A prototype of irrigation and monitoring system for small producers: a case study in Ibirité-MG-Brazil

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ABSTRACT
Water scarcity has been a major limiting factor in Brazilian agriculture, where the activity consumes a significant amount of water, energy, and agricultural inputs, besides degrading watercourses. Despite Brazil boasting a remarkable hydrographic network, it consists of a disproportionate distribution in various regions of its territory. One such region where agricultural activity is present is the municipality of Ibirité, focusing on the external community near the IFMG-Ibirité campus. Due to a great use of Paraopeba River Basin in irrigation, there is a need to manage water resources for this primary sector, aiming to meet various demands and avoid conflicts over water usage. Therefore, this present work aims to implement basic concepts of Precision Agriculture within the community surrounding the IFMG-Ibirité. Precision Agriculture is a modern approach to farming that uses data analytics and technology to optimize the use of resources in agriculture, including water, energy, and agricultural inputs. The approach uses sensors, drones, and other tools to collect data on soil moisture, temperature, and other factors that affect crop growth. This data is then analyzed using machine learning algorithms to provide insights that help farmers optimize their farming practices. The results of the present work have shown that the development of a monitoring and data acquisition system regarding irrigation (water consumption) and energy usage guarantee greater viability and efficiency in vegetable production, promoting a more sustainable economy. With the help of Precision Agriculture, farmers can optimize water usage in their fields, reduce energy consumption, and improve crop yields. In addition to improving the efficiency of farming practices, Precision Agriculture can also help farmers reduce the environmental impact of their activities. By optimizing water usage, farmers can reduce the amount of water that is wasted or lost to runoff, which can help protect watercourses and other natural resources in Ibirité region.

Keywords: innovation, precision agriculture, sustainability, embedded electronic systems.

1 INTRODUCTION

Monitoring and obtaining data using sensors are fundamental strategies for the sustainable development of plantations. The term employed for the application of these strategies in the agricultural sector is Precision Agriculture (PA). In this sense, PA, among various issues, seeks to observe and implement solutions that allow for the appropriate use of resources, especially water and energy.

Water is one of the main limiting factors in Brazilian agriculture (Sentelhas et al., 2015) and (Battisti et al., 2018). This activity consumes a significant amount of water, energy, and agricultural inputs, in addition to degrading watercourses. Although Brazil has a diverse and abundant hydrographic system, some regions suffer from scarcity and disproportionality of water resources.

According to data from CIBAPAR (Intermunicipal Consortium of the Paraopeba River Basin), of the 189 valid permits in the basin, 40.2% are related to irrigation, and 20.6% are related to the industrial sector (Silva et al., 2015). This highlights the need for water resource management in this primary sector to meet various demands and avoid conflicts over water use.

The region surrounding Federal Institute of Minas Gerais (IFMG) Ibirité campus is approximately 80 hectares of vegetable cultivation (IBGE, 2010). This region heavily relies on water resources from the Paraopeba River basin, as it still uses traditional management tools, notably sprinkler irrigation. This irrigation system sometimes excessively uses water, resulting in the waste of this resource. Moreover, improper use of the irrigation system can lead to increased electricity costs, as the irrigation system is usually based on pumping systems.

Therefore, this initial study aims to implement basic Precision Agriculture concepts in the community surrounding IFMG-Ibirité in the future. In summary, the objective is to build a monitoring and data acquisition system related to water consumption in irrigation and energy consumption to ensure greater viability in vegetable production.

This paper explores the development and implementation of an initial irrigation and monitoring system tailored for precision agriculture among small-scale producers. Using a case study in Ibirité, MG, Brazil, the focus is on reducing water and energy consumption to optimize crop productivity, aiming for operational efficiency and more effective utilization of available resources.

2 METHODOLOGY

The methodology is divided into three main steps. The first one aims at socio-environmental analysis, approached in an extensionist manner, seeking information from the local community involved in vegetable production. To achieve this, a census was conducted in this stage, where the involved students conducted interviews with local producers, intending to gather data and metrics regarding production models, costs, productivity, among other fundamental variables for vegetable agriculture.

The second step is directed towards product innovation. Tests were conducted to validate the consumer market, assess how the proposed solution aligns with some of the United Nations Sustainable Development Goals (SDGs) (Nações unidas Brasil, 2022), and evaluate the economic feasibility of the product.

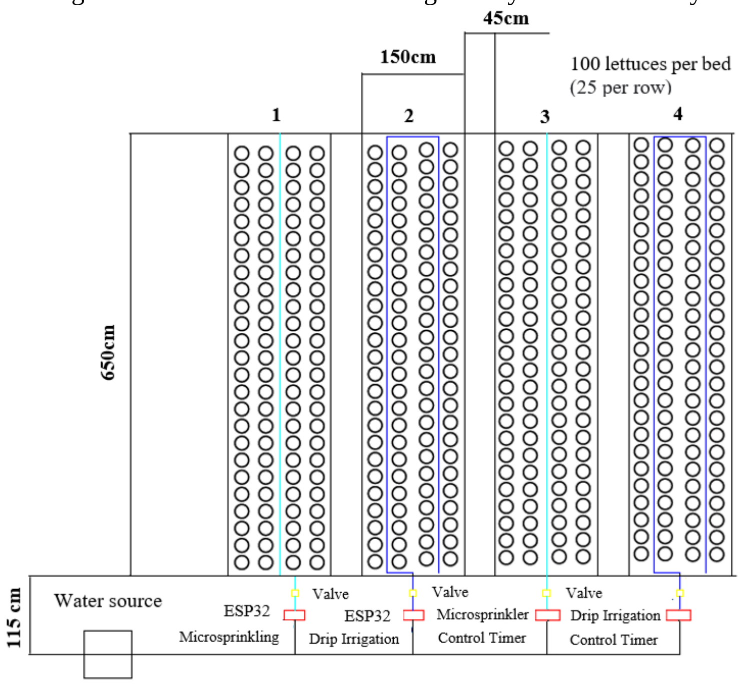
The third step involves applied research. Engaged student fellows built and implemented an automated vegetable garden aiming to simulate, in a controlled environment, the production process of lettuce, a vegetable commonly produced in the region surrounding the campus.

In this research process, four beds with dimensions of 6m x 1.2m were constructed, as outlined below and in Figure 1:

- Bed 1: Control Sample - sprinkler irrigation system using a timer.
- Bed 2: Control Sample - drip irrigation system using a timer.
- Bed 3: Hypothesis 1 (Automated Sprinkler System) - irrigation system with intelligent monitoring and control through sprinklers.
- Bed 4: Hypothesis 2 (Automated Drip System) - irrigation system with intelligent monitoring and control through drip irrigation.

Figure 1 illustrates the general scheme of the irrigation system under study.

Figure 1 General scheme of the irrigation system under study.



Source: The Authors (2022)

The automation of irrigation occurs through sensors installed in each bed, a low-cost microcontroller, and electromechanical actuators for water pumping.

For recording and storing collected data, a digital platform was developed, integrated with the microcontroller via wireless communication. This allows remote monitoring of the automated garden as in (Assis, 2022).

2.1 LOCAL SOCIO-ENVIROMENTAL ANALYSIS

The research study was conducted among local producers in the Ibirité-MG region. In total, 10 local farmers were interviewed with the objective of understanding the functioning of irrigation methods and the main challenges to achieve quality production while optimizing water and electricity usage. This represents a significant local amount, since those are the biggest farms in the IFMG surroundings. During the interviews, a questionnaire comprising various questions related to planting culture information, conventional irrigation methods, soil management, and interest in the proposed automated irrigation solution was utilized.

2.1.1 Methods for irrigation

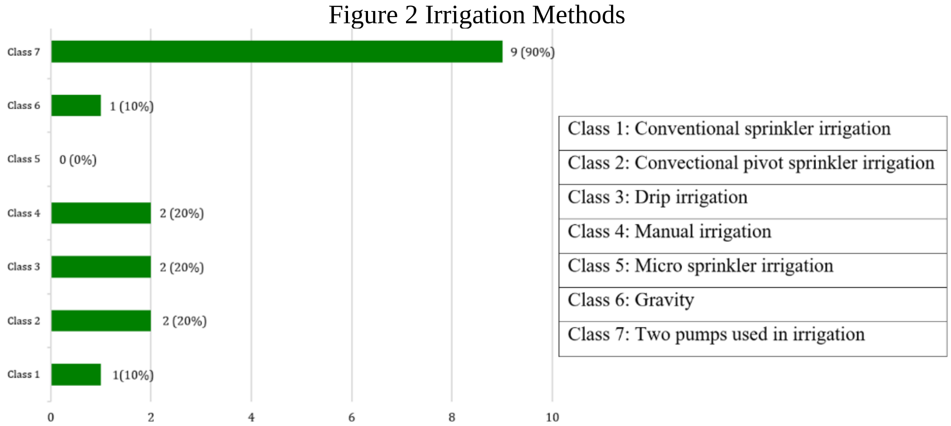
The primary method used in the garden was conventional sprinkler irrigation, as indicated in Figure 2. The main advantages of this method are highlighted below (Frizzone, 2017).

Advantages of the sprinkler method:

- Allows usage in permeable and sandy soils (difficulty retaining water). This is because the sprinkler system conducts continuous irrigation but with lower water volume.
- Enables easy disassembly of equipment due to strategically designed accessories.
- Reduces labor in mechanized or permanent systems, thus lowering producer costs.
- Can be used to protect crops from frosts or reduce the microclimate temperature in the fields.
- Ensures greater water efficiency due to closed conduits that prevent losses from evaporation or infiltration.

- Enables nighttime irrigation when temperatures are cooler, resulting in greater savings for the producer.
- Can be installed on irregular or steep terrain.
- Promotes better oxygenation of water, allowing the use of wastewater.
- Guarantees greater uniformity in water distribution across the field.
- Occupies less space in the plantation as it does not have furrows or channels.
- Facilitates the application of pesticides and fertilizers (fertigation).

Figure 2 Irrigation Methods

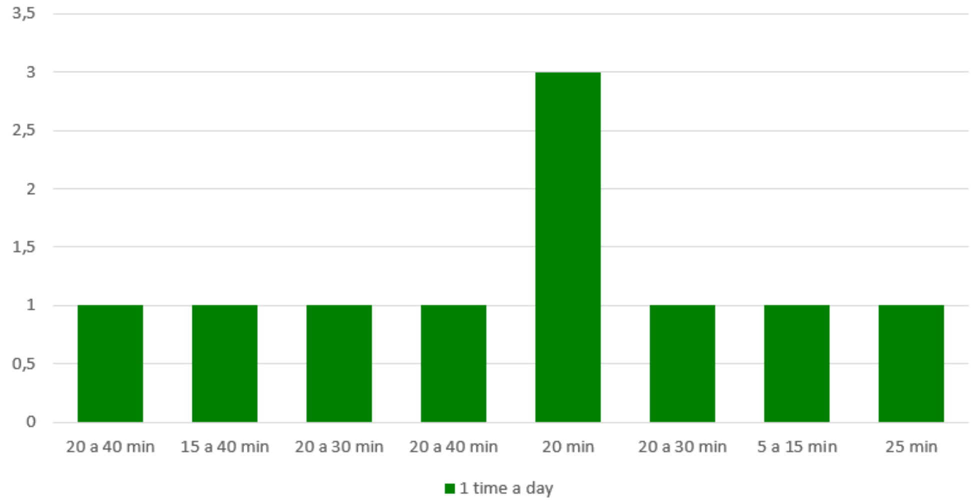


Source: The Authors (2022)

2.1.2 Daily operation periods of the irrigation system

Farmers currently activate their irrigation systems for an average of 22.5 minutes per day. However, due to the absence of soil moisture data, they tend to turn on the sprinklers more than necessary daily, resulting in excessive water consumption.

Figure 3 Irrigation System Operation Periods



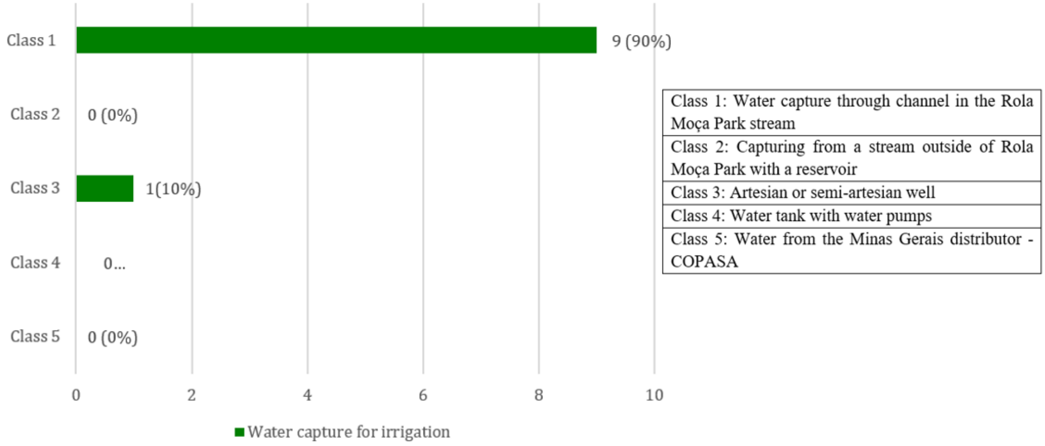
Source: The Authors (2022)

2.1.3 Water collection

Water for irrigation is collected from a stream in Rola Moça Park (Ibirité-MG), where it's stored in tanks for use in planting. This water isn't accounted for by the water distributor, meaning there's no charge for urban maintenance, and there's no monitoring of the quantity of water used in irrigation. This statement is supported when questioning the use of water during dry periods; in most responses, local farmers stated that there's no reduction in water collection.

Meanwhile, in the Ibirité regions, there's water rationing in households during low rainfall periods. The Rola Moça water sources contribute to the region's supply (Prefeitura de Ibirité, 2018). In efforts to preserve the green areas near the springs, during discussions to propose a partnership with COPASA, we became acquainted with the Pro-Mananciais project. This Socioenvironmental Program for the Protection and Recovery of Water Sources – Pro-Mananciais aims to protect and restore the micro-watersheds and recharge areas of aquifers used for public water supply in cities operated by COPASA.

Figure 4 Water Collection

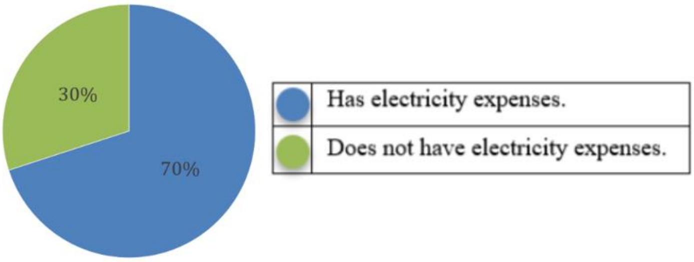


Source: The Authors (2022)

2.1.4 Electricity expenditure

Mostly, 70% of the respondents use electricity solely for water pumping for the irrigation system, as vegetable processing (washing, cooling, packaging, etc.) is not carried out by the producer.

Figure 5 Use of electricity for pumping



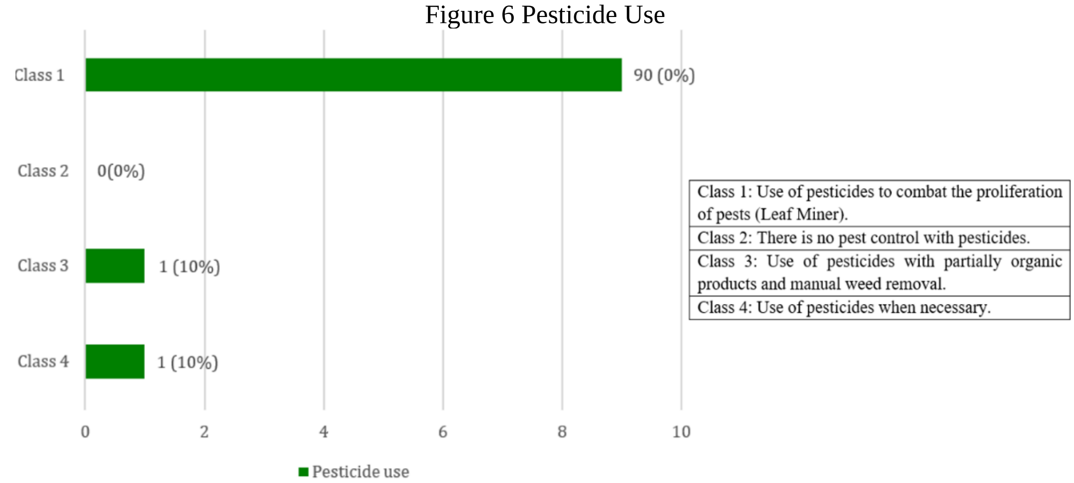
Source: The Authors (2022)

Furthermore, complementing this information, it was found that the average energy expenditure by farmers amounts to approximately R$1,600.00 for electric water pumping expenses. To reduce costs, a solar-powered irrigation system provides optimization of water usage and a long-term return on investment.

2.1.5 Pest control and pesticide use

Generally, pest control is carried out using pesticides, as observed in Figure 6. The primary use of these chemicals is as a fungicide. It should be emphasized that the use of pesticides in vegetables, especially fungicides, dangerously and frequently exposes not only the consumer's health but also the environment and workers to chemical contamination through pesticide use (Almeida, 2009).

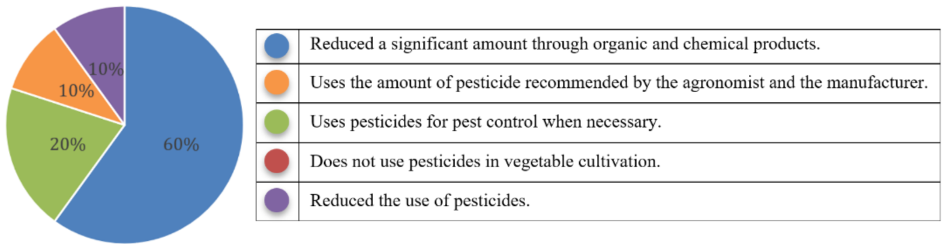
Figure 6 Pesticide Use



Source: The Authors (2022)

Although the use of pesticides is evident, farmers have shown receptiveness to proposals for organic pest control methods and already indicate a reduction in the use of these chemicals. Some suggested methods to reduce pesticide use focus on agroecology: composting, the use of natural pesticides, crop rotation, and planting diversity.

Figure 7 Trend of Reduction in Pesticide Use



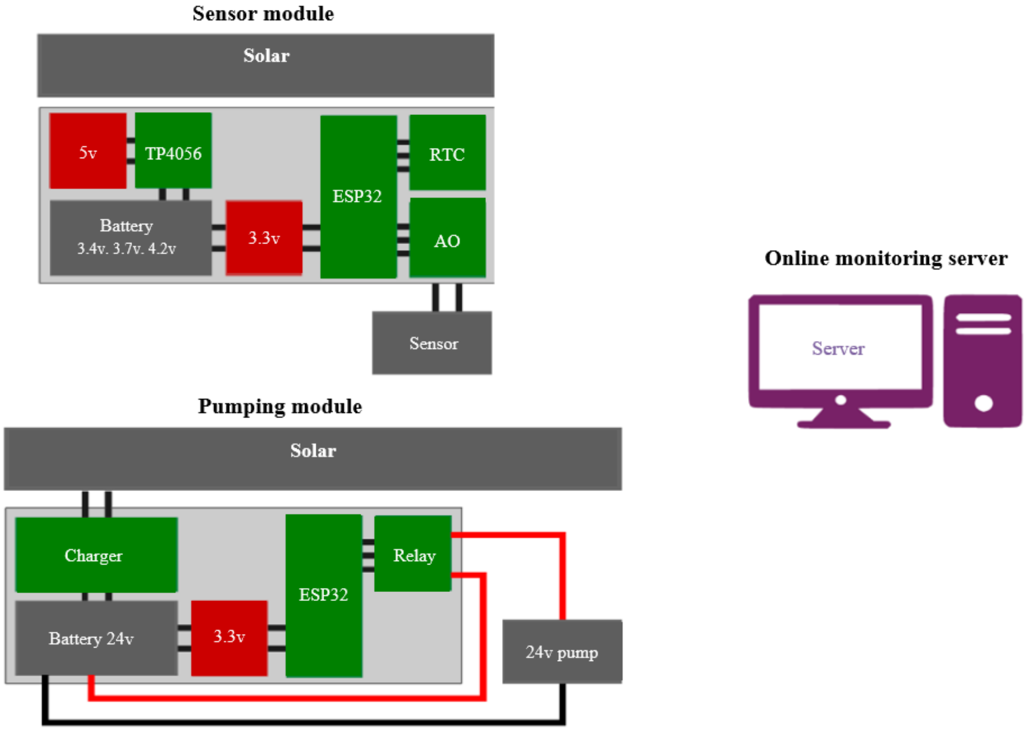
Source: The Authors (2022)

2.1.6 Value proposition

After all the research and study of the issues involved in the vegetable cultivation process in the IFMG campus Ibirité region, an automated solution has been developed to address some evident needs for more sustainable development.

The model created, currently in the testing phase, is presented in Figure 8. This architecture consists of two electronic modules and an online server. With this structure, it allows control of the activation of solenoid valves and the irrigation pump, monitoring of soil moisture levels through sensors, and remote system monitoring through a server as in (Lino, 2017).

Figure 8 Automated Irrigation System Architecture



Source: The Authors (2022)

In this sense, the automated garden solution aims to add the following values to vegetable production:

- Water resource savings.
- Energy cost savings.
- Remote monitoring.
- Increased production efficiency.
- Data-driven decision-making.

2.3 TECHNOLOGICAL ANALYSIS

The technological proposal of the automated irrigation system is based on an embedded electronic structure integrated into a communication system. For this purpose, the main element used is the ESP32, which is a small microcontroller with wireless communication capabilities through Wi-Fi.

The main devices present in the developed electronic boards and in the pumping are described in the next subsections.

2.3.1 Microcontroller - ESP32

Given the functionalities presented previously, the decision was made to use the ESP32 family of microcontrollers. This line of microcontrollers is manufactured by ESPRESSIF. The adoption of this line is justified due to the following characteristics:

- Low power consumption.
- It incorporates the main communication interfaces in a single package - Wi-Fi, Bluetooth, SPI/SDIO, and I2C/UART.
- Low cost.
- Extensive documentation available.

These characteristics of the ESP32 make it an excellent choice for the irrigation system since all the functionalities required by this system are met by this microcontroller. Figure 14 shows the commercial version of the ESP32 from the WROOM Series mounted on the DevKitC development module.

2.3.2 Temperature sensor

The DS18B20 Temperature Sensor is a digital sensor that performs measurements in the range of -55°C to 125°C, in dry, humid, or submerged environments, without the need for an external component, and it displays values in degrees Celsius. The DS18B20 has an accuracy of ±0.5°C in the measurement range of -10°C to 85°C. Additionally, it presents distinct measurement ranges, offering increments of 0.5°C (9 bits), 0.25°C (10 bits), 0.125°C (11 bits), and 0.0625°C (12 bits), with the latter being the standard resolution (Fernandes, 2017).

2.3.3 Soil moisture sensor

The HD-38 Soil Moisture Sensor is an electronic device designed for measuring soil moisture. The HD-38 features metal terminals with a length of 85mm, easily inserted into the soil.

To simplify the connection with microcontrollers, this sensor already has a module that reads the data generated by the probe and forwards the information to the microcontroller through a digital or analog interface. This sensor model operates with a voltage range from 3.3V to 12V DC and a current less than 20mA. The sensor's measurement range is from -25ºC to 85ºC.

2.3.4 Water flow sensor

The flow sensor is used to measure the amount of water passing through the irrigation pipeline. The model of sensor used (YF-S401) can measure water flow from 0.3 to 6 liters per minute, sending pulses to the microcontroller with the gathered information. This sensor operates with a maximum pressure of 0.8MPa. Electrically, the sensor operates with a voltage range from 5 to 24V DC and a current of 15mA.

2.3.5 Solenoid valve

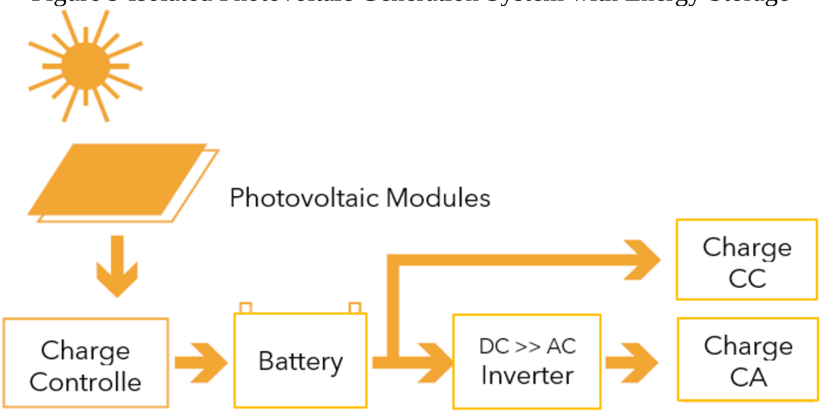
The normally open solenoid valve is used to control water flow. This Solenoid Valve, when powered at 24V DC, allows water flow and blocks the flow when it is not energized.

2.3.6 Pumping system with photovoltaic panel

Isolated photovoltaic systems have no connection to the power grid. In other words, they are autonomous systems capable of generating all the energy required by the loads without the need for another energy source. These systems are widely used in remote areas where there is no electrical distribution network.

Isolated systems can be further classified as systems without energy storage and systems with energy storage. Figure 9 shows a system with energy storage.

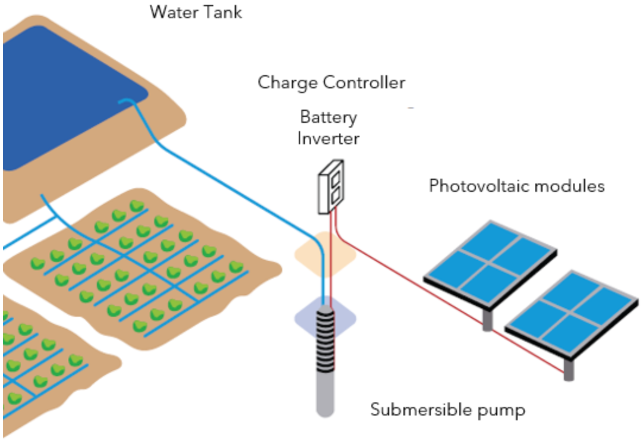
Figure 9 Isolated Photovoltaic Generation System with Energy Storage



Source: The Authors (2022)

The irrigation system by pumping fits perfectly into this model of photovoltaic system, especially in rural areas where there is often an unreliable electrical grid. As the irrigation system sometimes needs to operate at night, the use of an energy storage system becomes necessary. Therefore, the solution found for the pumping irrigation system is an isolated photovoltaic system with an energy storage arrangement as in Figure 10.

Figure 10 Water Pumping System with Photovoltaic Solar Energy



Source: The Authors (2022)

A simplified calculation method was used for the sizing of the photovoltaic pumping system, considering only the pump power and the estimated consumption (VILLALVA, 2015). For this purpose, the following considerations are made:

- Pumping equipment: 1 hp (750 W) submersible pump.
- Daily operating time of the pump: 1.5 hours.
- Battery voltage level: 12V.
- Battery discharge depth: 20%.
- Autonomy time: 3 hours (represents 2 days of pump operation).

2.3.7 Online monitoring system

The online monitoring system is a fundamental part to assist in data-driven decision-making, enabling more accurate and sustainable decisions in the medium and long term. To ensure connectivity and practicality, an architecture for data publication in a Google spreadsheet (Google Sheets) was used. This spreadsheet records sensor readings every 10 minutes. Such an architecture is presented in Figure 11.

The operational cycle stages of this architecture are as follows:

- ESP32 connects to your Wi-Fi network.
- Reading of temperature and humidity.
- ESP32 communicates with the IFTTT Webhooks service.
- Publishing of readings in a Google Sheets spreadsheet.

- After publishing the readings, the ESP32 enters a low-power mode for 10 minutes.
- After 10 minutes, the ESP wakes up, connects to Wi-Fi, and the process repeats.

It is worth mentioning that the proposed system is an IoT (Internet of Things) solution. Although device control is done locally, the storage and retrieval of data are published on the internet, providing convenience to the user who can remotely evaluate if there are any faults or issues with the irrigation system.

The use of Google Sheets is intentional as it is free, simple, and, most importantly, reliable. Another crucial aspect is the use of IFTTT (https://ifttt.com), which enables automatic interactions between services or devices. In this case, IFTTT acts as a third-party integration system, hiding the complexity of integrating information systems from different manufacturers.

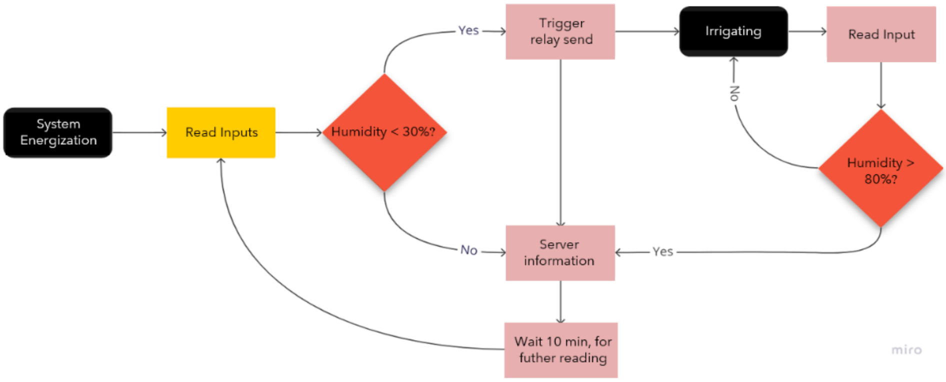
Figure 11 Illustration of a Cloud-based Weather Station with ESP32

Source: RANDOM TUTORIALS

2.4 CONTROL LOGIC

The control logic of the irrigation system is relatively simple, with moisture being the primary variable of interest. Therefore, as shown in Figure 12, initially, the microcontroller performs its initialization/power-up routine and then reads the sensor signals. If the soil moisture is below 30%, the relay that controls the 24V valve operation is activated, initiating irrigation. Subsequently, a new reading of the sensors is taken, cyclically checking if the soil moisture has reached 80%. Once this value is attained, the current moisture value is transmitted to Google Sheets, and the microcontroller is put into a low-power state (deep sleep mode) for 10 minutes. After this time, the cycle of sensor reading, and moisture assessment is repeated.

Figure 12 Control Logic's Flowchart



Source: The Authors (2022)

3 RESULTS AND DISCUSSIONS

The developed prototype, as shown in the Figure 13 and 14, was applied to a controlled garden within the IFMG Ibirité campus.

Figure 13 Prototype Installed in one of the Lettuce Beds at IFMG Ibirité Campus

Source: The Authors (2022)

Figure 14 Lettuce Beds at IFMG Ibirité Campus Structured with Automatic Irrigation Systems and Timed Irrigation Sysems for Statistical Control.

Source: The Authors (2022)

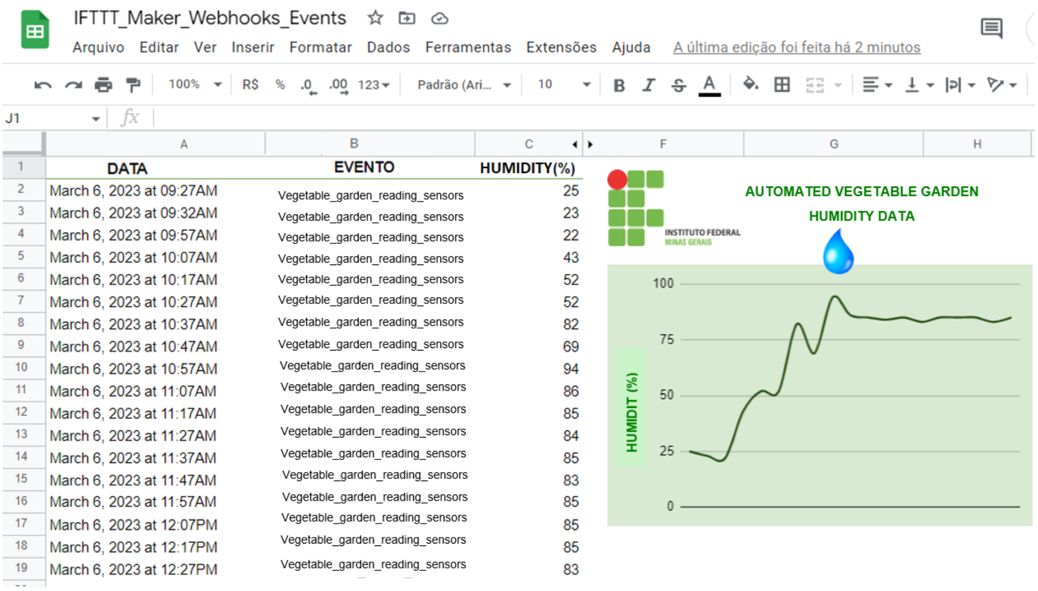
The results were affected due to the planting period. In December 2022 and January 2023, the Ibirité region experienced a high volume of rainfall. The substantial rainfall hindered the proper functioning of the prototype as the soil became waterlogged, causing the moisture sensors to malfunction. Productivity was severely impacted, resulting in underdeveloped plants with aesthetically irregular shapes, rendering the vegetables unsuitable for commercialization as shown in Figure 15 and Figure 16.

Figure 15 Result - Lettuce Planted in the Bed Using the Drip Irrigation Technique (shot in 01/12/2023)

Source: The Authors (2022)

To validate the online monitoring proposal, an initial data collection test was conducted. For this purpose, only soil moisture was observed during March 6th, 2023. Figure 16 presents the screenshot with the collected data and the corresponding graph for that day.

Figure 16 Screenshot of the Soil Moisture Monitoring Spreadsheet on 03/06/2023 (Google Sheets)



DATA	EVENTO	HUMIDITY(%)
March 6, 2023 at 09:27AM	Vegetable_garden_reading_sensors	25
March 6, 2023 at 09:32AM	Vegetable_garden_reading_sensors	23
March 6, 2023 at 09:57AM	Vegetable_garden_reading_sensors	22
March 6, 2023 at 10:07AM	Vegetable_garden_reading_sensors	43
March 6, 2023 at 10:17AM	Vegetable_garden_reading_sensors	52
March 6, 2023 at 10:27AM	Vegetable_garden_reading_sensors	52
March 6, 2023 at 10:37AM	Vegetable_garden_reading_sensors	82
March 6, 2023 at 10:47AM	Vegetable_garden_reading_sensors	69
March 6, 2023 at 10:57AM	Vegetable_garden_reading_sensors	94
March 6, 2023 at 11:07AM	Vegetable_garden_reading_sensors	86
March 6, 2023 at 11:17AM	Vegetable_garden_reading_sensors	85
March 6, 2023 at 11:27AM	Vegetable_garden_reading_sensors	84
March 6, 2023 at 11:37AM	Vegetable_garden_reading_sensors	85
March 6, 2023 at 11:47AM	Vegetable_garden_reading_sensors	83
March 6, 2023 at 11:57AM	Vegetable_garden_reading_sensors	85
March 6, 2023 at 12:07PM	Vegetable_garden_reading_sensors	85
March 6, 2023 at 12:17PM	Vegetable_garden_reading_sensors	85
March 6, 2023 at 12:27PM	Vegetable_garden_reading_sensors	83

Source: The Authors (2022)

4 CONCLUSIONS

This article explored the use of Precision Agriculture (PA) in a community of the small producers that cultivates vegetables, with a focus on improving water and energy efficiency. The study was centered around the IFMG Ibirité campus region and proposed a prototype for an automated system to monitor and control irrigation. Despite challenges related to weather that affected the prototype's results, the model demonstrated the potential for cost-effective and resource-saving benefits.

During the development of the project, it was realized that the management practices used in vegetable cultivation are not aligned with the concept of sustainability. The use of pesticides and lack of control over water resources contrast with the global trend of sustainable agricultural systems. Uncontrolled usage of water resources can lead to water shortages, which can harm both the producer and the community that depends on these resources. As per Brazilian law num. 9.433, water is a resource of the public domain. Hence, it can be concluded that the automated irrigation system has several benefits for users, such as efficient use of water and energy resources, and monitoring that enables data-driven decision-making.

Upon final analysis, this project shows significant potential for socio-environmental and technological impact, offering more sustainable alternatives for agricultural production for small producers.

In further work we pretend reduce the bed sizes and refine the proposed electronic architecture to better control environmental variables, especially rain and wind, have been planned. Finally, with the system's improvement, more data will be gathered, we will provide new information for more informed decision-making regarding water and electricity consumption.

REFERENCES

ALMEIDA, V. E. S. D., Carneiro, F. F., & Vilela, N. J. (2009). Agrotóxicos em hortaliças: segurança alimentar, riscos socioambientais e políticas públicas para promoção da saúde. Tempus Actas em saúde coletiva, 4(4), 84-99.

Assis, L. B. D. (2022). Sistema de irrigação automatizada utilizando plataforma Arduino. Sistema de irrigação automatizada utilizando plataforma Arduino.

Battisti, R., Sentelhas, P. C., Pascoalino, J. A. L., Sako, H., de Sá Dantas, J. P., & Moraes, M. F. (2018). Soybean yield gap in the areas of yield contest in Brazil. International Journal of Plant Production, 12, 159-168.

BRASIL. Lei num. 9.433 de 8 de janeiro de 1997, institui a Política Nacional de Recursos Hídricos; cria o Sistema Nacional de Gerenciamento de Recursos Hídricos; e dá outras providências., Brasília, 1997.

da Silva, B. M. B., da Silva, D. D., & Moreira, M. C. (2015). Índices para a gestão e planejamento de recursos hídricos na bacia do rio Paraopeba, Estado de Minas Gerais. Revista Ambiente & Água, 10, 685-697.

Fernandes, D. G. (2017). Sistema automatizado de controle de estufas para cultivo de hortaliças.

FRIZZONE, J.A. OS MÉTODOS DE IRRIGAÇÃO. Notas de Aula da disciplina LEB 1571 – Irrigação. Departamento de Engenharia de Biossistemas. Curso de Graduação em Engenharia Agronômica. ESALQ/USP, Piracicaba, SP, 2017.

IBGE, I. (2010). Censo demográfico 2010. IBGE: Insituto Brasileiro de Geografia e, 34-35

LINO, D. R., NETO, B. P. L., DE QUEIROZ, L. L., FEITOSA, P. B., RODRIGUES, A. A., & TEIXEIRA, A. D. S. (2017). Irrigação automatizada com plataforma de desenvolvimento arduino na horta didática da universidade federal do ceará. Irriga, 1(1), 85-93.

NAÇÕES UNIDAS BRASIL. Objetivos de Desenvolvimento Sustentável, 2022. Available in: https://brasil.un.org/pt-br/sdgs. Entry in: November 10th, 2022.

PREFEITURA DE IBIRITÉ, 2018. Histórico. Available in: http://www.ibirite.mg.gov.br/detalhe-da-materia/info/historia/6506. Entry in1; May 2nd, 2019.

RANDOM TUTORIALS, 2022. DIY Cloud Weather Station with ESP32/ESP8266 (MySQL Database and PHP). Available in: https://randomnerdtutorials.com/cloud-weather-station-esp32-esp8266/. Entry in: November 4th, 2022.

Sentelhas, P. C., Battisti, R., Câmara, G. M. S., Farias, J. R. B., Hampf, A. C., & Nendel, C. (2015). The soybean yield gap in Brazil–magnitude, causes and possible solutions for sustainable production. The journal of agricultural science, 153(8), 1394-1411.

VILLALVA, M. G. Energia Solar Fotovoltaica Conceitos e Aplicações.2ª Ed. Editora Saraiva. São Paulo, 2015.