level sensor	Senix	ToughSonic
Soil moisture sensor	METER Group	TEROS 10
Antenna	Taoglass	Multiband
PCB	Tres Ríos	Own design
Microcontroller	Microchip	AT91SAM3X8E

Drifters are equipped with a shield/daughterboard with own design using Arduino NANO with GPS (4 clicks), 900 MHz Long-Range RF Module (XBEE XSC PRO) to communicate with RiverDrone and a data logger. The objective of Drifters is to map the river flow velocity during specific river conditions and measure other parameters such as water temperature (Table 3).

RiverDrone has a shield/daughterboard with own design using Arduino MEGA with a 3G cellular communication (SIM5320A) to connect to the central server, and a 900 MHz Long-Range RF Module (XBEE XSC PRO) to communicate with the Drifters. More information and specifications are summarised in Table 4. The objective of RiverDrone is to locate drifters by sending a frame in broadcast so that each drifter responds to the request. The drifter's response message will contain GPS location, speed and signal strength of the 900 MHz radio. The signal strength is used to estimate the distance between drifter and RiverDrone. After this, the RiverDrone will search and communicate with the drifter to recover it later.

Table 3 | *Drifter* specifications

Devices	Manufacturer name	Description
GPS	MikroE	4 Click
MicroSD card breakout board	Adafruit	microSDHC
Case	Pelican	1010
Battery	Generic	lipo
900 MHz Long-Range RF Module	DIGI	Xbee XSC PRO
Antenna	Taoglass	Flexible
PCB	Tres Ríos	Own design
Microcontroller	Microchip	ATmega328

Table 4 | *RiverDrone* specifications

Devices	Manufacturer name	Description
3G Radio	SIMCom	SIM5320A
Case	Steren	IP65
Battery	Generic	lipo
900 MHz Long-Range RF Module	DIGI	Xbee XSC PRO
Antenna	Taoglass	Multiband
PCB	Tres Ríos	Own design
Microcontroller	Microchip	AT91SAM3X8E

Web application development

Water level, soil moisture and weather data are transmitted through 3G/4G network and Wi-Fi (for the weather stations on public buildings) to the server and are uploaded and displayed on a web application (screenshot in Figure 5; http://tairda.siteldi.mx/ewin). Data are transmitted every 3 min, but the rate can be changed for a coarser temporal resolution from the server. From the web application dashboard, information of the last 2 h can also be viewed in charts. It is also possible to download historical data across different sensor nodes as csv or text files. The web application runs on a 64-bit Debian operating system. Both the front end and the back end were developed in NodeJS. The MongoDB database was used for its ease of use in IoT solutions, and the communication protocol used between the server and the nodes is MQTT.

TESTS AND RESULTS

A part of the web application platform is open to the public where real-time water level and weather parameters can be visualised. Another part of the application allows access and download of historical information using

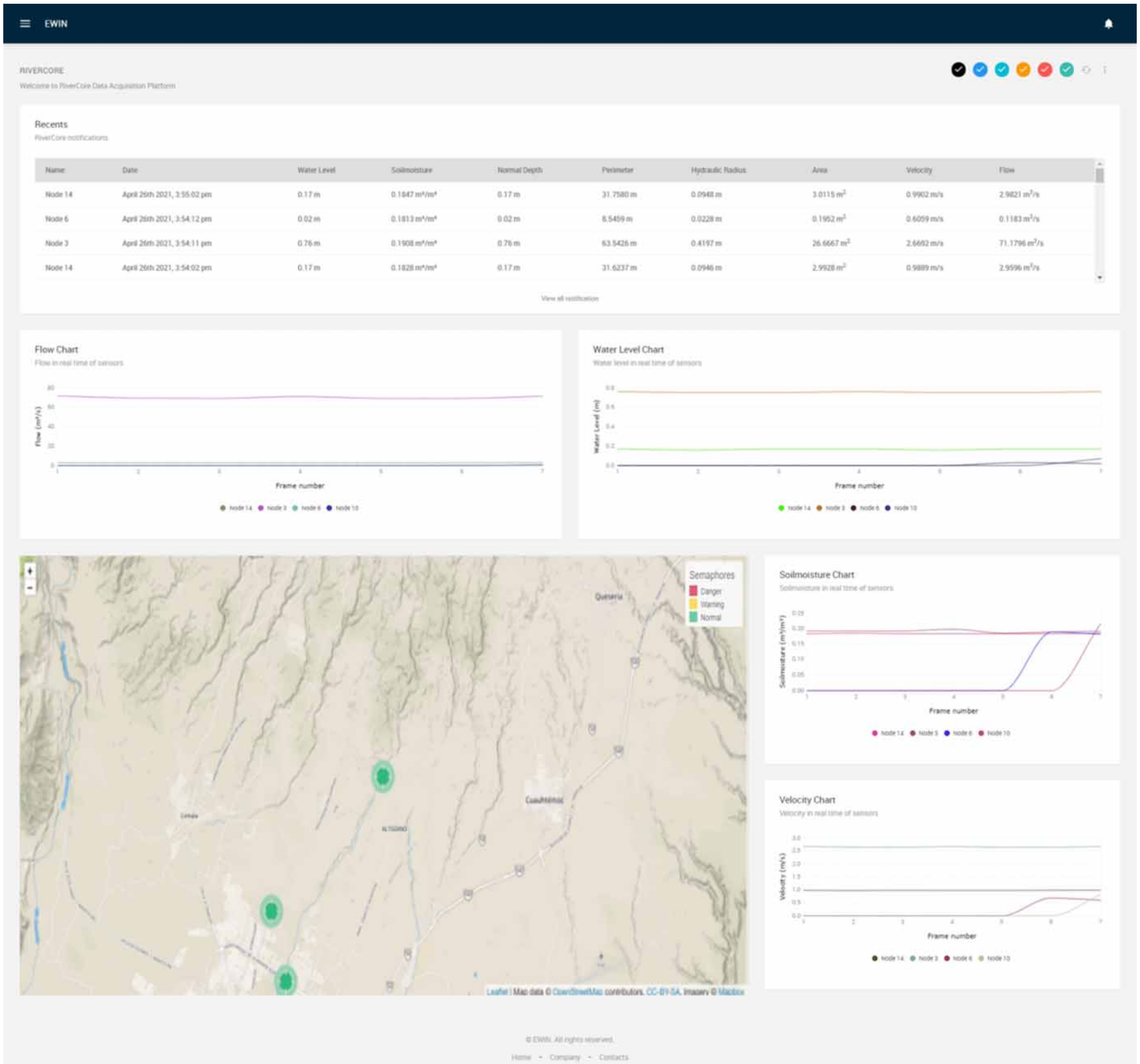

Figure 5 | Screen shot of the web application dashboard.

specific access key. At the moment, access key is generally given to specific collaborators such as experts, policy-makers and stakeholders mentioned above. Using historical data, analyses of the hydrometeorological events can be performed.

To demonstrate the network performance and its ability to collect and transfer the data in real-time during flood events, we used three different tropical storm events that occurred during the wet season of 2019: tropical cyclone Lorena, Narda and Priscilla (Table 5). These events generated significant rainfall and damage such as collapse of bridges, the destruction of roads and the flooding of critical infrastructure (e.g. schools, hospitals and

Table 5 | Tropical cyclone storms that affected Colima-Villa de Álvarez metropolitan area in 2019

Storm name	Date
Lorena	18–22 September 2019
Narda	27 September–1 October 2019
Priscila	19–20 October 2019

government offices). Our network monitoring system captured these three events' hydrometeorological data, and their analyses are discussed in the following section. During the event periods, the data were collected and sent to the server every 5 min but for practical reasons, the data were aggregated to 10 min in the following analyses.

Figure 6 shows the tracks and storm locations of the three tropical cyclones; only the tropical storm Narda entered the state of Colima as a hurricane. Though Lorena made landfall in the neighbouring state of Jalisco, its hydrometeorological effects were significant throughout the state of Colima. Priscilla was generated off the coast of Colima, and it quickly degraded and entered the state territory as a tropical depression.

Lorena storm

The storm Lorena generated in the Pacific basin and its effects on Colima-Villa de Álvarez metropolitan area occurred on 18 September 2019 at 4:00 pm Figure 7(a) shows the hyetograph recorded by the weather station nodes across the network. The maximum accumulated precipitation during the event was 157.82 mm recorded at node 6.

During the Lorena event, six weather station nodes out of eight were continuously in operation and did not lose the connection during the peak of the event. Figures 8(b)–8(d) show the spatial distribution of the precipitation across the area interpolated using kriging. The spatial interpolation showed that the network is well distributed spatially and allowed the capture of rainfall differences across the

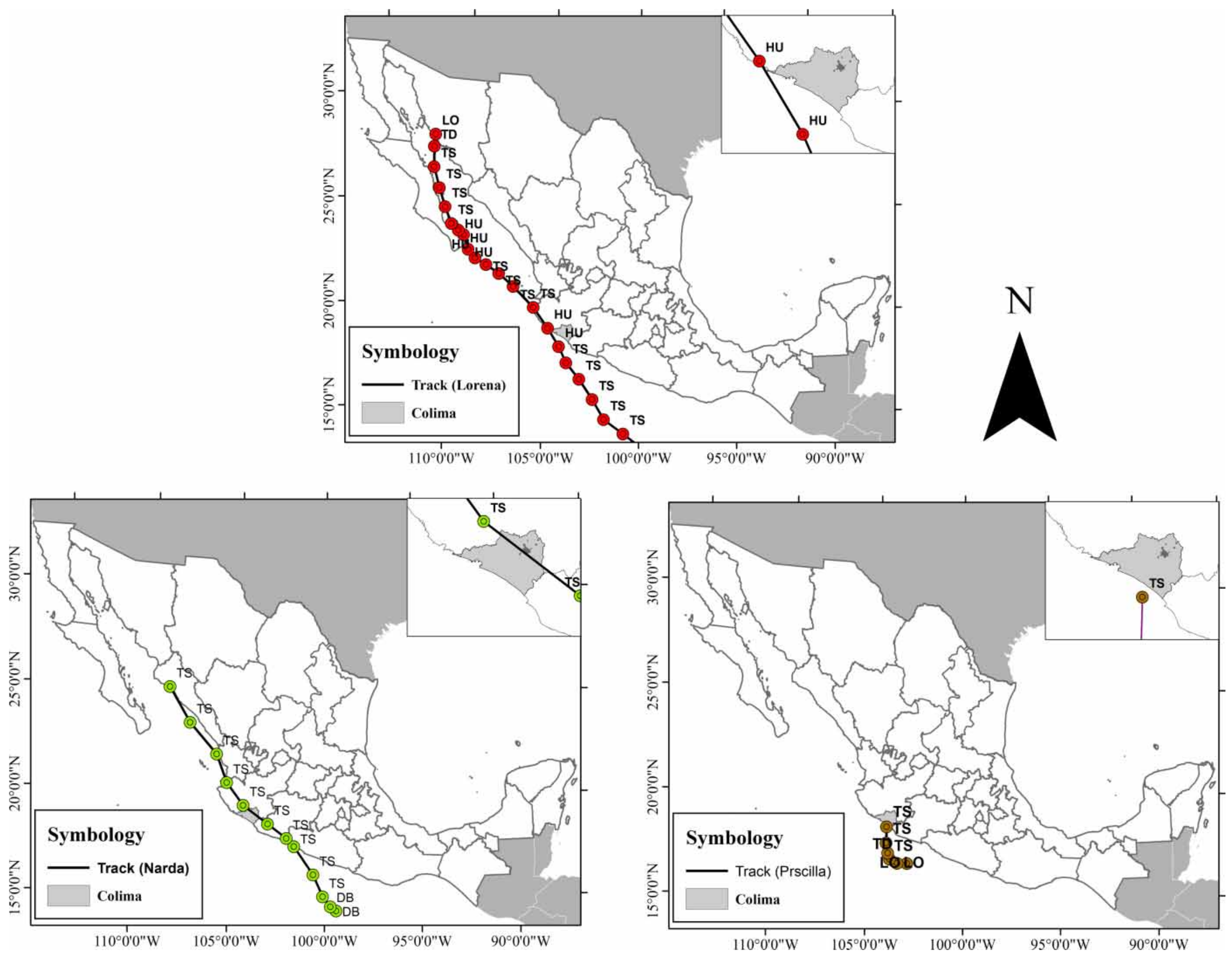

Figure 6 | Tropical cyclone tracks of Lorena (upper map) Narda (left) and Priscilla (right).

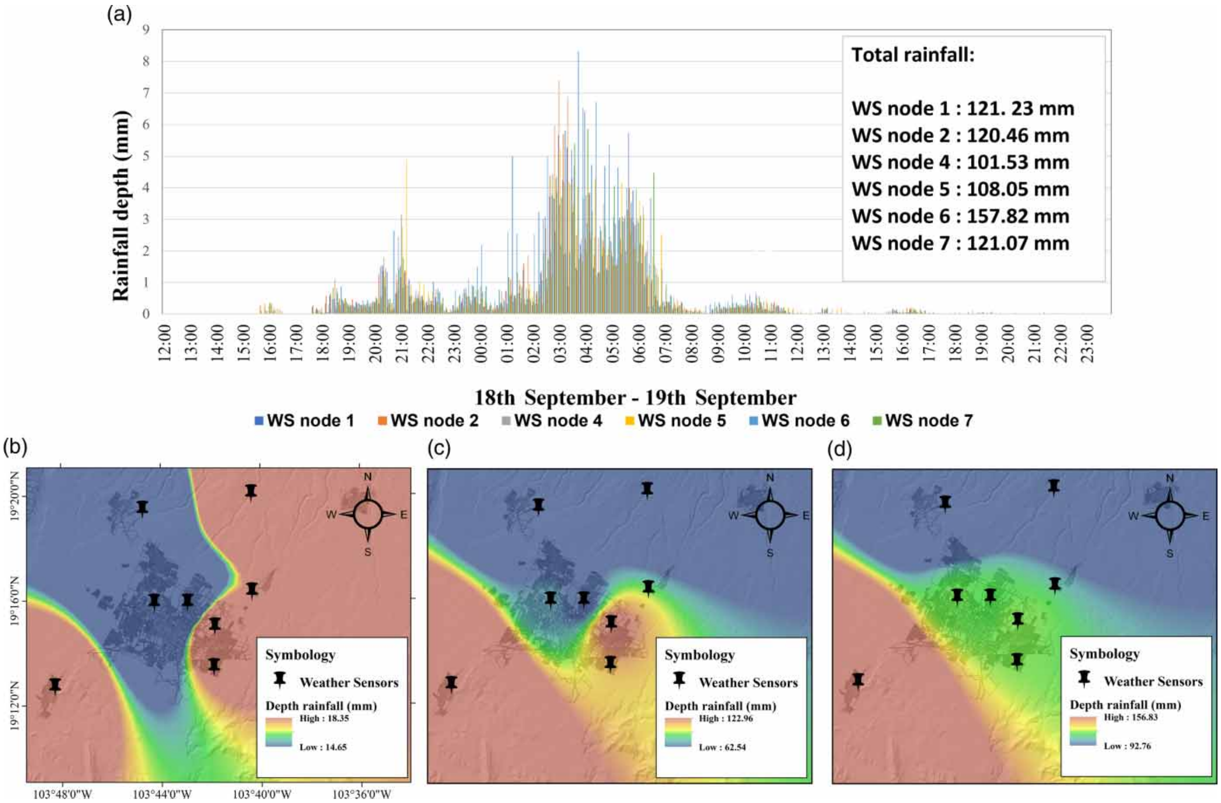

Figure 7 | Upper panel: (a) hyetograph of Lorena Tropical Cyclone. Bottom panel: (b) cumulative rainfall between 15:00 and 22:00 on 18 September, (c) cumulative rainfall between 15:00 on 18 September and 05:00 on 19 September and (d) total rainfall depth in mm.

metropolitan area. The precipitation's pattern coincides with the trajectory of Lorena, which was parallel to the coast of Colima. The maximum rainfall in the state of Colima was recorded at the Tecomán 343 mm station, which is located near the coast. This information was provided by the local water agency's network of stations, which have records of daily accumulated rainfall.

Narda storm

On September 29 at 10:00 am, the National Meteorological Service (SMN) reported the formation of the Potential Tropical Cyclone '16-E', south-southwest of Guerrero, which would travel parallel to the coasts of the Mexican Pacific. On the same day at 22:00, the SMN reported that from Potential Tropical Cyclone '16-E', tropical Storm 'Narda' had formed off the coast Guerrero and that it maintained its displacement parallel to the shores of the Mexican Pacific, causing heavy rains as it passes.

The effects of Narda started to be felt in Colima area on September 29 at 2:10 pm; Figure 8(a) shows the precipitation height hyetographs recorded by six of the eight meteorological stations. The effects of Narda in the city of Colima were felt from 14:10 from September 29 to September 30 at 10:00 am.

The spatial distribution of accumulated precipitation is shown in Figure 8 (bottom panels). Higher precipitation is recorded in the southern part of the city. A critical point detected was that 7 h after the storm started, flooding problems began to appear in the city. The storm caused significant damage to infrastructure such as flooding and damage to roads.

Priscilla storm

Tropical cyclone Priscilla was the most destructive event of the 2019 wet season. It triggered many emergencies for the population and the National Water Commission. The storm was formed on Sunday, 20 October, off the coast of western

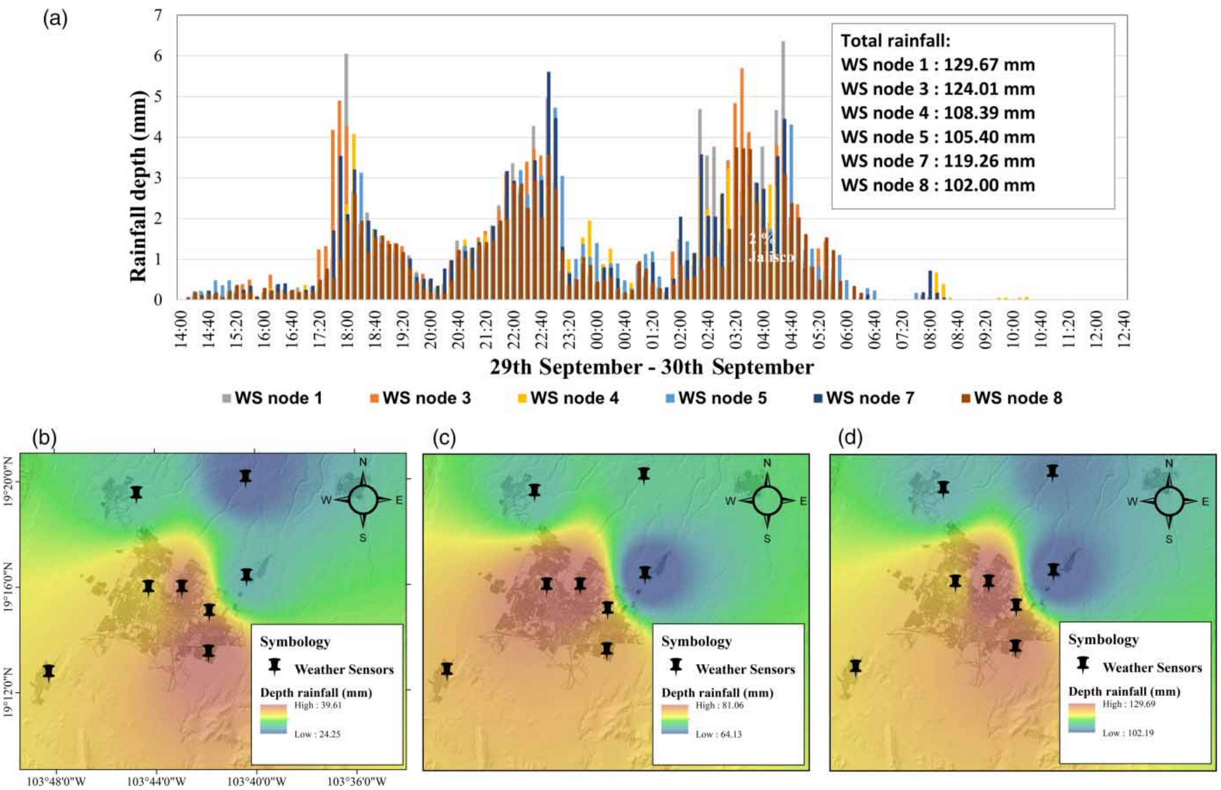

Figure 8 | Upper panel: (a) hyetograph of Narda Tropical Cyclone. Bottom panel: (b) cumulative rainfall in the first 7 h (29 September), (c) cumulative rainfall in the early 12 h (29–30 September) and (d) total rainfall (29–30 September).

Mexico. Due to its proximity to the coastal populations of the state of Colima, the event was closely monitored. However, Priscilla ceased to be a tropical storm as it weakened after making landfall. The government cancelled a tropical storm warning for the state of Colima.

The analysis of the precipitation records generated, as a result of this event, allowed to identify increases in the water level of urban rivers appeared since a day before (19 October) a mesoscale phenomenon that registers up to 40 mm the Colima-Villa Álvarez metropolitan area (Figure 9(a)). During the Priscilla pass, the maximum precipitation recorded across the network was 21 mm (20 October). Figure 9 (bottom panel) shows cumulative rainfall on 18 October and 19 October.

Hydrological modelling

The preliminary hydrological model for the Colima river system was tested as well. We simulate the rainfall–runoff process for extreme hydrometeorological events. The model was built in HEC-HMS in version 4.4.1. The rainfall–runoff process simulation was generated on an event scale for the period between 18 September 2019 and 20 September 2019 (Figure 10). The infiltration method used was the curve number, while the transformation model was the synthetic unit hydrograph developed by the Soil Conservation Service of the US Department of Agriculture. Based on the water level records at Node 14, located in the upper part of the catchment, the curve number (N) and the initial abstraction (Ia) were calibrated. These parameters are related to the loss by infiltration. Flow rates were obtained from the levels recorded with the sonic sensor and a rating curve (flow-discharge) generated based on a two-dimensional hydraulic model. We used Iber which is an open-source program and the software used to construct the hydraulic model in each node.

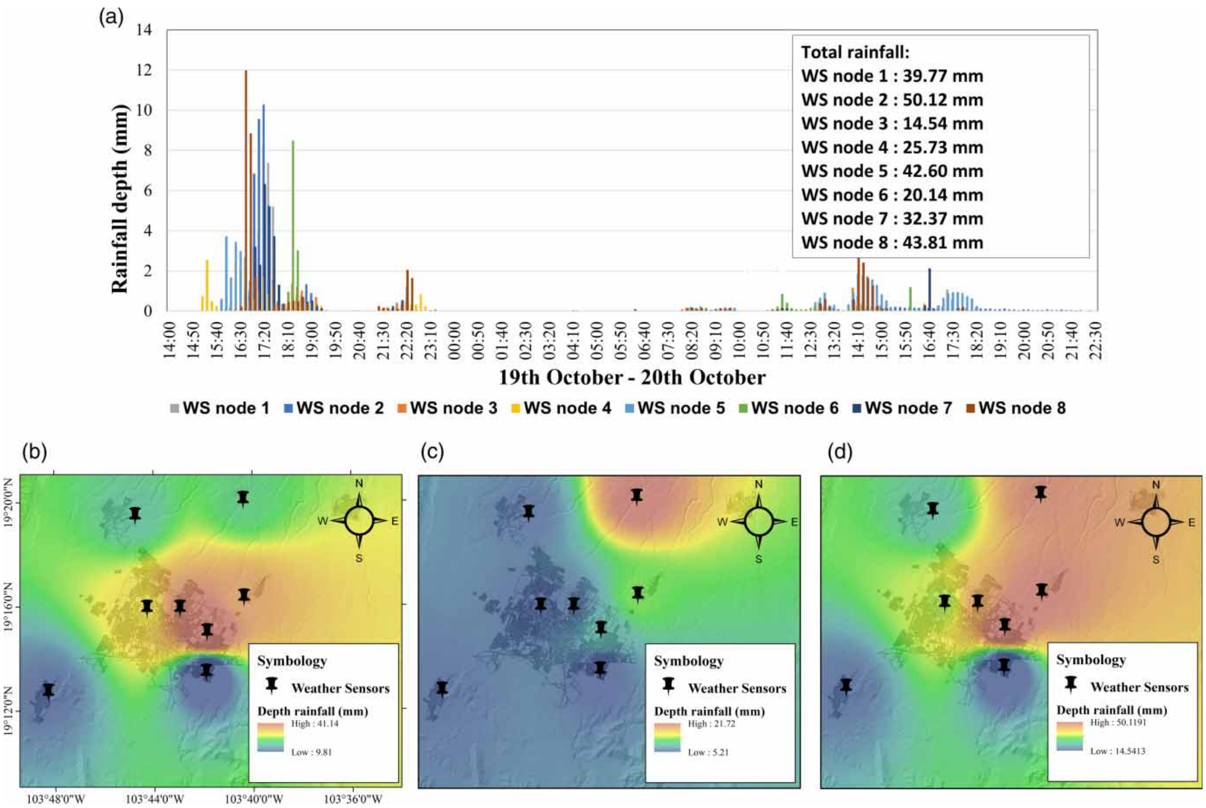

Figure 9 | Upper panel: (a) hyetograph of Priscilla Tropical Cyclone. Bottom panel: (b) cumulative rainfall on 18 October, (c) cumulative rainfall on 19 October and (d) total rainfall (18–19 October).

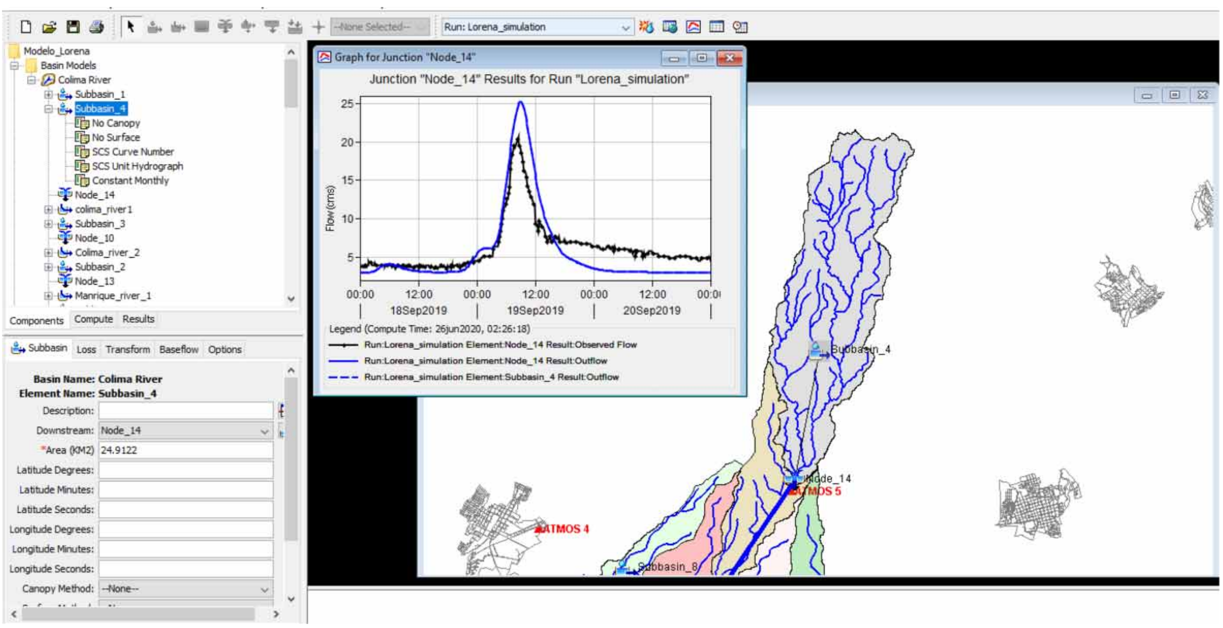

Figure 10 | Simulation of the rainfall–runoff process of the Colima river system (Node 14).

Drifters and *RiverDrone* experiments

The Drifter experiments were performed on 28 February 2020, in Coquimatlán, Colima, Mexico, between approximately 9 am and 12 pm (Figure 11). The site was selected for its suitability, easy accessibility and safety of the team. The following steps were performed to conduct the experiment:

- define the suitable river stretch for releasing and collecting the drifters,
- release the three drifters at the same time,
- follow and captured the drifter at the exit point, and extract the microSD card, and
- check the web application for data upload.

The Drifter path and its associated data are obtained and visualised on the web application's map as illustrated in Figure 12.

Table 6 summarises the data collected and related to the water velocity and the distance of Drifter journey.

RiverDrone experiment was performed on 25 January 2020, in Manzanillo, Colima, Mexico. The objective of the experiment was to examine the ability of the RiverDrone to search and find the drifters. The experiment was conducted in a first place in an open sea, and Drifter-Sniffer was tested to obtain real-time coordinates of the drifter location for their respective collection:

- The drifter released in the sea about 2 km from the Drifter-Sniffer.
- The location of the Drifters displayed on the web application is when the Drifter-Sniffer detects a drifter using the 3G network.
- Drifter are manually collected and data are uploaded to the server.

Figure 13 shows the drifter path along with its locations and velocities.

Dissemination of results

To disseminate the results and emphasise the importance of such systems for water monitoring in an urban environment, three workshops were conducted throughout the project life and a final workshop was organised in January 2020 (Figure 14). In this workshop, participants include local authorities, decision-makers, policymakers, stakeholders, academics and students to discuss the results and ways of supporting the project and improving the system towards an operational system for flood monitoring in Colima. The official presenting video of the project can be found here: https://www.youtube.com/watch?v=7MHIVOkaf-c.

CONCLUSIONS

This paper presents development phases and experiments of an IoT-based network of sensors for fluvial water level monitoring and food warning system for the urban area of Colima-Villa de Álvarez in Mexico. The network is composed of (1) eight fixed nodes (RiverCore) collecting fluvial water level across the main rivers in Colima city, (2) eight

Figure 11 | Location of the drifter experiment.

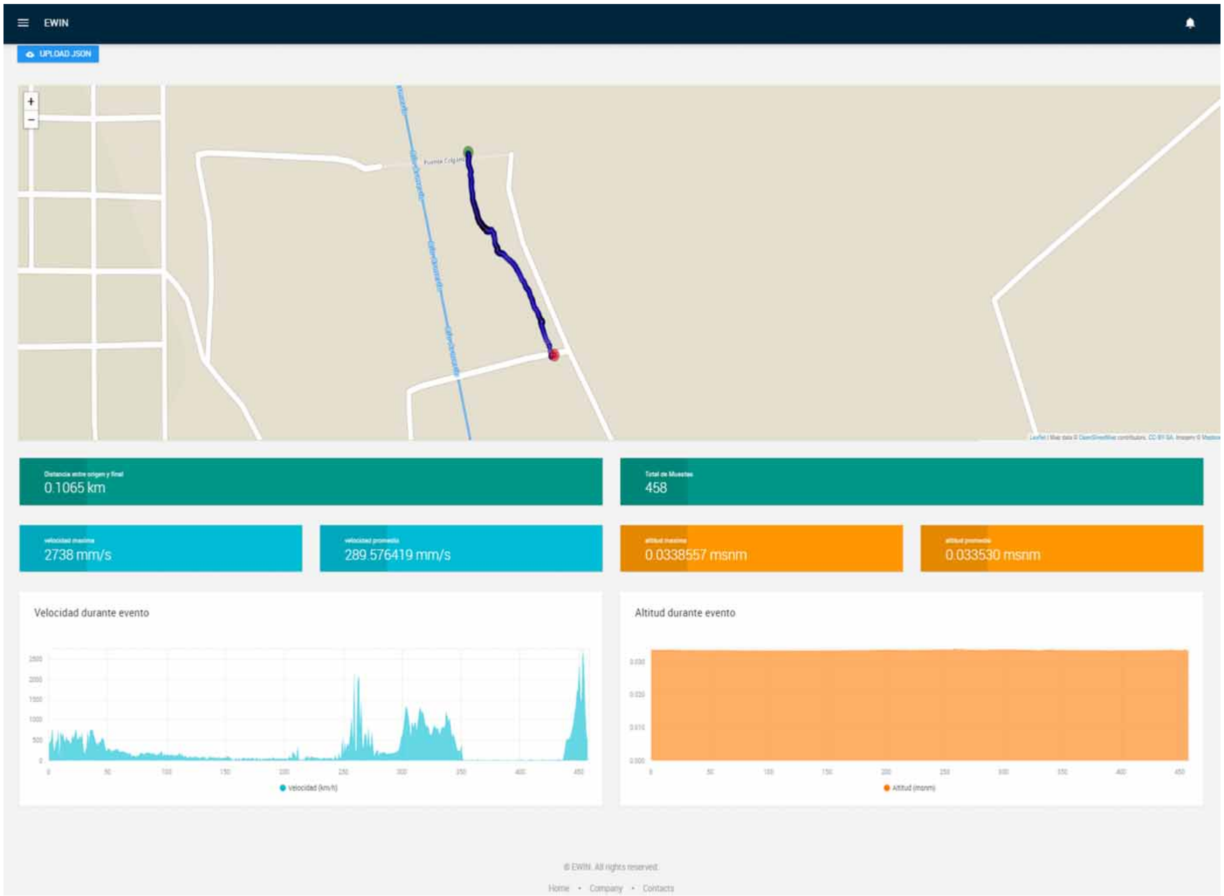

Figure 12 | Drifter tracking as seen on the web application.

Table 6 | Data retrieved from the experiment

Drifter	
Distance from the first to the last check point.	0.1065 km
Average speed	0.2895 m/s

weather stations distributed across the catchment areas collecting at least seven weather parameters and (3) dynamic supporting sensors (i.e. Drifters and RiverDrones) used to collect data during specific events. Soil moisture data are also collected using sensors connected to several nodes across the catchment.

Experiments of the network system conducted during the three main tropical storm events that occurred during the 2019 tropical cyclones season (storm Lorena 18–22 September, storm Narda September 27–October 1 and Priscila 19–20 October) demonstrated the robustness of the network to sense river levels and meteorological conditions across the city in real-time providing relevant information for flood monitoring and waning. The continuous data collection is also critical for developing hydrological and flood inundation modelling and mapping in this area where no datasets were available previously.

The work conducted throughout the project also demonstrated the importance of the multidisciplinary approach to problem-solving of flooding issues. This multidisciplinary and participatory work not only improved the outcomes but also optimised the resources used in the process. Many countries in Latin America have introduced early warning systems to minimise their flood impacts. However, most systems are not always effective due to poor robustness of the sensor's network and the high costs. Our IoT-based wireless sensor network is relatively low cost and can be replicated in areas where large budgets for flood prevention measures are not available.

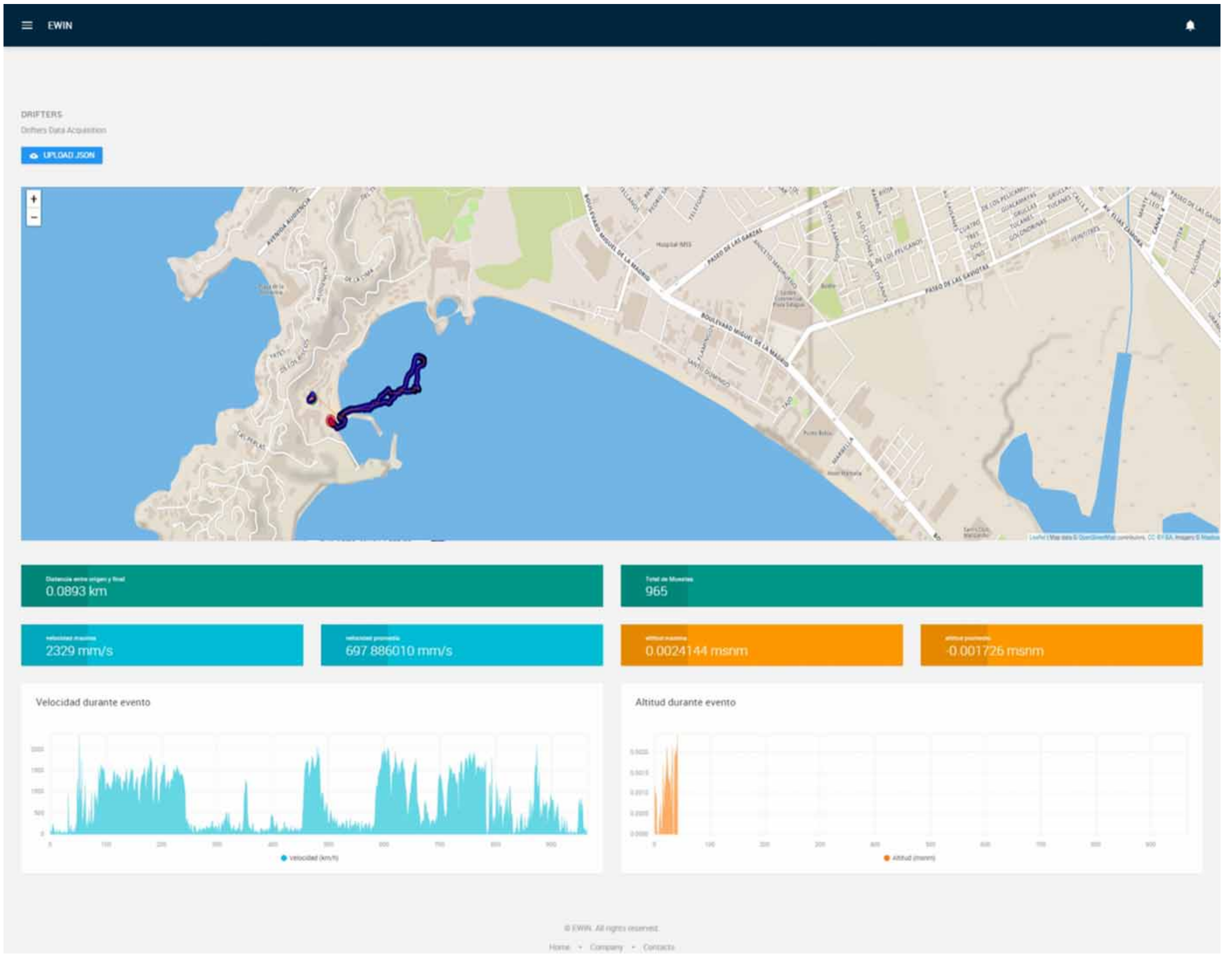

Figure 13 | Analysis MicroSD on web platform.

Figure 14 | Photos from the project January 2020 workshop.

The system proposed in this paper can provide information to the relevant flood management and emergency services and authorities to reduce risk, loss of life, damage to property and the environment; however, the system alone is not the solution to flooding problems; civil society, volunteers, organised voluntary work organisations and community organisations must be involved, in collaboration with public institutions. Women's participation is essential for effective disaster risk management. School children and youth are agents of change and must be given the space and ways to contribute to disaster risk reduction.

In terms of improvements and limitations, it is necessary to keep maintaining the system regularly and correct data issues and bugs when necessary. Additional new functionalities in the web application are needed such as easily choosing time intervals for sampling, appending the quality of the GPS signal to the datalogger. Sensor security and vandalism has been an issue although, in our network, we used higher towers and protected the sensors under bridges with a metal box. For the drifter sensors, overall, more tests are needed and it is convenient to add new functions to the current system since at the moment it does not show the distance or the intensity of the signal between the drifter and the sniffer.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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