Low-cost autonomous labmade device for monitoring physicochemical parameters in aquatic ecosystems

Carlos H. B. M. Filho[a], Lucas M. B. D. Falcão[a], Marcos F. M. Ferreira[a], Cintya D'A. E. S. Barbosa[a], Rodrigo S. Viana[a], Vânia L. G. Teles[b], Daniela S. Anunciação[a]

[a] Instituto de Química e Biotecnologia, Universidade Federal de Alagoas, Brazil
[b] Centro de Tecnologia, Universidade Federal de Alagoas, Brazil

Abstract: Assessing the water quality of the Mundaú-Manguaba Estuarine Lagoon Complex (CELMM) is of crucial importance to the surrounding populations. Thus, we are focusing on developing a low-cost arrangement using the Arduino Mega 2560 Rev3 board and an Ender-5 S1 3D printer to meet this demand. Initial tests were carried out with mercury based on the contamination data of this element at the CELMM. Analysis by Cold Vapor Atomic Fluorescence Spectroscopy (CVAFS) revealed that this contaminant was not adsorbed by the filaments used to print the device (ABS and PLA), which will allow both to be used to build the device's compartments.

Keywords: Arduino; Water quality; Physicochemical parameters; Mercury; CV-AFS.

1. INTRODUCTION

The Mundaú-Manguaba Estuarine Lagoon Complex (CELMM) is one of the most socioeconomically and environmentally representative environmental compartments in the state of Alagoas. Considered one of the most important ecosystems in Brazil, it covers a total area of 7844 km² with a tropical and semi-humid climate with two well-defined seasons: dry (September to March) and wet (April to August) [1,2]. Its formation is due to the Mundaú River, which flows into the lagoon of the same name, and the Paraíba do Meio and Sumaúma rivers, which flow into the Manguaba lagoon [3].

However, despite the importance that these ecosystems play for human populations and for several species of organisms that depend on them, the impact due to anthropogenic activities has been increasingly frequent, causing changes in their environmental conditions [4].

The preservation of water quality in aquatic ecosystems is a historical challenge that dates back to the ancestral communities that inhabited regions such as the CELMM. Over time, the complex has witnessed the transformation of its surroundings with the advent of industrial and urban growth, bringing with it new challenges related to pollution and contamination by metals of high toxic potential. In this scenario, the importance of continuous monitoring of physicochemical parameters is highlighted, becoming essential for the understanding and conservation of this ecosystem. The Mundaú Lagoon, an ancestrally relevant natural resource for local communities, has undergone significant changes due to industrial and urban development, making it vulnerable to pollution from anthropogenic activities. Studies have reported high levels of highly toxic metals in the CELMM [5] and, in recent years, mercury ion levels have been quantified above the limit established by Brazilian legislation for Class 1 brackish waters. Mercury ions are the target of several environmental researches due to their high toxicity, bioaccumulation and biomagnification, which can cause serious effects on the neurological system [6].

According to Costa (2022) [7] the Hg content present in the water of Laguna Mundaú is in a concentration range of 0.02 to 1.64 μg L-1 (inorganic Hg) and 0.2 to 5.45 μg L-1 (organic Hg). According to Eysink, Pádua & Martins (1988) [8], possible mercury contamination comes from the manufacture of medicines (vaccine), thermometers and catalysts in chlorine industries. As it is a difficult element to analyze and of high risk to health, it is noted the importance of innovations to facilitate the physicochemical and control analyzes in the aquatic environment that are easy to access and low cost.

In response to this problem, we present the design and development of a low-cost autonomous device, based on open source technology with the Arduino platform and integrated sensors. The manufacture of the device through 3D printing with PLA reflects the commitment to environmental sustainability, aligning with the guidelines of the competent bodies, such as the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) and the National Water Agency (ANA), which seek to promote the adoption of ecologically responsible practices for the conservation of water resources.

Developed in 2005 by Massimo Banzi, David Cuartielles, David Mellis, Gianluca Martino and Tom Igoe, Arduino is an open source electronic platform used to create prototypes of autonomous and/or interactive systems. Currently, there are several models available divided into families (Nano, MKR and Classic), as well as shields (expansion boards for direct connection with the respective compatible Arduino board), which increase functionalities in the developed project through communication interfaces (bluetooth, Wi-Fi, ethernet and the like), sensors (temperature, air and soil humidity, pH, infrared, ultrasonic, movement, etc.), displays, motors and correlates. To program the various Arduino boards it is necessary to use the C/C++ programming language (however, the framework is based on "Wiring"), and using the Integrated Development Environment (IDE), based on "Processing" [9].

Arduino has a low cost, it is multiplatform (Windows, Linux and Machintosh OSX), the IDE is "clean" and flexible design, because it is open source, there is a wide documentation about the software and hardware. Due to its advantages over other systems (Raspberry pi, for example), it is possible to use it to build accessible scientific instruments, expose chemical and physical principles, in addition to its use in robotics, 3D printing, Internet of Things (IoT) and other embedded environments [9].

The developed device aims to offer an innovative and affordable solution for the continuous monitoring of key physicochemical parameters in aquatic ecosystems, allowing data collection in an accurate and reliable way. The selected parameters, including pH, dissolved oxygen, temperature and turbidity, are fundamental for the assessment of biogeochemical processes and the health of aquatic ecosystems. When comparing traditional methodologies for measuring physicochemical parameters with the developed autonomous device, it is possible to highlight the significant advantages offered by this technology. While conventional techniques require manual sample collection and analysis in the laboratory, the device allows continuous and real-time data collection, providing immediately updated information. This innovative approach enables rapid detection of changes in water quality, allowing corrective measures to be implemented more efficiently. In summary, this study represents a valuable contribution to the field of environmental monitoring by addressing historical aspects, industrial impacts and heavy metal contamination in the Mundaú Lagoon. The integration of these elements highlights the importance of preserving water resources for the maintenance of biodiversity and the well-being of local communities. Through the convergence of science, technology and sustainability, the low-cost autonomous device represents an important step in the search for the conservation and protection of aquatic ecosystems, ensuring the quality of water resources for future generations.

2. METHODOLOGY

Cleaning of glassware and preparation of solutions were performed with ultrapure water of resistivity equivalent to 18.2 MΩ.cm-1 using a Master System MS2000 reverse osmosis purifier (Gehaka, São Paulo, Brazil).

2.1. Materials Decontamination

All glassware used in the experiments was washed with ultrapure water and immersed in an acid bath (HNO3 10% v/v) for at least 12h. Upon removal from the acid bath, the material was washed again with ultrapure water and dried at room temperature on previously decontaminated trays.

2.2. Reagents and Solution Preparation

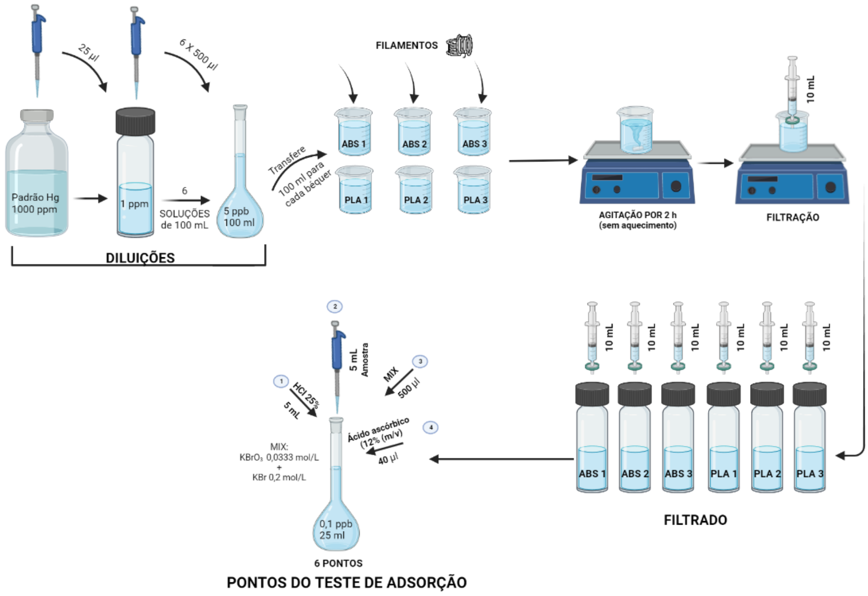
The reagents used were of analytical purity. Mercury (Hg) standard solutions were prepared from its respective commercial standard (SpecSol, São Paulo, Brazil). The following reagents were also used: stannous chloride dihydrate (Merck, São Paulo, Brazil), potassium bromate (Êxodo Científica, São Paulo, Brazil), L-ascorbic acid (Merck, São Paulo, Brazil), HCl solution 12 mol.L-1 (Merck, São Paulo, Brazil).

2.3. Separation Techniques

It began with the preparation of the analytical curve, performing the formation of the HCl solution 25% (v/v), dilution of the mercury standard of 1000 ppm to a stock solution of 5 ppb (µg/L) of mercury in order to facilitate the dilutions of the points of the curve that are in the concentration range of 0 to 1 ppb, also performed the formation of a MIX solution of KBrO3 (0. 0333 mol/L) and KBr (0.2 mol/L), were added to the points of the curve respectively in the same order of preparation. 0333 mol/L) and KBr (0.2 mol/L) and the preparation of ascorbic acid 12% (w/v), were added to the curve points respectively in the same order of preparation. Subsequently, solutions of HCl 5% (v/v) and Tin Chloride 25% (w/v) were prepared for use in the cold vapor atomic fluorescence spectroscopy (CVAFS) equipment.

To avoid loss of mercury by volatilization, the adsorption kinetics test of the filaments was performed together so that both the curve and the adsorption test could be analysed on the same day. For the test, three samples of each filament were separated and immersed in different containers containing a solution of 5 ppb of mercury, at the same time the triplicates of each filament were placed at the same time in a low rotation agitation without heating for two hours. At the end of the time, each sample was filtered with a cellulose acetate membrane and a syringe, taking a 5 mL aliquot of the filtrate and adding it to a 25 mL volumetric flask, resulting in a fivefold dilution (1 ppb), completing the test in the same way as the preparation of the analytical curve (see Figure 2).

FIgure 1. Filament adsorption kinetics test procedure.



2.4. Characterization Techniques

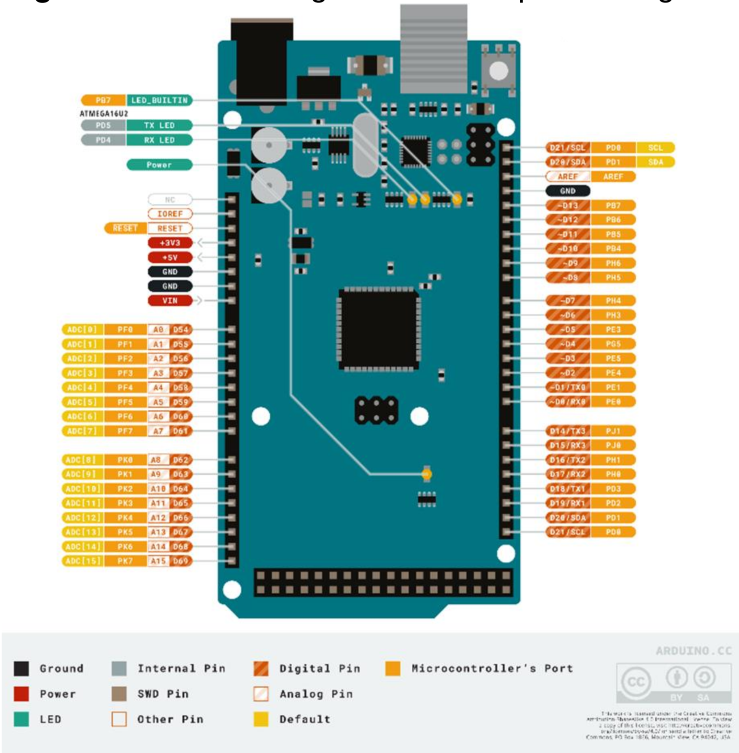
2.4.1. Cold vapour atomic fluorescence spectroscopy

Used in the measurement of trace volatile heavy metals such as mercury, the cold vapor CV-AFS utilizes the unique characteristic of mercury that allows for the measurement of vapors at room temperature. Free mercury atoms in a carrier gas are excited by a collimated ultraviolet light source with a wavelength of 253.7 nm. The excited atoms re-radiate the absorbed energy (fluoresce) at this same wavelength. Unlike the directional excitation source, fluorescence is omnidirectional, so it can be detected using a photomultiplier tube or a UV photodiode.

2.5. Arduino device

The prototype of the device was designed using the Arduino Mega 2560 Rev3 model (Figure 1) which has the ATmega2560 microcontroller, 8 bits with 54 digital I/O pins (in which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), 16 MHz clock, USB connector, ICSP and reset button. In addition, the recommended input voltage is 7-12V, 256 KB of flash memory (8KB of which is intended for the bootloader), 8 KB of SRAM, 4 KB of EEPROM, being able to supply 20 mA to the I/O pins and 50 mA to the 3.3V pin [10].

Figure 2. Arduino Mega 2560 Rev3 pinout diagram.



ARDUINO, adapted

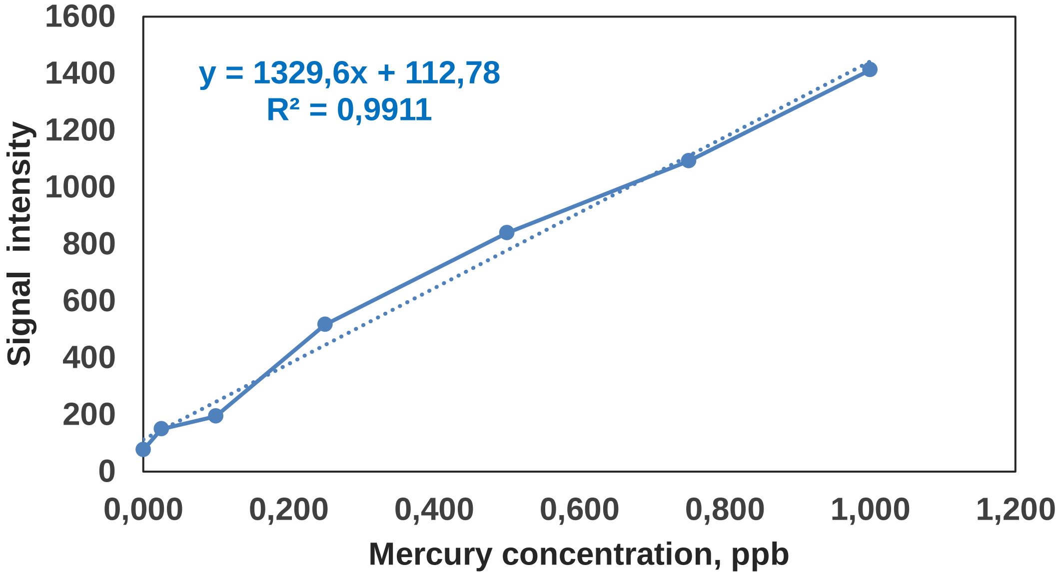
2.6. 3D printer

The 3D printer used was an Ender-5 S1 (Creality, Shenzhen, China) with the maximum print dimensions up to 220x220x280 mm, filament diameter of 1.75 mm, support for various filaments (PLA, PETG, ABS, TPU, PC, ASA and HIPS) and with a maximum temperature in the extruder and table of 300 °C and 110 °C, respectively, in addition to the maximum print speed being 250 mm/s [11].

3. RESULTS AND DISCUSSION

The calibration curve referring to the analytical response for mercury concentrations from 0 to 1 ppb is represented in figure 3.

Figure 3. Mercury calibration curve from 0 - 1 ppb. R2 values above 0.99 are considered acceptable for analyses involving mercury.



Regarding the adsorption test of ABS and PLA filaments, they presented average intensities of 1410.5293 ± 5.05 and 1386.3901 ± 8.28, equivalent to 99.88% and 98.17%, respectively, in relation to the mercury standard of 1 ppb (1412.153). This shows that both filaments are suitable for building the device, as they do not adsorb mercury.

4. CONCLUSION

The absence of mercury adsorption on ABS and PLA filaments is a promising finding for the construction of a device that is immersed in waters contaminated by this highly toxic element. This inertness of the filaments is fundamental to ensure the functionality and reliability of the device, since any interaction between the material and mercury could compromise its effectiveness.

In addition, the use of PLA and ABS filaments allows for greater versatility in the construction of the device. This flexibility is essential to ensure the efficiency of the device and its adaptation to different environmental scenarios.

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We are grateful for the trust placed in our project and for the opportunity to grow as researchers, exploring new ideas and broadening the horizons of knowledge.

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