Contributions to Reduce the Gap on Water Quality Analysis in Chile and Latin America: State of the Art

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Abstract— The global environmental crisis is one of the serious threats facing humanity, specifically water pollution has become one of the main concerns of all societies, due to the harmful effects it has on health, as it endangers all living beings. This paper presents a state of the art in the advances of water quality monitoring systems that can help prevent these adverse effects, however, there is a gap between progress in this area in developed countries and Latin American countries. On the other hand, decision making to mitigate the negative impacts requires a programmable platform. IoT technologies, with real-time data collection are explored, evidencing the existence of alternatives for communication such as WiFi, LoRa, 4G, among others, implemented in devices based on Arduino Uno or Raspberry Pi. On the other hand, the most used data processing, modeling and classification techniques have been those based on Machine Learning, given their advantages for data science, which reflects their potential in the use of water quality analysis systems.

***keywords*—Water Quality, IoT, Machine Learning, Python**

I. Introduction

The global environmental crisis is one of the serious threats facing humanity [1], and environmental pollution has become one of the main concerns of all societies due to its harmful effects on health [2], as it endangers human beings and other species, such as animals and plants. According to the World Health Organization (WHO), more than 30% of people suffer from diseases caused by consuming unclean water [3]. Recently, it has been reported that about 1.5 million people die each year due to diseases caused by the consumption of contaminated water [4]. Therefore, knowing the levels of different contaminants in water - which directly or indirectly influence the contamination of fruits and vegetables - is crucial. Additionally, contaminants such as antibiotics, pesticides, heavy metals can cause fertility disorders, neurodegenerative diseases and alterations of the immune system [2].

Nowadays, due to the rapid growth of human development, industrialization and increasing population density have boosted our economy and lifestyles but have also contributed to environmental pollution. Some industries release hazardous substances into the air and water with precarious – or even without any treatment - leading to the depletion of nature [3].

The specific study on water quality has not received as much attention in Chile and Latin America in general, as studies on air pollution have done [5], resulting in the existence of uninvestigated areas leaving a gap for the contribution of new forms of analysis of such contamination [6].

In Chile, according to the information provided by the Ministry of the Environment (MMA, *Ministerio del Medio Ambiente*), through decrees, the rivers and lakes whose pollution parameters are monitored are defined. For this purpose, an air and water quality control plan is developed which, according to the information provided by this agency in its web page, are annual plans for the control of rivers and lakes. [7]. In conjunction with this, it defines the monitoring points, as well as the frequency of these inspections. In relation to the latter, and by way of example, in Exempt Resolution No. 10 of January 4, 2023, the following is stated [7], sets the environmental monitoring program for environmental quality standards for that year. Within this program, out of a total of 38 inspections of polluting elements, 33 inspections were carried out for air and only 5 for water, with 13% of the resources dedicated to water quality monitoring. [7].

On the other hand, in developed countries such as the United States, a water quality monitoring network has been implemented with more than 7500 data collection points distributed over a wide geographical area of the country [8]. In this network, data can be found since 1960, which provides information on the main contaminating elements of water quality, including pH, conductivity, dissolved oxygen, hardness, temperature, total dissolved solids, among other parameters.

Maintaining water quality is essential and to achieve this objective, the analysis of the chemical, physical and biological characteristics of the water allows to check its suitability for the intended use [9]. This analysis is a process of measuring and evaluating water quality parameters to verify whether they conform to prescribed standards, but manual inspection is a tedious task and its analysis lacks accuracy [10]. For this reason, thanks to technological advances, there are automated techniques in which hardware (sensors, remote communication equipment, among others) and software tools are adopted, such as those based on machine learning, which allows to solve prediction or classification problems from historical data sets [10].

Recent international studies seek to determine the main contaminants present in water, analyze its quality through the

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measurement and evaluation of the different components and then, as a result, define the water quality and project the behavior of the different parameters. [3]. For this purpose, a series of techniques and tools based on Artificial Intelligence (AI), including data mining, have been developed, such as Machine Learning (ML) tools [11]. However, in order to validate these predictions, it is necessary to obtain data over a long period of time, for which it is generally necessary to years of measurements are required [12] [13].

II. WATER QUALITY MONITORING

Water has existed on Earth for 3 billion years and is considered one of the extremely essential and fundamental components for the survival of living beings, therefore, having water, free of contaminants, is basic to satisfy this need [3]. All societies, ecologies and productions need abundant supplies of clean water, with a level of purity defined as safe [4] for agriculture, drinking water, sanitation and energy production [1].

One of the main problems suffered by the oceans, as well as freshwater sources such as lakes and rivers, is pollution, which is defined as the damage caused to water, air and the environment in general by harmful substances or waste [14], therefore preserving the quality of this resource has become an urgent matter for humans and water ecosystems [15].

A series of tools based on IoT communications platforms have been developed to create a network for monitoring the main parameters that measure water quality [10],[16],[17], among which are conductivity, dissolved oxygen, pH, total dissolved solids, temperature, turbidity, etc. [12].

Water quality depends on physical, chemical and biological factors contained in the water [18]. A variation in the values of parameters such as electrical conductivity, dissolved oxygen, pH, temperature or turbidity causes a change in water quality [19]. Table I shows a summary of the definition of some parameters that influence water quality.

Each of the parameters has a range or maximum allowable value which has been defined by the WHO [19], whose objective is to ensure consumption free of risks to human health and living beings in general, including vegetable crops and plantations [20].

TABLE I
DEFINITION OF WATER QUALITY PARAMETERS

Parameter	Definition
Conductivity	Electrical conductivity of water
Hardness	Concentration of dissolved minerals
pH	Acid or alkaline water status indicator
Dissolved Oxygen	Quantity of oxygen molecules dissolved in water
Dissolved solids	Presence of salts, minerals, organic compounds
Temperature	Measurement of thermal energy in water
Turbidity	Amount of solid matter in suspension

It should be noted that these parameters are widely accepted by Latin American countries, as well as by developed countries. Table II shows the reference values of the main parameters that indicate water quality [20].

III. WATER QUALITY ANALYSIS MODELS

Water quality models have been studied since 1926, with Streeter and Phelps [6] being the first to propose and develop a model called Streeter-Phelps (S-P), which is based on oxygen balance and is a one-dimensional steady-state water quality assessment model. It has been widely used, but is difficult to apply in complex environments as it only analyzes oxygen balance [6].

Subsequently, researchers from both European and North American countries studied new water quality models, such as the Thomas model, the Dobbins-Camp model, and the O'Connon model based on the Streeter-Phelps model [6], among others. Later, models QUAL2E and QUAL2K, CE-QUAL-W2 and CE-QUAL-W2 were proposed [6], the water quality analysis simulation program WASP (Water Quality Analysis Simulation Program), the Soil and Water Assessment Tool (SWAT), etc., which have been widely used for water quality analysis [6]. In general, these are techniques that are mainly based on statistical mathematics such as time series prediction or the statistical model of Kolmogorov–Smirnov among others [21]. At present, although water quality prediction models have matured and are suitable for simulation in rivers, lakes, reservoirs, they are models that usually require a lot of data on pollutant parameters that measure water quality [6].

Thanks to the development of AI and with the widespread application of ML in different fields [12], in recent years there has been a surge of new and emerging technologies that enable the handling of large amounts of data. AI is a technology that can deliver potential solutions to pollution data analysis problems. ML is a branch of AI, which offers a strategy for making decisions and predicting the behavior of environmental variables based on historical data [2]. As a complement to the above, Data Mining is used to address nonlinear equation problems, which has been applied to the study and analysis of water quality [1].

Some of the ML techniques used in the study of the behavior of the contamination parameters present in the water are Recurrent Neural Network (RNN) [15], Support Vector Machine (SVM) [15], [20], [22], Support Vector Regression

TABLE II
WATER QUALITY PARAMETERS ACCORDING TO WHO [20]

Parameter	Safe range
Conductivity	200 o 400 µS/cm
Hardness as $CaCO_3$	500 mg/l
Dissolved Oxygen	5 a 14.6 mg/l
pH	6.5 a 8.5
Total dissolved solids	1000 mg/l
Temperature	NA
Turbidity	0 a 5 NTU

(SVR) [3] which is the regression version of SVM, Back Propagation [6], [20] [23], Fuzzy [23], and hybrid methods combining the aforementioned methods [6], [23]. There are also research papers where techniques are applied to as Euclidean distance [20], confusion matrix, [4], [22], Decision Tree [4], [24] or the technique of Naive Bayes [15], [25], [24]. Another technique used is called ARIMA (Autoregressive Integrated Moving Average) which consists of a prediction method based on a sequence of historical data that are analyzed as a random sequence [26], and specifically, the Principal Component Analysis technique is used (PCA) to obtain the appropriate data and apply SVM [15].

Other techniques currently used in hydrological processes as well as in the analysis of water quality are algorithms such as M5P, Random Tree (RT), Random Forest (RF), Bagging (BA), Reduce Error Pruning Tree (REPT), Random Committee (RC) [1], etc.

Complementing the above, there are works that use Computer Vision for the analysis of contaminants present in water, but this area of study is focused on the detection of objects, which are visualized with the naked eye [27].

IV. DATABASES

One of the critical aspects when analyzing the pollutant parameters that allow defining water quality is the collection and availability of data, since ML algorithms, for their correct operation, require large amounts of data of good quality, the latter being understood as reliable and representative data [2].

A set of data, collected from a monitoring system, without proper processing, is not useful for analysis since most of them include noise, missing values, excessive amount of data, as well as incoherent information, among other problems. Given the above, it is necessary to process them in such a way as to form a useful database to be used as input for an ML tool. One of the strategies is the application of techniques such as PCA, which is mainly used to reduce the number of data that are not useful and create a consistent DB, which is one of the most complex and time-consuming steps in the implementation of a system to analyze, determine and predict water quality [11].

The data used in the research work carried out at [15] are derived from two main sources, which are existing databases and data obtained from real-time measurements [15], [18], [22]. Regarding existing DB, some of them can be found on websites such as Kaggle [12], Goa State Pollution Control Board (GSPCB) [3] or other sources. In addition to the above, data are available from governmental entities through the corresponding ministries, such as in India [23], Abu Dhabi [28], Delhi [4] among others.

Some studies have worked with data obtained from monitoring points implemented for this purpose, which collect data over extended periods of time, generating a database suitable for further analysis. In other cases, they have used existing databases in the ministries of the environment, as in the case of studies carried out in South Korea [21], in other countries have worked with data made available from online sources by government agencies, as in the case of studies carried out in India [23] and other studies have used data obtained from ponds specially installed for this purpose in which water samples of the following have been taken different natural sources [29]. Table III shows these results.

V. WATER MONITORING PLATFORMS - HARDWARE

A water monitoring platform requires hardware and software to perform its assigned task. The hardware is composed of subgroups: sensors and IoT communications.

The sensors are responsible for measuring and collecting data for each of the parameters of the water quality monitoring system. The IoT communications network is responsible for the transmission of information from the collection point to the data storage point for processing [29]. Considering that the sensors are an essential part of the network, it is as complex as the number of parameters to be measured, so the definition of the parameters to be monitored must be made considering this condition. Regarding the communications network, the technology to be used depends strongly on the distances to be covered for monitoring the parameters, and there are several alternatives such as WiFi, LoRa, 4G, among others [29]. Fig. 1 shows a general schematic of a water quality monitoring system using Arduino Uno.

TABLE III
SUMMARY OF REFERENCES AND THEIR MAIN CONTRIBUTION

Reference	Techniques	Parameters	BD	Results
[3]	kNN, SVR, DTR, RF	pH, T°, BOD, turbidity	Kaggle, GSPCB	kNN lowest error
[4]	*Naïve Bayes, SVM*	pH, T°, conductivity and DO	BD of the Delhi government	kNN achieves accuracy of 99,65%
[10]	RF, LR, SVM	Uses different parameters	Uses hypothetical data found on the Internet	Best result with LR
[11]	*Decision Tree,* ANN	pH, DO, hardness, total dissolved solids	BD of the Iraqi ministry of environment	DT better response time. ANN better accuracy and error rate
[12]	SVM, XGBoost	pH, conductivity DO	Kaggle and the government of India	SVM 67% v/s 94% of XGBoost
[15]	RF, Extra Tree, Decision Tree	pH, conductivity, turbidity, DO.	Samples from 10 different points	RF delivers the best result
[23]	DT y Neurofuzzy	pH, hardness, calcium content	BD online	DT better result.
[22]	SVM with RBF and Polynomial Kernel	pH, conductivity, hardness, turbidity.	BD contains 59 samples from various locations	RBF and Polinomial performance were greater than 80%. RBF was the best

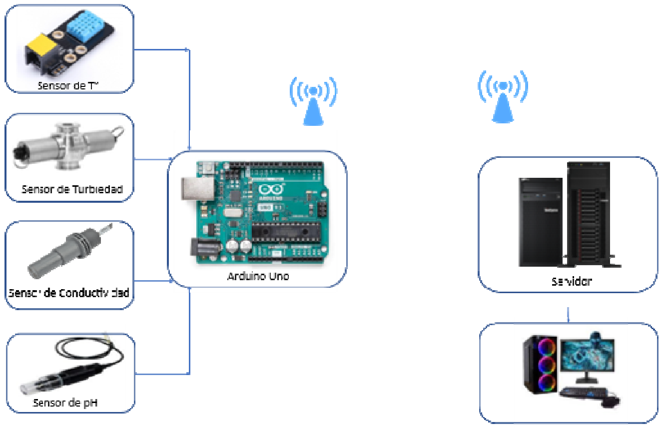

Fig. 1. Hardware schematic diagram for a monitoring system using Arduino.

Within the hardware of a water quality monitoring system is the microprocessor, which, for the purposes of an IoT network are Arduino Uno and Raspberry Pi. One of the most important characteristic of Arduino boards is that they consist of a flexible and easy-to-use hardware and software part that allows you to add sensors as needed [30].

One of the developed configurations is based on Arduino Uno whose microcontroller is ATMega328, which includes pH, turbidity and temperature sensors, where the communication is WiFi and the data is sent to the cloud for further processing [20].

Another configuration is based on the ESP32 microcontroller with pH and temperature sensors, where data is processed in the microcontroller and then sent to the cloud through LoRa32 nodes for further analysis based on an application developed in Android for faster viewing on a smartphone [29], [31]. The use of pH, turbidity and temperature sensors in conjunction with Arduino Uno and the Dragino Shell working in conjunction with a LoRa Gateway, is another of the alternatives proposed [32].

Another microcontroller used for the implementation of a water quality parameter monitoring system is the ESP8266 which has an integrated WiFi module and is of low cost. In conjunction with this microcontroller, a flow sensor, turbidity sensor, pH sensor and temperature sensor are used, which are connected to the microcontroller [17], [30]. Sensor reading data is transmitted to the Google Firebase database via the built-in WiFi module or via the LoRa module if no WiFi signal is available [30]. Table IV shows some microprocessors used in water quality monitoring systems.

TABLE IV
HARDWARE USED IN MONITORING SYSTEMS

Microprocessor	Sensors	Communications
AT Mega328	pH, temperature and turbidity	WiFi with the cloud
ESP32	pH, temperature	LoRa32
Arduino – Shell Dragino	pH, temperature turbidity	Gateway LoRa
Arduino mega 2560	pH, oxidation potential, temperature and turbidity	N/A
ESP8266	Flow, pH, temperature and turbidity	WiFi - LoRa
MSP340	pH, temperature, turbidity	LoRa
PIC18F2520	pH, pH, temperature, turbidity, ultrasound	WIR-1186
MCP3208	pH, temperature and turbidity	GPRS – SIM card

VI. WATER MONITORING PLATFORMS – SOFTWARE

As for the software, one of the alternatives proposed is the development of Python programs that periodically request data from a web site [33], [34]. The data are coded in Action Message Format and are encapsulated in the messaging service Flex [33].

For the development of Window 10 compatible platforms, Microsoft Visual Studio software is used to visualize the results in a Window 10 environment [35].

Those works that simulate the behavior of the different parameters, obtained from databases, use Matlab as a software platform, which allows them to analyze the results by applying different tools for ML [22], [23], [25] [36].

C language is another software used. One of its advantages is that it can run almost as fast as assembly code. The entire IoT configuration and its operation are coded in C programming. Once all the coding part is done, the executed code is stored on an SD card and inserted into the Raspberry Pi. Spyder is an open-source platform (IDE) for Python programming with Anaconda. Spyder integrates several Python packages, along with NumPy, SciPy Matplotlib, Pandas, IPython, SymPy and Cython as alternative source code. Finally, using ML techniques, data classification is done [25]. Table V summarizes the main software packages used in water quality prediction models and related analyses.

VII. CONCLUSION

In this the most up-to-date global research worldwide on water quality monitoring models and the main tools used from the

TABLE V
SOFTWARE USED IN MONITORING SYSTEMS

Reference	Software	Techniques	Results
[22]	MatLab R2021A	SVM with RBF and Polynomial Kernel	RBF was the best and greater than 80%
[23]	MatLab	ML with DT and AI with Neurofuzzy	ML with DT better than the AI with Neurofuzzy
[25]	Python with Anaconda using Pandas.	Naive Bayes, LR, RF.	Obtains all the techniques used to process the data
[34]	Python	LSTM, BP, LSTM-BP	LSTM-BP has better performance than each one
[35]	Microsoft Visual Studio – Windows 10	SVM	It was implemented for Data Tx using IoT. Response time was less than 10 s
[36]	MatLab/Simulink	Transmits sensor parameters from T°, conductivity and pH without data processing	Compare different frequency in LoRa system for data Tx

perspective of the parameters monitored, machine learning tools used, the databases, microprocessors, IoT communications systems and the main software packages.

In Chile, although there are water quality monitoring systems, these are basic systems that allow obtaining information on water quality, however, sampling is not permanent in time, generating sporadic data from different monitoring points, since this is done a few times a year depending on those established by the competent authority.

Artificial intelligence and machine learning tools, given the characteristics of being tools for the analysis of large volumes of data, there are very good alternatives for model development to analyze and predict the behavior of the main water pollutants.

Water quality monitoring systems are based on the use of low power consumption microprocessors that have the appropriate processing capacity for the proposed objective, such as Arduino Uno and Raspberry PI. In conjunction with these microprocessors, the use of IoT transmission systems, such as LoRa technology, helps to have optimal systems.

In terms of software tools, MatLab and Python deliver excellent results, both being suitable for the implementation of a water quality monitoring system.

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