Mobile Networks and Applications (2023) 28:65–81
https://doi.org/10.1007/s11036-022-01994-8

LoRa-based Network for Water Quality Monitoring in Coastal Areas

Sandra Sendra[1] · Lorena Parra[1] · Jose M. Jimenez[1] · Laura Garcia[1] · Jaime Lloret[1]

Accepted: 27 September 2021 / Published online: 12 July 2022

Abstract

Agriculture Farming activity near to rivers and coastal areas sometimes imply spills of chemical and fertilizers products in aquifers and rivers. These spill highly affect the water quality in rivers' mouths and beaches close to those rivers. The presence of these elements can worse the quality for its normal use, even for its enjoying. When this polluted water reaches the sea can also have problematic consequences for fauna and flora. For this reason, it is important to rapidly detect where these spills are taking place and where the water does not have the minimum of quality to be used. In this article we propose the design and implementation of a LoRa (Long Range) based wireless sensor network for monitoring the quality of water in coastal areas, rivers and ditches with the aim to generate an observatory of water quality of the monitored areas. This network is composed by several wireless sensor nodes endowed with several sensors to physically measure parameters of water quality, such as turbidity, temperature, etc., and weather conditions such as temperature and relative humidity. The data collected by the sensors is sent to a gateway that forwards them to our storage database. The database is used to create an observatory that will permit the monitoring of the environment where the network is deployed. We test different devices to select the one that presents the best performance. Finally, the final solution is tested in a real environment for checking its correct operation. Two different tests will be carried out. The first test checks the correct operation of sensors and the network architecture while the second test show us the devices performance in terms of coverage.

Keywords The Things Network (TTN) · Wireless Sensor Network (WSN) · Long Range (LoRa) · LoRaWAN · Observatory · Water quality · Monitoring · Sensors

1 Introduction

Along the 8,000 km of Spain's coastline, there are numerous protected natural spaces and countless areas with a high ecological value that provide great biodiversity. Particularly, the Mediterranean coast of Spain has 10 specially protected areas [1]. These spaces are part of the appeal of Spain's coast which receives thousands of tourists that are key in the economic development of the coast. This has led to the development of the coastal areas and the increase of the offer of activities with facilities such as nautical and sports stations, marinas, or yacht clubs. Other important economic activities in coastal areas are fishing and aquaculture, which are great sources of income for the primary sector [2].

Despite the importance of the coastal areas, some problems have arisen regarding the quality of the water. Some protected areas are in a critical state due to the presence of fertilizers and chemical products such as Zinc, dissolved salts [3] and nitrates [4, 5]. Furthermore, the climate change is generating the increase of the overall temperature in environment and water bodies [6]. This has led to the loss of marine fauna and has affected both the fishing and tourist activities in the area [7]. Likely, the water quality of some bathing areas was below the standard and resulted in them being closed [8]. In most cases, the contamination of the water is due to the location of close-by agriculture fields

✉ Sandra Sendra
sansenco@upv.es

Lorena Parra
loparbo@doctor.upv.es

Jose M. Jimenez
jojiher@dcom.upv.es

Laura Garcia
laugarg2@teleco.upv.es

Jaime Lloret
jlloret@dcom.upv.es

[1] Instituto de Investigación para la Gestión Integrada de zonas Costeras (IGIC), Universitat Politècnica de València, Camino de Vera, s/n., 46022 València, Spain

leading to contaminated water discharge that can happen both intentionally and unintentionally [9]. However, other ports are a source of contamination as well due to the presence of hydrocarbons [10]. Considering the deterioration that waters in coastal areas are experiencing, it is important to implement solutions in order to restore water quality.

When monitoring water quality, it is necessary to detect, count and classify the varied anomalies so as to determine the actions to correct each problem. This is performed by deploying Wireless Sensor Networks (WSN) on the water so as to gather real-time or periodical data from both water and environmental conditions and forward it utilizing wireless technologies [11, 12]. The gathered information is stored and analyzed to generate alarms. Algorithms and data processing techniques so as to both detect and solve unwanted events [13]. Furthermore, the creation of observatories that collect the data from each of the monitoring locations and apply artificial intelligence and Big Data techniques to determine the quality of coastal waters is being fomented [14]. However, for the case of marine environments, the utilized wireless technology should be able to cover wide areas as it is not possible to provide wired connectivity.

LoRa (Long Range) is a wireless protocol that has been gaining interest in the recent years and provides long-distance connectivity through the use of free frequency bands, which leads to a cost reduction. Its low energy consumption is suitable for WSN, particularly for environments where the access to the nodes is difficult and changing batteries is costly in time, in personnel, and monetarily. Furthermore, the LoRaWAN (Long Range Wide Area Network) protocol implements triple encryption and grant bidirectional data forwarding for packets with small payloads. Therefore, the use of LoRa for monitoring coastal areas is the best solution for providing long-range and cost-effective wireless connection.

Considering the needs of water quality monitoring solutions and the adequacy of LoRa for this purpose, in this paper, a LoRa network with water quality monitoring sensors is presented. The sensor networks are comprised of a buoy with low-cost sensors that monitor water turbidity, salinity levels, water temperature [13], presence of oils and fuels, and meteorological parameters such as air temperature or relative humidity. The system is intended to be deployed at the end of ditches and streams that discharge their water in bathing areas, beaches, and ports and thus, real tests have been performed in this type of environment. The data is then forwarded wirelessly to a gateway and then to a database. An observatory provides access to the data enabling data analysis, real-time monitoring, and display of data history. The presented system can be applied to port managing activities, agriculture, or aquaculture [15] among other usages. It is also a tool to promote beaches with the blue flag representing the good quality of its waters, increasing the tourist activities in those areas as a result. Lastly, the data can be accessed through a web portal in real-time.

The rest of the paper is organized as follows. The related work on other studies on water quality monitoring systems is presented in Section 2. The implemented system, the hardware and the software resources utilized to implement the nodes are described in Section 3. Section 4 discuss the tests and results. Finally, the conclusion and future work are presented in Section 5.

2 Related work

In this section, some related works associated to our proposal where WSNs are used to monitor the water quality in stressed areas such as Mediterranean basin [16].

There are authors who have carried out surveys on water quality. For example, Pule et al. [17] conducted a study about WSN, to monitor water quality. In the study, they compared and evaluated, among other characteristics, sensor node architectures in terms of monitored parameters, wireless communication standards, power supply architectures, and autonomy. They agree the need to ensure water quality, due to the high rate of deaths worldwide caused by waterborne diseases.

Adu-Manu et al. [18] review methods for water quality monitoring (WQM), from traditional manual methods to more technologically advanced methods employing WSN for on-site WQM. Recent developments in sensing devices, data acquisition procedures, communications and network architectures, and power management schemes to keep a long-lasting WQM system operational are noteworthy. Also, they discuss about the issues that need to be addressed to advance WQM automation, using WSN.

Some authors like Jia [19] presents a system to monitor the quality of water and air in wetlands. The system uses LoRa technology to send the collected data to the base station and a data fusion algorithm to reduce the amount of data that is sent. In this way, it was able to improve network performance and reduce energy consumption. Yan-Ting et al. [20] provide a real-time Internet of Things (IoT) water quality monitoring system based on LoRaWAN to monitor water temperature, turbidity, conductivity, and pH in Dong Lake at National Dong Hwa University. Das et al. [21] implement a water quality verification system (pH, conductivity, and temperature) in real-time through various sensors. Through an alert system, messages are sent to officials, in case of detecting contamination.

Water quality monitoring studies have been presented in the infrastructure of a smart city. For example, Chen et al. [22] presented a multi-parameter water quality monitoring system, collecting data in real-time at high frequency, from the floating harbor of Bristol, and display it online. They used the Smart city infrastructure as a plug & play platform for wireless communication, data processing, storage, and redistribution. The project demonstrated how IoT can be used in environmental monitoring systems to provide details of variations in water quality.

Some authors present studies from the point of view of the implementation of low-cost systems. Simitha et al. [23] develop a monitoring system based on IoT and WSN. Through this system they collect water quality data in real-time, to better preserve and manage water resources. Their goal is to achieve a low-cost, low-power system, using LoRa modules and the LoRaWAN communication protocol, to transmit sensor values to the ThinkSpeak platform and perform additional analysis. Among the monitored water quality parameters are temperature, pH, and turbidity, while dissolved oxygen (DO) is calculated using the DO-temperature dependence equation.

Other authors use unmanned surface vehicles (USVs) to create a water quality monitoring system. Wu et al. [24] propose a mobile water quality monitoring system, based on LoRa and IoT technologies used by USV, to monitor various water parameters in Lake Dardanelle, Arkansas. They integrate a set of sensors in a mobile platform that sends the data to a LoRa platform. They designed a long-range, low-cost system to send data via LoRa to The Things Network (TTN) cloud.

Finally, Saravanan et al. [25] propose a SCADA system that integrates with IoT technology for monitoring water quality in real time. Physical parameters such as temperature, turbidity and color are treated in the system. The system was designed to reduce labor, reduce costs, and increase efficiency in water distribution and monitoring.

Unlike existing works, this paper shows the design, development, and implementation of a wireless sensor network in a real environment for water quality monitoring. In addition, a web-based user interface has been developed. This user interface made citizens part of this project to see and know the quality of water in rivers and, thus, make them aware of the importance of keeping rivers clean and avoiding uncontrolled discharges.

3 Overall proposal description

This section presents the development of the proposed monitoring system. These descriptions include the different hardware elements as well as the web-based user interface and the server platform used to collect and store the data.

3.1 System overview

In order to design and implement our WSN for water quality monitoring, we have used the LoRa technology. LoRa is, currently, one of the wireless technology used to monitor the evolution of crops and weather conditions in farming. It is included into the category of a low-power wide-area networks (LPWAN) [26]. According to the manufacturers, LoRa is featured by its long coverage being able to transmit up to several tens of kilometres, considering an adequate and unobstructed direct vision in the Fresnel area between the gateway and end devices [27, 28]. So, LoRaWAN is a network protocol that uses LoRa technology for LPWAN to communicate and manage devices based on LoRa technology. For deployments in rural environments, most studies show a coverage around 20 km while in urban environments, LoRa is able to reach up to 5 km. These differences are caused mainly by the high dependence with the building materials and the reflections and refractions on the obstacles Finally, this technology permit the sending of small packets of data between 0.3 kbps and 5.5 kbps.

According to the LoRaWAN standard, this technology is based on an infrastructure architecture. The LoRa Gateway is placed in the center of the topology and is in charge of receiving the traffic and data from the all LoRa nodes present in the network. The gateway forwards the data from sensors to the server where it is stored and processed. To store the data, we included the Data Storage integration service provided by The Things Network (TTN) [29]. Data Storage integration is a database (DB) that permits a period of one week of storage. Additionally, we extract the data from the DB to be graphically visualized using Ubidots Platform. Ubidots Platform is also an integration that TTN offers without any cost. Finally, the proposed system includes a website to permit the reading of data to any user or target group interested on this information such as researchers, citizens, students, etc. As Fig. 1 shows, the dashboard is able to extract data from the different nodes, such as data sensors, its position, or ID and presents them in a graph. The nodes' positions are shown in a map.

3.2 Hardware used to design and implement our water quality monitoring system

This subsection presents the most important features of the different elements used to design and implement our nodes. To perform our tests, we used 3 different models of LoRa nodes in terms of coverage. Finally, the device with best results are used to implement the proposed system showed in the previous section.

3.2.1 Lora gateway and end devices

As we showed before, in order to deploy a LoRa-based network, it is required the presence of end devices, such as nodes and a gateway. Currently, there are several options and brands to design this sort of network. In our case, we

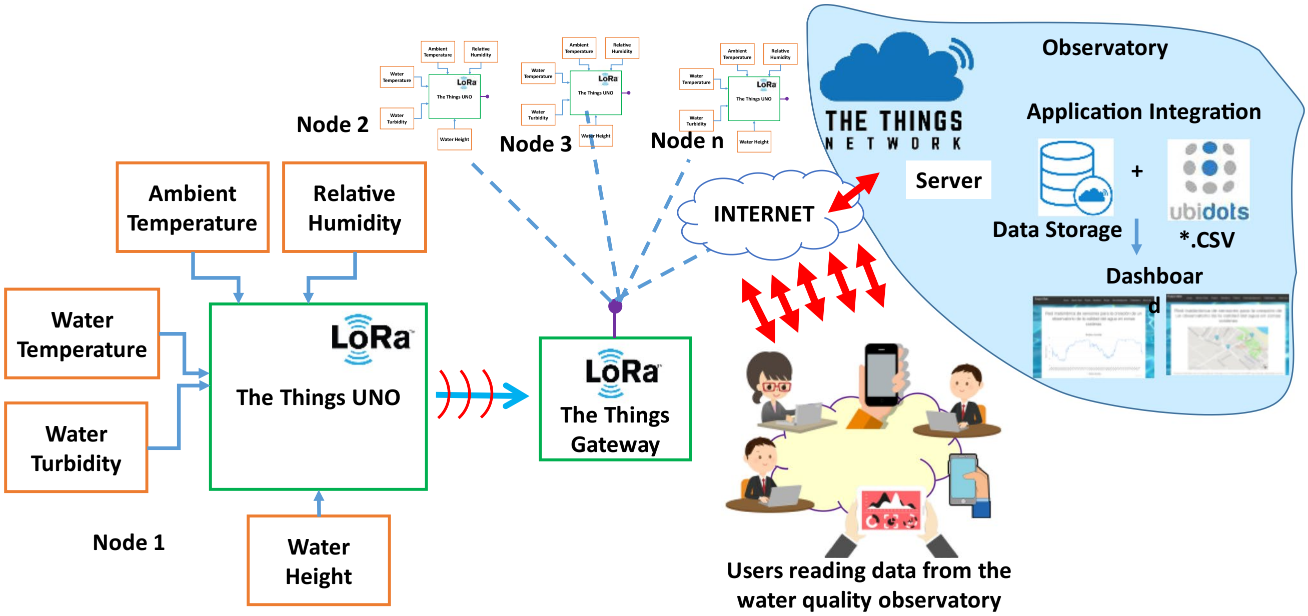


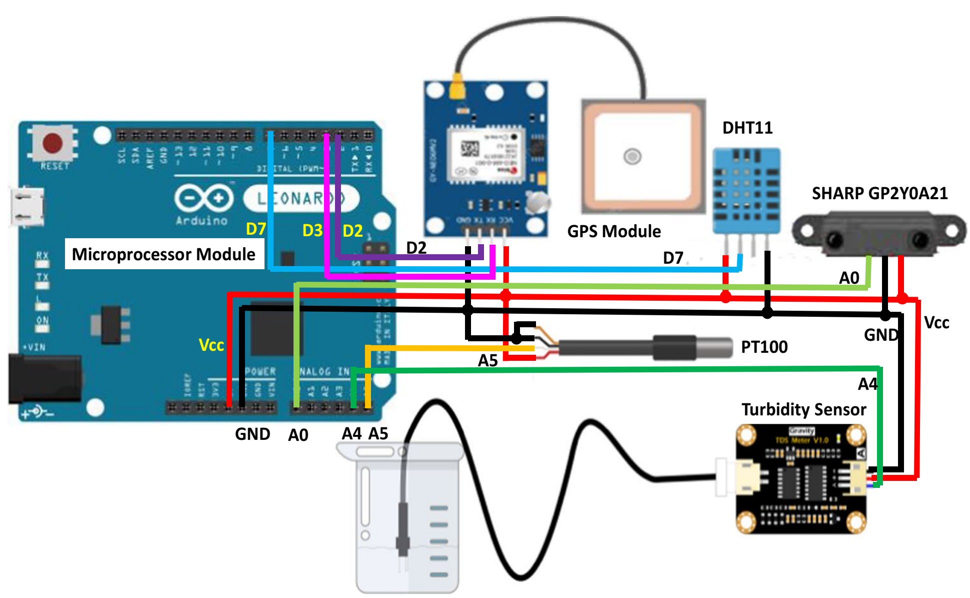
Fig. 1 Overall Proposed system

have selected some devices from The Things Network and Heltec Automation.

The Things Gateway [30] is a LoRaWAN gateway or base station able to connect LoRa end devices that grants them access to the internet to send the collected data to the server. The Things Gateway is based on open source hardware and software standards. It operates at 868 MHz to be used in the EU and 915 MHz to be deployed in US. The gateway contains an external antenna of 14 dB gain. According to the device specifications, only one gateway device is able to manage thousands of nodes placed inside the coverage wireless range of up to 6 miles (10 km). The Things Uno module [31] is a Leonardo board with a Microchip LoRaWAN RN2483 module and an on-board antenna. It is fully compatible with the Arduino IDE and existing shields. This fact gives popularity to this hardware and facilitates its configuration and programming. To develop a LoRa network as the one described in Fig. 1, it will be needed to combine a gateway and several nodes. With this, we would be able to deploy an IoT network for embedded, sensing and connected city applications with up to 10 km range coverage. Figure 2 shows the network devices from TTN.

Heltec Automation also manufactures LoRa devices. In our experiments, we also include Heltec LoRa WiFi 32 v2

Fig. 2 Diagram of the deployed node



nodes to compare the performance of both devices. The test with these low-cost nodes were performed utilizing Heltec LoRa WiFi 32 v2 nodes of two different frequencies, i.e., 433 MHz and 868 MHz nodes. These nodes have a ESP32 microprocessor and a SX1276/SX1278 LoRa chip [32]. In this case, the Gateway was implemented with one of these devices configures as a Gateway and other as a end device.

3.2.2 Sensors used to collect data from water

- Turbidity Sensor. The analog turbidity sensor is able to monitor the water quality taking into account the total suspended particles in water. This sensor can give both analog and digital response as a function of the amount of total suspended particles in the liquid. It works with 5 V (max. current consumption: 40 mA). The turbidity sensor offers an output value from 0 to 4.5 V (Operating temperature between 5 ℃ and 90 ℃) [33].
- Temperature and Humidity Sensor. To measure the ambient temperature and relative humidity, our solution includes a DHT11 sensor [34] that gives a digital output thanks to its small 8-bit microcontroller. The DHT11 sensor can measure temperature in the range of 0°C to 50°C (Error: ± 2°C) and relative humidity in the range of 20% to 90% (Error: ± 5%).
- Water temperature sensor. To measure the water temperature, we use a 3-wire RTD resistance. The working range of this sensor is comprised between -50 °C and + 300 ºC. The variation of temperature coefficient is 0.00385 Ω/°C.
- Water height. To measure the water height, we use an SHARP GP2Y0A21 sensor [35]. It permits measuring the distance to an obstacle within the range of 4 to 30 cm. The sensor is composed by three different elements, i.e., (1) an infrared emitting diode (IRED), (2) a sensitive position detector (PSD) and, (3) a signal processor circuit. This sensor is not affected by difference in the reflectivity of the materials or operating temperature.
- GPS module. The GY-GPS6MV2 [36] module includes a U-Blox NEO 6 M serial module on the PCB, a factory-configured EEPROM, a button cell battery to hold configuration data in EEPROM memory and, an LED indicator and a ceramic antenna. The use of this module is recommended in open environment for a correct signal reception.

After analysing the features and working ranges of each sensor, they are combined and mounted to deploy our nodes and perform the tests. Figure 2 shows a diagram of the deployed node while Fig. 3 shows a picture of the LoRa node and sensors inside a PLA case to protect the hardware. Figure 4 shows a diagram on how the nodes will be placed inside the water while Fig. 5 shows the sensor node in a plastic drum with real river water sample during preliminary tests.

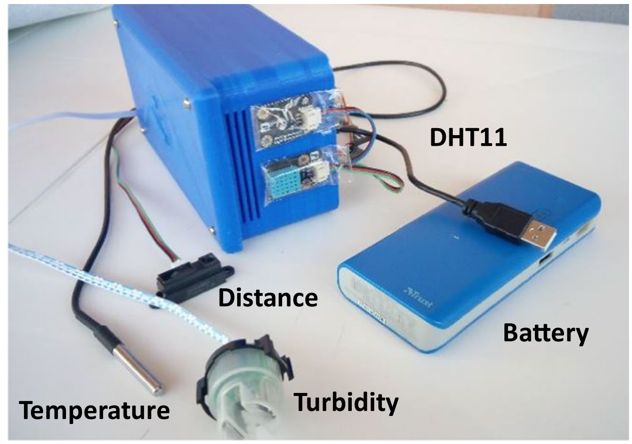


Fig. 3 Pictures of the deployed node

3.3 The things network platform

According to the LoRaWAN network architecture [37], it is based on a star topology where the main element is the gateway. It is in charge of forwarding packets between the sensor nodes and the network server. The network server takes those packets and forwards them to an application server. In LoRaWAN, the security issues are addressed by a symmetric model of session keys derived from the keys associated to each device. To connect the network to the Internet, it is required to have an active access through the conventional TCP/IP network protocol. Additionally, the end devices will be connected to the Internet using an available LoRaWAN network, provided by one or more gateways. The Gateway will collect the data from the different nodes included in the coverage area of the gateway and will connect them to the rest of the network. Finally, the data will be accessible by using protocols such as HTTP or MQTT [38] (Message Queuing Telemetry Transport), all of them supported by TTN.

The Things Network (TTN) is an open community created to facilitate the deployment of LoRa and LoRaWAN networks. It creates a distributed and decentralized network thousands LoRa Gateways to give support to IoT solutions. It is based on the open source hardware and software philosophy. The novelty of this open community is that this enormous network has been created thanks to the collaboration of citizens and researchers who install gateways to provide coverage to other users and to allow the connectivity between the end devices and the applications deployed on the Internet. Nowadays, the TTN community is composed by more than 18,800 gateways of 144,761 members and more than 117,000 nodes across 151 countries.

Fig. 4 LoRa Gateway and Nodes used to deploy our network

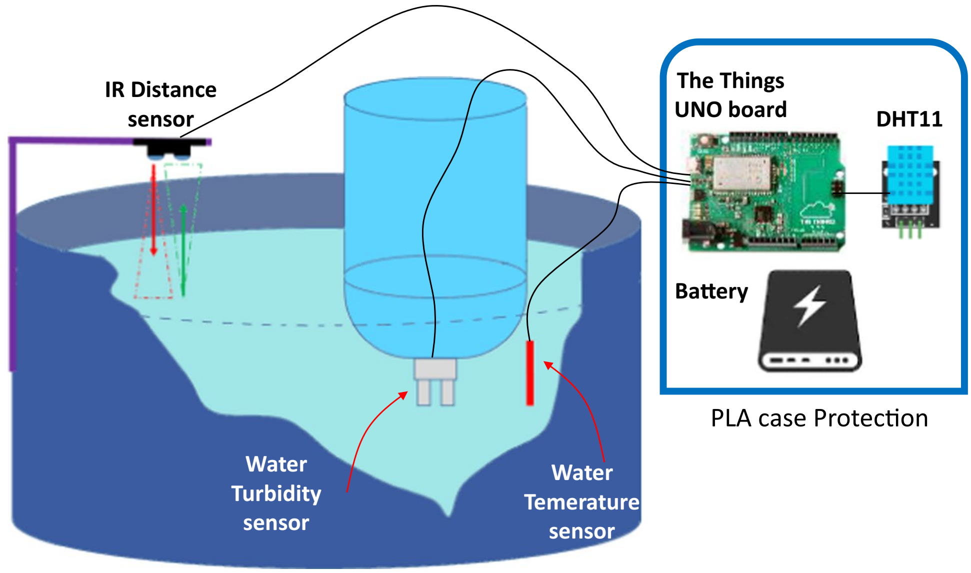


Fig. 5 Sensor node in a plastic drum with river water sample

3.4 Web-based user interface to visualize the collected data

In order to make easy the data visualization we develop a Web-based user interfaces. It permits to the users the interact with the information saved on our servers using a web browser. In this case, the web browser acts as a client that will perform requests to the server to graphically show the stored data. Ubidots is an IoT platform that allows sending sensor data to the cloud, configuring dashboards and alerts, connecting with other platforms and producing data maps in real time of end-to-end IoT solutions through HTTP, MQTT, TCP and UDP protocols [39]. The website shows the main page places the location of nodes on a map. If we click the nodes, we can see a summary of the last value collected by the node as a small pop-up window. The collected data is retrieved from the server using HTTP protocol and Node.js JSON parser to execute request methods for real time asynchronous events. Figure 6 presents the scheme of the developed website. Although the web browser executes HTTP methods to request data stored in the server, the requested data is sent to the TTN storage database as a JavaScript Object Notation (JSON) file. This format file can be easily managed and processed by Ubidots. In order to connect TTN and Ubidots, it is necessary to configure the TTN payloads to in our application console to efficiently decode the content messages. Integrating Ubidots in TTN, we will be able to take data from the TTN Storage database to finally show it in our website. Additionally, this configuration permits the nodes pushing information from the LoRa network to the TTN server and from the TTN server to Ubidots. To save the data in our database, each entry is included in a csv file. This kind of files is commonly used to build databases. Each new data includes name of node, its GPS position, the Node id, and finally, the token for each device. A user can select the node to consult by clicking on it through the map. This generates a pop-up window with the last collected values. The Website permit visualizing the historic data of the sensors, represented in different graphs, and see their evolution over time.

4 Results of nodes performance and final solution

This section shows the results nodes performance and the operation of final solution in a real environment. In these tests, we firstly have tested the coverage of the modules under study. From these results, we have selected the one that shows the best results and finally the proposed solution is implemented and tested. The tests have been performed in a semi-urban scenario. In this scenario, single-family semi-detached houses are predominant.

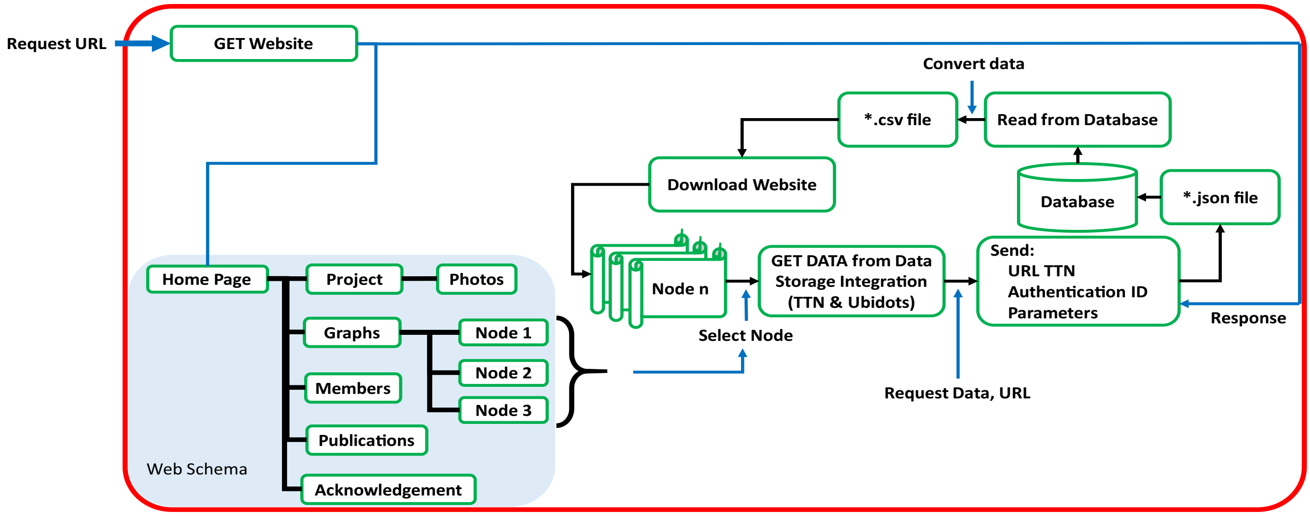


Fig. 6 Scheme of the developed website

In order to know the performance of each node, we use a gateway placed on a fixed position and an end device that is placed on different positions. Figure 7 shows the surface covered to check the signal levels detected by our node, and the Received Signal Strength Indicator (RSSI) measured for The Things UNO module that works at 868 MHz. The maximum distance at which the node managed to send data was 910 m. Figures 8 and 9 presents the values of RSSI measured for Heltec Module when it works at 433 MHz (Fig. 8) that reaches a distance of 600 m and when it works at 868 MHz (Fig. 9) that reaches a distance of 150 m.

The results related to the signal transmission for the different tested devices are presented in Fig. 10. On the one hand, Fig. 10(a), (b) and (c) compare the results of RSSI obtained as a function of the distance for the three tested devices. On the other hand, Fig. 10(d) shows the results of SNR obtained as a function of the distance in the device with better signal quality in terms of RSSI. The distance was measured from the gateway (which is our reference point), to the node that collects the data. It should be taken into account that the selected area to perform this test has several buildings with a height lower than 10 m. Despite this, the height of the buildings obstructs the signal propagation, significantly deteriorate the SNR and reduces RSSI levels. Figure 10 shows the comparison of the network performance in terms of RSSI (in black circles) of two similar

Fig. 7 Values of RSSI measured for The Things UNO module

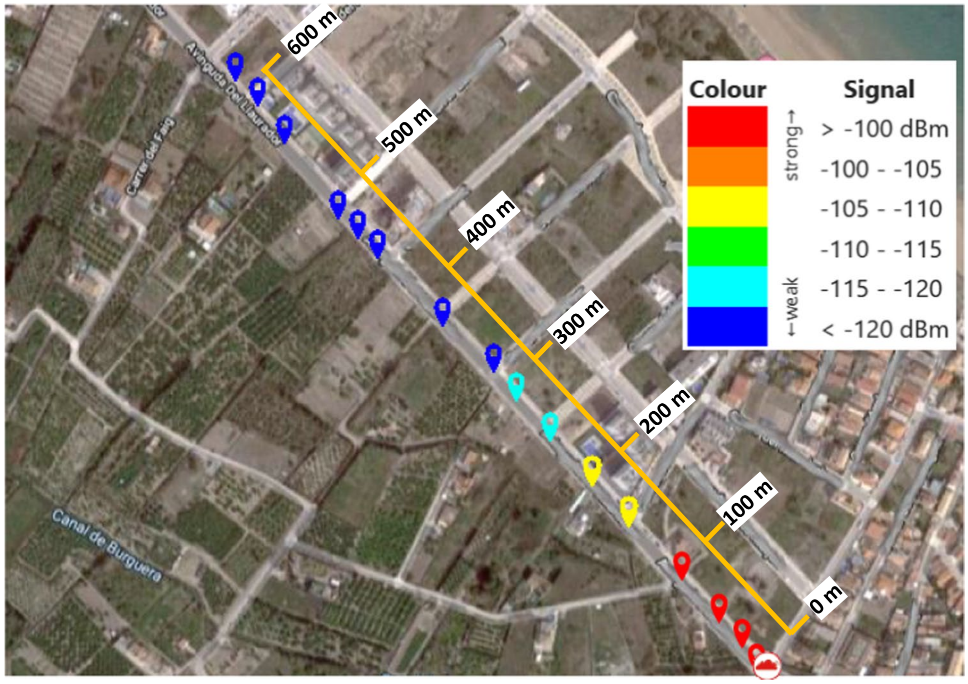


Fig. 8 RSSI for Heltec Module at 433 MHz

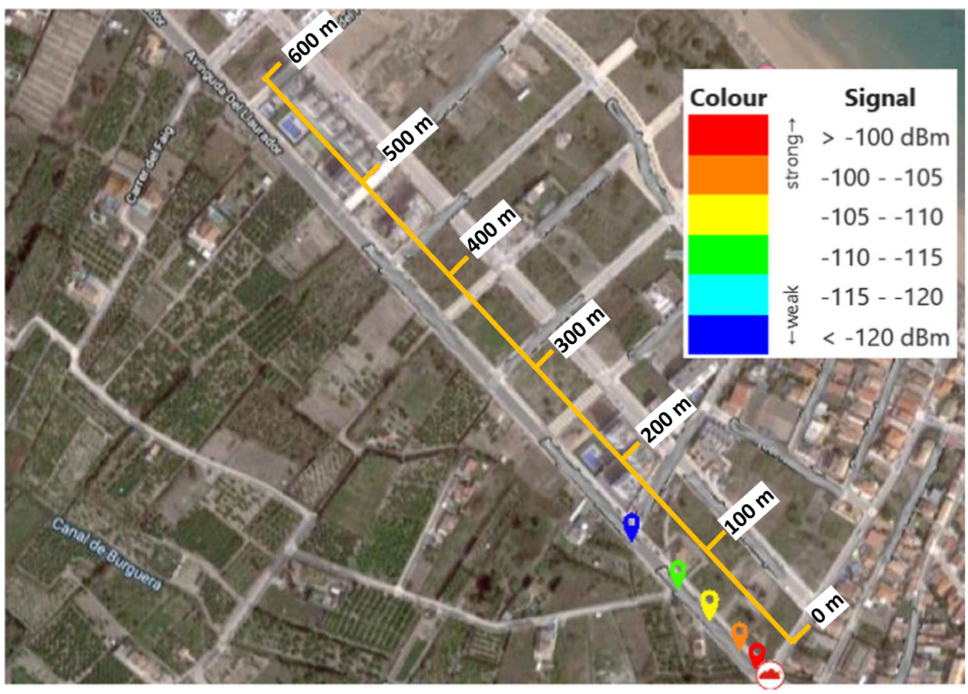


Fig. 9 RSSI for Heltec Module at 868 MHz

devices emitting at a different wavelength (Heltec 434 MHz and Heltec 868 MHz), Fig. 10(a) and (b). We can identify in Fig. 10a that this device is able to outweigh the performance of the device of Fig. 10b. While the Heltec 434 MHz is capable of maintaining signal transmission until 600 m, the Heltec 868 MHz only reaches 150 m. In Fig. 10, we can also compare the performance of two devices emitting at the same wavelength, the Heltec 868 MHz and Things Uno module 868 MHz as Fig. 10(b) and (c). The Things Uno module 868 MHz provides good signal transmission until 915 m. Figure 10(b) and (c) also present the adjusted mathematical models (blue line) with the prediction and confidence intervals (grey and green lines). As we can see, it was possible to collect data at 910 m from the gateway using the Things Uno module 868 MHz. In Fig. 10(d), we analyze the SNR for this device. Moreover, the average value of SNR

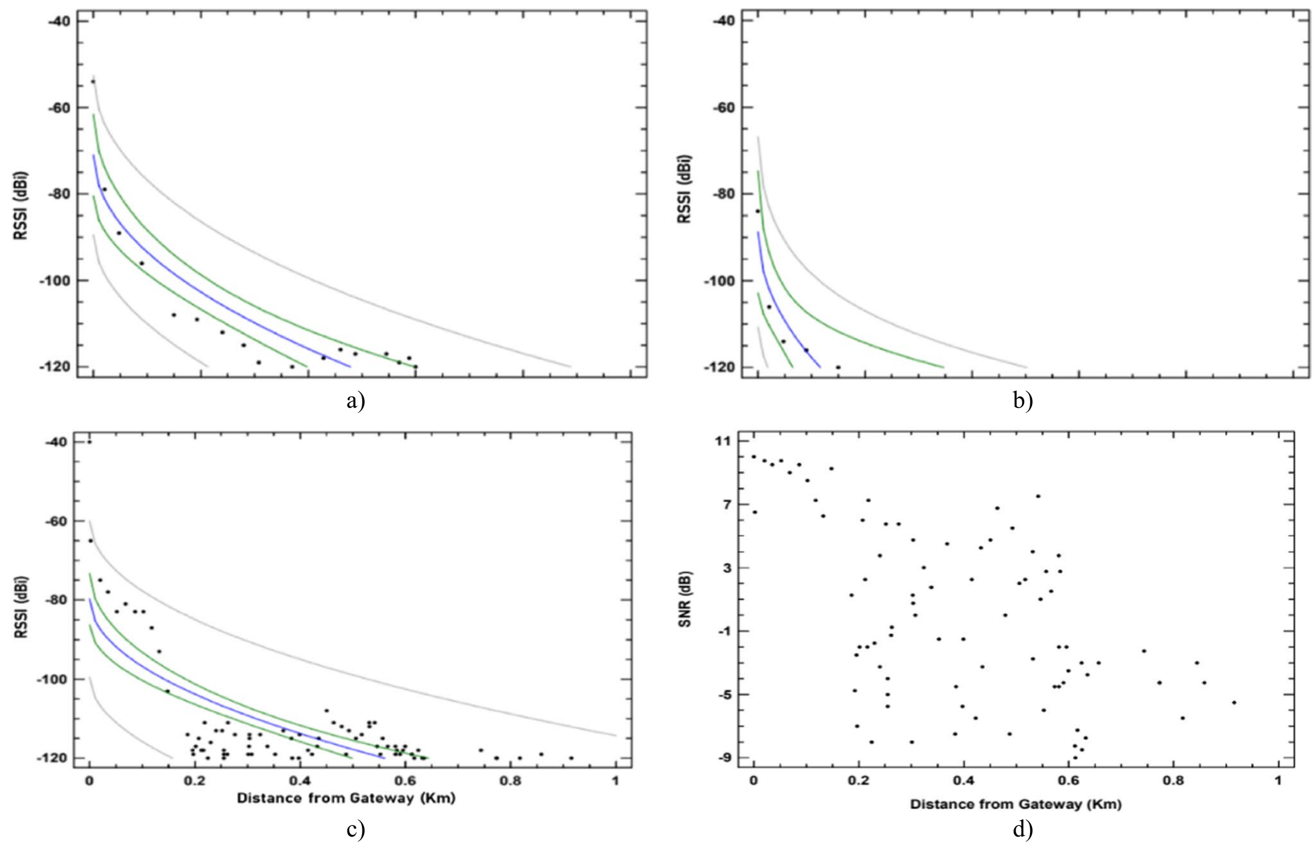


Fig. 10 Values of RSSI and SNR as a function of the distance to the gateway for the tested nodes. **a**) Heltec 434 MHz. **b**) Heltec 868 MHz. **c**) The Things Uno module 868 MHz. **d**) Values of SNR as a function of the distance to the gateway for The Things Uno module 868 MHz

Table 1 Statistical information of obtained models

	Heltec 434 MHz	Heltec 868 MHz	Things Uno module 868 MHz
p-value	0.000	0.000	0.000
Correlation coefficient	-0.918574	-0.947842	-0.754762
MAE	5.96726	3.69143	7.33314

was around 0 dB, which indicates that the signal levels are balanced with the received noise levels. Therefore, we can conclude that these devices can correctly deploy a network area of 900 m in diameter.

The mathematical models are presented in Eqs. 1, 2, and 3 for Heltec 434 MHz, Heltec 868 MHz, and Things Uno module 868 MHz. Table 1 presents the statistical information of the obtained mathematical models. It must be noted that since the number of measurement points is different for each case, the statistical data cannot be used to compare the performance of the devices, only to compare the obtained models.

$$\text{RSSI (dBi)} = -70.9922 - 2.24075 * \sqrt{\text{Distance (m)}} \quad (1)$$

$$\text{RSSI (dBi)} = -88.7203 - 2.90035 * \sqrt{\text{Distance (m)}} \quad (2)$$

$$\text{RSSI (dBi)} = -79.7437 - 53.7591 * \sqrt{\text{Distance (m)}} \quad (3)$$

To test our final solution, we select the The Things UNO Module since its results are quite better. To do it, we use 3 different nodes placed on the green points of Fig. 11. Two of these nodes were placed directly in the river while the other one was placed in a swimming pool.

We used three different nodes The LoRa gateway (identified by the red point in Fig. 11) was placed inside a building. Moreover, each node was configured to send data every 5 min. The rest of time, the node is in sleep mode. Figure 8 shows the placement of nodes and gateway. Figure 12 shows the positions of nodes to perform the experiments. In the following figures, we will display the monitored parameters to compare the results of two scenarios: cloudy pool water (Node 1) which is used as control point where water conditions are known, and ditch water (Node 2 and Node 3).

Fig. 11 Position of nodes and gateway

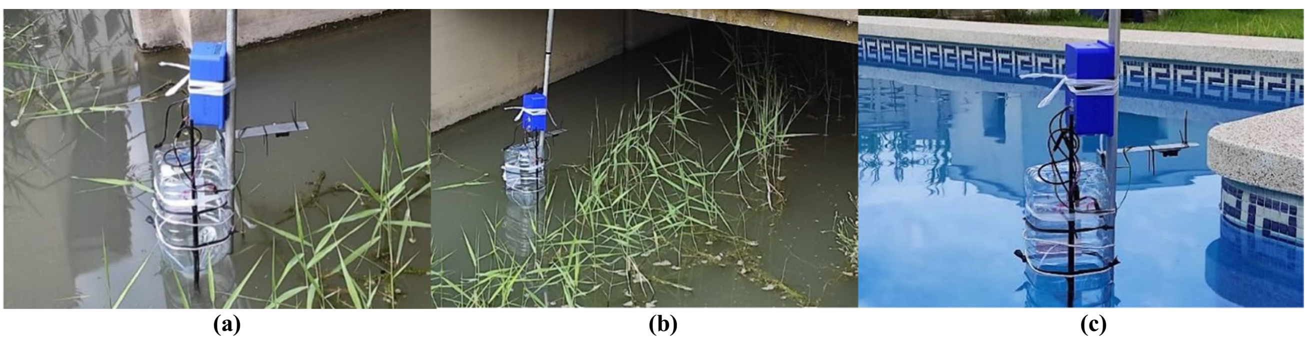


Fig. 12 Places where nodes have been placed to perform the experiments. (**a**) Position of Node 2 in the river (**b**) Position of Node 3 in the river (**c**) Node 1 in the swimming pool

The relative humidity sensed by the DTH11 is displayed in Fig. 13. Node 1, in red, represented the data of the pool; meanwhile, Node 2 and 3 (blue and black) depict the data in ditch water. Analyzing the data, we can identify that the higher values of relative humidity are reached during the night in the three locations. With the gathered data, it is possible to analyze if the data patterns can be used to identify the type of areas in which the node is deployed. Bering this in mind, we are going to compare the data of each node statistically (See Figs. 13 and 14). We can see that in the pool node, Node 1, the values are slightly lower than for the ditch nodes. The data do not follow a normal distribution; thus, non-parametric methods have to be used to compare the locations. The Kruskal–Wallis test confirms that data series are different. Nonetheless, the test results indicate that data of Node1 and 2 are similar and Node 3 are statistically different. The most probable reason for these differences is the location of each node during the testing process as well as the amount of sun exposure. DHT11 sensor also measures air temperature. Figure 15 shows the sensed air temperature in the three locations. Comparing the sensed values in each location we can see that air temperature registered by Node 2 and Node 3 are practically the same, following the same trend and similar values. Meanwhile, Node 1 is the one that reached the highest air temperature values. The Box and Whisker diagram is presented to outline the observed trends and differences among locations (see Fig. 16). The Kruskal–Wallis test confirms that data series are different. There are differences statistically significant among the three datasets.

Water levels were measured using Sharp GP2Y0A41SK0F. Though in this case, water levels in pool water and ditch water are not significant for the sake of this study, Fig. 17 helps demonstrate the functioning of this

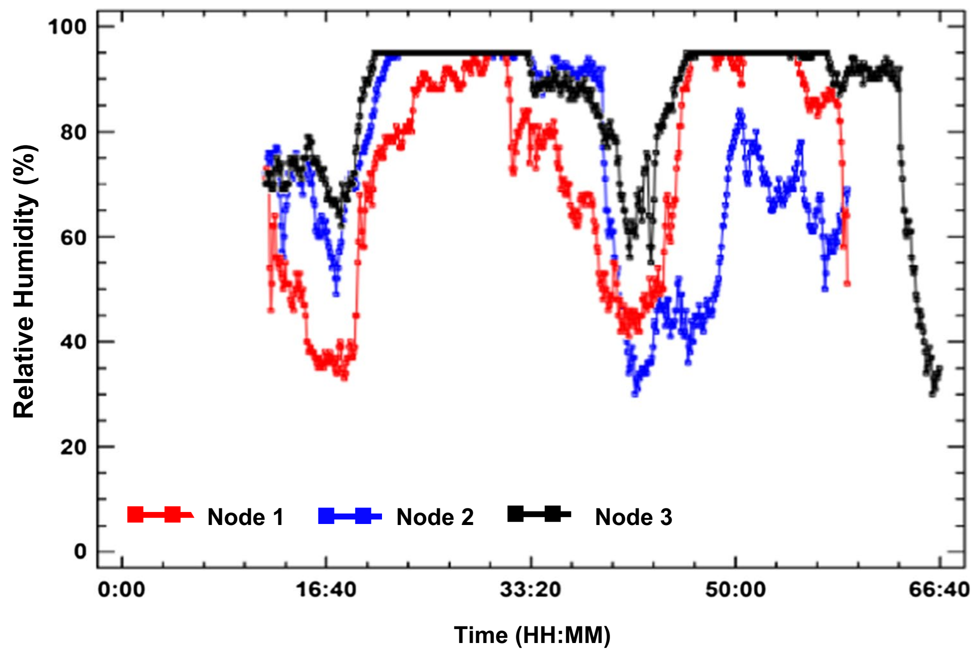


Fig. 13 Relative humidity in % at the three locations

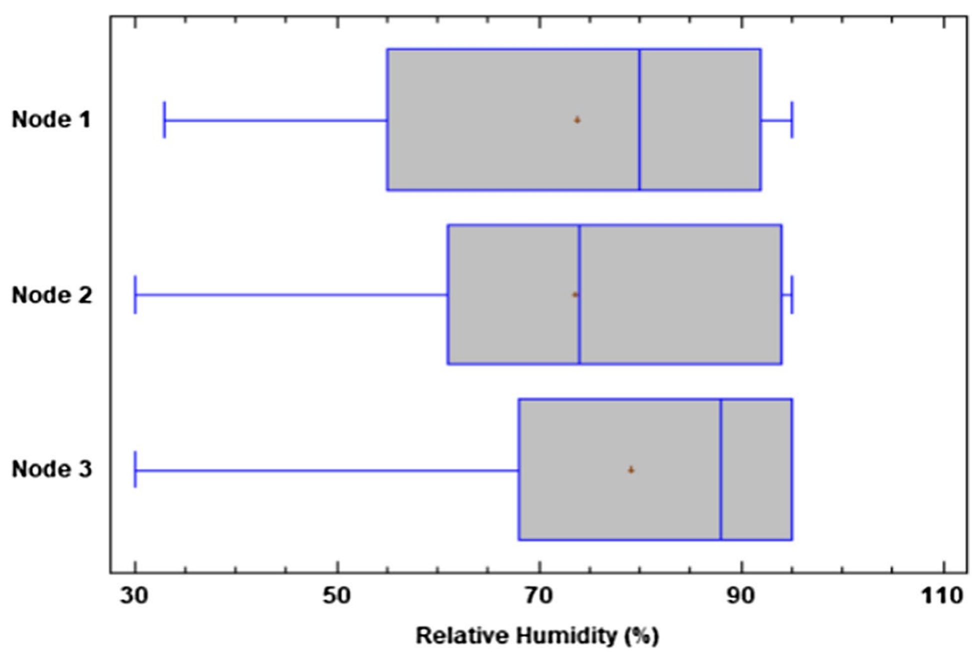


Fig. 14 Box and Whiskers diagram for Relative Humidity

sensor. As it can be seen, water levels measured by Node 1 (pool water) are much lower than the ones measured by Node 2 and Node 3 (real river water). The reason for this is that the buckets used in each test were different. However, this graph shows some fluctuations of water levels that the sensor's sampling rate can explain. The Box and Whisker diagram is presented to summarize the aforementioned trends; see Fig. 18.

Water temperature presented in Fig. 19 was measured using PT100 3-wire sensor. It shows the water temperature of pool water (Node 1) and real river water (Node 2 and Node 3). The Box and Whisker diagram (see Fig. 20) show the descriptive analysis indicates that data do not follow a normal distribution, and Kruskal–Wallis test confirms that datasets are statistically different, all of them. As figures show, water temperature in the ditch is generally higher than in pool water. This is because the volume of water (considering the depth) in the pool is greater than the depth in ditch. In addition, the water current is extremely low, so there is no continuous exchange of water and this causes that the water temperature in ditch is higher.

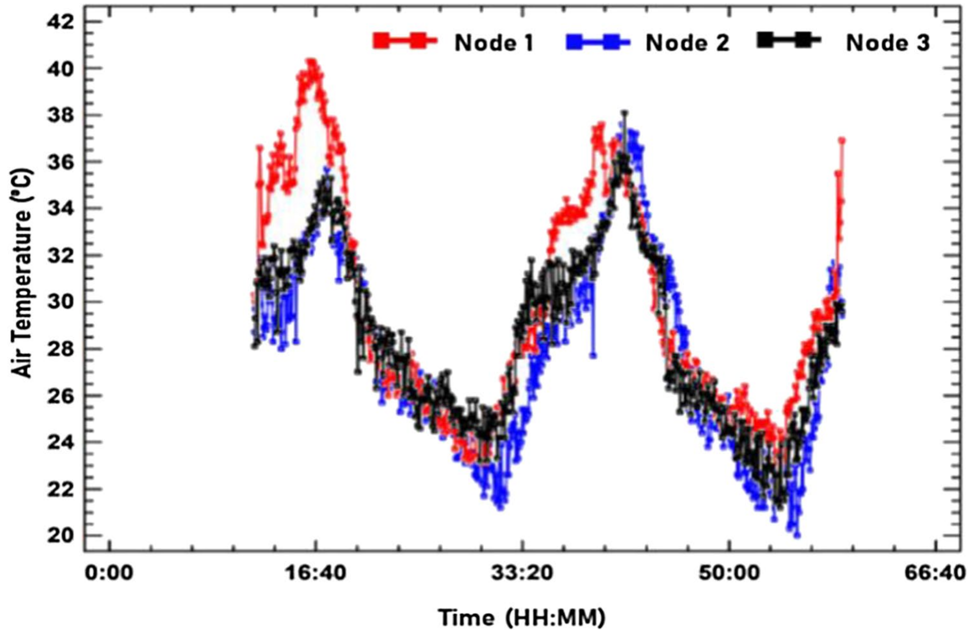


Fig. 15 Air temperature in °C at three location

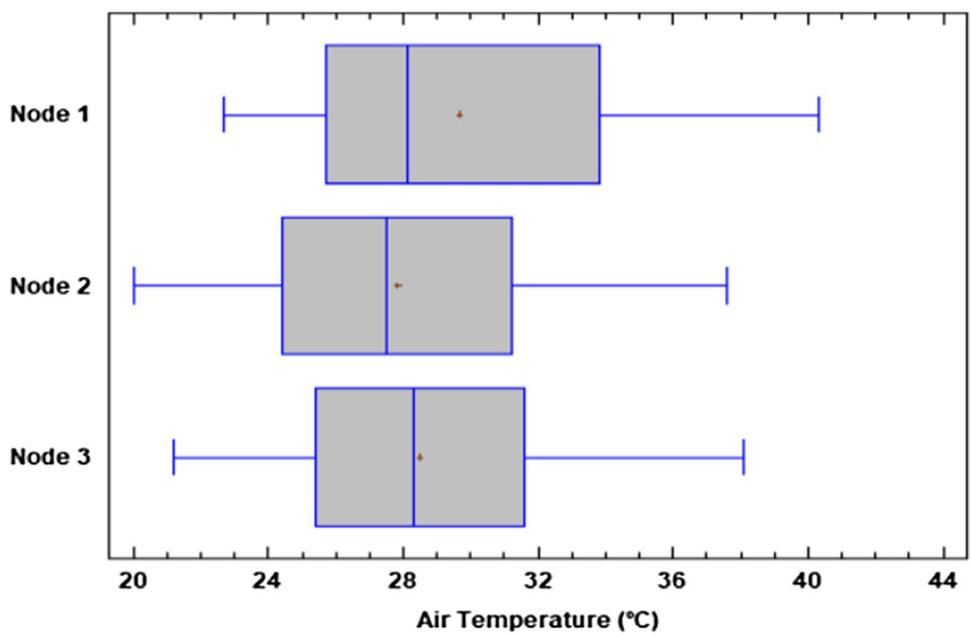


Fig. 16 Box and Whiskers diagram for Air temperature

Finally, gathered data of water turbidity is displayed in Fig. 21, Box and Whiskers diagram is displayed in Fig. 22. Water turbidity sensor SEN0189 allows measuring turbidity thanks to its relationship with output voltage. The Kruskal–Wallis test confirms that datasets are statistically different, all of them. However, we can identify that both nodes deployed in the river have a similar behaviour both days with an abduct increase of turbidity, it increases by almost 50%. Similar behaviour is observed in the pool, but it decreases slowly than in the river, and the increase appears a bit earlier. In the river, this change is detected in the afternoons from 17:00 to 19:00; the peak in the pool is detected at 12:30. This change, and the fact of its cyclic tendency (daily tendency), might indicate that the exposure to sun and shadow is affecting the sensor measurements.

5 Conclusion and future work

The conservation and restoration of limited resources, such as water, is nowadays an important topic. Additionally, when a problem of pollution in water is detected is also important

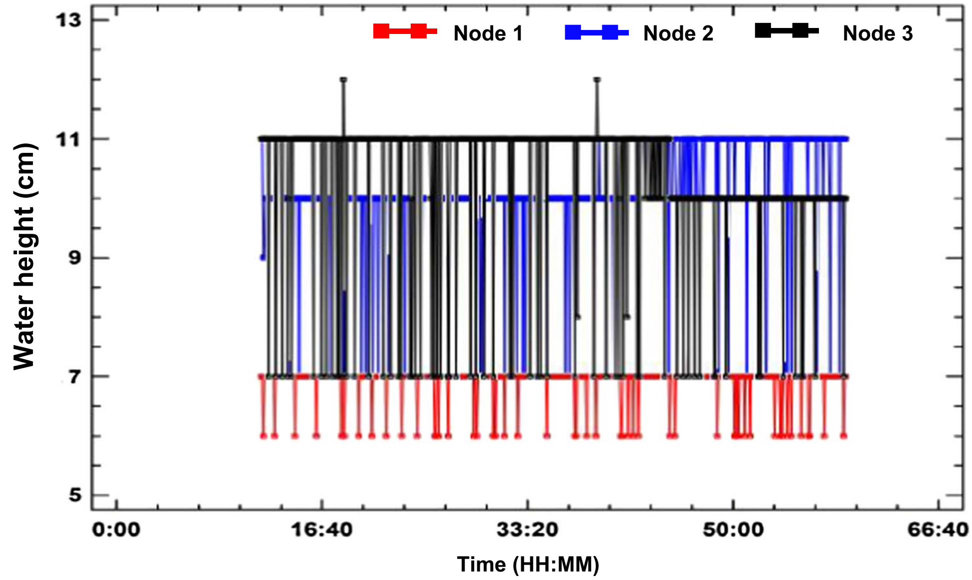


Fig. 17 Water height in cm at three locations

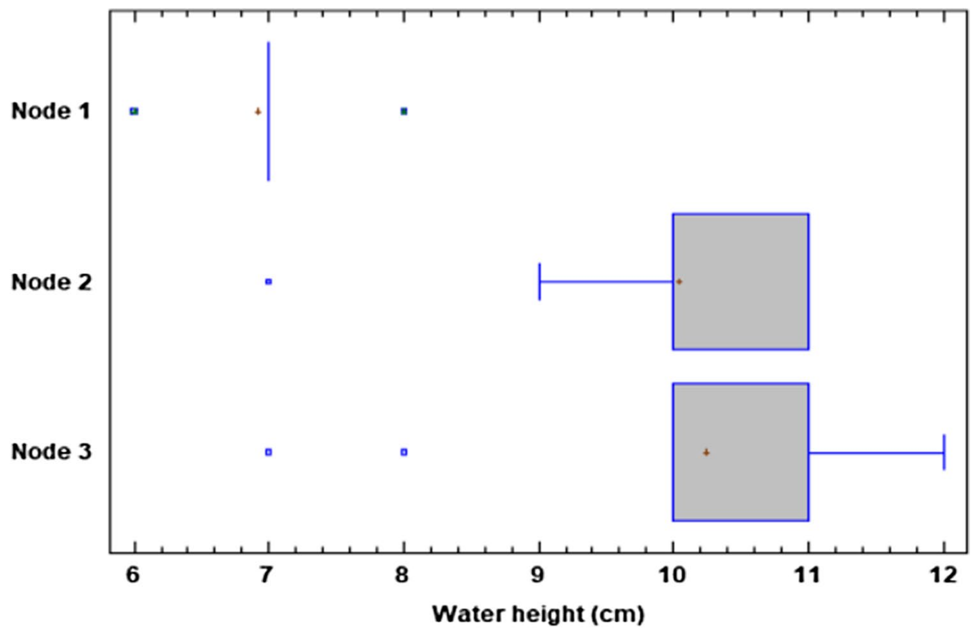


Fig. 18 Box and Whiskers diagram for water height

to quickly detect the source of place where the spill is taking of. In order to carry out this task it could be feasible the use of modern and affordable technologies for controlling the status of sensible areas where these problems can cause a high impact. In this sense, it is also important to aware citizens about the importance of conserving those natural zones and make them part of these initiatives.

This paper has presented the design, development and test of LoRa-based IoT solution that permits the real-time water quality monitoring of several points in a river. The system is composed by a LoRa-based network that includes several wireless nodes able to collect information from the environment and to send it to a storage server to finally permit its visualizing in a website. We have tested different LoRa devices from two different manufacturers (TTN and Heltec) to check its real performance and the results have shown that TTN devices present better results in terms of network coverage and RSSI levels. Regarding to the The Things UNO module and according to the device's specifications, we could reach up to 10 km (without obstacles). However, we performed the coverage tests in a semi-urban scenario and the maximum distance reached in our experiments was only 910 m, which is much lower than the expected one. The Heltec modules have presented poor results with distances of 600 m for 433 MHz.

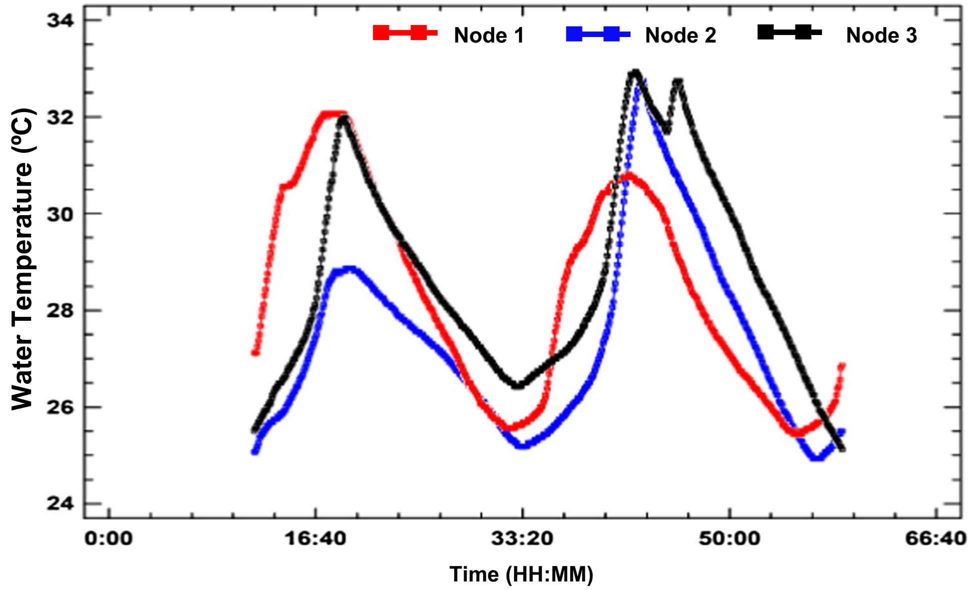


Fig. 19 Water temperature in °C at each location

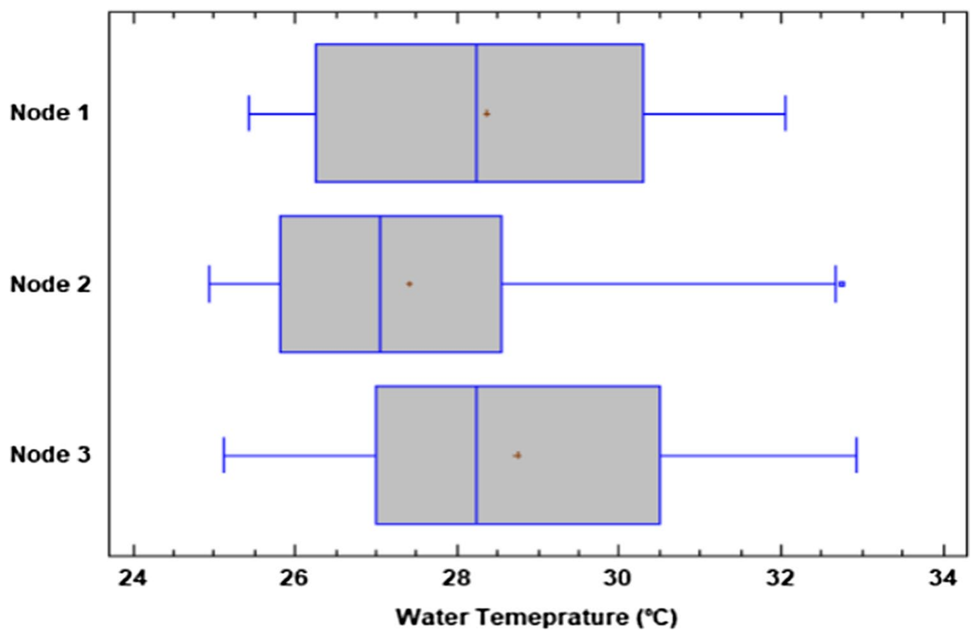


Fig. 20 Box and Whiskers diagram for water temperature

Nowadays, there is an increasing interest on the collection of massive data that has to be filtered and formatted according to some rules. With that we can create observatories for applying modern techniques of Big Data and artificial intelligence algorithms to detect abnormal patterns that can help us to detect problems and to enhance the sustainability of a productive sector using real data. As future works would like to enhance the LoRa network performance in terms of coverage by integrating more gateways and nodes. We want to extend our system to monitor more events and problems in agriculture and water bodies monitoring by including more sensors. With all this new information, we would like to increase the information included in our database to create big and useful observatory where the application of Big Data techniques and artificial intelligence algorithms will permit us to generate smart decisions, creating alarms when a problem is detected to finally solve it.

The infrastructure proposed in this paper has many extensions and applications. A network of these characteristics allows monitoring water quality in harbours and areas with aquaculture activity. In addition, it can help promote tourist activity in an area ("blue tourism") and ensure that water activities are carried out in waters of excellent quality. Including some more temperature and water level sensors,

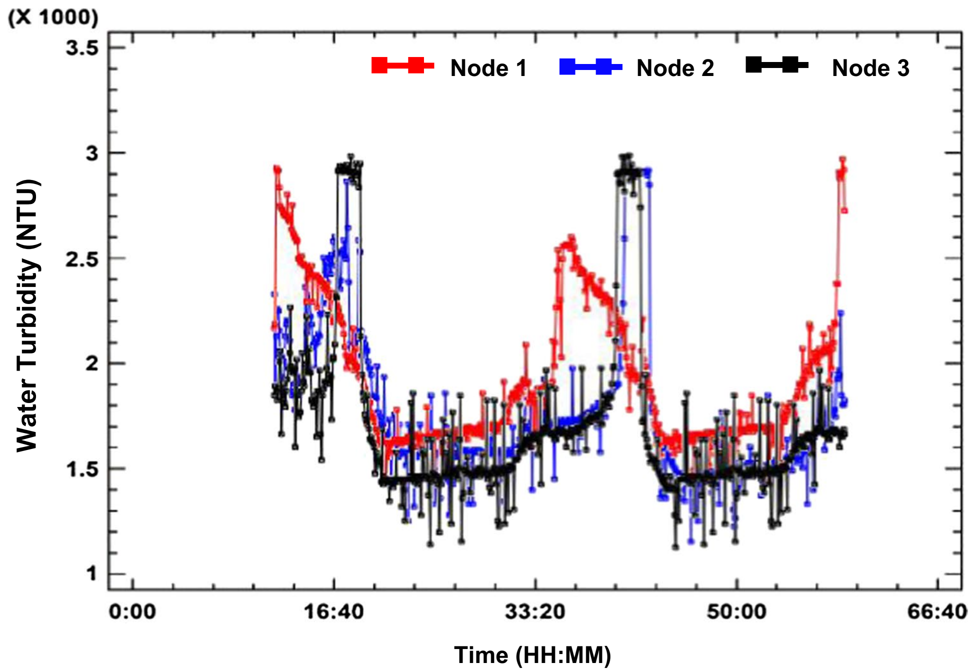


Fig. 21 Water turbidity in NTU at the three locations

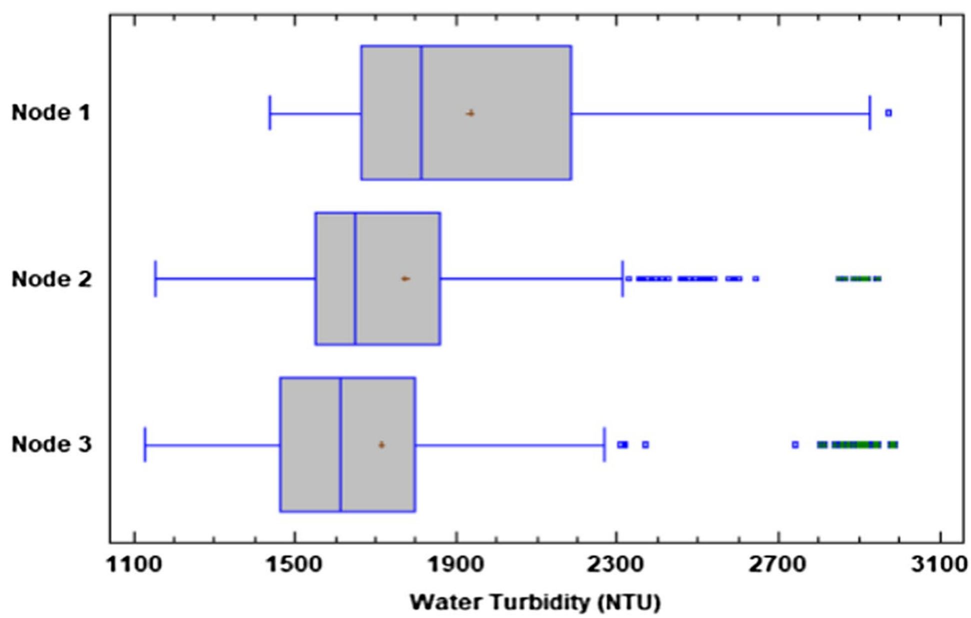


Fig. 22 Box and Whiskers diagram for water turbidity

it is possible to use our system in alluvial or intense agricultural zones where underground water is extracted from boreholes. The use of low-cost water level sensors could be useful to develop a network to monitor the fluctuation of the groundwater level and assess the aquifer health, the presence of nitrates [40] recharges, and discharges. Also, the use of temperature sensors in groundwaters could be useful to detect areas where high volumes of water are being pumped.

Finally, we want to improve the LoRa technology performance by including new modifications in the routing protocols and modifying the original features to be able to transmit heavier files [41, 42].

References

1. SPAMIs. Regional Activity Centre for Specially Protected Areas. Available at: http://www.rac-spa.org/spami [Last access: August 20, 2021]
2. Instituto Nacional de Estadística (INE. "España en cifras 2018". Available at: https://www.ine.es/prodyser/espa_cifras/2018/

files/assets/common/downloads/publication.pdf?uni=4f7e7b429c56ccbc4bf56b3e93ebc47b [Last access: August 20, 2021]
3. Panno SV, Hackley KC, Hwang HH, Greenberg SE, Krapac IG, Landsberger S, O'kelly DJ (2006) Characterization and identification of Na-Cl sources in ground water. Ground Water 44(2):176–187
4. Martínez-Bastida JJ, Arauzo M, Valladolid M (2010) Intrinsic and specific vulnerability of groundwater in central Spain: the risk of nitrate pollution. Hydrogeol J 18(3):681–698
5. Wakida FT, Lerner DN (2005) Non-agricultural sources of groundwater nitrate: A review and case study'. Water Res 39(1):3–16
6. Vo PT, Ngo HH, Guo W, Zhou JL, Nguyen PD, Listowski A, Wang XC (2014) A mini-review on the impacts of climate change on wastewater reclamation and reuse. Sci Total Environ 494–495:9–17
7. Belmonte Espejo P (2018). El Mar Menor, en la encrucijada. (Online Article). Published June 4, 2018. Available at: https://www.eldiario.es/murcia/murcia_y_aparte/Mar-Menor-encrucijada_6_778732142.html [Last access: August 20, 2021]
8. Vera Oliva MC (2018) Oliva prohibirá el baño en tres ríos al hallar restos fecales proceden-tes de acequias. (Online article), Published August 2, 2018. Available at: https://www.lasprovincias.es/safor/oliva-prohibira-bano-20180802002812-ntvo.html [Last access: August 20, 2021]
9. Autoridad Portuaria de Melilla – Puerto de Melilla, "Estudio Medioambiental". Available at: http://www.puertodemelilla.es/images/documentos/ampliacion_puerto/estudio_impacto_ambiental.pdf [Last access: August 20, 2021]
10. Parra L, Sendra S, Jimenez JM, Lloret J (2015) Smart system to detect and track pollution in marine environments. In proc. of 2015 IEEE Int. Conf. on Com-munication Workshop (ICCW). London (UK), pp. 1503–1508
11. Xu G, Shi Y, Sun X, Shen W (2019) Internet of Things in Marine Environment Monitoring: A Review. Sensors 19(7):1711
12. Parra Boronat L, Sendra S, Lloret J, Bosch Roig I (2015) Development and test of conductivity sensor for monitoring groundwater resources to optimize the water management in Smart City environments. Sensors 15(9):20990–21015
13. Sendra S, Parra L, Lloret J, Jiménez JM (2015) Oceanographic multisensor buoy based on low cost sensors for posidonia meadows monitoring in mediterranean sea. J Sensors 920168
14. Ministerio de Fomento. Recomendaciones para obras marítimas ROM 5.1–13 - Calidad de las aguas litorales en áreas portuarias. Available at: http://www.puertos.es/gl-es/BibliotecaV2/ROM%205.1-13.pdf [Last access: August 20, 2021]
15. Parra L, Sendra S, Lloret J, Rodrigues JJ (2017) Design and deployment of a smart system for data gathering in aquaculture tanks using wireless sensor networks. Int J Commun Syst 30(16):e3335
16. Uche J, Martínez-Gracia A, Círez F, Carmona U (2015) Environmental impact of water supply and water use in a Mediterranean water stressed region. J Clean Prod 88:196–204
17. Pule M, Yahya A, Chuma J (2017) Wireless sensor networks: A survey on monitoring water quality. J Appl Res Technol 15:562–570
18. Adu-Manu KS, Tapparello C, Heinzelman W, Katsriku FA, Abdulai JD (2017) Water quality monitoring using wireless sensor networks: current trends and future research directions. ACM Trans Sensor Netw 30(1)
19. Jia Y (2020) LoRa-Based WSNs Construction and Low-Power Data Collection Strategy for Wetland Environmental Monitoring. Wireless Pers Commun 114:1533–1555
20. Yan-Ting L, Bo-Yi L, Xiao-Feng Y, Zong-Xuan C, Zi-Xian Y, Wei-Hong L, Song-Yi H, Jun-Lin L, Jing-Wen P, Jen-Yeu C (2018) A Solar powered long range real-time water quality monitoring system by LoRaWAN. 2018 27th Wireless and Optical Communication Conference (WOCC). Hualien, Taiwan
21. Das B, Jain PC (2017) Real-time water quality monitoring system using Internet of Things. 2017 Int. Conf. on Computer, Communications and Electronics (Comptelix). Jaipur, India
22. Chen Y, Han D (2018) Water quality monitoring in smart city: A pilot project. Autom Constr 89:307–316
23. Simitha KM, Subodh Raj MS (2019) IoT and WSN based water quality monitoring system. In proc. of 2019 3rd International conference on Electronics, Communication and Aerospace Technology (ICECA), June 2–14, 2019, Coimbatore, India, pp. 205–210
24. Wu N, Khan M (2019) LoRa-based internet-of-things: a water quality monitoring system. In: 2019 SoutheastCon, April 11–14, 2019, Huntsville, Alabama-USA, pp. 1–4
25. Saravanan K, Anusuya E, Kumar R, Son LH (2018) Real-time water quality monitoring using Internet of Things in SCADA. Environ Monit Assess 190:1–16
26. LoRa Documentation. Available online: https://lora.readthedocs.io/en/latest/ [Last access: August 20, 2021]
27. Benites B, Chávez E, Medina J, Vidal R, Chauca M (2019) LoRaWAN applied in Swarm Drones: A focus on the use of fog for the management of water resources in Lima-Peru. In proc. of the 5th International Conference on Mechatronics and Robotics Engineering, February 16–19, 2019, Rome, Italy, pp. 171–176
28. Sanchez-Iborra R, Sanchez-Gomez J, Ballesta-Viñas J, Cano MD, Skarmeta AF (2018) Performance evaluation of LoRa considering scenario conditions. Sensors 18:772
29. The Things Network website. Available at: https://www.thethingsnetwork.org/ [Last access: August 20, 2021]
30. The Things Gateway features. In The Things Network website. Available at: https://www.thethingsnetwork.org/docs/gateways/gateway/ [Last access: August 20, 2021]
31. The Things UNO features. In The Things Network website. Available at: https://www.thethingsnetwork.org/docs/devices/uno/ [Last access: August 20, 2021]
32. WIFI LoRa 32 (V2) – Heltec Automation features. In Heltec website. Available at: https://heltec.org/project/wifi-lora-32/ [Last access: August 20, 2021]
33. Analog Turbidity Sensor features. Available at: https://wiki.dfrobot.com/Turbidity_sensor_SKU__SEN0189 [Last access: August 20, 2021]
34. Datasheet of DTH11 Sensor. Available online: https://components101.com/dht11-temperature-sensor. [Last access: A April 28, 2021]
35. Sharp GP2Y0A41SK0F sensor features. Available at: http://www.farnell.com/datasheets/2364614.pdf?_ga=2.92005150.540766343.1598431848-1376214988.1597914665 [Last access: August 20, 2021]
36. GY-GPS6MV2 sensor features. Available at: https://www.epitran.it/ebayDrive/datasheet/NEO6MV2.pdf [Last access: August 20, 2021]
37. LoRaWAN™ Architecture. In Microchip website. Available at: https://microchipdeveloper.com/lora:lorawan-architecture. [Last access: August 20, 2021]
38. UBIDOTS Platform. Available at: https://ubidots.com/platform/ [Last access: August 20, 2021]
39. MQTT Specifications. Available at: https://mqtt.org/mqtt-specification/ [Last access: August 20, 2021]

40. Mostaza-Colado D, Carreño-Conde F, Rasines-Ladero R, Iepure S (2018) Hydrogeochemical characterization of a shallow alluvial aquifer: 1 baseline for groundwater quality assessment and resource management. Sci Total Environ 639(15):1110–1125
41. Khasawneh AM, Kaiwartya O, Abualigah LM, Lloret J (2020) Green computing in underwater wireless sensor networks pressure centric energy modeling. IEEE Syst J 14(4):4735–4745
42. Rathore RS, Sangwan S, Mazumdar S, Kaiwartya O, Adhikari K, Kharel R, Song H (2020) W-GUN: Whale optimization for energy and delay-centric green underwater networks. Sensors 20(5):1377