Acta Scientiarum

http://periodicos.uem.br/ojs
ISSN on-line: 1807-8664
Doi: 10.4025/actascitechnol.v45i1.63130
CC BY

INFORMATICS

# Internet of Things experimental platform for real-time water monitoring: a case study of the Araranguá River estuary

**Analúcia Schiaffino Morales[1,2*], Carla de Abreu D´Aquino[2], Rauan Bernardo Pires Klaus[1], Gustavo da Silva Vargas[1], Marcos Antonio Martins Giassi[2] and Fabrício de Oliveira Ourique[1,2]**

[1]Programa de Graduação em Engenharia da Computação, Universidade Federal de Santa Catarina, Rod. Gov. Jorge Lacerda, 3201, Jardim das Avenidas, 88906-072, Araranguá, Santa Catarina, Brazil. [2]Programa de Pós-Graduação em Energia e Sustentabilidade, Universidade Federal de Santa Catarina, Rua Pedro João Pereira, 150, Mato Alto, 88905-120, Araranguá, Santa Catarina, Brazil. *Author for correspondence. E-mail: analucia.morales@ufsc.br

**ABSTRACT**. The Internet of Things (IoT) is a technology that can be employed to monitor several sectors, mostly precision agriculture, where environmental data can be used to better manage resources, reduce costs, and improve the use of natural resources. This work proposes the application of cloud-based IoT for monitoring irrigation water in rice fields. Southern Brazil was chosen as a case study because it suffers from water pollution problems due to urban activities, coal mining, and the inflow of saline water into the Araranguá River estuary. All these factors can compromise the water quality for irrigation. The presence of salt in irrigation water can compromise rice growth, making its monitoring essential for successful cultivation. Currently, the rice farmer needs to travel to the riverbank to assess the water quality using a manual sensor. This procedure demands time and resources and is not always efficient. The technology helps indicate whether the water is of quality to irrigate crops, helping the farmers decide whether to use that water to irrigate their fields. The solution is based on low-cost wireless sensor network devices, with subsequent transmission of data from the gateway using the network mobile phone cloud. Data collected were also accessed by the smartphone through a mobile application. This system was implemented for testing in the Araranguá River estuary, southern Santa Catarina, Brazil. Also, it appears as an option for farmers who need to monitor the quality of the water channel of the crop, thus avoiding the loss and reduction in crop productivity because the system can be continuously monitored and show notifications to the user. The highlights of this work were prototyping a complete solution to help the farmer using a smartphone application.

**Keywords**: Internet of Things (IoT); water monitoring; wireless sensor networks; smartphone application; precision agriculture.

Received on april 02, 2022
Accepted on march 02, 2023

## Introduction

Internet of Things or IoT proposes connecting people, objects, and other devices in real-time through communication and data transmission technologies, aiding in decision-making processes in different areas of knowledge (Elazhary, 2019; Haxhibeqiri et al., 2018; Kumar et al., 2019). In recent years, new communication protocols have been introduced on the market, associated with a series of new sensors and other electronic components necessary to leverage applications in different areas. There are, however, a number of advantages and challenges associated with using IoT in agriculture, some of which were identified by the university project, such as the difficulty of communication over a large area and the difficulty of wireless transmission, the lack of cell coverage in the area where rice producers operate, the cost of soil sensors, and the cost of drones. In the last years, an action plan presented by the Ministry of Science and Technology (BNDES, 2017) demonstrates the interest in the government's acceleration of implementing the Internet of Things in Brazil. This can increase the economy's competitiveness, strengthen national production chains and promote the population's quality of life. The document highlights four areas: cities, health, rural, and industries. For the rural area, the following strategic points are considered: the efficient use of natural resources, machinery, health security, and innovation.

In addition, population growth increases demand for water and energy production for both urban uses and uses in food production. Also, climate change observed in recent decades generate impacts on the environment, and all these factors contribute to an increase in water scarcity and an alert for undue water usage. According to Lichtenberg et al. (2014), one way to mitigate this problem is to improve the efficiency of irrigation processes by combining precision equipment and decision support systems. In the scientific literature, there are experimental proposals for water quality monitoring and applications to turn out more efficient irrigation systems.

Several articles were searched in the leading scientific databases available on the Capes Portal, especially IEEE and Science Direct. Eight articles (Table 1) highlighted data transmission using different types of network protocols and data collection with different kinds of sensors, mainly applied to agriculture issues. Normally, studies address the accuracy of data collected by sensors, associating this information with integrated systems to assist in decision-making and the management of food production processes (Bwambale et al., 2022; Dholu & Ghodinde, 2018; Kamienski et al., 2019; Lichtenberg et al., 2014; Palazzi et al., 2019).

**Table 1**. Related works in the scientific literature.

| Work | Reference | Description | Sensors | Network |
|---|---|---|---|---|
| 1 | (Payero et al., 2021) | The system contributes to decision-making in irrigation scheduling. It collects and transmits soil moisture data and allows the user to observe in real time the data through a computer or smartphone. | Groundwater tension using a solid-state electrical resistance sensor (Watermark). Volumetric water content (VWC) measuring soil dielectric constant using capacitance/frequency domain (EC-5) | Cellular network |
| 2 | (Laphatphakkhanut et al., 2020) | IoT-based intelligent rice cultivation field monitoring system for irrigation control. The authors applied three irrigation methods, namely: Modern Irrigation System (SIM), which uses a self-developed Maxii Station meteorological monitoring station (with IoT), and two conventional methods, Alternate Wetting and Drying (MSA) and Flood Irrigation (II). | Humidity, temperature, wind speed, radiation, and rainfall | Not included. |
| 3 | (Arko et al., 2019) | IoT-based intelligent water and environment management system for rice production in a controlled environment monitors environmental factors and automatically reacts to them. | Ultrasonic sensors that identify the crop stage, soil pH sensor, temperature, and light sensors | Arduino, ESP32 with Wi-Fi connection, |
| 4 | (Chowdury et al., 2019) | The continuous river water quality monitoring system uses a wireless sensor network with low power consumption, low cost, and high detection accuracy. | Water pH, turbidity, and total dissolved solids (TDS) | Arduino, ESP8266 and Wi-Fi |
| 5 | (Dahane et al., 2019) | Automated irrigation management platform using wireless sensor network to collect, transmit and process physical parameters of agricultural land along with weather forecast information to efficiently manage irrigation. | Soil moisture, air temperature, air humidity, water level, water flow, light intensity, and Fuel Gas (vapors) for crop safety | nRF2401 |
| 6 | (Gloria et al., 2019) | Irrigation system with wireless sensor networks to retrieve real-time environmental data to optimize irrigation times with sensors for air temperature and humidity, and soil moisture | Temperature, humidity, and soil moisture | LoRA Wan |
| 7 | (Dholu & Ghodinde, 2018) | Sensor network capable of measuring temperature, air, and soil moisture parameters and sending a signal to activate the irrigation valve, based on these parameters. | Temperature, humidity, and soil moisture | ESP32 and Wi-Fi |
| 8 | (Goap et al., 2018) | Intelligent system for predicting a field's irrigation requirements using the detection of physical parameters along with weather forecast data from the Internet. | Soil, air temperature and humidity sensor, relay switch | Arduino, Raspberry Pi and ZigBee |

All studies had experimental purposes, similar to the proposed in this paper. However, these studies were consulted about their prototypes and communication protocols to help in understanding the different approaches and understand the problem context. The two studies on rice irrigation are shown in Table 1, works 2 and 3. These studies differ in some aspects, the first focusing on water use and describing three kinds of irrigation models that are very different from what is commonly used in the south of Santa Catarina. The authors emphasize water consumption at different stages of the plant. The second work provides a prototype and analyzes the water consumption of plants at various stages of development.

Study number five was another interesting experiment using the radiofrequency NRF2401, the same used in our research (Dahane et al., 2019). However, the authors tested only in laboratory conditions, and no results were provided regarding the transmission behavior of NRF2401 modules. Furthermore, none of the eight works discussed any Internet of Things reference model.

The proposed work was developed into the Araranguá River Monitoring System Project (SisMoRA) of the Federal University of Santa Catarina, from 2018 to 2020. A primary objective of the study was to develop technological alternatives for a remote monitoring system in the Araranguá River to analyze physical-chemical parameters and to assist with irrigation. One of the area's only parameters monitored by rice producers is the water salinity. This process, when performed, is done manually and requires the person to move to the Araranguá River banks, where water pumps are installed, to measure the water quality. The region lacks intelligent solutions to facilitate and improve water quality monitoring for irrigation. Moreover, rice producers rarely use Internet applications and solutions, and WhatsApp is usually used as a communication tool. Furthermore, they use climate consult service through the EPAGRI/CIRAM site. This information was gathered during an interview with some rice producers as part of another project developed with UK funding and governed by a Non-Disclosure Agreement.

## Material and methods

This section is organized into both important subsections and presents the features of the study area and the requirements of the experimental platform proposal.

### Study area

The Araranguá River valley watershed is located in the south of the state of Santa Catarina (SC), Brazil, with about 3,020 km². The Araranguá River is formed by the confluence of the Itoupavas and Mãe Luzia rivers, with a length of about 35 km before meeting the sea (Figure 1). According to the D'aquino et al. (2010), the salt wedge can penetrate more than 40 km into the Araranguá River, covering much of the rice growing area where all the irrigation water supply comes to the river.


**Figure 1.** Araranguá River estuary (28°54'57.21"S and 49°24'08.20"W, satellite image by Google Earth free version).

The Araranguá River estuary is characterized as a river-flood-dominated estuary (Couceiro et al., 2021; D'aquino et al., 2010; Silvestrini & D'Aquino, 2020) (Couceiro et al., 2021), which means the discharge controls most of the hydrodynamics in the estuary. The penetration of salt is mainly influenced by the discharge (rainfall in the watershed).

Considered the second-largest producing state, only behind Rio Grande do Sul, Santa Catarina, in 2019, planted and harvested more than 149,000 hectares irrigated rice. According to EPAGRI in 2020, irrigated rice was responsible for the highest Gross Value of Production (GVP), corresponding to approximately BRL 865 million (USD 168 million) for the state of Santa Catarina. Among the producing counties, Araranguá stands out, concentrating 39% total cultivated area, or approximately 58 thousand hectares (Trabaquini et al., 2020). Several irrigated rice cultivation properties are located in the flood region of the Araranguá River. Rice is a hydrophilic plant, that is, its cultivation requires a lot of water to develop. Most of the production in SC is irrigated rice. Most farmers in the state's southern region use the irrigation method based on flooded ground. This requires high consumption of good quality water and, in almost all locations in the area, water is abstracted from rivers (Martins & Poletto, 2022).

A questionnaire-based survey was performed with rice farmers to check the technologies present in rice production in the Araranguá River valley. They were questioned about technologies used in the field, and also asked about information technologies. All producers pointed a GPS as a technology used in the field, especially for a more precise application of agricultural inputs. One of the producers has his own silo, highlighted the automated system for controlling humidity and temperature in the silo. About 25% has a handheld conductivity meter to measure river salinity. The question about technology of information, 100% pointed Whatsapp as a technology, revealing that they had a group to disclose when the salt went into the river to alert the farmers who do not have conductivity meter to turn off the water pumps.

This survey with the farms from Araranguá are in line with the recommendations of Martins & Poletto (2022), who carried out a study on the influence of salinity on rice cultivation in a neighboring estuarine region (50 km south) and found that: EC levels of 2,000 – 3,000 μS cm cause chlorosis, leaf curling, and necrosis of old leaves, interfering with the development of irrigated rice seedlings. The results underscore that farmers need to measure salinity to avoid irrigating rice crops with saline water. Currently, farmers use unsophisticated and imprecise methods to detect the presence of salt in water.

## Experimental IoT platform

Precision agriculture is a method used to manage rural properties with Information Technology (IT) to ensure that production and soil receive exactly the required nutrients. The purpose of precision agriculture is to ensure profitability, sustainability, and, the environment's protection. Associated with IoT resources, it is possible to monitor resources that are essential for food production due to the integration of this area with sensors, communication and synchronization systems.

As rice is sensitive to salt, and considering the production of irrigated rice in the region, there is an interest in monitoring salinity in the Araranguá River estuary. Salinity is just one of the parameters that can be considered. Still, according to the related works mentioned in Table 1, it is possible to connect other sensors to the network, such as turbidity sensors, temperature sensors, etc., and use these resources to improve irrigation processes, forming a platform.

The requirements to develop a solution for this region have been studied during the last few years. This region has economic activity based on agriculture, and the rice production area has Internet connectivity throughout its extension. Initial project requirements identified salinity monitoring as the most important question for rice producers. International Telecommunication Union (ITU) has been leading the coordinated development of globally interoperable telecommunication technologies and policies since 1865. Internet of Things, machine-to-machine, and next-generation networks are among the standards it has developed. In 2016, the Recommendation ITU-T-Y.4460 - Architectural reference models of devices for the Internet of Things applications were released. The document presented the model to applications, based on a classification of devices that employ processing power and communication capabilities. Also, this document presents the functional entities and their interaction with IoT devices. In addition, the ITU-T reference presents some examples, including irrigation applications. However, the reported irrigation pattern differs from the one used by rice farmers in the south of Santa Catarina, which is produced with water management from the river. The required infrastructure for the proposed work consists of sensors, communication networks, and cloud servers. Highlighting the employment of low-cost equipment to locally test the solution proposed. In addition, the reference model also promotes interoperability among various IoT applications and communication protocols (Kafle et al., 2016). This reference model was also mentioned in a published article entitled Architecture framework of IoT-based food and farm systems: A multiple cases, which describes 19 use cases that were categorized in 5 coherent trials that aim to address the most relevant challenges for the concerned sector (Verdouw et al., 2019). The work presents an important contribution to this theme analyzing 19 case studies in the agro-food area and must be considered in future works. The agri-food IoT domain is a challenge from both perspectives: technical and organizational. IoT devices have to operate in adverse environments in which agricultural production depends largely on environmental conditions, such as climate, soil, water, diseases, and water. Normally, most food plantations are open air, in different conditions such as hot, cold, windy, and rainy, also extreme climate events, such as dry or extratropical cyclones. IoT devices must be able to communicate and have energy conditions to operate in such rural areas. Furthermore, there is the seasonal challenge. Food production takes time, is very slow, and manifests uncertainty about the weather conditions. In addition, at the same time, consumers require safe and healthy products. Rural organizations usually have a high number of small and medium producers, resulting in a lack of investments and even a lack of technical and management skills to successfully invest in IoT solutions. Consequently, the authors indicate several barriers to technological advances in this area and mention several works even in the experimental stage (Verdouw et al., 2019).

The results of this work were obtained in the period between 2018 and 2021, based on resources available on that occasion. Prospecting low-cost solutions for producers in this area by testing equipment and available technology. Figure 2 illustrates the architecture of the proposal platform.

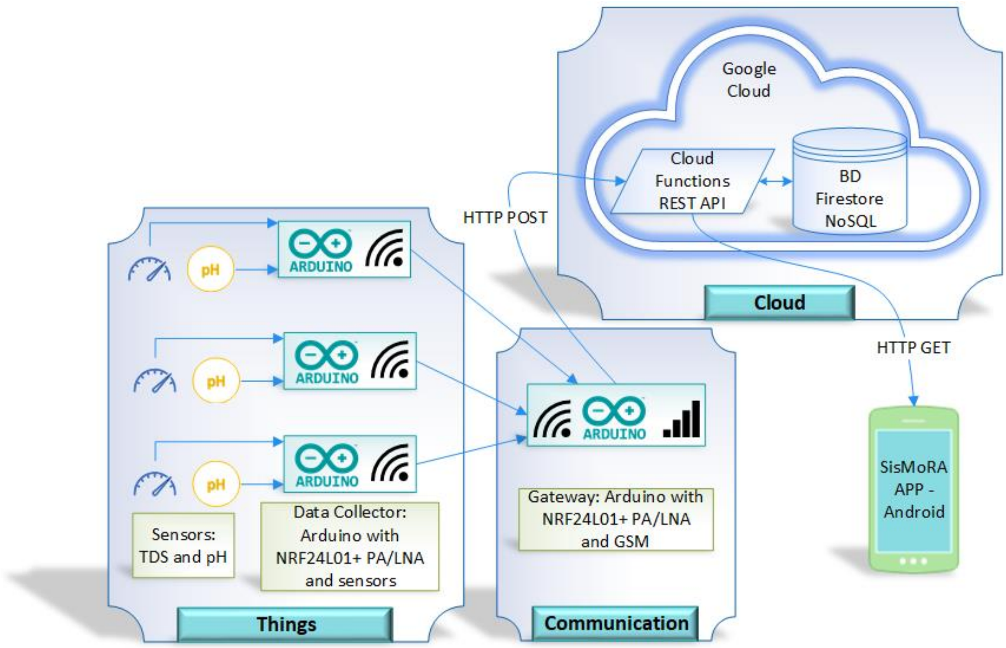


**Figure 2.** Details of the platform components.

The proposed architecture has three layers: perception layer, consisting of water pH (Potential of Hydrogen) and TDS (Total Dissolved Solids) sensors, coupled to a microcontroller unit (Arduino) with NRF24L01+PA/LNA radiofrequency modules; a communication layer that has a Master node and GSM/GPRS shield for interface with the mobile network. And finally, a cloud layer with an HTTP API is responsible for receiving and storing data in a non-relational database. The data is distributed through an application developed for smartphones.

## Perception layer

The water pH measurement uses a Gravity sensor: SEN0161, which presents an accurate reading, measuring values from 0 to 14 on the pH scale with an error of approximately ±0.1. This sensor provides easy integration with the microcontroller; however, it is meant to be used in a laboratory and cannot be immersed for long periods. Nevertheless, this sensor fulfills the need for measurements for platform testing purposes. Natural and anthropogenic processes influence the TDS index. The TDS measurement was obtained with a TDS-KS0429 device, which measures the amount of organic and inorganic substances diluted in water. In this work, the TDS sensor is used as an option for the conductivity meter due to its feasibility.

The conductivity of this river water was estimated using conversion to conductivity measurement. In order to classify measured TDS indices for natural waters, Rusydi (2018) used a relationship that involved multiplying EC conductivity (dS/m) by a constant K(640). Despite this, the conversion process loses precision. This conversion constant is also estimated by other works, such as Ali et al. (2012), which studied TDS equivalence and conductivity values in water polluted by industrial activity. Conversion values range from 550 to 800, according to Iyasele & David Idiata (2015). A low-cost conductivity meter was previously developed for salinity measurement, as well as Zigbee-type transmitters (IEEE 802.15.4), demonstrating that, in the future, it is possible to invest in the development of a conductivity meter appropriate for the project, with a buoy that can be placed directly in the river. In comparison to a commercial conductivity sensor, TDS testing significantly reduces the solution's cost.

### Communication layer

Communication is implemented through radio frequency transmission with NRF24L01+PA/LNA transceiver (PA-Power Amplifier/ LNA - Low-Noise Amplifier). The sensor nodes constituting the perception layer were designed using an Arduino UNO microcontroller. Once the signals were collected, data is transferred to the communication layer. These nodes have a range of up to 1,000 meters in open spaces without obstacles, at 250kbps rate. They operate in the 2.4GHz ISM (Industrial Scientific and Medic) frequency band, using 126 channels of 1MHz bandwidth, and use ESB+ protocol for data transmission. At shorter distances, they can transfer up to 2Mbps. These modules can be configured to work in different network topologies, such as direct connections between modules (P2P), stars, or even trees. The libraries used are available on GitHub (Doxygen, 2020).

The master node (or gateway) coordinates the sensor network. It has the task of receiving and pre-processing the data read by collector nodes and forwarding configuration messages to network nodes. This node is built from an Arduino MEGA, a nRF24L01+PA/LNA module, and a GSM-GPRS SIM900 shield. The latter is composed of a global system for mobile communication, or GSM (Global System for Mobile Communication). This technology was chosen to direct long-distance transmission to the cloud through the designed API. Figure 3 illustrates the network scheme with the collector nodes and the sensor network gateway.

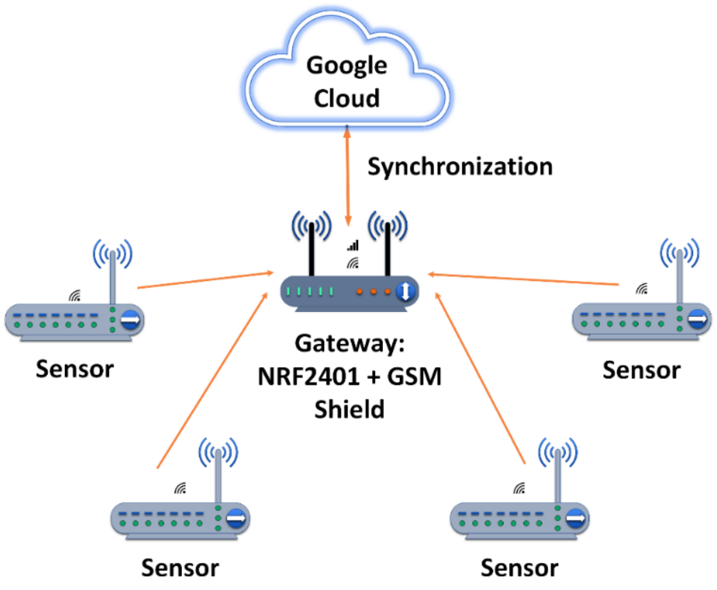


**Figure 3.** Network scheme of the communication layer.

### Cloud layer

The cloud layer was developed through an API, designed using Google Firebase. In addition to supporting serverless services, Firebase also provides non-relational database services, authentication services, hosting, and machine learning models to aid the web or mobile application development process. One of the characteristics of applications that follow the serverless architecture is the on-demand operation, causing the service to scale based on the frequency of requests automatically (Mell & Grance, 2011). Figure 4 shows the modules developed during the work.

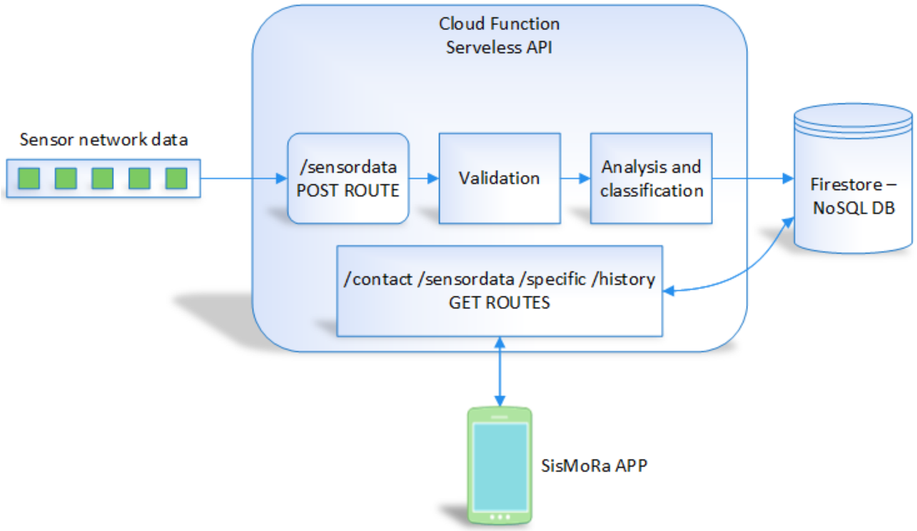


**Figure 4.** Cloud layer.

The developed modules of the cloud layer were described in detail as follows (Figure 4):

- Entry route/sensor data: through GSM messages and HTTP POST requests, data is received from the communication layer. The received data are TDS value; pH value; sensor identifier number in base 8; voltage of the battery connected to the node in Volts; flag to identify sensor errors; and water pump identifier corresponding to the sensor.
- Data validation: step to check if the fields present in a read are current in the received request
- Analysis and classification: API performs water classification based on the pH and TDS parameters. The category is based on the analysis of the TDS index, converted into a conductivity metric, and the pH index. The water status is classified as "GOOD", "CAUTION" or "POOR". Regarding the tolerance limits, according to Fraga et al. (2010), the growth of the rice plant begins to be affected by the salinity level of water when it presents conductivity values of approximately 2dS/m, and pH levels must remain close to 6, according to Parfitt et al. (2017).
- Upload to the database: after processing the data received by the sensor network, the API sends it to a non-relational database, also served in the cloud. To securely communicate with the database, an access key was generated in Google Firebase services, allowing the API to store or read information from the database. The communication between API and database is abstracted by the firebase-admin Software Development Kit (SDK), made available by Google for Node JS language.
- Data access routes: Among the routes that read information from the database, through GET requests, are: /sensor data, which collects data from the last reading of each sensor; /specific, which fetches the data, given a specific date; /history, which returns older data as of a specific date; and /contact, which returns data related to contacting the platform administrator.

## Smartphone application

A smartphone application was developed as an end-user interface to test the viability of the architecture and access to the network data. Designed using React Native JavaScript, it employs HTTP GET requests in predefined routes in the API, the project's backend. The application can collect data from the last reading taken by the network, data from measurements made by each sensor, history of readings, and even individual history of each sensor's readings. In Figure 5, it is possible to visualize the screens projected to the system.

Figure 5a shows the first screen presented to the user when the application is started. This presents a map of the sensors/pump location and the data referring to the last reading performed by the sensor network. In addition to the map, the water quality for each irrigation point, displayed visually according to the color scale that indicates: blue marker means that the water has the necessary conditions for irrigation, yellow marker represents physicochemical characteristics on the threshold between acceptable and inappropriate (caution), and red marker indicates indices outside standards considered necessary for water use. By clicking on each marker, the last read values are displayed. It is also possible to access the ranking by clicking on each marker on the map.


**Figure 5.** Smartphone app.

The history of readings performed by the sensory network is shown on the second screen (Figure 5b). When the user searches for readings taken on a specific day, up to four readings are initially shown on the screen. If the user wants to obtain more data from that day or older data, they can use the "Load more data" button. After loading the data of interest, it is possible to use the button "View graphs" to visualize the fluctuation of the indices read by each sensor.

The third screen (Figure 5c) shows a list of sensors integrating the data loaded on the history page. By selecting one of the sensors in the list, the user is presented with graphs referring to past readings, on the fourth screen (Figure 5d).

The application also has a screen referring to the "contact" menu, in which the user has contact with the developer and technical assistance for both software and hardware. Finally, a system was configured to send emails and messages through the WhatsApp application to the developer if the system presented an error.

## Results and discussion

### Preliminary results

The test measurements were taken on November 14 and 18, 2020, on the river bank. The network was configured at one-minute intervals, and it immediately passed on to the nodes. Table 2 lists the data read during the network tests.

The test's performance aimed to validate the application built and the API, which did not show errors during the tests. Higher sensitivity to different configurations and external disturbances was found in the sensor network, as expected for WSN behavior (Landaluce et al., 2020; Nikoukar et al., 2018). Among the main factors compromising network operation is electromagnetic interference, caused by other devices operating physically close or on the same channels as the network transceivers. In evaluating using point-to-point communication, there were problems regarding the loss of some packets during communications. So, settings for forwarding packets in case of non-receipt were added to the nodes, mitigating this problem.

**Table 2.** Data obtained with the system during each test.

| Data read on Nov, 14 | | | | Data read on Nov, 18 | | | |
|---|---|---|---|---|---|---|---|
| Data | pH | TDS | Status | Data | pH | TDS | Irrigation |
| 1:55:20PM | 4.8 | 884.04 | POOR | 6:07:57PM | 5.47 | 983.45 | CAUTION |
| 1:56:20PM | 4.9 | 879.56 | POOR | 6:08:58PM | 5.86 | 990.13 | GOOD |
| 1:57:22PM | 4.78 | 880.12 | POOR | 6:09:58PM | 5.67 | 978.25 | GOOD |
| 1:58:23PM | 4.92 | 882.05 | POOR | 6:11:00PM | 5.48 | 981.03 | CAUTION |

To validate the data path through the platform and its operation, the three parts of the system were integrated and tested in a river environment as proposed for its final continuous operation. After combining the sensor network with the API and the API with the application, the sensory network was taken to a measurement point on the banks of the Araranguá River (Figure 6). The pH sensor was calibrated using a neutral solution (pH=7).

Water pH is an indicative of water quality and it can make the water unsuitable for irrigation. Values of pH during the tests always remained above the indicator for a healthy environment, as verified by Silvestrini & D'Aquino (2020), mainly because of the mine acid drainage water influence. Even with this pH level, water was indicated in the app as "GOOD", because for rice crops, the main factor for plant development is the presence of salt, and the TDS indices remained within the appropriate limit (Table 2).


**Figure 6.** Google maps image of the test region on the banks of the Araranguá River estuary.

The communication to the application happened immediately after the readings, thus validating the proposed data path. Although the application does not automatically update with each new reading made by the sensory network, it constantly searches for the most recently read information when updating the screen or manually restarting the application. These upgrade options are still being improved. The read data can also be presented in graphs and visualized through the application.

As presented in preliminary tests, the system appears as an option for farmers who need to monitor the quality of the water inlet of the crops. Three visits to the field were made and the solution proposal was present to the farmers, and all of them pointed the importance of the system and highlighted the main benefits: i) labor to move to measure salinity and turn on/off the pumps manually would be used in the cultivation; ii) reduced the risk of salt water entering the courts; iii) increased production; iv) energy savings (pumps on when not needed); v) better use of river water. This avoids the loss and reduction in crop productivity because the system can help to continuously monitor the physical parameters of water and present notifications to the user. This article presented a solution to measure salinity using a TDS sensor. An important point to highlight is the high cost of the salinity sensor, which requires a high investment from the local farmers. So, we tested an alternative by using TDS. Also, the salinity problem for rice growers is an aspect of the south of Brazil. River water irrigation is quite common in this region, and it is affected by salt in the water, primarily due to lack of rain and climate change.

## Discussion

The development of a similar wireless data collection network, employing Arduino microcontroller and NRF24L01, was proposed by Dahane et al. (2019), which aimed to optimize irrigation water use based on data collected by the sensor network. The authors focused on developing a compact and sustainable system and did not report any communication or data loss problems, validating its operation, and obtaining water savings with the proposed approach. Even with preliminary data, it was possible to analyze and discuss the results.

The IoT-based water and environment management system was developed for rice producers by Arko et al. (2019). The method proposed monitors and controls the influencing factors. The authors looked for an alternative to help farmers to save time, as in the present work. However, they did not investigate water quality, and their applications were validated only in a controlled environment (laboratory).

Regarding monitoring river water quality, Chowdury et al. (2019) presented a system using big data analytics integrated with IoT to make people aware of contaminated water. The system was built using pH, turbidity, temperature, and TDS sensors, an Arduino microcontroller, Wi-Fi modules (ESP8266) for communication, and a display. The proposed system also has a cloud for data storage, and data analysis is done with an Artificial Neural Network that classifies the water as "good" or "bad". Their difficulties were in collecting and evaluating the system data and in the presentation that was limited to the LCD. As a result, the rice grower was able to make better decisions by using an end-user application that gathered parameters from water.

A robust sensor network is exposed by Gloria et al. (2019), used to retrieve environmental data and measure parameters, such as air and soil temperature and humidity to optimize irrigation times. The authors used LoraWan technology for communication, which is a technology that has low power consumption in addition to long-range communication. This study highlighted the importance of collecting data in the field using a network of sensors due to the farmer's time savings and irrigation expenses, which can reduce water consumption by up to 25% for the case exposed by the authors by applying monitoring. The use of other communication technologies can be implemented in our solution.

In this work and the scientific literature, the main difficulties were the development of the sensor network, data collection, and the precision they offer due to the influence on the results. The present work highlights the proposed platform employing a low-cost wireless sensor network. When mentioning that the proposed solution is low cost, we are referring to the amount spent on this prototype, which is much lower than the cost of a single piece of equipment used to measure salinity in rivers with a buoy and GPS transmitter, which costs around U$ 700 dollars. Based on a quick calculation, five NRF2401 modules would cost approximately U$ 300. As a result of ocean influence, salinity problems can extend 45km along the Araranguá River. The smartphone application was developed to provide the farmer with information about salinity by collecting physical parameters during rice irrigation.

## Conclusion

An experimental platform was proposed to monitor water parameters of the Araranguá River. The prototype was built from NRF24L01+PA/LNA transceivers, microcontrollers, and pH and TDS sensors, together with a serverless API and a mobile application for Android devices. The proposed system collects the data locally and at the same time transfers this data to the Google Cloud, which the user can access through the smartphone.

The salt wedge present in the Araranguá River region can reach 45 km, and the levels of pH can be extremely low due to mine acid water drainage. The prototype presents, as a result, the feasibility of building an IoT platform to assist in salinity and pH control in the water used for irrigation at different points of rice properties. The ease of collecting data and transmitting it directly to the smartphone represents a breakthrough in the region's irrigated rice production process. The characteristics expected from an IoT platform were ensured by the design, access to data, long-range distribution (via smartphone), mobility, and ease of use, as presented in the article. However, to have a more complete solution in terms of long-range technology, it is recommended other communication technology, such as LoRA or sub-1GHz, or even other technologies that operate in the 900MHz band due to the extension of the wedge.

The proposed smartphone application is intuitive and straightforward, representing a solution accessible to end users. However, as seen in the literature, the proposed sensor network can be improved by evaluating more parameters of water quality. This work represents the first initiative of its kind in the region showing the first results of a cloud-based IoT application for monitoring irrigation water from irrigated rice fields in the Araranguá River basin valley in southern Brazil.

## References

Ali, N. S., Mo, K., & Kim, M. (2012). A case study on the relationship between conductivity and dissolved solids to evaluate the potential for reuse of reclaimed industrial wastewater. *KSCE Journal of Civil Engineering*, *16*(5), 708–713. DOI: https://doi.org/10.1007/S12205-012-1581-X

Arko, A. R., Khan, S. H., Biswas, M. H., Imran, A., Kafi, A. H., & Antara, R. S. I. (2019). IOT based smart water and environment management system of paddy rice at different growth stages. *Proceedings - 2019 IEEE International Conference on Internet of Things and Intelligence System, IoTaIS 2019*, 154–160. DOI: https://doi.org/10.1109/IOTAIS47347.2019.8980424

Banco Nacional do Desenvolvimento [BNDES]. (2017). *Internet das Coisas: um plano de ação para o Brasil - Relatório de Aprofundamento de Verticais – Saúde*. Retrieved from https://bitlybr.com/MbFPd

Chowdury, M. S. U., Emran, T. B., Ghosh, S., Pathak, A., Alam, M. M., Absar, N., Andersson, K., & Hossain, M. S. (2019). IoT Based Real-time River Water Quality Monitoring System. *Procedia Computer Science*, *155*, 161-168. DOI: https://doi.org/10.1016/j.procs.2019.08.025

Couceiro, M. A. A., Schettini, C. A. F., & Siegle, E. (2021). Modeling an arrested salt-wedge estuary subjected to variable river flow. *Regional Studies in Marine Science*, *47*. DOI: https://doi.org/10.1016/J.RSMA.2021.101993

D'aquino, C. D. A., Filho, J. P., Augusto, C., & Schettini, F. (2010). Fluvial Modulation of Hydrodynamics and Salt Transport In a Highly Stratified Estuary. *Brazilian Journal of Oceanography*, *58*(2), 165–175.

Dahane, A., Dahane, A., Kechar, B., Kechar, B., Meddah, Y., Meddah, Y., ... Benabdellah, O. (2019). Automated irrigation management platform using a wireless sensor Network. In *Sixth International Conference on Internet of Things: Systems, Management and Security [IOTSMS] (*p. 610-615). DOI: https://doi.org/10.1109/IOTSMS48152.2019.8939170

Dholu, M., & Ghodinde, K. A. (2018). Internet of Things (IoT) for Precision Agriculture Application. In *Proceedings of the 2nd International Conference on Trends in Electronics and Informatics [ICOEI]* (p. 339-342). DOI: https://doi.org/10.1109/ICOEI.2018.8553720

Doxygen. (2020). *Optimized RF24 Network Layer for NRF24L01 radios*. Newly Optimized RF24Network Layer. Retrieved from https://nrf24.github.io/RF24/

Elazhary, H. (2019). Internet of Things (IoT), mobile cloud, cloudlet, mobile IoT, IoT cloud, fog, mobile edge, and edge emerging computing paradigms: Disambiguation and research directions. *Journal of Network and Computer Applications*, *128*, 105-140. DOI: https://doi.org/10.1016/j.jnca.2018.10.021

Fraga, T. I., Carmona, F. de C., Anghinoni, I., & Marcolin, E. (2010). Attributes of irrigated rice and soil solution as affected by salinity levels of the water layer. *Revista Brasileira de Ciência Do Solo*, *34*(4), 1049-1057. DOI: https://doi.org/10.1590/S0100-06832010000400005

Gloria, A., Dionisio, C., Simões, G., Sebastião, P., & Souto, N. (2019). WSN Application for sustainable water management in irrigation systems. In *5th World Forum on Internet of Things (WF-IoT)*. Retrieved from https://ieeexplore.ieee.org/document/8767278

Goap, A., Sharma, D., Shukla, A. K., & Rama Krishna, C. (2018). An IoT based smart irrigation management system using Machine learning and open source technologies. *Computers and Electronics in Agriculture*, *155*, 41-49. DOI: https://doi.org/10.1016/J.COMPAG.2018.09.040

Haxhibeqiri, J., De Poorter, E., Moerman, I., & Hoebeke, J. (2018). A survey of LoRaWAN for IoT: From technology to application. *Sensors*, *18*(11). DOI: https://doi.org/10.3390/s18113995

Iyasele, J. U., & David Idiata, D. (2015). Investigation of the relationship between electrical conductivity and total dissolved solids for mono-valent, di-valent and tri-valent metal compounds. *International Journal of Engineering Research and Reviews*, *3*(1), 40–48.

Kafle, V. P., Fukushima, Y., & Harai, H. (2016). Internet of things standardization in itu and prospective networking technologies. *IEEE Communications Magazine*, *54*(9), 43–49. DOI: https://doi.org/10.1109/MCOM.2016.7565271

Kumar, S., Tiwari, P., & Zymbler, M. (2019). Internet of Things is a revolutionary approach for future technology enhancement: a review. *Journal of Big Data*, *6*(1). DOI: https://doi.org/10.1186/s40537-019-0268-2

Landaluce, H., Arjona, L., Perallos, A., Falcone, F., Angulo, I., & Muralter, F. (2020). A review of iot sensing applications and challenges using RFID and wireless sensor networks. *Sensors*, *20*(9), 1–18. DOI: https://doi.org/10.3390/s20092495

Laphatphakkhanut, R., Puttrawutichai, S., Dechkrong, P. et al. (2020). IoT-based smart crop-field monitoring of rice cultivation system for irrigation control and its effect on water footprint mitigation. *Paddy and Water Environment*, *19*, 699-707. DOI: https://doi.org/10.1007/s10333-021-00868-1

Martins, M. C., & Poletto, N. (2022). Salinity study of irrigation waters used in rice fields. *Revista de Ciências Agroveterinárias, 21*(2), 27-34. DOI: https://doi.org/10.5965/223811712112022027

Mell, P. M., & Grance, T. (2011). *The NIST definition of cloud computing*. DOI: https://doi.org/10.6028/NIST.SP.800-145

Nikoukar, A., Raza, S., Poole, A., Gunes, M., & Dezfouli, B. (2018). Low-power wireless for the internet of things: Standards and applications. *IEEE Access*, *6*, 67893–67926. DOI: https://doi.org/10.1109/ACCESS.2018.2879189

Parfitt, M. J. B., Concenço, G., Scivittaro, W. B., Andres, A., Trombetta Da Silva, J., & Pinto, M. A. B. (2017). Soil and Water Management for Sprinkler Irrigated Rice in Southern Brazil. *Advances in International Rice Research*. DOI: https://doi.org/10.5772/66024

Payero, J. O., Marshall, M. W., Farmaha, B. S., Davis, R. H., & Nafchi, A. M. (2021). Development and Application of Cell-Phone-Based Internet of Things (IoT) Systems for Soil Moisture Monitoring. *Agricultural Sciences*, *12*(5), 549–564. DOI: https://doi.org/10.4236/AS.2021.125035

Rusydi, A. F. (2018). Correlation between conductivity and total dissolved solid in various type of water: A review. *Global Colloquium on GeoSciences and Engineering 2017*, 1–6. DOI: https://doi.org/10.1088/1755-1315/118/1/012019

Silvestrini, T. A. M., & D'Aquino, C. D. A. (2020). Dinâmica dos parâmetros oceanográficos em um estuário impactado por atividades de mineração de carvão. *Pesquisas Em Geociências*, *47*(3), e103404. DOI: https://doi.org/10.22456/1807-9806.109992

Trabaquini, Kleber, & (EPAGRI). (2020). *Epagri conclui mapeamento da área de arroz por imagens de satélite – Epagri*. Retrieved from https://www.epagri.sc.gov.br/index.php/2020/07/31/epagri-conclui-mapeamento-por-imagens-de-satelite-da-area-de-cultivo-de-arroz/

Verdouw, C., Sundmaeker, H., Tekinerdogan, B., Conzon, D., & Montanaro, T. (2019). Architecture framework of IoT-based food and farm systems: A multiple case study. *Computers and Electronics in Agriculture*, *165*, 104939. DOI: https://doi.org/10.1016/j.compag.2019.104939