Participation in the Stockholm Junior Water Prize 2025

CONTROLLING WATER IN MARKET GARDENING : MONITORING WATER QUALITY, CHATBOT FOR IMPROVING SKILLS AND SMART IRRIGATION

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Benin

Summary

Urban market gardening is an essential source of food, employment, and income in Benin. However, this production relies heavily on the use of uncontrolled water. This exposes the crops, often consumed raw, to high risks of microbiological and chemical contamination. Local studies have revealed the presence of fecal coliforms, excessive turbidity, and non-compliant residues in irrigation water.

Yet, market gardeners lack simple tools to monitor water quality and apply treatments adapted to their context. This raises a dual challenge: protecting consumer health and ensuring sustainable and credible market gardening production.

To address this issue, the project proposes a three-part technological and educational solution:

- **Real-time detection of** water quality via economical sensors (pH, turbidity, TDS)
- **A conversational assistant (chatbot)** accessible via WhatsApp, which trains and improves the market gardener's skills, while helping him to understand the malfunctions and anomalies recorded;
- **Smart irrigation**, taking into account soil moisture, the crop, its growth stage and weather forecasts in order to optimally manage the available water stock and guarantee healthy harvests.

This project is part of a dynamic of strengthening local capacities and securing agricultural practices, while directly contributing to SDGs 3 (health: by reducing the risks of diseases linked to the consumption of products irrigated with contaminated water), 4 (education: by improving the skills of market gardeners), 6 (clean water: by encouraging the use of clean and monitored water) and 12 (responsible consumption: by promoting responsible management of water resources).

The sensors accurately detected critical thresholds (pH, turbidity, TDS), and the device responded efficiently, averaging 34 seconds for pH changes, 17 seconds for turbidity changes, and 11 seconds for conductivity and TDS. It displayed a relative accuracy rate of 93% for coliform determination. The chatbot correctly interpreted the data. Smart irrigation management resulted in water savings of up to 50% without impacting yields.

List of abbreviations and acronyms

- pH: Hydrogen Potential
- TDS: Total Dissolved Solids
- SDG: Sustainable Development Goals
- CXG: Codex Alimentarius
- API : Application Programming Interface
- ETP : Full-Time Equivalent
- FAO : Food and Agriculture Organization
- OMS : World Health Organization

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I. Introduction

In Benin's cities, fresh vegetables occupy a central place on our plates. Lettuce, carrots, cabbage, etc. These market garden products are grown near urban areas to meet growing demand. They supply markets, family kitchens, and street vendors. And yet, behind this doubly essential activity lies a problem: **the consequences of using water of questionable quality to irrigate these crops.**

At various sites in Benin, market gardeners water their crops with whatever water they have available. Most often, this water is used untreated. As a result, it may contain dangerous microbes, chemicals, and even organic matter that ends up directly in the vegetables we sometimes eat raw.

To ensure consumer health, the international food standard "CODEX ALIMENTARIUS" requires regular monitoring of water used for irrigating crops and urgent action if evidence of contamination is detected. **How can a Beninese market gardener, with very limited resources, responsible for the health of the people through his activity, and a novice in water treatment issues, meet these requirements?**

This is precisely the problem our project aims to address. To achieve this, we have designed an inexpensive device capable of monitoring the quality of the water used in real time, helping market gardeners understand the malfunctions detected and learn how to resolve them, and effectively managing the treated water, allowing them to water only when it is truly necessary, taking into account soil moisture, the plant's needs, and even the upcoming weather.

Beyond a simple electronic assembly or an agricultural solution, our project is at the crossroads of several major issues: technology, to make innovation accessible where resources are limited; education, by supporting market gardeners towards a better understanding of water-related risks; public health, by reducing invisible dangers in our daily diet; and finally, sustainable development, by promoting responsible practices, adapted to the local context.

II. Project issues and objectives

A. Problematic

In several urban areas of Benin, market gardeners irrigate their vegetables every day with water from wells, backwaters, or gutters. According to the study conducted at the Houéyiho site (Agbossou et al., 2020), it was revealed that this water contains fecal and total coliforms, heavy metals such as lead, copper, and zinc, as well as highly harmful organochlorine pesticides. According to the same study, "lettuce is the most contaminated vegetable," even when it is eaten raw. In other words, invisible pathogens can pass directly onto consumers' plates.

This situation threatens public health, particularly for children, pregnant women, and the elderly. Despite the warning raised by this study, market gardeners still lack access to systems to ensure the quality of the water they use. We believe this situation persists due to a lack of alternatives.

And yet, market gardening is an essential activity in Benin, both in terms of food and economy. According to another study (Alinsato & Yagbedo, 2018), national consumption of fresh vegetables already reached 74,000 tons in 2002, or approximately 80 kg per capita per year. Vegetables such as lettuce, carrots, cabbage, and nightshade, often eaten raw, are grown in all regions of Benin, especially in urban and peri-urban areas using manual irrigation.

Faced with this dual observation of "polluted irrigation water and the vital importance of healthy vegetables," it is becoming urgent to offer a solution adapted to market gardeners, easy to use and respectful of the environment. This is what leads us to focus our study on the creation of a smart device, capable of alerting on poor water quality, helping the market gardener to treat the water and better managing the treated water according to the needs of the plants.

B. Project objectives

Our project aims to:

- Design and test a smart device to alert market gardeners about the quality of water used to irrigate market garden crops intended for raw consumption,
- To train and improve the skills of market gardeners, thus contributing to water treatment where necessary
- Effectively manage treated water based on the plants' actual needs.

III. Literature review

We will rely mainly on the CODEX ALIMENTARIUS, the international food standard drawn up by FAO and WHO.

➢ **The importance of water in the food chain**

Water is used in all stages of food production, including irrigation, washing fresh vegetables, processing, and consumption. Poor water quality can lead to the transmission of diseases, microbiological contaminants (coliforms, E. coli, Salmonella, etc.) or chemical residues. The CODEX ALIMENTARIUS reminds us of this by stating: "***Water can be a vector for the transmission of diseases, contamination or undesirable organoleptic attributes***." (CXG 100-2023, p. 2).

➢ **The "fit for purpose" approach**

Rather than systematically requiring potable water, the directive recommends a risk-based approach, depending on the intended use of the water (irrigation, washing, processing). Microbiological risk analysis helps determine whether the water is "fit for its intended purpose." It then specifies that: "***Water must always be suitable for each intended purpose. [...] The risk-based approach helps assess the need for treatment and determine whether the water is fit for its intended use***." (CXG 100-2023, pp. 2-3).

➢ **Contaminations specific to fresh products consumed raw**

Vegetables eaten raw are the most vulnerable to water contamination. Lettuce, carrots, or herbs can be directly contaminated with fecal coliforms, Giardia, E. coli, Salmonella, etc., especially if water touches the edible part. This statement is emphasized in these themes: "***Water can be a source of contamination for all pathogenic microorganisms associated with the consumption of fresh produce***." (CXG 100-2023, Appendix I, p. 7)

- **Irrigation methods and risk level**

Sprinkler or flood irrigation significantly increases the risk of contamination, unlike drip or subsurface irrigation. It is essential to adjust the irrigation system according to the type of crop. This statement is supported by: "***"Overhead irrigation presents the highest level of contamination risk when the water wets the edible part of the plant."***(CXG 100-2023, Appendix I, p. 11).

- **Microbiological monitoring and sampling frequency**

The water used must be regularly monitored, depending on the nature of the source (deep well, surface water, wastewater) and the use (direct contact or not). The use of indicator organisms such as E. coli is recommended. This requirement, one of the objectives of our project, was emphasized by the standard by: "***Producers must assess the microbiological quality of the water and define corrective actions in the event of unacceptable results."*****(**CXG 100-2023, p. 10) and "The main indicator organisms are E. coli and enterococci." (CXG 100-2023, p. 16).

- **Microbiological monitoring and sampling frequency**

Hazardous water (wastewater, surface water) must be treated to make it reusable. Recommended treatments include:

- Natural sedimentation,
- Filtering,
- Disinfection (chlorine, ozone, UVC),
- Use of biocides or filter plants (phyto-purification, outside Codex but consistent).

As a title, the standard specifies that: "***Water reprocessing must ensure that hazards are eliminated, controlled or reduced to an acceptable level."***(CXG 100-2023, p. 5).

For improved food security, irrigation remains a strategic lever. According to the FAO, irrigation is one of the main levers for addressing the effects of climate change on agriculture, particularly in developing countries. Zita Antoine Ondoa's training module highlights that irrigation can significantly increase agricultural yields, provided that water resources are managed rationally, economically, and sustainably. It emphasizes that simple equipment, adapted to local realities, promotes producer autonomy. This approach supports the project's choice to offer light automation via valves controlled according to detected water quality.

IV. Research methodology

In this section, we describe the different methods used to carry out our project. We will also explain the choice of tools and equipment used. It will be presented by proposed solution axis to the different challenges identified, namely: microbiological monitoring, contribution to water treatment and automated management of treated water according to the needs of the plants.

A. Solution axis n°1: Microbiological monitoring

Virtually non-existent in market gardening practice, water quality monitoring systems are becoming a necessity for this activity. It will allow us to detect in real time the presence of microbiological contaminants in the water used for irrigation, particularly fecal and total coliforms.

❖ ***Materials and tools used***

The experimental setup combines electronic hardware, sensors, and open-source software. The main elements are:

- A transparent container, Clean water (serving as a test base), Simulated contaminants (see below)
- Suitable microbiological sensors: Soil moisture; Water pH; TDS (dissolved solids); Turbidity; Flow meter.
- Indicator lights (color LEDs: blue for pH, green for turbidity and red for TDS)
- Microcontroller (ESP32 board)
- Power supply system and sensor wiring
- Stopwatch and logbook

❖ ***Experimental protocol***

The aim will be to evaluate the capacity of microbiological sensors to detect in real time the presence of contaminants in water intended for market garden irrigation, through a system of indicator lights (LEDs) which alerts to the presence of contaminants at an abnormal dose.

Experimental procedure: it will be done in three (03) stages

- **Preparation of test solution**: we will prepare three solutions (named A, B, C) presumed to be of poor quality. In the laboratory, we will measure the pH, turbidity, TDS and conductivity for each solution. This will confirm the poor quality of the prepared solutions by referring to the standards provided for this purpose.

- **Initial setup**: we will fill the container with prepared solution, then connect and calibrate the sensors and observe the indicator light indication.
- **Data collection and recording**: we will record the reaction time (after the introduction of the lights). We will record each reaction for documentation.

B. Solution axis no. 2: contribution to water treatment

The aim will be to evaluate the use and effectiveness of digital assistance (chatbot) in the market gardener's decision-making process. Our project, through this solution, will support the market gardener in understanding the problem detected and will offer natural and accessible treatment solutions.

❖ ***Materials and tools used***

- Central data processing unit: Arduino IDE (microcontroller)
- Data transmission module (Wi-Fi, GSM or Bluetooth)
- Digital platform & chatbot: web or mobile platform accessible on smartphone (access via browser)
- Chatbot interface developed using simple tools (Dialogflow, Telegram bot, WhatsApp bot)

❖ ***Experimental protocol:***it will be done in two stages

- **Access to assistance**: a number is made available to market gardeners to access the assistance platform.
- **Generation of recommendations via the chatbot:** The chatbot is activated as soon as the market gardener connects via the number provided. It guides the interpretation of the data collected by the sensors, finds natural and ecological solutions for the repair of malfunctions and, above all, guides for the best conservation of the treated water.

C. Solution axis no. 3: automated management of treated water

Our solution will optimize the use of treated water by adapting it to the specific needs of each vegetable crop, particularly those consumed raw. This will provide precise irrigation, avoiding water waste, reducing the risk of recontamination of vegetables, and ensuring optimal crop growth.

- ***Materials and tools used***
  - **valves**electromagnetic.
  - The Agromonitoring API and the Stormglass API

- ***Experimental protocol***:

  Three tests will be carried out to ensure the effectiveness of the device:

- **Design of low-cost irrigation systems**: it will be a smart drip system using ESP32 to automate irrigation by measuring soil moisture, temperature, air humidity and flow rate, controlling irrigation via the Blynk application. It will be combined with the open-source platform on Arduino/ESP32 developed for humidity and temperature sensors.
- **Weather Assistance Test**: one of the innovations of our project is the integration of weather forecasting to properly use limited water stocks. The Stormglass API offers detailed forecasts (UV, rain, humidity) to optimize daily and weekly irrigation, reducing unnecessary watering by up to 25%. The Agromonitoring API provides NDVI indices from satellites to assess crop stress and adapt irrigation and fertilization planning. The device is integrated into the chatbot. As soon as the market gardener simulates it, the device displays the forecasts and concludes with simple sentences: total rainfall expected in the next 5 days, "Minimum irrigation possible", or "must irrigate" or "do not irrigate".
- **Automatic irrigation trigger test in relation to water quality data**: we will fill 3 pots with sterile substrate (dry potting soil). After inserting the humidity sensors into each pot at a depth of 10 cm, we will program the ESP32 to record the humidity values after 10 minutes, while integrating a critical humidity threshold to trigger automatic watering according to the plant's need for growth. The ESP32 decides: If humidity < threshold and no rain expected → open the solenoid valve for 2 minutes. If simulated rain expected in 6 hours → postpone irrigation. The ESP32 closes the solenoid valve once the humidity threshold is reached.

V. Presentation and interpretation of results

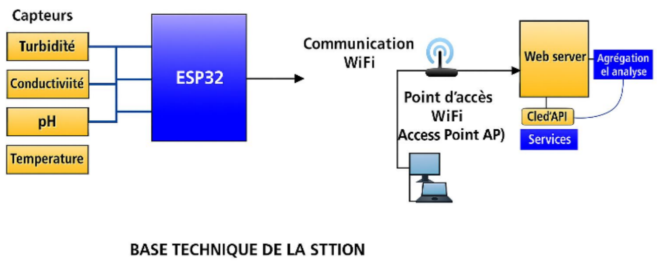


Figure 1: overall diagram of the device

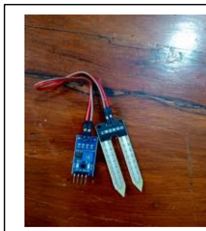
A. Solution axis n°1: Microbiological monitoring

- ***Test solutions***

Solution	**pH**	**NTU**	**Conductivity**	**TDS mg/l**
A (domestic wastewater)	9.70	1853.33	990	990
B (water mixed with mud)	6.50	800,416	723	723
C (water mixed with cloudy matter: animal feces)	6.03	1197.92	934	934

Table 1: Recorded data/sources: laboratories

- ***Calibrating the sensors***



Humidity sensor

EPS32 card

pH sensor

Flow meter

TDS sensor

Turbidity sensor

Valve

	pH	NTU Turbidity	Conductivity us/cm	TDS mg/l
Standards	6.5 – 8.5	≤ 5 NTU	≤ 700 µS/cm (water intended for	≤ 500 mg/L

Table 2: Codex Alimentarius standards for drinking water

- ***Reactions observed:***

Solutions	**Reaction time** (seconds)			
	pH	**Turbidity**	**Conductivity**	**TDS**
A (domestic wastewater)	37	15	10	10
B (water mixed with mud)	No reaction	19	13	14
C (water mixed with cloudy matter:	31	17	10	10

Table 3: Sensor reaction times

From these results, we can conclude that the device reacts efficiently with an average of 34 seconds for the pH variation, 17 seconds for the turbidity variation, 11 seconds for the conductivity and TDS.

In addition to data, our device effectively contributes to the determination of coliforms in the tested water. The operation is presented as follows:

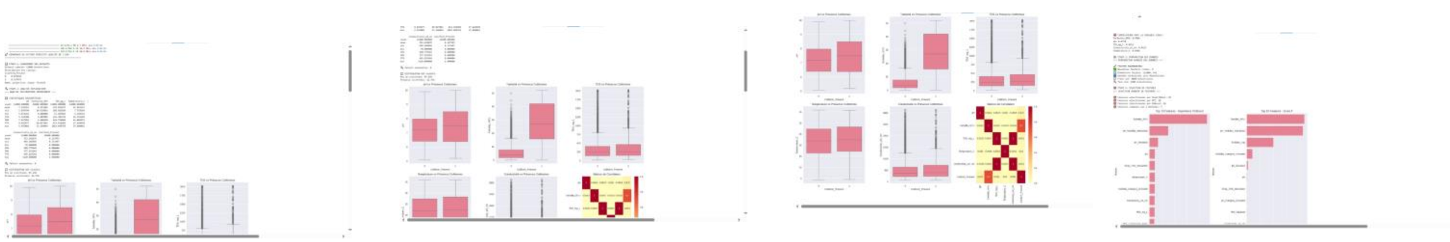
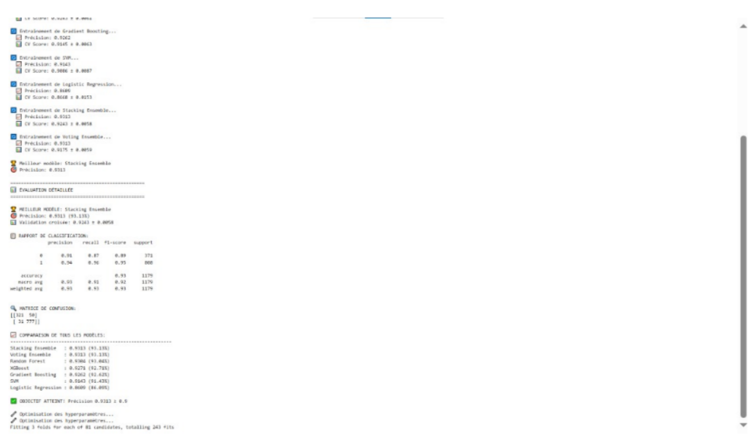


Figure 2: Analysis table linked to the presence of coliforms



When determining coliform bacteria (fecal and total), our device has an accuracy rate of 93%.

Figure 3 : presentation of the accuracy rate for determining coliform

B. Solution axis no. 2: contribution to water treatment

This axis will be considered effective as soon as the chatbot is made available.

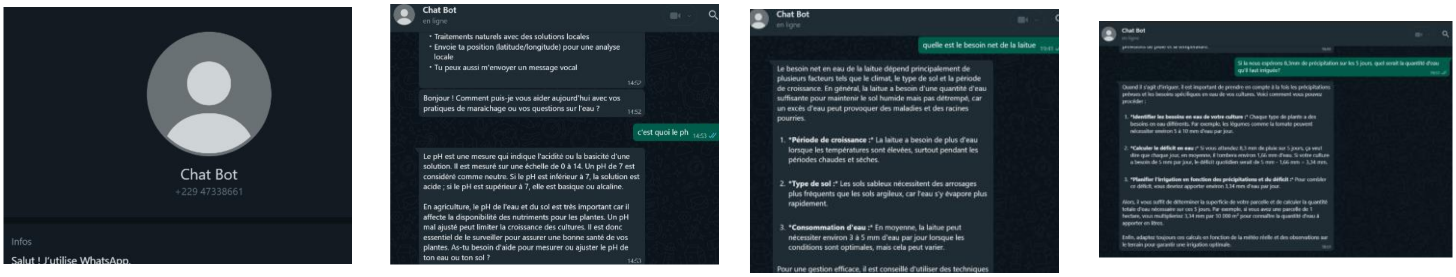


Figure 4: Some results of the chatbot proving its effectiveness

Above are some of the results recorded on the chatbot. It confirms its educational role, especially for market gardeners who lack the necessary knowledge to interpret water-related malfunctions. This allows us to confirm its effectiveness and usefulness.

C. Solution axis no. 3: intelligent management of treated water

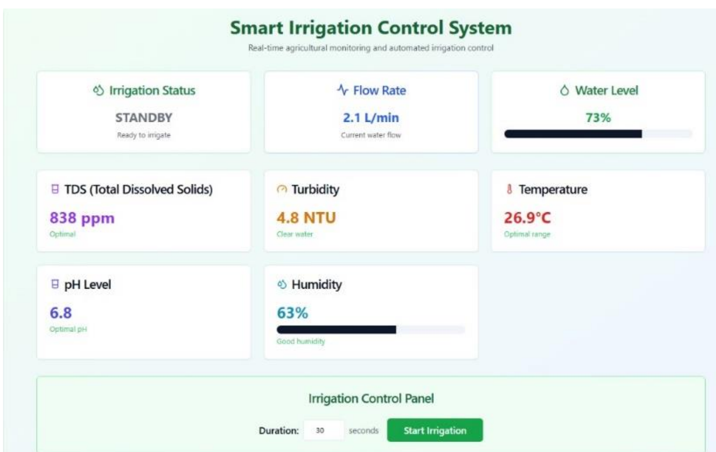


Figure 5: Irrigation system control panel

To release the right amount of water the plant needs, our system takes into account the water balance. It is based on monitoring precipitation, potential evapotranspiration (PET), and the soil's useful reserve. The effectiveness of our system will depend on its ability to answer two questions: when should we water, and how much? Our answers to these questions lead us to integrate humidity sensors and weather data.

- **Weather simulation**

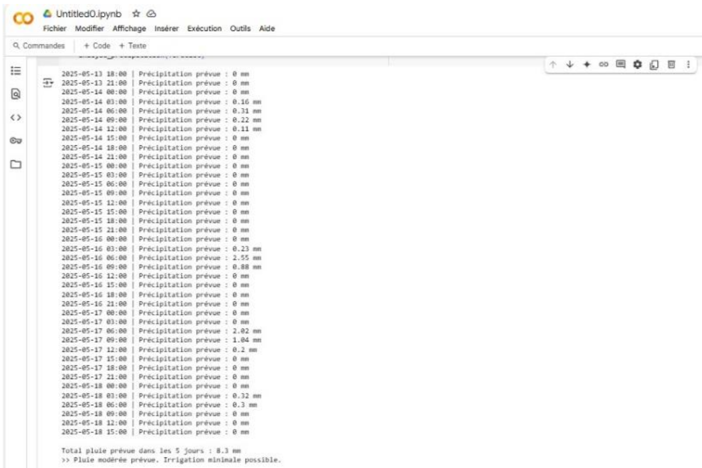


Figure 5 is the result of the weather simulation. The expected amount of precipitation over a 5-day period was recorded. This was followed by an irrigation recommendation. This will allow us to release only the "Net irrigation water requirement."

Figure 6: Weather simulation, source: our device

The 'Net Irrigation Water Requirement' is the amount of water needed to meet the crop's water needs, less the amount brought to the field by rainfall, runoff, groundwater and water stored in the soil, plus losses through runoff, infiltration and percolation. This requirement is also estimated by the chatbot (see Figure 4)

This allows the plants to be watered only if sufficient rainfall is not forecast. If we consider the estimated daily requirement (which is 3 to 5 mm) while the meteorological estimate is 8.3 mm, the device will save about 40%. (see figure 4)

- **Smart irrigation:**

The smart irrigation system's testing has proven to be autonomous and efficient. The chatbot helps the market gardener determine the amount of water to irrigate (based exclusively on the water balance).

When an anomaly is detected in the irrigation water (excessive turbidity, abnormal pH, high TDS), the device reacts: the main valve closes automatically to interrupt irrigation with potentially contaminated water and the secondary valve connected to the treated water tank opens, ensuring continuity of irrigation with safe water.

- **Trigger simulation**

To achieve usable results, we have composed substrates with a moderate to high water retention capacity, close to market gardening conditions (loose, light, aerated soil). The mixture is made up of potting soil, fine sand, and coconut fiber.

Jar	Initial time	Initial humidity	Rain forecast?	ESP32 Action	Duration of action (min)
1	0:00	28	No	Open valve	02
2	0:00	22	No	Open valve	02
3	0:00	27	Yes	Closed valve	-

Jar	Time of collection	Humidity after	ESP32 Action	Total duration of
1 (put the source of the	0:10	33	Closed valve	01'45
2	0:10	28	Open valve	02
3 + rain simulation	0:10	35	Closed valve	-

Interpretation

- Pot 1: The system detected humidity below the threshold (28%), opened the valve, then automatically closed it as soon as the humidity reached 33%, in less than 2 minutes.
- Pot 2: Very low humidity (22%). The valve remained open for 2 minutes to reach a level of 28%, but has not yet reached the threshold, so remains activated.
- Pot 3: Although humidity was initially low (27%), the system detected forecasted rain, suspended irrigation, and the simulated rain allowed a natural rise to 35%.

The system therefore reacted autonomously, targetedly and economically, avoiding unnecessary irrigation on pot 3.

VI. Conclusion

Our project is not limited to a technical solution. It lies at the intersection of technology, education, public health, and sustainable development. By giving market gardeners the means to understand the quality of the water they use in real time, we are introducing an accessible innovation, based on simple sensors, digital tools, and local practices. But beyond technology, we are placing people at the center: the market gardener becomes an actor in their own health security, better informed, better equipped, and capable of making informed decisions. It is also a training and awareness-raising project, which helps consumers adopt simple but essential actions for their health.

The sensors accurately detected critical thresholds (pH, turbidity, TDS), and the device responded efficiently, averaging 34 seconds for pH changes, 17 seconds for turbidity changes, and 11 seconds for conductivity and TDS. It displayed a relative accuracy rate of 93% for coliform determination. The chatbot correctly interpreted the data. Smart irrigation management resulted in water savings of up to 50% without impacting yields.

This project directly contributes to several Sustainable Development Goals:

- **SDG 3**– Good health and well-being, by reducing the risks of diseases linked to the consumption of products irrigated with contaminated water;
- **SDG 4**– Quality education, improving the skills of market gardeners;
- **SDG 6**– Clean water and sanitation, encouraging the use of clean and monitored water;
- **SDG 12**– Responsible consumption and production, promoting responsible management of water resources.

In short, better monitoring of water not only means better farming, but also better protection of people and the planet.

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