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Monitoring the Hydrogen Potential of a River in the Central Andes of Peru From the Cloud

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ABSTRACT

The hydrogen potential is one of the parameters of the water which is variable in rivers throughout their journey over the cities, so the objective of the work was to monitor (from the cloud) the pH of the Upamayu river waters (Huancavelica region), located in the Central Andes of Peru. An electronic system was implemented, comprising: DS18B20 temperature sensor, 4502C pH sensor, ESP32 controller, NEO 6M GPS global positioning system, LabVIEW NXG platform, in addition to the web server developed in ThingSpeak. The measurements were established under the protocol for water resources of Peru. As a result, a pH monitoring system of the waters of the river under study was verified. Through the sensors, it takes the data and sends them to the web server located in the cloud via the implemented algorithm. The data read from any remote place through an application implemented in LabVIEW NXG, representing the monitoring station on a GIS map. It was concluded that the values of the hydrogen potential are different in relation to its territorial distribution and in the dry season. Varying pH after the discharge of polluting sources of the population and the places of cattle raising was found; likewise, regeneration of the waters at a certain distance was shown.

Keywords: pH, remote meter, web server, polluted water, GIS visualization

INTRODUCTION

Since time immemorial, rivers have transported the waste generated by different human activities (Zhang et al., 2021). Water has a high purification capacity, either due to its natural cycle or by microorganisms that improve resilience, making it suitable for plant cultivation (Falkenmark & Wang-Erlandsson, 2021; Liu et al., 2020). The longer the crossing of a river through cities is the more exposed to pollution, many times due to the lack of laws that protect it or due to the fact that sewage is not adequately treated (Bruce et al., 2020).

The rivers of Latin America are polluted with toxic elements due to emerging pollutants, these pollutants increased in the last decade, as mentioned in the work on the review of pollutants in river waters that circulate in urban areas carried out by Peña-Guzmán et al. (2019), who found in numerous investigations carrier out in Brazil and Mexico that the main pollutants in the river are pharmaceutical and personal hygiene products, as well as effluents from wastewater treatment plants. In Latin America and the Caribbean, there is a high dependence on the food irrigated with the water from rivers. Therefore, to achieve sustainable development, it is important to improve water quality and governance, integrating with the technological systems that allow monitoring its quality (Mahlknecht et al., 2020).

A Custodio & Peñaloza study was carried out in the Cunas river in the department of Junín in Peru (2021), the data on the physical-chemical parameters of the waters of this river were collected manually, indicating the lack of a program to monitor and conserve the aquatic environment. Grande et al. (2019) characterized the hydrogeochemistry of the Negro River, in Peru, along its course, concluding that the river is contaminated in a massive way by the sulfurous material from the Cordillera Blanca, producing direct oxidation for sulfates, hydrogen ions and the generation of acid that must be constantly monitored. Likewise, it is necessary to recover the waters previously used in homes using some technology (Carbajal-Morán et al., 2021), before being discharged into the river beds.

The high rainfall on the western slope of the Central Andes of Peru, due to its topography, generates the washing of the surfaces, introducing physicochemical compounds to the waters of the rivers, producing relative changes in values that reach up to 25%, as established in the experiments conducted in the Mantaro basin by Saavedra et al. (2020).

It is necessary to constantly verify the quality of river waters as it is a vital element for the subsistence of the aquatic ecosystem; Therefore, in this work it was proposed to implement a system to remotely monitor (from the cloud) the concentration of the pH in the waters of the Upamayu river along its path that crosses four districts of the province of Tayacaja, Huancavelica-Peru.

MATERIALS AND METHODS

Study area

The work was conducted on the path of the waters of the Upamayu river, located as the point of origin monitoring station 0 at a latitude -12.341171°, longitude -74.970485° and altitude 4124 meters above sea level. The final point was latitude -12.338028°, longitude -74.826365° and altitude 3175, which represents monitoring station 24; 10 km from the mouth of the most important river in the central Andes of Peru such as the Mantaro river in the province of Tayacaja, Huancavelica – Peru. Figure 1 shows the source of the river and the final station for monitoring the pH of the river.

Figure 1. Source of the river and the final station of monitoring the pH of the river

On the path of the river, which crosses the urban areas of the districts of Acraquia, Ahuaycha, Pampas and Daniel Hernández, 24 stations were installed for monitoring the pH and temperature of the waters of the Upamayu river. The polluted waters of these four urban areas are stored in four oxidation wells with discharge to the river under study, for which the pH and temperature samples had to be taken immediately before and after each oxidation well within the established framework by the national protocol for monitoring the quality of surface water resources in Peru (ANA, 2016).

Data collection instruments

An electronic data collection system was implemented consisting of: pH sensor, temperature sensor, ESP 32 microcontroller, GPS NEO 6M. In Figure 2, the general diagram of the electronic system that allowed data collection is presented.

pH sensor

Measuring the pH of the river water along its path is very useful to establish the level of contamination. The pH meter has electrodes and requires calibration for proper application (Scidle, 2017). This meter detects the level of acidity or alkalinity in a certain solution on the varying pH scale between 0 and 14. The pH

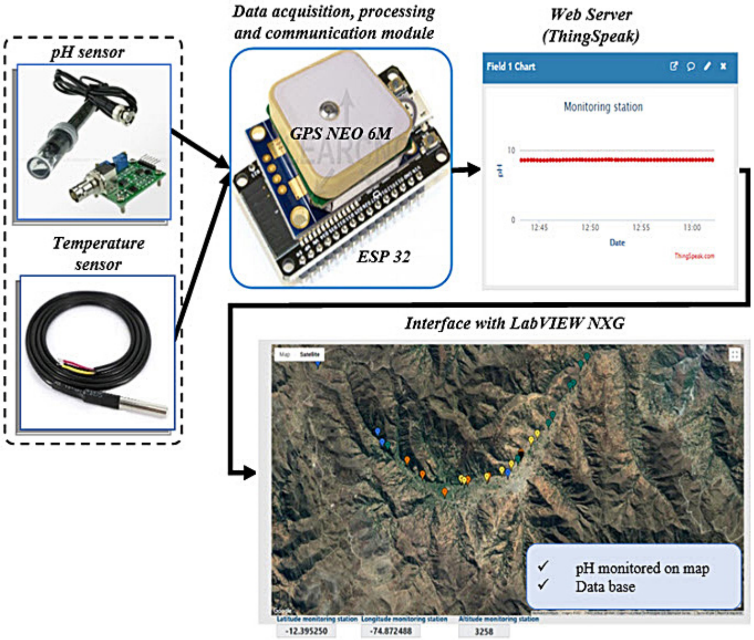

Figure 2. General diagram of the electronic data collection and analysis system

value represents the amount of hydrogen ions $[H]^+$ in river waters. It requires a signal conditioning circuit to be sent to the ESP32 microprocessor. The pH sensor was calibrated using the offset and span potentiometers found on the electronic card in Figure 3.

The pH sensor was calibrated at three points using buffer solutions; pH 4.003 with 3.04 millivolts (mV), pH = 6.864 with 2.54 mV and pH = 10.0 with 1.97 mV, having obtained equation 1 with R2 = 0.9999 to calculate the "pH" dependent on the signal (χ) coming from the sensor in mV, such as seen in Figure 4.

$$pH = -5.5961x + 21.04 \tag{1}$$

The pH reading of the river waters was based on the algorithm presented in the flow diagram of Figure 5 that was implemented in the ESP32 processor. With the slope m = –5.5961 and the constant b = 21.04 and "Sensor pH" is the signal (χ) from the sensor measured in mV. It starts with taking 30 samples to improve the precision of the pH data; then the pH of the river water is averaged and calculated.

Temperature sensor

The water temperature of the Upamayu river was measured by means of the DS18B20 digital sensor with a measurement range from -55 to 125°C, with a configurable resolution of 9 to 12 bits, with a capture time of less than 750 ms,

Figure 3. PH meter calibration module, probe and buffers

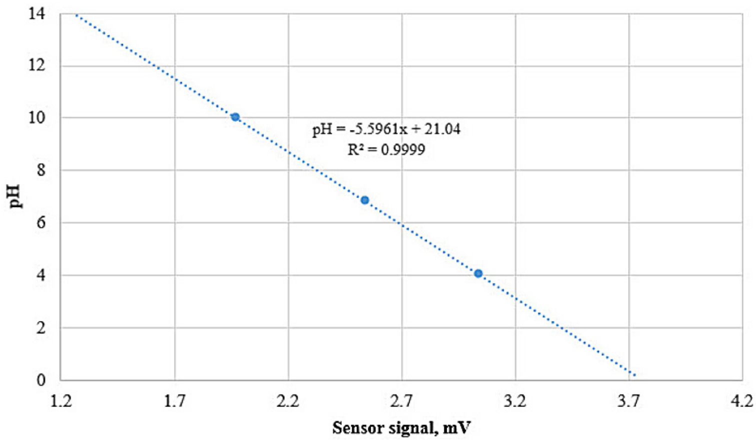

Figure 4. Three-point pH sensor calibration curve

with a power supply of 3.0 V to 5.0 V. It uses the 1-Wire protocol to communicate (MakerElectronico, 2021); this protocol communicates whit the sensors on the same bus by a single pin. This sensor has a special protector that allowed it to be immersed in the waters of the river.

The temperature data was obtained by programming in the ESP32 processor, including special libraries developed for this sensor that made it possible to communicate the data through a single connection bus; selecting the address "0" of the sensor and carrying out the temperature measurement (see Figure 6), which is then sent through the ThingSpeak to one of the corresponding fields.

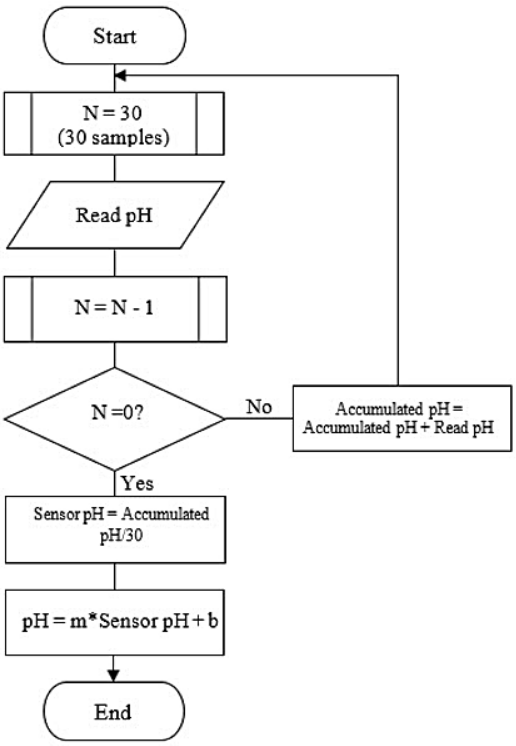

Figure 5. PH sensor measurement flow chart

Geoposition with GPS

The geoposition of each monitoring station was determined with GPS NEO 6M that is powered with 5 V, with a serial communication of 9600 bits per second (bps) and ceramic antenna for the detection of global positioning satellite signals (Ublox, 2016).

GPS NEO 6M allowed obtaining the longitude, latitude and altitude of the 24 monitoring stations previously defined in strategic places and with ease of access. A special library was used for the GPS for Arduino configured in the ESP32 processor with a communication at 9600 bps. The geographic positions of the latitude and longitude stations had four integers with a precision of six decimal places, while the altitude only required four integers and two decimal places of precision. These measurements were performed using the diagram in Figure 7.

ESP32

It is a powerful processor created by Espressif Systems, as it is included in the DEVKIT V1 NodeMCU-32 development board; it allows the construction of IoT (Internet of Things) projects. At the connectivity level, it allows Wi-Fi connection: 802.11 b/g/n/e/a 2.4 GHz higher than 150 Mbit/s. In addition, it includes internally a large number of peripherals for connection with: touch sensors, Hall effect sensor, high impedance amplifiers, interface for SD card, Ethernet, UART, I^2S and I^2C as seen in the diagram of Figure 8 obtained by Espressif Systems (2020). These characteristics enabled the work integrating the sensors of pH, temperature and the GPS NEO 6M.

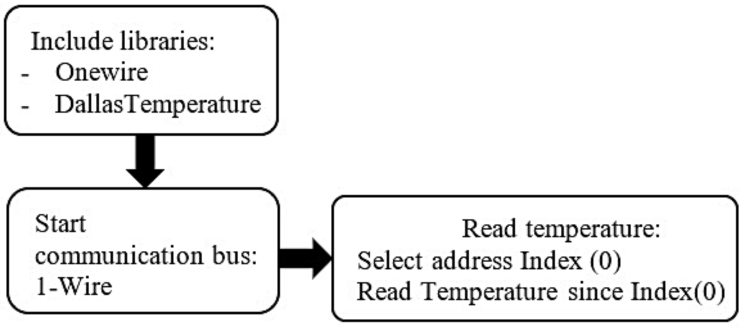

Figure 6. Temperature measurement flow chart with DS18B20 sensor

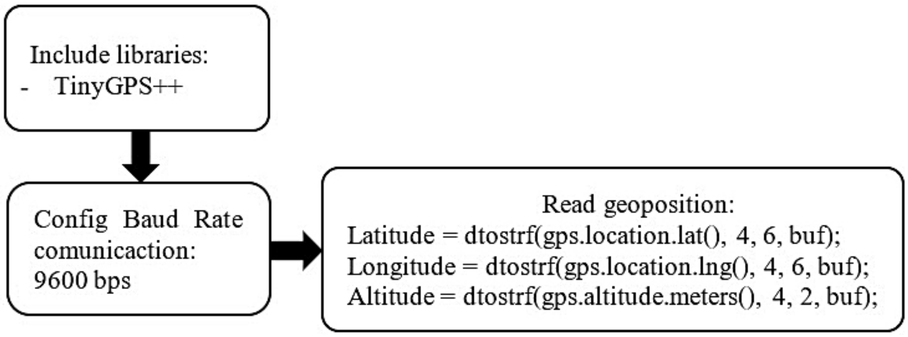

Figure 7. Latitude, longitude and altitude measurement flow chart with GPS NEO 6M

The programming was carried out on the Arduino Integrated Development Environment (IDE) platform, which is a tool supported on Windows, macOS and Linux, written in the Java programming language. It is used to develop the applications compatible with Arduino, such as the ESP32 processor.

Data acquisition

The data from the NEO 6M GPS, pH, temperature, longitude, latitude and altitude sensors were acquired by the ESP32 processor and sent to the 5 respective fields of the web server channel configured in ThingSpeak, using the

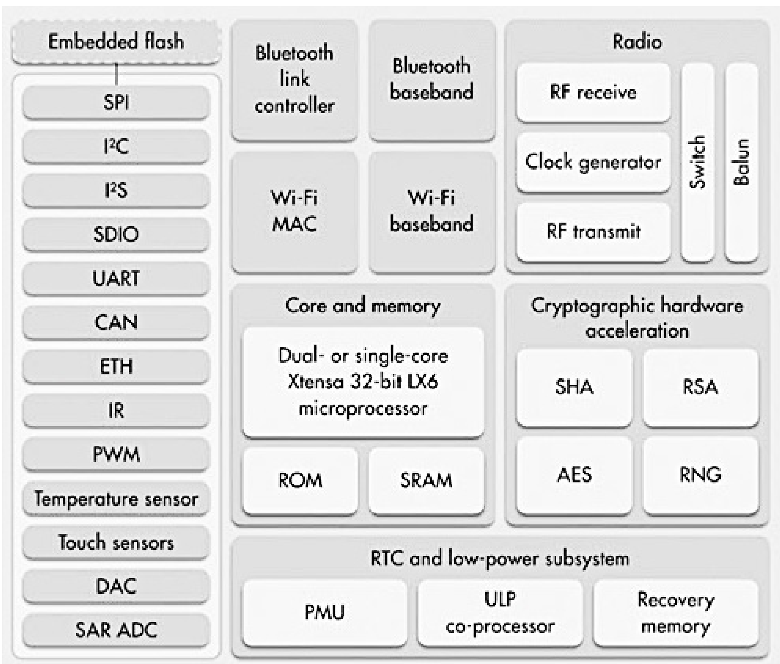

Figure 8. ESP32 processor function diagram

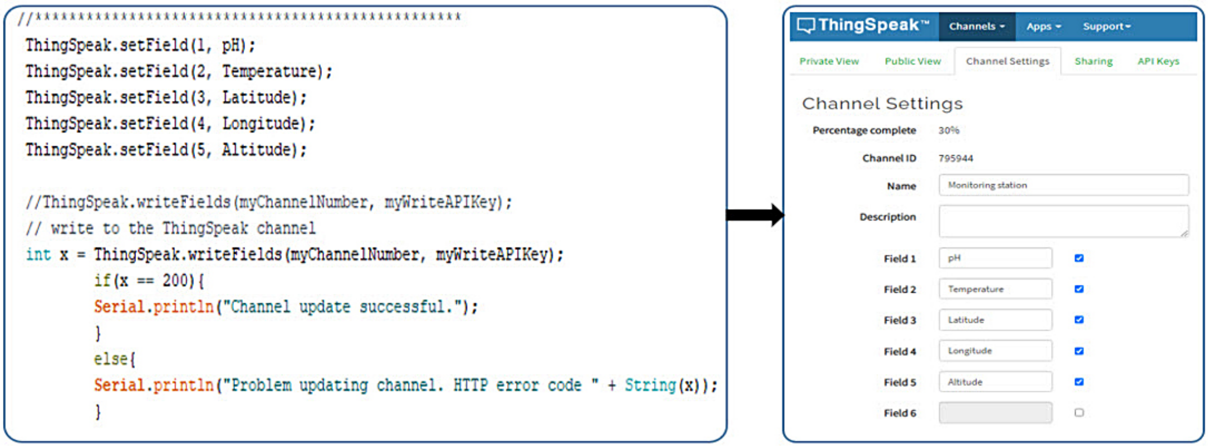

Figure 9. Configuration of the fields in the communication channel with the web server

myWriteAPIKey = "U8NNOJHOHAA0VAGF" (see Figure 9).

Graphical interface

The graphical interface was developed in LabVIEW NXG trial version (2021), through the link https://api.thingspeak.com/channels/795944/feeds/last.json?api_key=UJ85H7KOJ52OY8EF the data is obtained from the web server located in the cloud through the Http Get toolkit and decoded by the application JSON (see Figure 10), to later be displayed on a GIS map.

The geolocation values were displayed on the satellite GIS map of Figure 11, establishing the 24 monitoring points or stations along the river's path.

The temperature and pH levels of the different monitoring stations were displayed on the historical diagrams (a) and (b) of Figure 12, these values are related to the previously selected monitoring station, and visual alarms can be established for the high and low levels of temperature and pH.

Water quality assessment index as a function of the pH parameter

The assessment of the quality of the water can be understood as the evaluation of its chemical, physical and biological composition in relation to the natural quality. In order to interpret the monitoring data, there are water quality indices (WQI) and contamination indices (ICO), which reduce a large number of parameters to a simple expression that is easy to interpret (Torres et al., 2009). Next, the equation 2 for the water quality index of the United States National Sanitation Foundation (NFS-WQI) is presented.

$$WQI = \sum_{i=1}^{9} (Q_i * w_i) \tag{2}$$

Being: Q_i the quality factor of the variable, depends on the magnitude of the variable and is independent of the rest, the one used in this study is for pH with i = 2 , with a weight W_2 = 0.12.

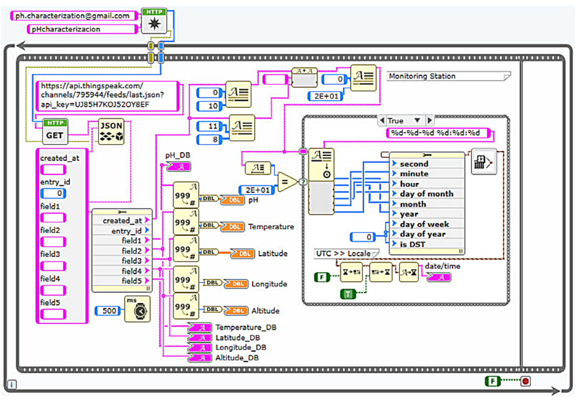

Figure 10. Data acquisition diagram from cloud web server

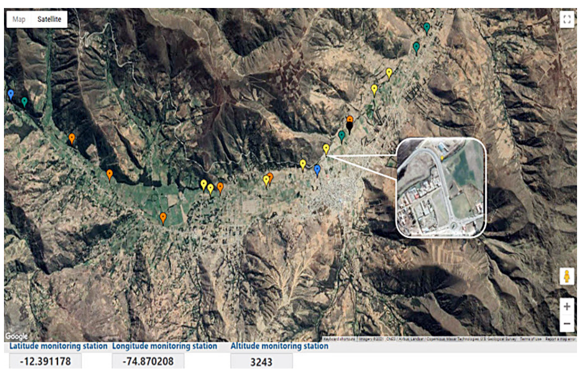

Figure 11. Values display map for each monitoring station

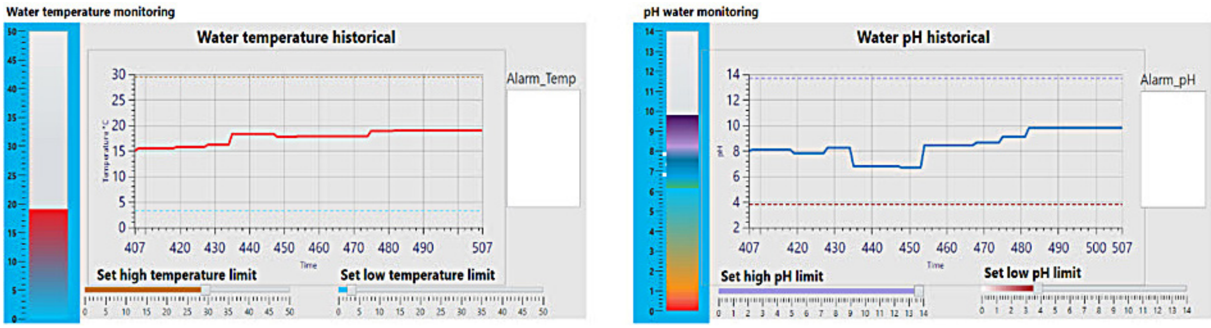

Figure 12. Historical data display of water parameters (a) temperature and (b) pH

Figure 13 shows the NSF-WQI assessment for the observable pH with its respective value Q_i (Brown et al., 1972).

The pesos relative assigned to each parameter of the subscript are presented in Table 1; they are weighted between 0 and 1, in such a way that the sum is equal to one.

From the variables of Table 1, the pH variable of 0.12 weight was taken for its analysis of the river waters, throughout its entire journey; from the source to the mouth.

Of Q_2 value obtained the quality of the water can be determined as: excellent, good, fair, bad or very bad associating in the range of 0 to 100% (Brown et al., 1972), as shown in Table 2.

The characteristic function of the parameter pH in Figure 13, is determined by the following conditional function: *If* $pH < 2$; $Q_2 = 2$, *If* $pH < 12$; $Q_2 = 3$, *If* $2 <= pH < 7$; $Q_2 = 4.5431\ pH^2 - 23.77pH + 33.109$, *If* $7 <= pH < 8$, $Q_2 = -22\ pH^2 + 325\ pH - 1107$, *If* $8 <= pH < 12$, $Q_2 = 5.9567\ pH^2 - 139.33\ pH + 818.63$;

This function was implemented in the diagram in Figure 14, developed in LabVIEW NXG, associating the output to the water quality factor of the pH parameter.

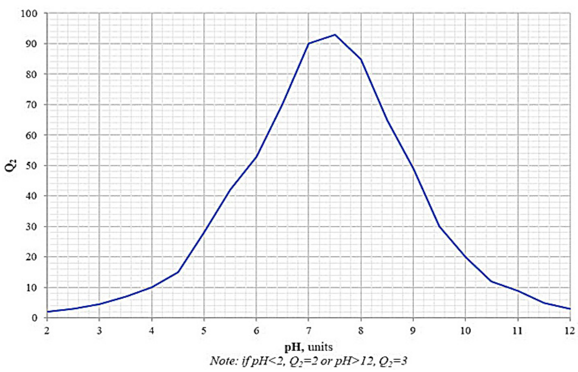

Fig. 13. Function for the evaluation of the quality factor of pH in water

The pH data characterized with the conditional function were sent to the monitoring interface; where each station is selected to view the pH data and its corresponding quality index (Q_2, %), as shown in Figure 15.

RESULTS AND DISCUSSION

The temperature and pH levels of the river water, were varying throughout the 24 monitoring stations, due to the different sources of contamination; among the causes are the residues from agriculture, livestock and the dumping of sewage from the population that are not adequately treated in the existing oxidation deposits. Due to the resilient regenerative capacity of water (Bedla & Halecki, 2021), the pH fluctuates at different levels as presented in Figure 16.

The water pH quality index was obtained for each monitoring station, as shown in Figure 17.

Table 3 shows the result obtained from the characterization of the pH of the 24 monitoring stations in the dry season April to May of the year 2021; being the one with the lowest quality index found in station 15 for a $pH = 9.79$ and $Q_2 = 24\%$, this shows that the Pampas-DH oxidation well is not operating and that all the water contaminated by the population is being discharged directly to the river waters. In monitoring station 4, the quality index $Q_2 = 40\%$ for a $pH = 5.40$ is given because this station is in a livestock area whose low pH biological waste is dumped directly into the river waters. The water arrives at monitoring station 24 with a pH of 8.

Characterization of the pH of the waters of the Upamayu river shows that this is a variant along its path (see Table 3), appearing at monitoring station 1; located at a latitude of -12.375030°, longitude -74.948003° and altitude of 4104 meters above sea level and the monitoring station 2

Table 1. Assigned weights to each water variable according to NSF-WQI

Variable (Q_i)	Weight (Wi)
Fecal coliforms (CF)	0.15
Hydrogen potential (pH)	0.12
Biochemistry of oxygen demand (BOD5)	0.10
Nitrates ($NO3^{-1}$)	0.10
Phosphates (PO4 3–)	0.10
Temperature change	0.10
Turbidity	0.08
Total dissolved solids (STD)	0.08
Dissolved oxygen (DO)	0.17

with qualifications of "Excellent" which is geolocated in the areas near the source of the river without the exposure to polluting sources. Monitoring stations 3, 14, 19–21 and 23–24 with a "Good" rating are located in remote areas beyond sources of contamination such as oxidation wells that discharge water into the river, this rating is achieved after the regeneration of water in its natural course. Monitoring stations 7–8, 10, 12–13, 17–18 and 22 with a "Regular" rating are located at distances greater than 200 meters from the

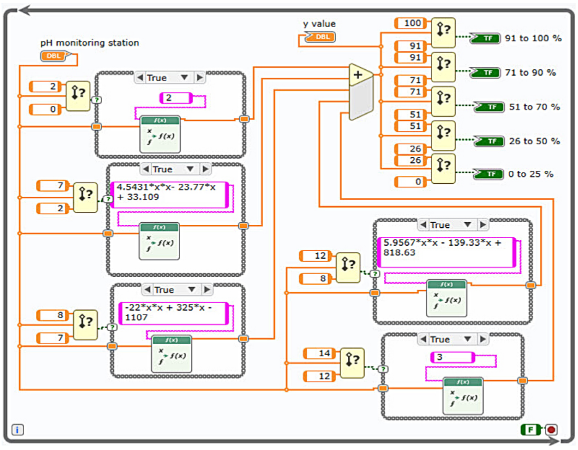

Figure 14. Diagram for calculating the river water pH quality factor for each monitoring station

Table 2. Water quality associated with the pH factor

Water quality	Q_2 (%)
Excellent	91–100
Good	71–90
Regular	51–70
Bad	26–50
Very bad	0–25

sources of contamination. Finally, monitoring stations 4–6, 9, 11 and 16 with a rating of "Bad" are the closest to the sources of pollution generated by agriculture, livestock and the population.

These results are consistent with those found by Peña-Guzmán et al. (2019), who determined that the effluents from wastewater treatment plants are a source that contaminates river water if proper treatment is not carried out. Likewise, the results show the high-water purification capacity by aquatic plants and the existing microorganisms that help resilience, making these waters suitable for use in crops, which is consistent with the study by Falkenmark & Wang-Erlandsson (2020).

Finally, it is necessary to improve the governance of river waters in order to reduce the uncertainties about how to evaluate and manage river waters in the future, which is consistent with the proposal of Xia et al. (2021), who proposes that it can be through a systemic approach that integrates the dimensions: water, ecosystem services, biological diversity and resilience, for sustainable development. On the other hand, Huang et al. (2021), proposes to investigate the meteorological conditions as a pattern of spatial quality of the water and the underlying factors that deteriorate the river. Likewise, as argued by Mahlknecht et al. (2020), it is necessary to improve the governance of water and infrastructure, integrating with technological systems that allow its quality to be constantly monitored and sustainability achieved (Kumar et al., 2021).

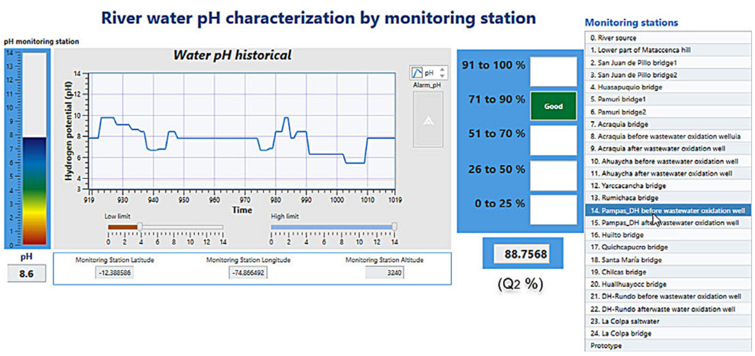

Figure 15. Interface for monitoring and characterizing the pH of river waters with data from the cloud

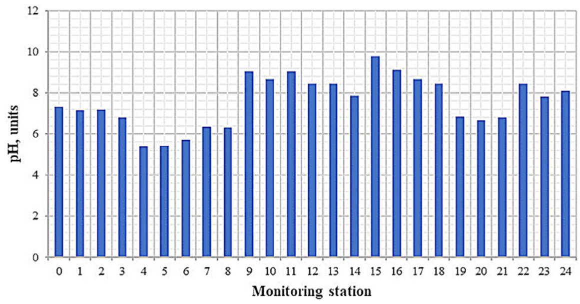

Figure 16. PH levels for each monitoring station

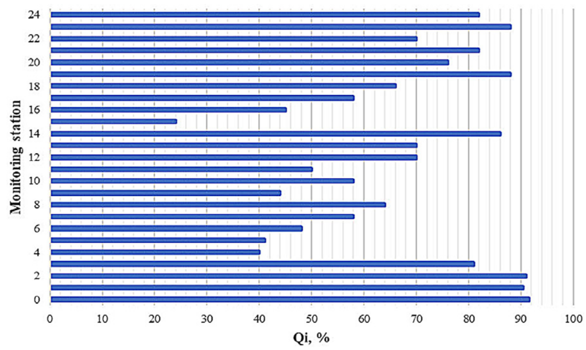

Figure 17. Quality factor of the pH variable for the 24 monitoring stations

CONCLUSIONS

A system was implemented to remotely monitor (from the cloud) the concentration of the hydrogen potential of the waters of the Upamayu river along its path that crosses four districts of the Tayacaja province of Huancavelica-Peru. It was found that the pH values are different in relation to their geospatial distribution in the dry season; presenting a varying pH after the discharge of polluting sources from agriculture, livestock and the urban population, recovering after a certain stretch of travel through the resilient nature of water.

Acknowledgments

We thank the direction of the Specialized Electronic Engineering Laboratory of the Universidad Nacional de Huancavelica, for the support with equipment and instruments for the implementation of the monitoring stations.

Table 3. Water quality based on the pH obtained

Monitoring station	Geographic location			Dry season		
	Latitude (°)	Longitude (°)	Altitude (m)	pH	Q_2, %	Water quality index
0	-12.340610	-74.982943	4124	7.34	91.50	Excellent
1	-12.375030	-74.948003	4104	7.14	90.5	Excellent
2	-12.380215	-74.945529	3399	7.19	91	Excellent
3	-12.381724	-74.942261	3370	6.80	81	Good
4	-12.389082	-74.930949	3310	5.40	40	Bad
5	-12.396222	-74.921970	3281	5.45	41	Bad
6	-12.404860	-74.909142	3265	5.70	48	Bad
7	-12.398305	-74.899490	3261	6.35	58	Regular
8	-12.399132	-74.897808	3260	6.31	64	Regular
9	-12.398823	-74.895520	3256	9.04	44	Bad
10	-12.397428	-74.884568	3249	8.65	58	Regular
11	-12.396943	-74.883660	3248	9.05	50	Bad
12	-12.394236	-74.875802	3247	8.44	70	Regular
13	-12.391178	-74.870208	3243	8.44	70	Regular
14	-12.388586	-74.866492	3240	7.84	86	Good
15	-12.386673	-74.864657	3239	9.79	24	Very bad
16	-12.385533	-74.864554	3238	9.11	45	Bad
17	-12.379238	-74.858725	3228	8.65	58	Regular
18	-12.375991	-74.855186	3223	8.44	66	Regular
19	-12.370835	-74.848690	3209	6.85	88	Good
20	-12.366904	-74.846182	3206	6.68	76	Good
21	-12.352242	-74.836177	3199	6.80	82	Good
22	-12.351131	-74.834148	3195	8.44	70	Regular
23	-12.341762	-74.829881	3185	7.81	88	Good
24	-12.338028	-74.826365	3175	8.10	82	Good

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