Author Accepted Version
A version of records is available at https://doi.org/10.1007/978-3-031-31289-2_15
In: Xu, H.(eds) Proceedings of the 5th International Symposium onWater Resource and Environmental Management. WREM2022. Environmental Science and Engineering. Springer, Cham

Smart monitoring of constructed wetlands to improve efficiency and water quality

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Abstract. The Smart monitoring of constructed wetlands to improve efficiency and water quality (SmarterCW) project aims to monitor biological wastewater treatment processes by gathering continuous data from remote water and environmental sensors. The acquired data can be processed and analyzed through data science tools to understand better the complex and coupled phenomena underneath wastewater treatment and monitor and optimize the system performance. The results will improve the efficiency and control of nature-based wastewater treatment technologies.

The methodology comprises the following tasks and activities: Implementation of a set of electrochemical sensors in the input and output flow streams of pilot-scale constructed wetlands; Acquisition of water quality parameters such as pH, electrical conductivity, temperature, and ionic compounds; Acquisition of environmental parameters, such as temperature and humidity; Application of data analysis tools to design and optimize conceptual models to correlate pollutants removal with operative parameters in green technologies for wastewater treatment. This methodology was applied to a patent-protected pilot-scale modular constructed wetland in which filling media consists of a mixture of solid waste. A high-level IoT communication layer structure complements the system to support remote real-time water and environmental monitoring, system performance, and data dissemination.

Keywords: Wastewater treatment, Sensor networks, Efficiency monitoring.

1 Introduction

Constructed wetlands (CW) consist of a nature-based solution (NBS) for wastewater treatment [1]. NBS technologies are greener solutions aiming to drive sustainable development [2]. CW are low-cost, ecological, and effective wastewater treatment systems [3]. CW can be applied to treat diverse types of wastewaters, including domestic [4], industrial [5], and greywater [6] among others, targeting different kinds of pollutants including conventional pollutants such as nutrients, but also specific compounds such as steroids and antibiotics [7], and heavy metals and metalloids [8], among others. Furthermore, CW can contribute to circular economy of water through the production of reclaimed water [9], valorization of solid waste as filling media [10], and valorization of the wetland plants for bioenergy applications [11].

There are several types of CW, but the common types comprise three main components [12]:

1. a water retention structure, such as a pond lined with an impervious membrane or a kind of container
2. a bed of granular filling material with adequate hydraulic permeability, such as gravel or solid waste
3. water-tolerant plants such as the macrophyte common read.

However, these technologies have some disadvantages related to a minor level of control than conventional technologies. As an example of a conventional solution, an anaerobic reactor treating wastewater can be operated at different flow rates, temperatures, and mixing intensities. Manipulating those parameters can adapt the process efficiency to changes in the wastewater composition. On the other hand, NBS such as CW has limited level of manipulation. Although some variants of CW can have notable improvements, such as tidal flow operation or bed aeration, in the most common CW systems, only the flow rate can be varied but to a low extend over the average designed value [13]. Thus, water quality parameters should be monitored at the higher available rate to optimize CW operation by the dynamic setting of the input wastewater flow rate. CW and NBS technologies commonly involve discrete water sampling and further analysis in a laboratory at a low frequency, such as daily, weekly, or even monthly sampling [10].

In the SmarterCW project, a set of sensors for continuous evaluation of the water quality aims to get insights on the system response to the change of the uncontrolled environmental variables, such as air temperature, humidity, speed, radiation intensity, and pluviometry, among others, and design a framework for future implementation of back control and optimization models.

The goal of this work consists of reporting the preliminary stages of the sensor network framework development based on physical water parameters, and presenting examples of the gathered data during a representative time of operation.

2 Material and Methods

2.1 CW prototype

The CW prototype is fully described in previous works [14]. The prototype consists of a modular planted bed filled with a mixture of solid waste, treating secondary-type domestic wastewater (Fig. 1). The bed has a surface area of 1.1 m2 and a depth of 0.5

m, planted with common reed (*Phragmites australis*). The water flows horizontally 0.1 m below the surface, with an average load of 40 L/day. The filling consists of four layers of three solid waste: a bottom layer and a top layer of fragmented limestone rock, a residue from construction activities; a layer of coal slag from a coal power plant above the bottom layer, and a layer of cork granulates from the cork industry, over the coal slag layer. Besides acting as a support for the plants and microorganisms community, the different solids contribute to wastewater treatment. The cork residues and coal slag play a role as sorbents for organic pollutants, and the limestone residues adsorb phosphorous compounds, a recalcitrant nutrient in wastewaters [15].

(a)

(b)

Fig.1. Picture of the CW prototype (a), and schema showing the filling media consisting in four layers of three recovered solid wastes (b).

2.2 Sensor network

Preliminary works are carried out using two sets of three sensors from Aqualabo (France): pH probe PHEHT, Dissolved Oxygen (DO) probe OPTOD, and Electrical Conductivity (EC) probe C4E, and two sets of integrated pH, EC, and Temperature probes (Groline HI 981420, Hanna Instruments, Germany). One set is located in the input flow, and one in the output flow of the CW prototype. The integrated Groline sets function as reference for the data acquisition system.

Fig. 2 presents the main framework for data acquisition and processing from the probes installed in the input and output streams of the CW prototype. The feedback from the input and the control system's output stream is a fundamental component to satisfy the requirements of a fully automated data acquisition system. The implemented hardware and communication software was selected based on optimizing costs but providing scalability for easy addition of more probes in the future.

Two ESP32 microcontrollers were used for the acquisition of water quality parameters from the sensors and controllers using the interface RS485 and are in charge for the implementation of two additional functions: on the input side, the ESP is responsible for the management of a peristaltic pump, the device used to control the variable of the close-loop systems. The ESP32 on the output side also has the additional function of controlling the discharge of water from the tank at the system outlet. The control information can be generated locally, through a Raspberry Pi (RPi) microprocessor or by the central monitoring platform software developed for the cloud. The RPi microcontroller also performs the functions of a gateway device providing connectivity, security, and data routing, between the private application network and the public Internet. The publish-subscribe standard message protocol MQTT (Message Queue Telemetry Transport) was used for local communications because is well suited for bidirectional data transmission from many local devices to a single central monitoring station. Finally, a cloud-based platform was developed to present data to the user and provide ways to interact with the application. This application provides a user-friendly interface for accessing, storing, controlling, and presenting the application parameters. The software package is designed to implement analytic algorithms to analyze time-series data and provide system insights, enabling the monitoring system to be more effective and efficient over time. The system was also designed to interact with Grafana and InfluxDB open-source monitoring tools.

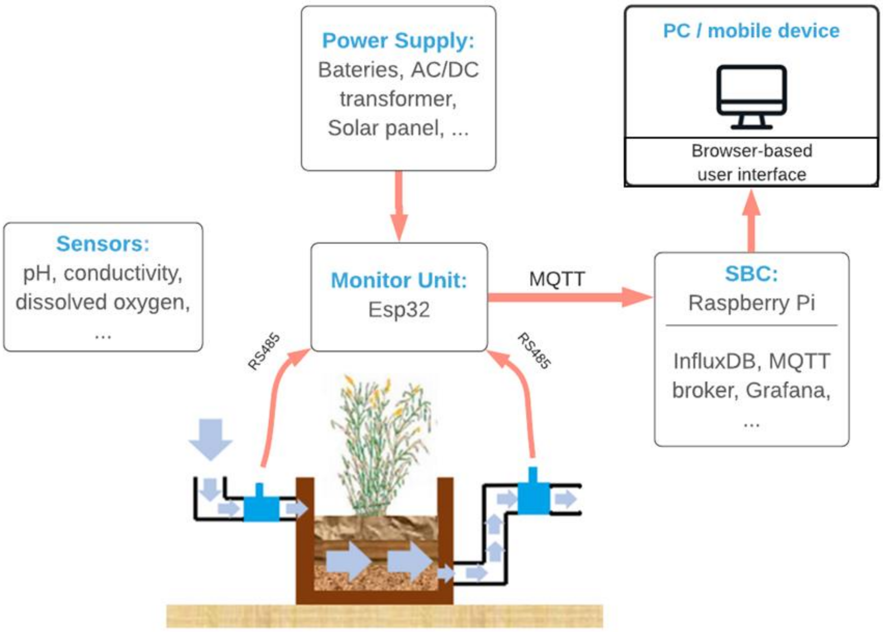

Fig.2. Scheme of the implemented sensor network in the CW prototype. SBC represents a Single Board Computer such as the Raspberry Pi used in this work.

2.3 Efficiency evaluation

In this work, the efficiency of wastewater treatment is computed using the Electrical Conductivity results. Although pH and DO help understand the physicochemical and biological phenomena that occur in CW, the EC is an indicator of the concentration of dissolved substances. It thus can be a reasonable indicator of the efficiency of wastewater treatment.

The treatment efficiency is computed from the readings of the EC probes in the input and output streams, according to equation (1).

$$\eta = (EC_{in} - EC_{out})/EC_{in} \times 100 \tag{1}$$

where EC_{in} and EC_{out} are the readings of the probes in the input and output streams, respectively, and η the treatment efficiency (%).

3 Results and Discussion

Fig.3 shows an example of the gathered data for a typical run of 4 days, with a probe sampling rate of 15 minutes. The output is strongly irregular, as already reported for CW facilities [16], showing a cyclical daily variation. The minimum EC values occur daily between 2 and 4 pm, and the maximum values occur daily between 10 and 12 pm. Minimum EC values imply higher dissolved solids removal efficiency. These results may be related to higher temperatures and solar radiation, improving the pollutants assimilation by the plants and by the microbiological community colonising the CW bed.

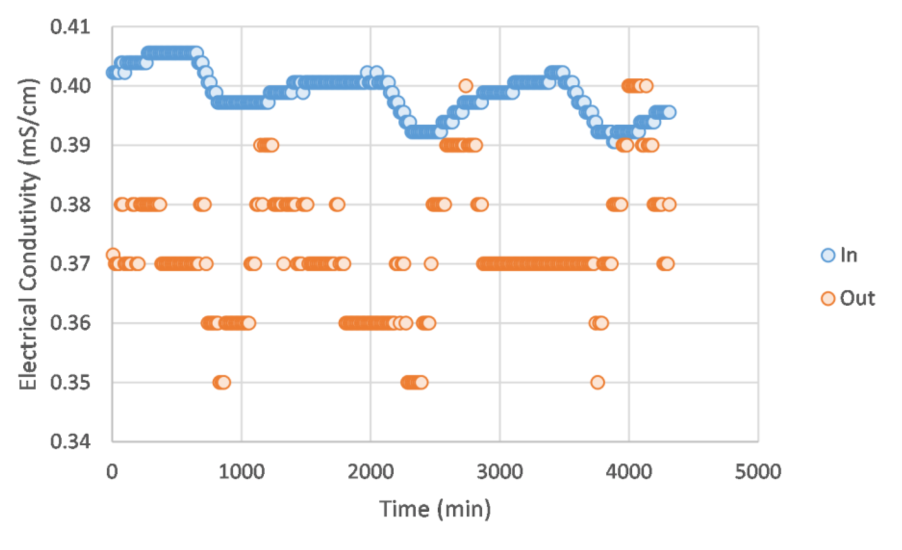

Fig.3. Example of registered EC in the input and output water streams in the CW prototype, obtained by the integrated set of sensors.

Considering a traditional sampling procedure, for example, by 10 am every day, the computed treatment efficiency is 9% ± 3%. However, computing the treatment efficiency using all the gathered data, the average efficiency is 7.2% ± 0.3%. Both differences in the average value and uncertainty interval are significant. In this example, a low-frequency sampling resulted in a 20% overvaluation of the treatment efficiency.

As previously introduced, CW, like other NBS systems, have a low degree of manipulation during operation. The most controllable parameter is the feed flow rate of wastewater. The continuous knowledge of the treatment efficiency can optimize the operation by maneuvering the input flow rate, increasing when the treatment efficiency increases, and reducing the flow rate when the treatment efficiency decreases. Moreover, the real-time monitoring of other variables, including environmental parameters, can further increase the capacity to adjust the input flow rate, making these systems more reliable and sustainable.

Presently, besides EC, also pH and DO probes are installed and their data is continuously gathered. The daily variation of pH and DO is presented in Figures 4 and 5, respectively. As for EC, the daily variation of pH and DO is cyclical, with special evidence on the DO behavior. The evaluation of these parameters only through low-frequent samplings can, also, present significant deviations to the average values, and lead to a deficient interpretation of the behavior of the CW.

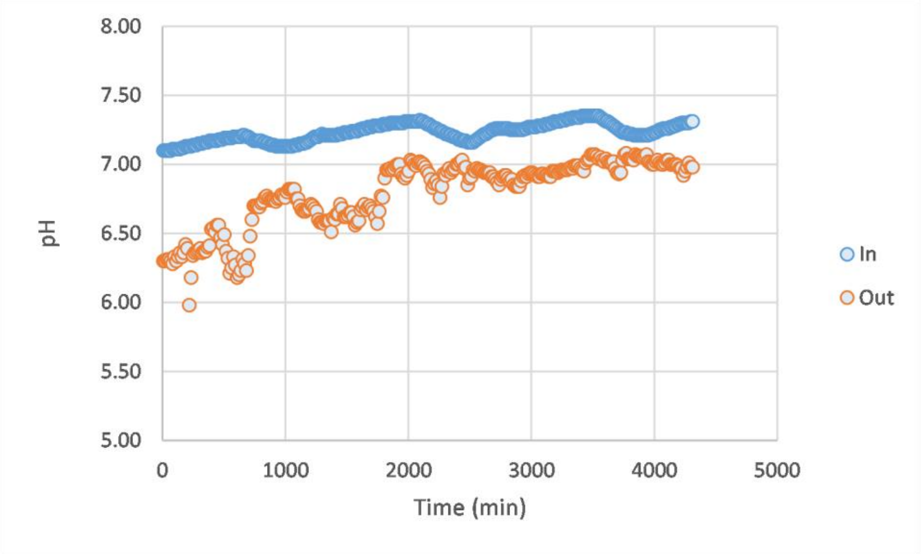

Fig.4. Example of registered pH in the input and output water streams in the CW prototype, obtained by the integrated set of sensors.

Current work is ongoing to install more sensors, such as COD, nitrate, ammonium, and phosphate probes. Those parameters present better understanding of CW efficiency than pH, EC, and DO, thus the future availability of them will allow the developing of models that can contribute to optimize CW operation. In addition, the sensor network under development can easily be applied to full-scale CW in real-field operation.

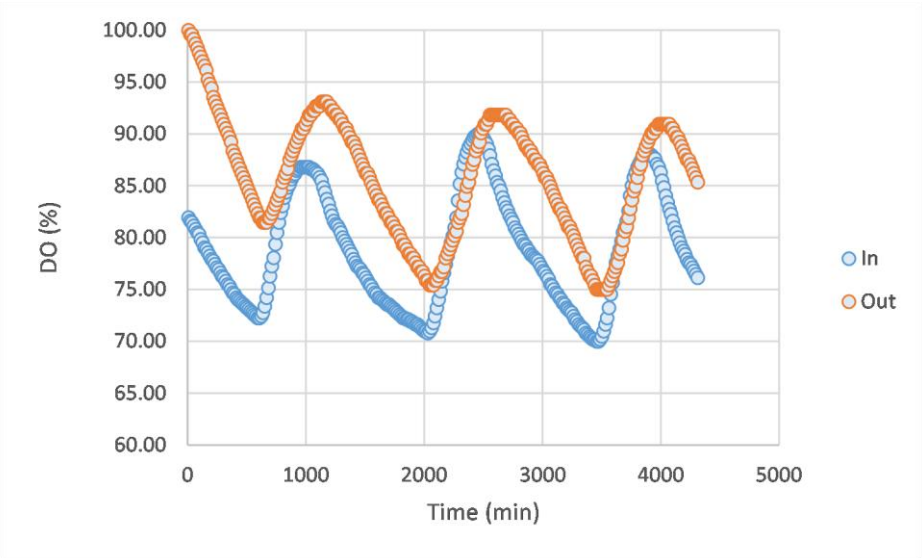

Fig.5. Example of registered EC in the input and output water streams in the CW prototype, obtained by the integrated set of sensors.

4 Conclusions and future work

Optimization of CW and other NBS wastewater treatment systems can increase their sustainability and promote better freshwater management. However, the control of those systems is limited, depending on reliable data on the treatment efficiency. The present work confirms that the efficiency of CW is not regular, changing on an hourly basis. Thus, a framework to continuously evaluate water quality parameters was developed, based on electrochemical probes using reliable but low-cost hardware and a communications environment.

Electrical conductivity, an indicator of dissolved compounds' presence, was selected as a representative water quality indicator. Results demonstrated that the evaluation of the treatment efficiency based on a daily sampling differs by 20% from the results obtained with a sampling rate of 15 minutes. Future work is ongoing to evaluate more water and environmental parameters, being a basis for applying data science tools to optimize the efficiency of CW and other NBS systems.

Acknowledgments

This research was supported by the Smart Cities Research Center under the grants UIDB/05567/2020 and UIDP/05567/2020 funded by The Portuguese Foundation for Science and Technology (FCT – Fundação para a Ciência e a Tecnologia, Portugal). The grant POCI-01-0145-FEDER-23314 is also acknowledged.

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