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Original Research

Monitoring the Behavior of Physicochemical Parameters in Tilapia Ponds Using a Prototype of a Semi-Automatic Water and Sediment Sampling System

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Abstract

The cultivation of tilapia in ponds, as well as other fish or aquaculture species, requires control over water or sediment quality (anions, cations, heavy metals, hydrocarbons, pesticides, nutrients, among others) at various stages of development. To this end, an instrument was developed that allows water or sediment samples to be taken at various depths, so that physical and chemical determinations of water or sediment quality can then be made. The prototype is semi-automatic and has the option of removing sediments from the bottom of the pond and taking a water sample with suspended sediments or taking a water sample without suspended sediments at a certain depth. In both cases, the sample volume is 600 mL. The prototype was used at 40 points in a tilapia pond. Using an API marine field kit, the pH, dissolved oxygen, temperature, nitrates, and nitrites were determined in each sample, and their non-homogeneity was observed, with variations within permissible limits. The sampling prototype is versatile, low-cost, and obtains the sample in 3.5 min for subsequent analysis with the field kit or transfer to a laboratory. The prototype is portable, weighs 5 kg, and allows for agile field operation. The sampling obtained in the case study allowed us to observe the influence of the pond's topography on the distribution of water quality parameters, which helps and guides the scheduling of pond water

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changes to obtain healthier and more abundant production, so that water and sediment quality sampling is a regular practice. This requires sampling instruments such as the one presented in this study. The device is inexpensive, making it accessible to low-income aquaculture farmers on the coast of Sinaloa and elsewhere. Furthermore, it is an easy-to-use, necessary, and valuable tool, as it allows for quality control of the water and suspended solids in the ponds to prevent and address risks of contamination or disease in the crops, thus ensuring sustainable aquaculture production. In case of breakdown, its parts are inexpensive and easy to replace.

Keywords: aquaculture, *in situ* sampling, water quality

Introduction

Aquaculture is the fastest-growing primary sector activity in the global economy, with a 7% annual growth over the last 10 years. In 2022, it generated 130.9 million tons [1]; its importance lies in its contribution to global fish production and the increase in demand for aquaculture products, which represent an alternative solution to global food needs [2-5] due to its high nutritional value and accessible costs [6, 7], in addition to generating social and economic benefits [8].

Many low-income food-deficit countries have become major fish producers, as the activity represents a way to alleviate poverty and improve the supply of fish products for the poor [9]. To address food poverty, tilapia production is relevant in aquaculture because of its technical feasibility. This activity is mainly driven by China, which is a world reference in this sector [10, 11].

This country is undergoing rapid global urbanization [12], which demands sustainable food production. Aquaculture is an important source of protein in the context of innovation, research, and development to improve production efficiency and add value to products [13]. Furthermore, it is estimated that the world population will reach 7.4 billion in 2030 and 8.5 billion in 2050, which means that governments around the world must support and promote healthy and environmentally friendly food sources. In this context, aquaculture will play a key role [14].

Mexico is one of the countries on the American continent that has a wide diversity of climates and ecosystems, which gives it ample natural potential for the cultivation of various fish species [15]. The national production of tilapia is a strategic fishery resource due to the important role it plays in food production [16]. This activity is practiced in large extensions in semi-intensive systems with high water replacement rates, susceptible to urban, agricultural, and industrial pollution [17, 18]; therefore, water quality must be monitored to ensure that it meets quality standards [19]. In addition to the above characteristic, the activity has mostly been developed empirically [20].

In this context, the growing demand for aquatic products has driven the development of more efficient and sustainable aquaculture technologies [21, 19] that are environmentally friendly [21-23].

The balance of the ecosystem is one of the challenges contemplated in the report “Our Common Future” and is presented in the ecological, economic, and social dimensions [24]. Thus, in the face of these challenges, optimal fisheries and aquaculture management, as well as the efficient use of marine resources, are essential for the sustainable development of this sector [25], where the use of technologies, from artisanal to industrialized, is necessary for the optimal development of aquaculture [26].

However, the expansion of freshwater aquaculture also poses environmental challenges such as pollution, nutrient accumulation, and fish escapes; therefore, environmental monitoring is essential to mitigate these impacts [18], and the restoration of aquatic ecosystems can be approached through physical, chemical, and biological techniques that promote a balance between production and conservation, for which it is recommended to optimize culture models, foster innovation, and strengthen institutional support [23, 22].

Even though the northwest region of Mexico has an important aquaculture infrastructure (processing plants, postlarvae production laboratories, research institutes, and universities), access to technological resources is limited to small and medium-sized aquaculture enterprises in the region, mainly due to the high costs they represent [15].

In the production of tilapia, as in the production of other aquaculture species in controlled spaces, technologies are used in the monitoring, diagnosis, prevention measures, and control of production processes [27].

Among the main physicochemical parameters that need to be monitored to maintain optimal production in aquaculture farming are temperature, dissolved oxygen, ammonium, salinity, pH, and water level in the pond. These directly affect animal health, feeding pattern, and growth rate of the organisms being cultured, so maintaining them within the recommended values is essential to achieve competitive performance [28].

The concentration of contaminants that affect tilapia development in controlled environments is found at the bottom of ponds or tanks where production takes place, where sediments accumulate, so sampling for these parameters is in an environment with sediments, where organic matter can be found, nitrogenous and phosphorous metabolites, heavy metals, as well as bacterial microorganisms that can trigger the release of toxic metabolites such as ammonia, nitrite, and hydrogen sulfide, which affect the health of the farmed animals and their ability to persist for a long time [29, 30], affecting the growth and survival of organisms [31].

Therefore, the development of aquaculture activity requires the monitoring of the physicochemical parameters of water in the aquaculture environment [32]. Tilapia producers must carry out specialized studies on sediments and organic matter that allow them to identify the conditions of the environment, in order to take corrective actions during the culture cycle [33, 34], since an alteration of these can impact production; for this reason, it is necessary to have automated on-site sampling systems that allow obtaining water samples with suspended sediments from the bottom of the ponds.

Furthermore, projected population growth reinforces the need to strengthen the productive capacities of aquaculture communities through support in training, infrastructure, and financing [14].

The most commonly used system for monitoring these physicochemical parameters is the use of buoys [35], but monitoring systems and devices have also been developed and tested, such as those shown in Table 1, which, in many cases, are beyond the financial reach of small-scale aquaculture producers.

The objective of this research is to design, develop, and apply a versatile, low-cost, semi-automatic prototype to obtain samples of water or water with suspended sediments in aquaculture or fish farming ponds. The prototype is applied at 40 points in a tilapia farm in the municipality of Guasave, Sinaloa, Mexico. Each water sample is measured for pH, dissolved oxygen, temperature, and nitrate concentrations using a marine field API kit.

Materials and Methods

Description of the Semi-Automatic Prototype for Collecting Sediment Water Samples in Aquaculture Ponds

The prototype for extracting sediment water samples in aquaculture ponds aims to facilitate the collection of water or sediment samples from the bottom of the ponds for aquaculture producers, who currently manually extract these samples and are often disturbed by the mixing of the water column.

The prototype is composed of three sections, which are: a) sediment removal system from the bottom of the pond, b) water or sediment sample collection tank, and c) electronic control system (Fig. 1).

a) Sediment removal system

In aquaculture, it is important to analyze the bottom of the ponds because inadequate management practices (mainly excess manure, fertilizer, and feed) can cause an increase in nutrient loads and ammonium concentration, which can lead to a decrease in oxygenation and impoverishment of the sediments at the bottom of the pond [43].

The system was designed to extract water from the bottom of the ponds and, if it is of interest, to remove sediment from the bottom for laboratory analysis; to do this, the sediment removal system is activated, leaving sediment in suspension in the water, and then capturing the water sample with suspended sediment. The aforementioned system consists of a brush with synthetic fiber bristles, embedded in an aluminum rod, which is coupled to a stainless-steel shaft that, when activated, performs a uniform circular movement (Fig. 2a)).

This shaft is connected to a hermetic sealing system consisting of a conical plastic base, crossed at its center

Table 1. Robotic systems and/or devices for monitoring parameters in aquaculture.

Prototype or device	Description	Author
Robotic fish	Potentially efficient, maneuverable, and silent underwater movement	[36]
Multi-agent robotic fish system	Collects marine information (water temperature and pollution level)	[37]
Robotic dolphin	Determines the pH value, electrical conductivity, and water temperature	[38]
Electronic module for automated fish farming	The model allows simulation of scenarios according to the age of the fish (weeks) and according to physicochemical parameters	[39]
Sensor network to monitor an aquaculture facility	Performs turbidity and temperature measurements in tanks, using a Fly Port as a node	[40]
Electronic prototype for monitoring physicochemical parameters in tilapia growing	Measures, monitors, and regulates the pH, temperature, DO, and ammonia levels of the aquarium system	[41]
Boat-shaped prototype for monitoring aquaculture species	Uses temperature, pH, and turbidity sensors	[42]
Prototype for automated monitoring of water quality parameters	Monitoring water quality parameters: dissolved oxygen, pH, salinity, and temperature	[28]

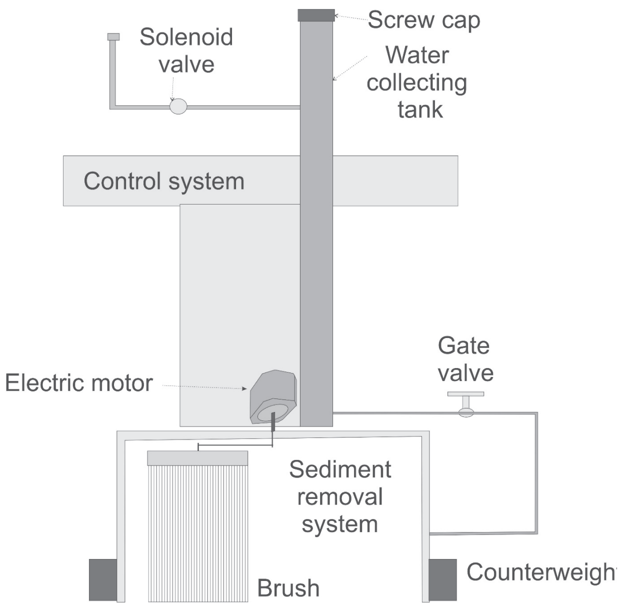

Fig. 1. Diagram of the functioning of the prototype sediment collector.

of symmetry by a metal bushing and a rubber O-ring. The function of this system is to prevent water from entering the geared motor from the outside at a torque of 20 kg-cm and damaging it. The geared motor is fixed on a circular PVC base of 5.08 cm diameter, and its circular movement is transmitted to the brush shaft, which removes the sediment from the bottom of the pond (Fig. 2b)).

b) Water and sediment sample collection tank

The collection tank has a capacity of 600 mL. To capture the water with suspended sediment, a solenoid valve is operated by 12V direct current, allowing the water to pass through a U-shaped tube of 1 inch diameter. This system is graphically described in Fig. 3, which, for a better understanding, is divided into three areas, which are detailed below. In Fig. 3a), a 6 inches diameter bell-type coupler can be observed, its function is to delimit the sampling zone for its subsequent passage to the collection tank. The sampling zone has small 3 mm perforations that allow the trapped air to be removed when water enters the device.

Fig. 3b) shows the external part of the 6 inches diameter coupler, described in Fig. 3a). In the lower part, two rolls of wire with a weight of 1 kg each were placed, so that the model goes to the bottom and remains vertical. In this same figure, the U-shaped system made of 1 inch PVC pipe and a manual stopcock that connects to the collection tank can be seen.

A third area, contained in Fig. 3c), shows the collection tank, which consists of a 3 inches diameter PVC pipe with a storage capacity of 600 mL of water with sediment. It is important to point out that, in the upper part of the prototype, there is a 3 inches tube in a transversal shape, hermetically sealed, where the electronic system that allows the activation of the sample collection routines is housed; in the same way, there is a plug with a hermetic seal that allows the user to extract the water samples manually, for which it is necessary to first close the stopcock shown in Fig. 3b).

c) Electronic system for the sediment water collector

The electronic system is composed of an Arduino Nano, a 5 V dual relay module, a 12 V solenoid valve, a 5 V UBEC output regulator, and a direct current power supply (3 lithium 18650 batteries in series). To keep the electronic system free of moisture, a 3 inches diameter PVC capsule was fabricated with a plastic screw cap at both ends and an O-ring to keep the system airtight (Fig. 4).

The routine, programmed in C++ Arduino language, operates when the equipment is switched on and takes 3 min and 20 sec to complete its entire work cycle. During this period of time, the operator must submerge the prototype to the bottom of the pond, for which the operator has 2 min; once this period of time has elapsed, the motor reducer is activated to make the brush rotate, 40 sec later, the electro valve is activated in parallel for 40 sec, which allows the water with sediment to be suctioned and enter the collection tank.

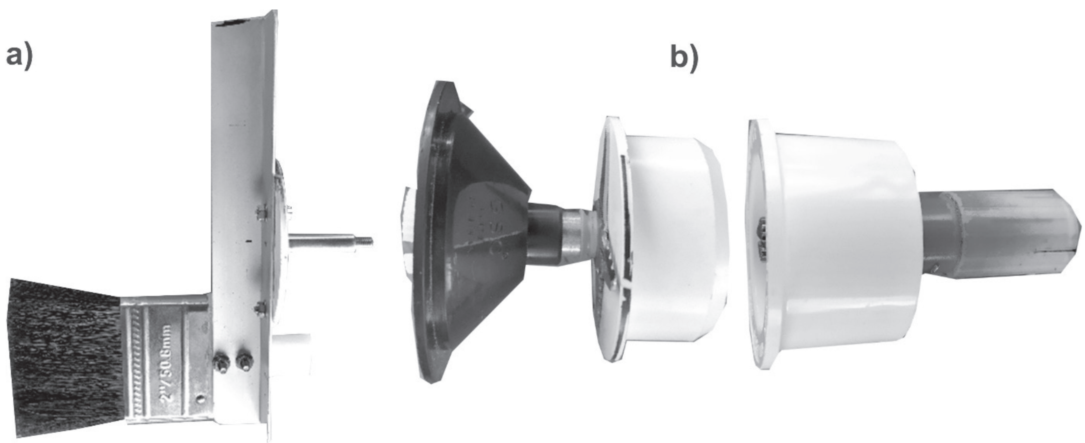

Fig. 2. Components of the system responsible for sediment removal.

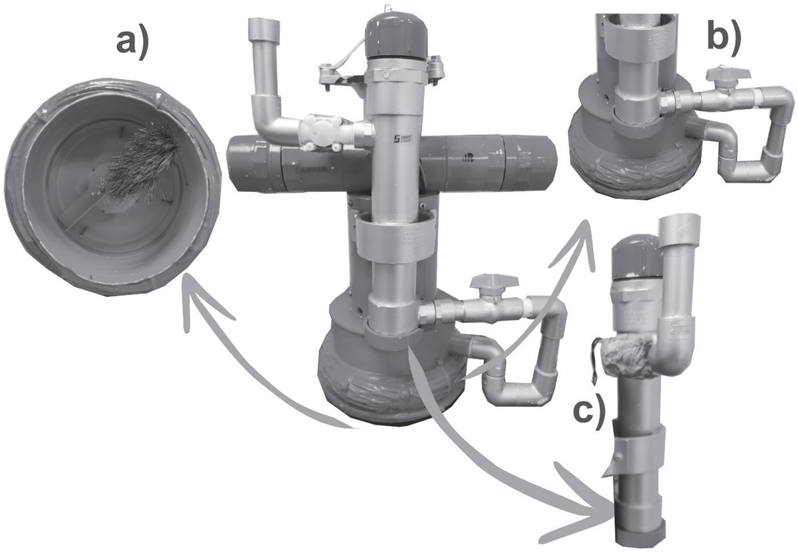

Fig. 3. Prototype sediment water collector. a) sediment removal system, b) siphon pipe and dead weight, and c) water sample storage tank.

When the routine is finished, the motor reducer stops, and the electro valve closes, allowing the prototype to be removed from the tank and the collected samples to be extracted. It is important to note that the equipment has the option of not activating the sediment removal system, for which a shutdown switch was installed, according to the sampling purposes.

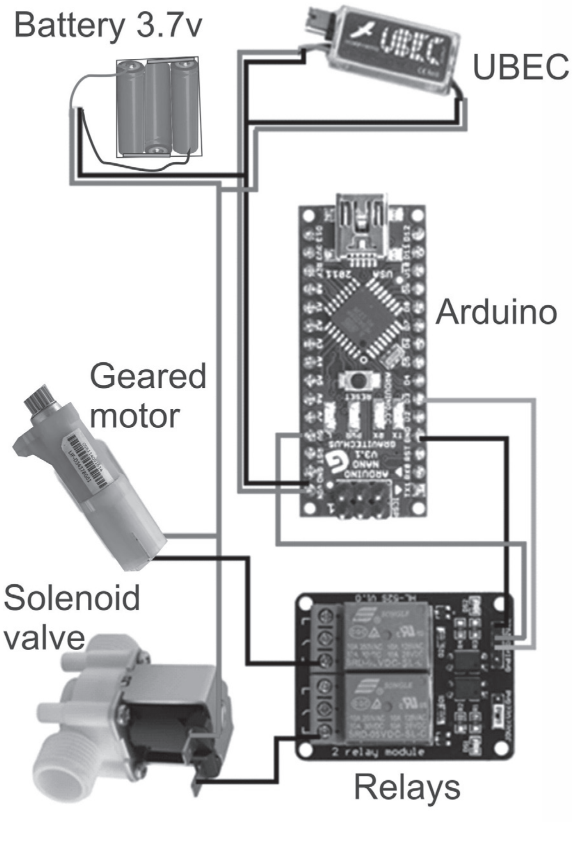

Fig. 4. Components of the prototype electronics system.

The prototype was coated with resin and fiberglass to protect it from corrosion, as well as a layer of paint to give it a finished and aesthetic look. In addition, a triangle-shaped handle was added to the upper base to take it out of the water, and a float to indicate the position of the equipment once it is underwater. Fig. 5 shows the practical application of the prototype, illustrating its operation in (a) a tank and (b) a pond, both dedicated to tilapia production.

Case Study

The prototype was tested in an aquaculture pond dedicated to tilapia farming located in the municipality of Guasave, Sinaloa, Mexico, measuring 70 m long and 20 m wide (Fig. 6). The study area is located in the coastal plain and deltas of Sonora and Sinaloa, predominantly Vertisols soils; the predominant climate in the region is dry very warm and hot, with an average annual temperature of 24.8°C (1986-2015 series) and an average annual precipitation of 875.6 mm (1986-2016 series), both at the Jaina meteorological station which is the closest to the study area [44].

With the help of the prototype under study, 40 water samples with sediment from the bottom of the pond were taken and stored in a 500 mL plastic container; in situ temperature and dissolved oxygen readings were measured and recorded using a previously calibrated YSI Life Science portable oximeter.

The samples were transferred to a portable analysis unit mounted at the same study site, where pH and nitrite, nitrate, and ammonium concentrations were determined using an API marine field kit, following the protocol established in the kit manual by Apifishcare [45] and the methodology for each of the physicochemical parameters as described in Table 2. The procedure was repeated for each of the 40 samples, and the time

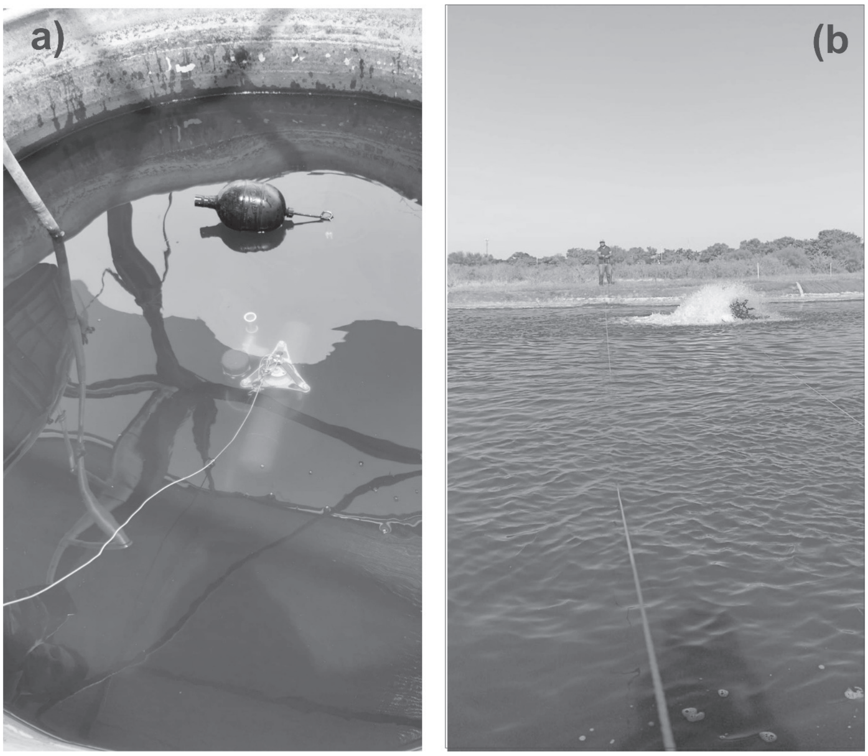

Fig. 5. Practical application of the prototype. a) in a tank and b) in a pond, both dedicated to tilapia production.

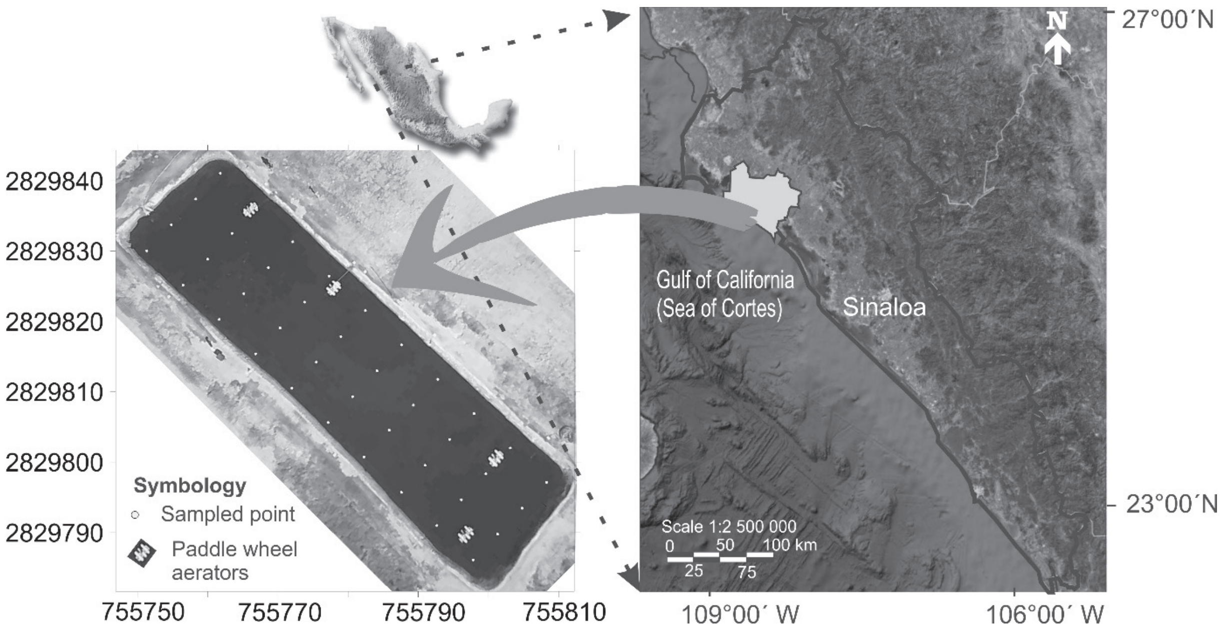

Fig. 6. Study area where the prototype was tested.

between sample collection and the start of analysis was less than 15 min.

Also, 411 topographic points were taken on the edge and inside the pond to know the behavior of the terrain relief, for which it was positioned with precise GNSS in RTK mode (real-time kinematics) through two SimpleRTK2B plates and two Ardusimple multiband antennas. It is important to note that the NTRIP (Emlid Caster) client protocol was used for reading corrections in conjunction with a cellular Internet connection.

Results and Discussion

A pond measuring 20×70 m^2 with tilapia was analyzed, and six physicochemical parameters (dissolved oxygen, temperature, pH, ammonium,

Table 2. Methodology used for different physicochemical parameters.

	Methodology used
pH	The sample was homogenized and, with the help of a BioPette Plus 100-1000 µL micropipette from Labnet International P3942-1000, 5 mL was added to a glass test tube; then, 5 drops of range pH test solution were added. The tube was placed on a tight lid and homogenized with the help of a Vevor VM-300 3000 RPM portable vortex. After 2 min, the pH value of the sample was recorded [45].
Ammonia	The sample was homogenized and, using a Labnet International BioPette Plus 100-1000 µL micropipette P3942-1000, 5 mL were added to a glass test tube; subsequently, 8 drops of the reagent test Solution 1 ammonia NH_3/NH_4^+, and 8 drops of the reagent test Solution 2 ammonia NH_3/NH_4^+ were added. The test tube was capped with the help of a vortex and shaken for 5 sec, and the ammonium value of the sample was read after 5 min [45].
Nitrite	The sample was homogenized and, using a Labnet International BioPette Plus 100-1000 µL micropipette P3942-1000, 5 mL were added to a glass test tube. Five drops of test solution nitrite NO_2^- were added, the cap was placed on the test tube and vortexed for 5 sec. The sample with the reagent was left to stand for 5 min to allow reaction time, and finally the nitrite concentration was read [45].
Nitrate	The sample was homogenized and 5 mL were added to a glass test tube with the aid of a Labnet International BioPette Plus 100-1000 µL micropipette P3942-1000; then, 10 drops of test Solution 1 nitrate NO_3^- were added. The test tube was capped and shaken vigorously for 30 s with the aid of a vortex. Then, 10 drops of test Solution 1 nitrate NO_3^- were added, followed by 10 drops of the reagent test Solution 2 nitrate NO_3^-. The test tube was capped and shaken vigorously for 30 s, then 10 drops of the reagent test solution 2 nitrate NO_3^- were added and the test tube was capped and shaken for 60 s in the same manner. Finally, the nitrate concentration of the sample was read after 5 min [45].

nitrite, and nitrate) were analyzed in 40 water samples with sediment (see Fig. 7). The behavior of each of the parameters in the pond was characterized as described below.

Dissolved Oxygen

Fig. 7a) shows the behavior of the dissolved oxygen values in the aquaculture pond, showing that the concentrations in the water samples ranged from 1.94 to 5.09 mg/L, the recommended optimum for *O. niloticus* is values higher than 2 or 3 mg/L [46], however, this species can withstand concentrations lower than 1 mg/L for short periods of time, but this can cause a decrease in food consumption and consequently in the growth of the fish [47].

It is also important to note that low dissolved oxygen values in aquaculture systems can be a stress factor, making it necessary in some farms to implement artificial aeration [48]. On the other hand, Bautista Covarrubias and Ruíz Velasco [49] establish that, for tilapia culture in geomembrane tanks, oxygen levels should be higher than 5 mg/L.

Temperature

The water temperature in the pond, at the different sampling points, had a slight variation from 25.3ºC to 29.3ºC (see Fig. 7b)), which is congruent considering that the water is stagnant (at least at that time there was no water replacement), the sampling time from 9:00 h to 13:00 h, and the ambient temperature from 25ºC to 32ºC. These values are in line with FAO [48], which states that, in freshwater fish aquaculture, the temperature varies between 24 and 32°C and the pH between 7 and 8.

pH

The pH values of the samples were in the range of 7.4-8.0, which indicates that the water is slightly basic throughout the pond (see Fig. 7c)) and is therefore within the range established as optimal [46], which is between 7 and 8. Luchini [50] states that tilapia survival is affected by low pH values in the water, pointing out that, in his experience, for pH values of 4, 40% of the population in the pond survives, while pH values above 10 result in significant mortalities.

Ammonium

Ammonium concentrations in ponds depend on fish waste and decomposition of uneaten feed [48], hence the importance of monitoring. In the study conducted in the pond, it was found that all water samples had ammonium values $\leq$ 1 mg/L. According to Saavedra [46], ammonium values for tilapia culture should be 0.1 mg/L maximum. When tilapias are exposed to non-ionizing ammonium concentrations above 1 mg/L for several weeks, it can affect survival, especially in fry and juveniles [47].

Nitrite

Nitrite values in the pond water recorded in the present study ranged from 0.25 to 0.50 mg/L (see Fig. 8a)), which are above the limit of 0.1 mg/L established for this species by Saavedra [46]. Bautista Covarrubias [49] points out that nitrite levels in water with values above 0.75 mg/L can cause stress in fish, and for concentrations above 5 mg/L, they can be toxic.

High concentrations of ammonia and nitrite are toxic, which affect the growth of fish and even make

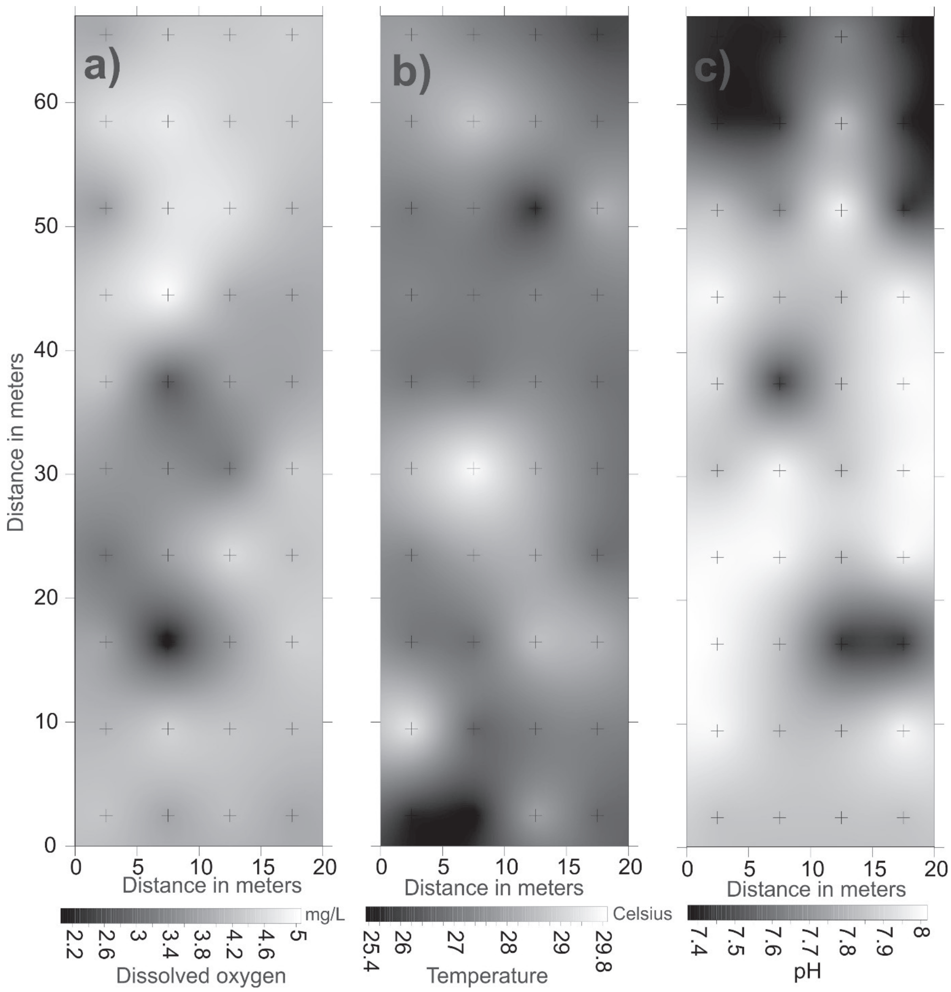

Fig. 7. Behavior of physicochemical parameters in aquaculture ponds: a) dissolved oxygen, b) temperature, and c) pH.

them vulnerable to disease, and can lead directly to death depending on the concentrations present [50].

Nitrates

Nitrate values in the pond water ranged from 10 to 160 mg/L (Fig. 8b)). According to Bautista Covarrubias [49], some points are toxic to fish, since, for tilapia culture in geomembrane tanks, nitrate levels between 0 and 40 mg/L are generally safe for tilapia, and values higher than 80 mg/L can be toxic.

This is attributed to the dynamics of sediment movement, since, in the direction of the points where nitrate values are highest, a slight subsidence of the surface has been observed. This may be the result of irregularities in the bottom of the pond where it is present, which due to its uneven geometry, cause sediments to accumulate, which, when the water circulates with the changes, these do not go with the current, but remain mostly in that place, so that in addition to the studies presented, a topographic survey of the pond was carried out to corroborate the assertions made.

From the analysis of the topography of the pond, it was found that the level of the water mirror is 17.1 m above mean sea level (masl); likewise, the deepest part has a level of 16 m in the northern portion of the pond, finding that in the southwestern portion there is a water column of approximately 60 cm, which could be related to high nitrate concentrations. Fig. 9 shows the behavior of the bottom level of the pond, which is similar to the dynamics of nitrate values (Fig. 7), demonstrating that high nitrate values are attributed to the accumulation of organic matter in the deeper parts of the pond, these are not incorporated into the outflow of water at the time of replacement and remain at the site, causing high nitrate levels to remain at these points, despite the inflow of new water from the replacement, affecting the fish.

The recommendation made to address this problem was to re-leveling the bottom of the pond and, considering that this is not an action that can be carried out immediately, it was suggested that the bottom be cut at the time of the water replacement, so that the sediment in these deep places is incorporated into the current and eliminated through the outflow site located in the corner where point (0,0) in Fig. 8b) occurs.

The determination of water quality in ponds for aquaculture or fish farming purposes is carried out via on-site measurements of certain parameters associated

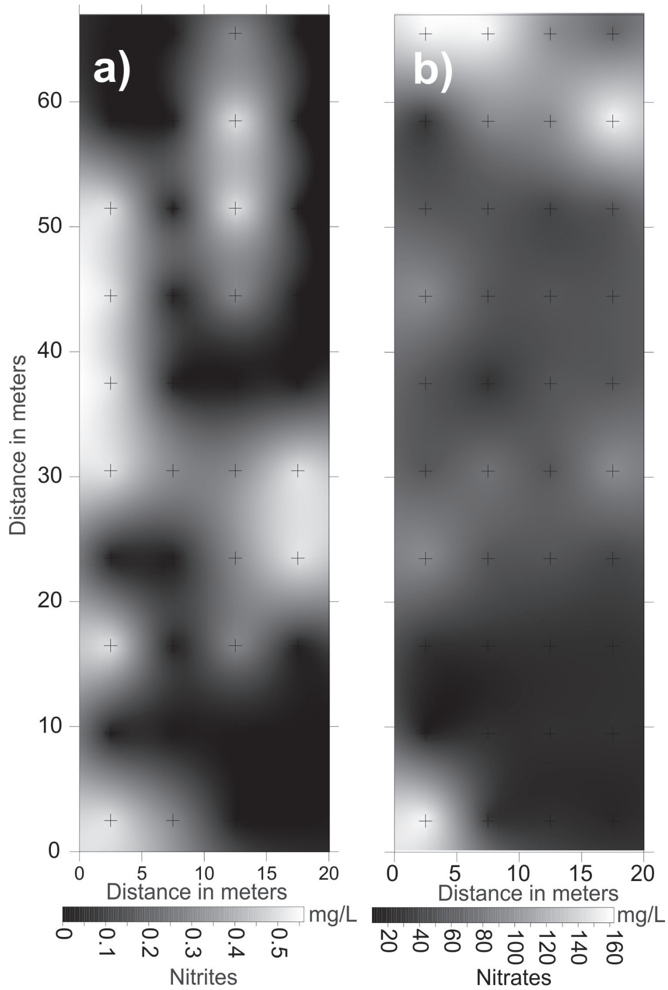

Fig. 8. Behavior of physicochemical parameters in aquaculture ponds: a) nitrites and b) nitrates.

with water quality or by obtaining water samples from which some parameters are measured in the field and others in the laboratory, depending on their complexity, such as heavy metals, pesticides, hydrocarbons, nutrients, and other toxic chemicals in sediments or water.

A large number of authors have developed real-time data acquisition systems using commercial electronic sensors (temperature, dissolved oxygen, pH, among others) that are affordable through programming and the use of the Internet of Things (IoT). In this way, measurements are sent to the cloud or stored in the acquisition system or sent to remote stations, facilitating real-time analysis. These methods are versatile and economical, but limited to a few parameters, unlike more complex ones that require water or sediment samples to be sent to a laboratory. Hence the importance of having an effective water and sediment sampling system that allows samples to be taken at various depths for subsequent analysis.

In addition to automated systems that use IoT, there are commercial multiparameter probes that can be placed at various depths, with the limitation that they do not cover the spectrum of possible parameters to be measured in toxic substances, such as pesticides, heavy metals, and hydrocarbons, among others.

Chekole [51] collected water samples using a polyvinyl chloride (PVC) tube perforated at various depths; Yossa et al. [43] sampled sediments in a pond using a PVC tube by moving it in a boat and inserting it into the bottom of the pond, then extracting it and taking the sediment sample for transfer to a laboratory. These mechanical schemes have the disadvantage of producing dissolutions when the water is agitated or sediments are displaced by the tube moving through the water column.

Lubembe et al. [52] 2024 used a 6-L Van Dorn sampling bottle to take water samples from Lake Kivu in the Democratic Republic of Congo. Van Dorn sampling bottles are available in volumes of 2.2, 3.2, 4.2, and 6.2 L. There are also Kemmerer bottles of 1.2, 2.2, 4.2, and 8.1 L, among others. These bottles allow a water sample to be obtained at a specific depth. They are placed at a certain depth, where the device is opened, filled, and hermetically sealed so that the sample is not contaminated. In contrast to the proposed device, this one allows not only water samples to be obtained, but also sediment samples. Furthermore, the device presented is low-cost in relation to the cost of the bottles.

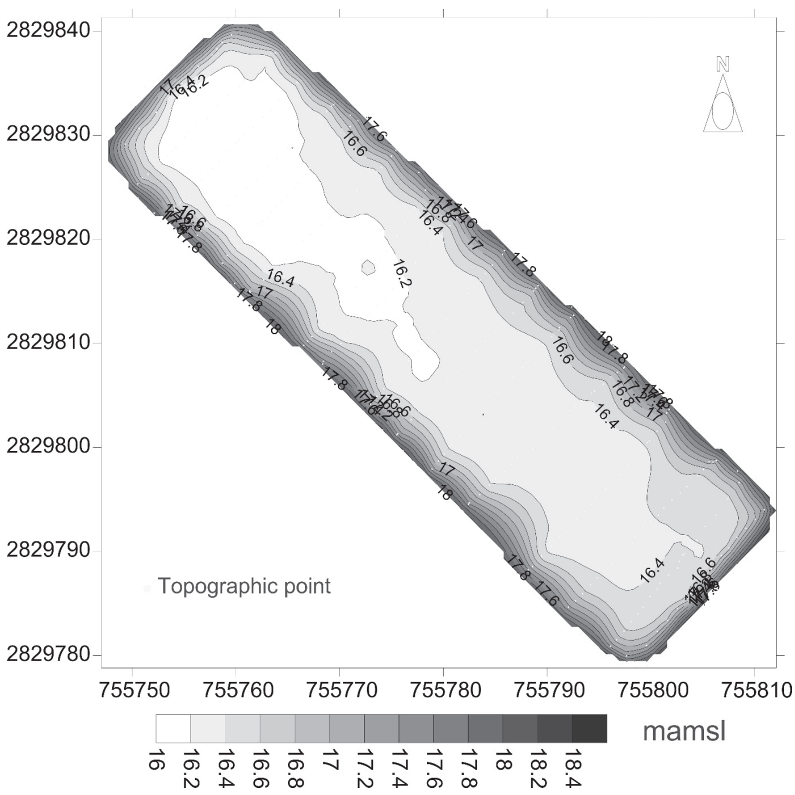

Fig. 9. Behavior of the topographic level on the farm.

Several authors use electronic sensors and the Internet of Things (IoT) to develop systems for monitoring water quality parameters in aquaculture and fish ponds, such as Hidayat et al. [53] who used hydrogen potential (pH), temperature, and turbidity sensors in catfish aquaculture; Hariyadi et al. [54] used temperature and pH sensors in fry rearing; Simbeye et al. [55] used wireless sensors to monitor critical parameters in fish aquaculture; Selvaganesh et al. [56] used pH and temperature sensors and added a servomotor system for programmed feeding of fish; Jomsri and Prangchumpol [57] used temperature, dissolved oxygen, pH, and turbidity sensors to improve survival rates of gurami fish; al-Badawi et al. [58] used temperature and pH sensors in discus fish farming; Olanubi et al. [59] used temperature, pH, and turbidity sensors in water quality monitoring for the growth of aquatic organisms; Tamim et al. [60] used sensors to measure pH, dissolved oxygen, temperature, and ammonia in fish production; Susanti et al. [61] used temperature, pH, and TDS sensors in pond fish farming; Ryuh et al. [37] and Wu et al. [38] perform in situ monitoring of temperature, electrical conductivity, and pH parameters using devices; Africa et al. [41] monitored pH, temperature, and dissolved oxygen in fry rearing.

These IoT systems have the limitation of not being able to obtain a water and/or sediment sample for the measurement of toxic substances in the field or laboratory, as these systems are limited to in situ measurement through electronic sensors configured in the system and are therefore not substitutes for a sampling system such as the one proposed.

On the other hand, Lubembe et al. [52] use a Multiparameter Field Probe Plus (YSI 550), which allows the measurement of temperature, pH, electrical conductivity, and dissolved oxygen concentration in situ at various depths in Lake Kivu in the Democratic Republic of Congo. Turbidity was determined using a portable turbidity probe, water transparency using a Secchi disk, and lake depth using a manual echo sounder. Peralta-García et al. [62] designed an electronic probe that integrates pH, total dissolved solids (TDS), and electrical conductivity (EC) sensors. These examples, among others, indicate that measurements using commercial or custom-designed probes have the same limitation as IoT systems: they do not capture water samples for complex analysis of water and sediment constituents.

The device developed takes the sample in situ in an automated manner, without affecting the integrity of the sample of interest, in a short time, and at a lower cost than commercial equipment.

When comparing the prototype with others, it was found that Yossa et al. [43] carried out sediment sampling at three points (inlet, center, and outlet), using collectors constructed in PVC pipe with different arrangements and to reach the bottom of the pond a boat was used, taking care not to disturb the environment, having the samples analyzed in the laboratory. Ryuh et al. [37] present a versatile fish and Wu et al. [38] a dolphin, both capable of maneuvering in the water and monitoring in situ parameters such as temperature, electrical conductivity, and pH.

Likewise, Africa et al. [41] created an aquaculture system capable of monitoring pH, temperature, dissolved oxygen, and from the available data calculates ammonia and then automatically regulates them in case any of these parameters go out of the established ranges, which they tested in two tanks of 1 m^3 capacity with 50 fry.

Juárez-Rosales et al. [63] state that the study of sediment is important throughout a culture because the concentration of major and minor nutrients in the sediment of the ponds, when it is a shrimp monoculture and in a tilapia-shrimp polyculture, increases during the production cycle.

Generally, sediment analysis in aquaculture ponds is carried out once the harvest is finished, after the water is drained and the bottom material is dry, so the sample is taken manually without complications and transported to the place of analysis [64], before the start of planting, to know the conditions of the pond and take measures to ensure that it is in the best conditions for the new cycle.

When it comes to analyzing water or sediment at different depths of the pond when it is active (fattening of organisms), the way in which the sample is collected is very important so that its integrity is not altered [65].

Unlike other devices used in water and sediment sampling, such as PVC tube adaptations [66], commercial sediment samplers [67], in situ sampling with this device allows for automated sampling, without problems affecting the integrity of the sample of interest, in a short time (3.5 min), and at a lower cost.

Finally, it should be noted that the device tested here is low-cost and allows a sample of water or sediment to be taken at a variable depth from the pond in 3.5 min. Sampling is essential for subsequent analysis in situ or in the laboratory, thus enabling efficient pond management and real-time decision-making for healthier and more abundant production through better control of water and sediment quality. Unlike sampling systems with sensors, this device provides a complete analysis spectrum, including heavy metals, nutrients, hydrocarbons, pesticides, and others. Sensors, on the other hand, are limited to certain physical or chemical parameters. Regular monitoring of pond water or sediments should be a standard practice for quality production, which requires instruments such as the one presented here.

Therefore, the device has the advantage of being inexpensive to build, mechanically simple to operate, capable of sampling liquids or suspended solids, easy to transport, and lightweight enough to be operated by one person or two in the case of sampling transects or on a boat. In case of breakdown, the parts are easy to replace, low-cost, and readily available on the market.

A disadvantage is that, at present, the device does not have a system for storing and transmitting field data in real time to a remote station, nor does it have a geopositioning device. Data recording is done in the field on a device other than the sampler. The geopositioning of the device in the pond is done by topographic and mechanical means associated with the location of the device in relation to a rope that moves along the length and width of the pond. Sensors with the above characteristics were not installed in order to keep the cost of the device down and to make its operation practical for aquaculturists.

Conclusions

A scheme of a portable, semi-automatic, and low-cost prototype for the collection of water and sediment (suspension) samples from the bottom of ponds planted with tilapia was presented, with the aim of determining water quality or analyzing sediments. In the case of the former, the physicochemical parameters of the water that influence the development of the culture were considered. To demonstrate its effectiveness, it was used in an aquaculture pond planted with tilapia, where 40 samples were obtained, analyzing in situ the behavior of six physicochemical parameters, which made it possible to determine the behavior in the pond and identify areas of toxicity. This information was useful for tilapia producers, as it allows them to correct possible irregularities that may arise during the development of the planting.

The device is easy to operate and can be operated by one or two people in the case of longitudinal or transverse transects of the aquaculture pond. In the event of breakdown, its parts are easy to replace and inexpensive.

Dissolved oxygen, temperature, pH, nitrites, nitrates, and topographic level revealed that behavior varied and that some areas were more vulnerable than others. This information is relevant for correcting production processes and maximizing benefits. It is important to emphasize that small producers require access to affordable technologies for production automation and monitoring for the control and management of culture ponds.

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Conflict of Interest

The authors declare no conflict of interest.

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