Design and implementation of a water quality monitoring system based on IoT and LPWAN: Case of Guiers lake, Senegal*

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Abstract. As the main freshwater reserve in Senegal, Guiers lake is facing socio-economic and ecological challenges. For several years, Guiers lake has been threatened by various sources of pollution, particularly related to industrial, domestic, agricultural, and fishing activities. Industrial activity results in the release of pollutants into the water which have detrimental effects on the environment and human health.
One of the major challenges in water resource management is quality control, which involves acquiring some informations about water, such as temperature, turbidity, conductivity, pH, and many other parameters. the level of presence of these parameters in the water can give information about the type and intensity of the pollution.
Many approaches have been developed to address the problem of water quality monitoring through the Internet of Things. The application of these different projects in a local context (Senegal) is difficult due to the logistics (internet coverage, etc.) and the cost of certain components.
Looking at the Senegalese context, this work is identified as a case study of the application of IoT technologies and low-energy LPWAN transmission in water quality monitoring. In particular, we will be using LoRa transmission technology in the access layer because of the many advantages of spread spectrum modulation.
The aim of this work is not only to clarify the potential application of IoT in the Lac de Guiers area, but also to answer an important question about the accuracy of IoT systems in measuring the physical and chemical variables of water.

Keywords: Internet Of Things · Low Power Wide Area Network · LoRa · Pollution.

1 Introduction

Located in northern Senegal, in the upper delta of the Senegal River, Guiers lake is considered as the largest lake in the country, covering an area of 300 square kilometers with a volume of 600 million cubic meters of water. It serves as the

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largest freshwater reserve in Senegal and also facilitates the development of over 30,000 hectares of irrigated land [2]. Lake Guiers is a hub for agricultural, fishing, pastoral, fish farming, and agro-industrial activities. For some time now, it has been facing a wave of pollution. The use of this polluted water is detrimental to public health, leading to diseases such as diarrhea, cholera, schistosomiasis, or liver flukes [7].

The need for effective monitoring, assessment, and control of water quality in Lake Guiers has become more pressing. Traditional methods relying on water sample collection, testing, and analysis in water analysis laboratories are not only costly but also fail to provide real-time data capture, analysis, and decision-making capabilities.
With the advent of IoT, systems are being proposed to monitor water quality [5, 4, 1, 3, 6, 9]. IoT systems, through sensors, facilitate the entire testing chain from data acquisition to processing and visualization. The objective of this project is to implement a low-cost et resilient acquisition system that will use a network of sensors to collect water quality parameters and send this data to our servers. Additionally, it aims to enable data visualization through a dedicated application. The issues at stake in this project include feasibility in the context of Lac de Guiers, which is located in an area far from the capital and not covered by operators, and the accuracy of such a system in measuring phisico-chemical parameters. In the course of this paper we will begin with an in-depth study of the literature and will finish with a validation phase and discussion of the prospects and outcomes of such a project.

2 The Guiers Lake: a development issue

The Guiers Lake represents more than just a resource; it embodies an entire social and economic dynamic. As the main source of drinking water in Senegal, it is crucial to consider how to preserve it from threats.

A recent survey conducted on Guiers Lake by our team reveals the concerns of the local populations regarding the danger posed by agricultural and industrial waste discharged into the lake.

During these investigations, the various users of the lake brought up numerous issues around the pollution caused by aquatic plants but also the industries installed with spills on the lake. The local population have clearly shown their fears about the possible repercussions of this pollution on them and their animals. On a more global level, pollution of the lake will have consequences for public health and could lead to a national health disaster. A water quality monitoring project is a control solution that will give the authorities a real-time idea of the level of degradation of the water and enable them to take action if necessary.

Fig. 1. Lake Guiers: a photo of the current state of the lake. The apparent greenish colour shows the advanced level of proliferation of aquatic plants.

3 Related work

There are several approaches that have been proposed over the years for remote monitoring of water quality. Broadly speaking, we identify 2 groups of approaches: on the one hand, projects based on the Internet of Things using sensors and telecommunication systems and, on the other, initiatives centred on the use of artificial intelligence, particularly computer vision, to assess water quality from satellite images.

A number of studies have been carried out on IoT-centric approaches.
(Varsha et al.) [4] propose an IoT-based water parameter monitoring system that utilizes an industrial multi-parameter sensor node. The sensor node employs a file system to backup sensor data in case of network loss. The communication technology between the nodes and sensors is GSM. On the server side, the data is stored and visualized through a web-based user interface. The limitations of this method are essentially related to the use of GSM communication technology. In fact, this technology requires fairly high energy consumption as well as network coverage by operators, which is not the case in our area.

Another project has been launched for a mini aviculture basin. (Ngom et al.) [5] presented a water quality monitoring system using LoRa transmission un systeme pour controler les parametres dans un bassin. This is a low-cost infrastructure consisting of a remote station for real-time data collection and a web platform for visualization and analysis.This project is similar to our approach in the use of LPWAN transmission technology, but at a smaller level. Our problem is more global, of the order of a lake. In addition, the sensors used in this project are very expensive and do not meet our needs for a low-cost system.

In this project (Roy et al.) [6] are studying a monitoring system consisting of various sensors for measuring the quality of spring water, a micro-controller for processing the collected data, and various communication systems. Additionally, the collected values will be compared to standard values, and if the values exceed the defined threshold, an automatic SMS alert will be sent to the user. Cette approche reste tres interessante avec l'utilsiation d'un systeme d'alerte. La difference avec notre projet sera essentiellement sur le nombre de parametres monitorer. en effet dans des effort d'optimsiation nous avons seulement decider de monitorer la temperature, la conductivite, la turbidite et le pH.

Another similar project is the (L. Lakshmanan et al.) approach [4] where it proposes a system using mainly 2 parameters, pH and Turbidity. and a wifi module on the monitoring station. This approach is not applicable in our context as we will have to deploy the monitoring station in water where it is absolutely impossible to have internet access from a WIFI module.

Alongside these approaches, a new way of thinking is emerging about the use of artificial intelligence.

In [9] (Yang et al.) introduce a new approach with a system based on remote sensing, the use of UAVs (Unmanned Aerial Vehicles) and Artificial Intelligence. This is a very promising approach, but we are faced with the problem of accessing resources such as high quality images in order to begin computer vision work. Our system needs to be as simple as possible for use in an environment with the minimum of rural conditions and ensure a sufficient level of precision.

We're going to take inspiration from the systems we've seen before and develop our approach by adopting a 3-level architecture: an acquisition station, a gateway and a server. We will be using a LoRa communication link between the station and the gateway. LoRa is the perfect network for energy-independent applications that do not handle very large data sets (between 51 and 222 bytes depending on the Spreading Factor).

4 Metrics related to water quality

As part of water quality estimation, several parameters are important, and their value distribution provides a precise indication of the level of degradation according to established standards. We have implemented a system that utilizes sensors to monitor **Turbidity**, **pH**, **Temperature**, **Electrical Conductivity**.

4.1 pH value

pH is an important variable in assessing water quality as it influences numerous biological and chemical processes within a body of water, as well as all associated water supply and treatment processes. It is a measurement of the concentration of hydrogen ions in a solution. The normal pH range is between 6.5 and 7.5. In drinking water, if the normal pH range is not maintained, it can cause irritation to the eyes, skin, and mucous membranes. It can also lead to skin disorders.

4.2 Temperature

Water temperature is a key characteristic of any body of water. It affects the density of water, its ability to support life, as well as its capacity to absorb gases and nutrients. It is a contributing factor to the accuracy of conductivity measurements. By incorporating temperature into the conductivity sensor, we can achieve a more accurate estimation.

4.3 Conductivity

Electrical conductivity, or specific conductance, is a measure of water's ability to conduct an electric current. It is sensitive to variations in dissolved solids, primarily mineral salts. The degree to which these salts dissociate into ions, the amount of electrical charge on each ion, ionic mobility, and the temperature of the solution all influence conductivity. Conductivity is expressed in microsiemens per centimeter (µS/cm). The conductivity of most freshwater ranges from 10 to 1000 µS/cm but can exceed 1000 µS/cm, especially in polluted waters or those receiving large amounts of runoff. In addition to being an approximate indicator of mineral content when other methods cannot be easily used, conductivity can be measured to establish a pollution zone.

4.4 Turbidity

Turbidity is a key indicator of water quality. It refers to the measurement of the degree of haziness or cloudiness of water. The turbidity of distributed water should never exceed 5.0 NTU (Nephelometric Turbidity Units). Turbidity can have significant effects on the microbial quality of drinking water. Microbial growth in water is particularly pronounced on the surfaces of particles and within flocs, which naturally occur in water or are formed during coagulation. This phenomenon is a result of the adsorption of nutrients to surfaces, enabling bacteria to grow more effectively (CFPT, 2002). Several studies have shown a link between turbidity and the presence of microorganisms (viruses, bacteria, and protozoa) in drinking water.

5 Analysis and design

In this section, we will provide an abstract representation of our system, both in terms of functionality and requirements. Additionally, we will establish a general architecture of the system, from data collection to storage in the server and visualization.

5.1 Requirements diagram

Through the use of SySML [8], which is a system modeling language, we have developed the requirements diagram. This diagram provides a graphical representation of a capability or constraint that needs to be fulfilled by the system. It can be seen as an interpretation of the specifications document.

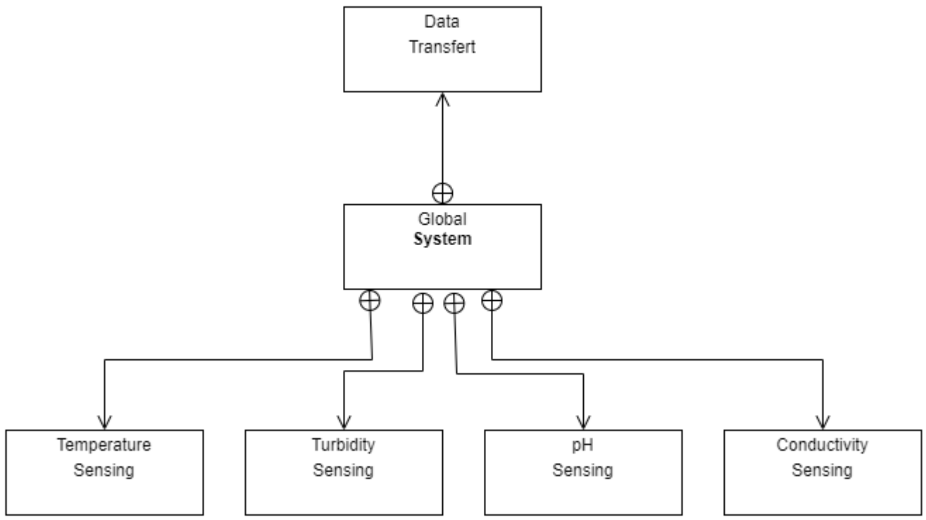

Fig. 2. Requirements diagram: This figure defines the functions of our station in terms of data acquisition and transfer using simple blocks.

5.2 General architecture of the system

Our system will be represented in three layers: the lower layer made up of the acquisition station, an intermediate layer with the gateway responsible for routing the data to the server, which represents the final layer (the application layer). in the figure 3 We clearly identify the sensors, the arduino MCU and a LoRa module that make up the station and that transmit the data to the gateway via communication on the amateur 433MHz frequency. The gateway is made up of a LoRa module and an ESP MCU. The gateway has a given frequency and sends the information to a server.

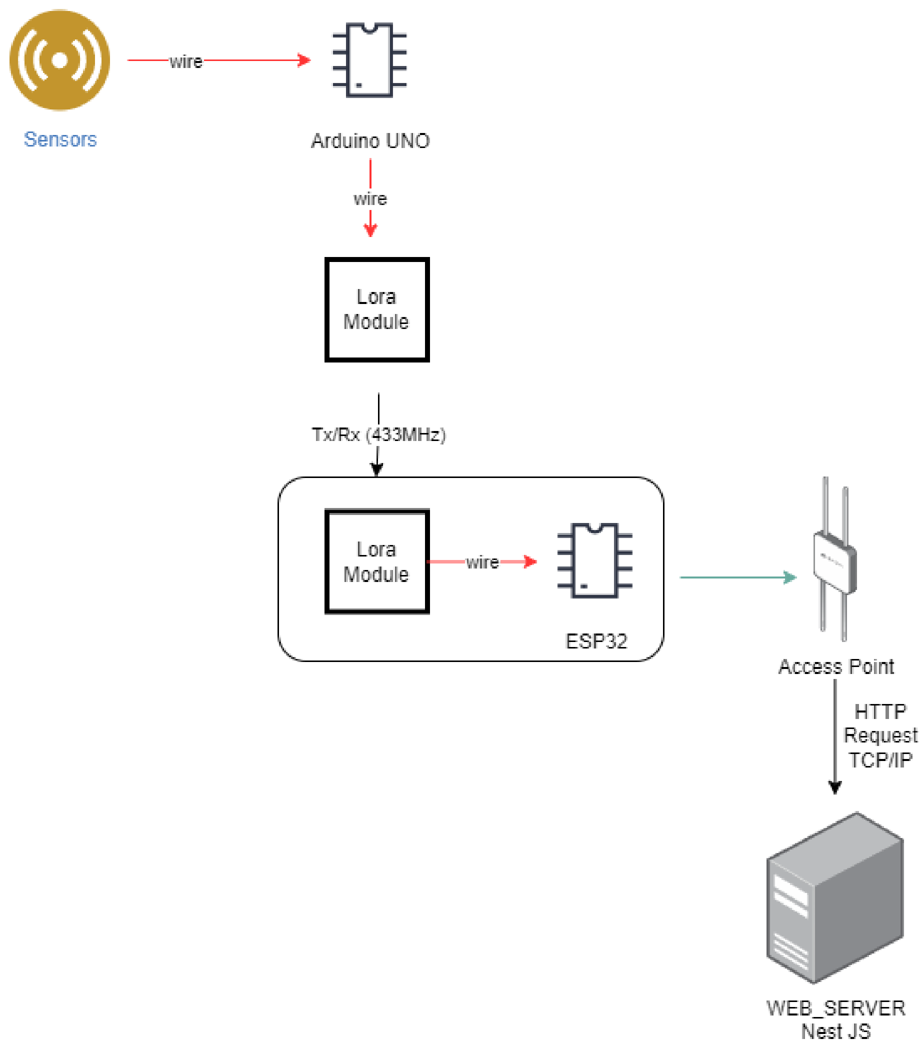

Fig. 3. System design: Global architecture of the system with 3 levels: the access layer, the distribution layer with the gateway and the application layer with our server.

5.3 Electrical design of station

In this section, we present an electrical diagram of the acquisition station. An electrical validation of the station was conducted to obtain an estimation of the overall energy consumption of the station. This simulation provides us with a solid basis for moving on to a prototype.

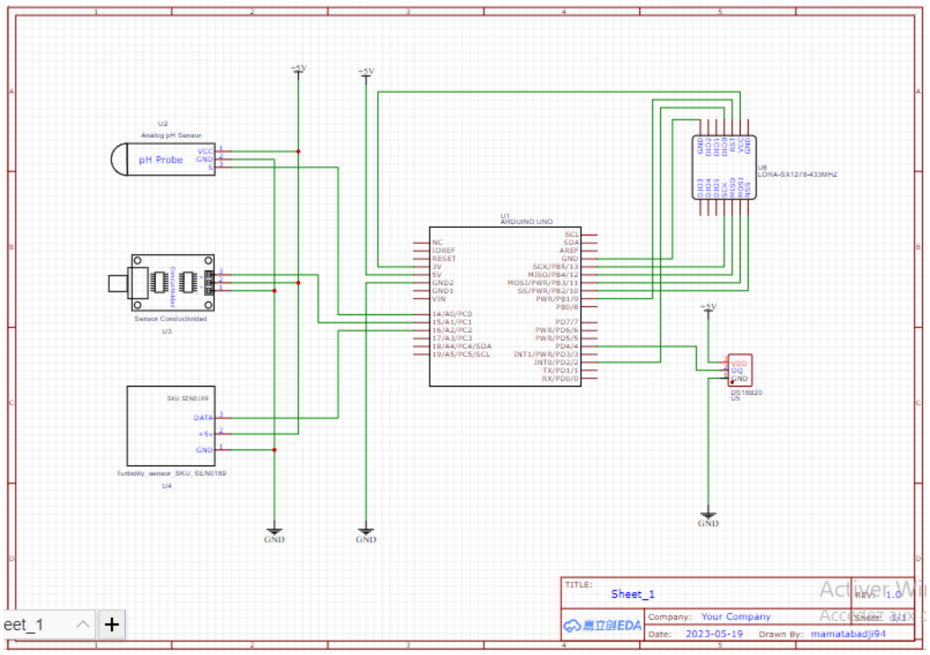

Fig. 4. Station Electrical Design: Electrical circuit and connection of the various components in the acquisition station

5.4 Electrical design of gateway

An electronic representation of our gateway will allow us, among other things, to have a detailed view of the gateway and perform electrical simulations on the system.

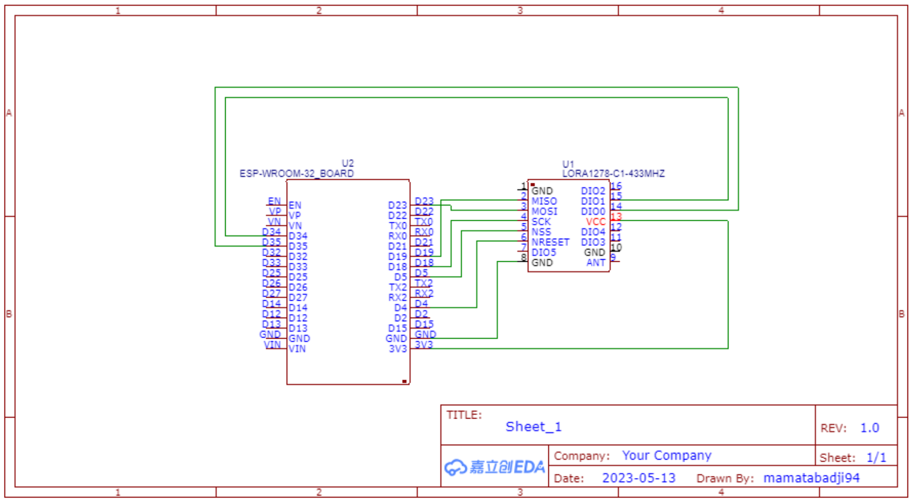

Fig. 5. Gateway Electrical Design: Electrical circuit and connection of the various components in the gateway

6 Synopsis

This diagram provides us with information about the flowchart of the programs installed on the station, from initialization to sensor data collection. It provides a chronological overview of the entire process. In the flowchart, we present the algorithm implemented at the board level for data retrieval and transmission to a remote server. The data is collected over a certain period of time. If this time limit is reached, the micro-controller collects sensor data sensor by sensor and forms a data frame for transmission.

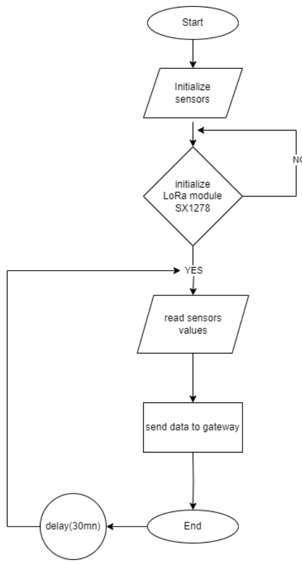

Fig. 6. Synopsis station: sequence of instructions in the acquisition station's calculation processor

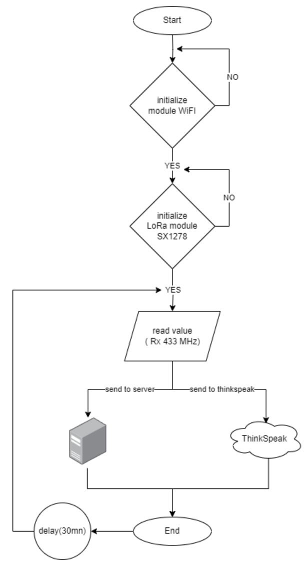

Fig. 7. Synopsis gateway: sequence of instructions in the gateway calculation processor

7 Communication Systems

7.1 Deployment zone

A physical characterization of the area is essential in order to optimize transmission. By choosing a LoRa network, we have the ability to transmit up to 15 km in direct line of sight. Therefore, the station and gateway can be located at a maximum distance of 15 km from each other. Additionally, the LoRa modulation ensures low power consumption, which is advantageous for deploying connected objects in remote locations. The station will be set up in a position close to the shore, while the gateway will be located on the premises of the Keur Momar Sar town hall, providing access to their networks. In our system, we have two main types of communication. The first is between the station and the gateway, which is done over LoRa. The second is a WiFi communication used to transfer the acquired data to remote servers in the cloud.

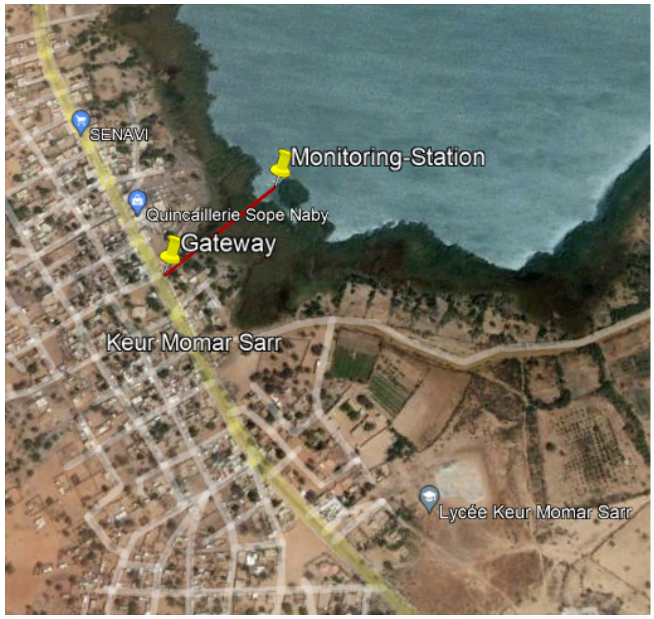

Fig. 8. Deployment area

7.2 Station-Gateway Communication: LoRa

The choice of LoRa is not random, indeed, being part of the LPWAN (Low Power Wide Area Network), it offers signal robustness and low power consumption thanks to its modulation. This modulation technique is an exclusive spread spectrum modulation derived from the existing Chirp Spread Spectrum (CSS) technology. LoRa provides a compromise between sensitivity and data rate while operating in a fixed bandwidth channel of 125 KHz or 500 KHz (for uplink channels) and 500 KHz (for downlink channels).

Additionally, LoRa utilizes orthogonal spreading factors. This allows the network to preserve the battery life of connected end nodes by performing adaptive optimizations of power levels and data rates for individual end nodes. For example, an end device located near a gateway needs to transmit data with a low spreading factor as very little link budget is required. However, an end device located several kilometers away from a gateway will need to transmit with a much higher spreading factor..
Semtech's LoRa Chirp Spread Spectrum (CSS) technology provides a low-cost, low-power alternative to Direct Sequence Spread Spectrum (DSSS) that is robust and does not require a highly precise reference clock.

We have chosen a LoRa module of Ra-01 type with the following characteristics:

Table 1. LoRa parameters

Frequency	Sensitivity	Power	Voltage
410MHz 525MHz	-140dBm	+22dBm	3.3V

8 Result and Analysis

8.1 Result

In the following, we will present the visualization of the data collected from a cloud platform called ThingSpeak. It allows creating a channel associated with fields and retrieves information from HTTP requests from the gateway. From these graphs, we have a time representation of our different parameters. According to established standards, thresholds are defined for each parameter to have an idea of the level of degradation of water quality.

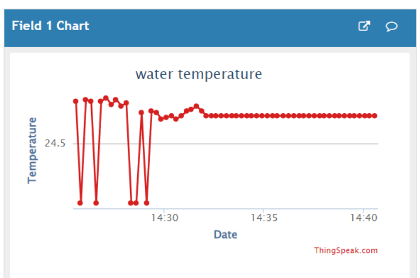

Fig. 9. temperature plot

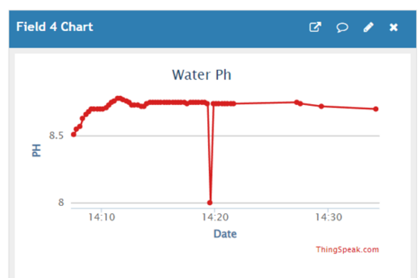

Fig. 10. pH plot

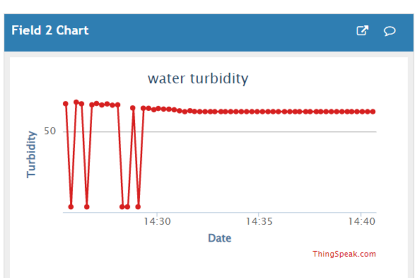

Fig. 11. Turbidity plot

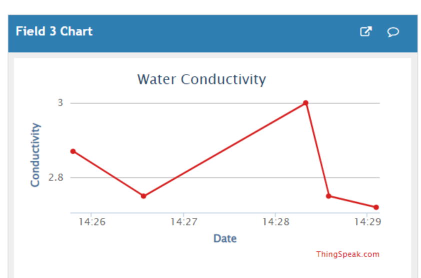

Fig. 12. Conductivity plot

The temporal representation of these parameters has enabled us to monitor the constants and gain an idea of their evolution. Once processed, these data will provide an overall idea of the level of pollution, based on standards set by the water quality regulation and control authority.

8.2 Laboratory Validation

In collaboration with the biological analysis laboratory of the Higher Polytechnic School of Dakar, we carried out a series of tests on the same sample to obtain values for parameters such as turbidity and pH. The results are shown in the table below.

Table 2. Laboratory result

Samples	Turbidity	pH	Hardness
3	3,81	7,35	3,40

Comparison and margins

- Turbidity: with the station, we have a turbidity value that stabilizes at around 3.50. This value is quite close to the 3.81 obtained with laboratory tests.
- PH: the station collects a pH value of around 8.6, while laboratory tests give a value of 7.35, giving a margin of -1.25.

In figure 13 we show the variation between the values collected by our station and the values of the samples tested at the laboratory.

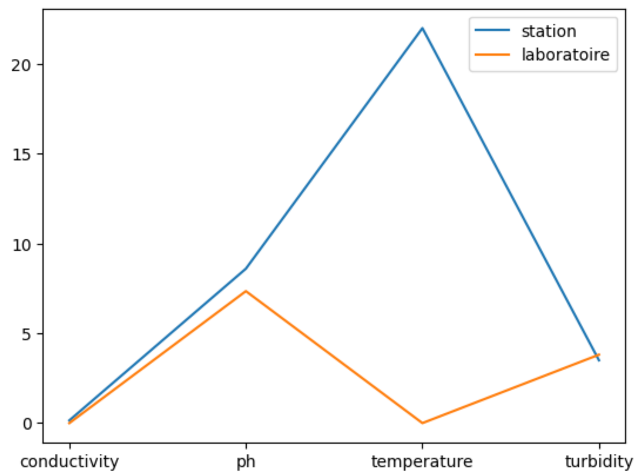

Fig. 13. Comparison of station and laboratory values

9 Conclusion and perspective

The aim of this project was to set up an intelligent water quality monitoring system using low-cost sensors and to verify the possibilities of application in the context of Senegal.

We set up a network of sensors to collect physico-chemical water parameters in real time, in order to monitor water quality. In this context, after the bibliographical study, we studied the existing systems, identifying their limitations in the first part. Then, in the second part, we identified the metrics to be monitored for the design and deployment of our system.

Finally, we were able to retrieve data in real time via the thingspeak cloud platform, where it is possible to observe variations in these parameters. With the communication model we developed, the monitoring station can be deployed over a distance of 15 km using LoRa technology.

Such a system is of capital importance for developing countries and can be mass-produced to allow a grid of waterways. This will enable the authorities to monitor developments and really understand the correlation between the growing number of industries being set up and the increasing levels of pollution. In the future, we plan to use deep learning models to output the corelation between the values of each parameter, with the aim of studying the profound impact of each parameter on the physical, chemical and biological equilibrium of the water.

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