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Treatment of domestic effluents using sustainable biofilter methods

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ABSTRACT

The discharge of effluents is a permanent environmental and sanitation concern. Efficient water management must include water treatment and reuse. It is therefore necessary to study treatment systems to improve their performance throughout the entire chain, from drinking water to wastewater or, more specifically, waste effluent. Currently, technologies using bio-filtration processes have proven to be an effective and low-cost method for treating industrial effluents and domestic sewage. In this study, a low-cost domestic sewage treatment system made up of biofilters and pipes was built on a bench model as a means of teaching practical classes, and its efficiency was also studied. The results showed that the equipment can be made from recyclable material and is low-cost, easy to detail technically and easy to handle and operate. The students involved can easily replicate the technology in their communities, thus spreading low-cost sanitation treatment technologies to low-income populations without access to conventional sanitation systems. The parameters pH, turbidity, chlorination, temperature, and electrical conductivity were all at acceptable levels for discharge into receiving bodies and domestic use.

1. Introduction

Sanitation in most regions of the world has been a serious global problem. Around 2.6 billion people do not have access to adequate sanitation. This figure is worrying, especially in the developing countries of which Mozambique is a part. Although we recognise the importance that basic sanitation plays in the health of rural and urban communities, particularly the poor. This scenario has the effect of exposing many people to greater vulnerability to infectious diseases and a vehicle for diseases such as diarrhoea and cholera [1].

Sewage or domestic effluent comes from any building with bathrooms, laundries and kitchens. It is made up of human waste, faeces and urine, and water produced in various daily activities, such as body grooming, food preparation, washing clothes and household utensils [2].

Over time, major pollution of all kinds has emerged, reflecting not only economic and social problems, but also the misuse of natural resources. As a result, it is not difficult to see a major environmental imbalance affecting human beings in general [3]. Water pollution is a major problem to be faced by societies, which have been degrading the environment at an ever-increasing rate for decades. The contamination of soils or bodies of water is due to the emission of polluting substances resulting from industrial processes, domestic sewage, motor vehicles and even agricultural activities [4].

Biological filters are devices made up of organic and inorganic materials and generally have four layers: the first is made up of organic material with a high population of micro-organisms and earthworms, to absorb and degrade the organic matter present in domestic sewage; the second layer has only organic material, providing new filtration of the effluent. The third and fourth layers are made up of stones to provide aeration and permeability in the system [5,6].

They can have aerobic and anaerobic zones on whose separation surface microorganisms settle and grow in the form of biofilms and in whose interstices, microorganisms can also proliferate in the form of granules and flocs. In these reactors, the support medium is immobile or completely immobile.

submerged. Among these reactors, biological infiltration filters stand out for their high operational safety and simpler operation and monitoring. These reactors are generally the most suitable for treating predominantly soluble waste, since the risk of clogging the support medium increases in proportion to the concentration of suspended solids [7,8].

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The type of audience that is orientated towards the proposed innovation is engineering students with an orientation towards studies related to the environment, water processing from 1st level to the last level, or even post-doctoral studies. Another important reason for this work is the understanding of basic wastewater treatment techniques at a general level and the easy accessibility of instrumental techniques applied to wastewater. This leads us to the goal of learning to understand biofilter wastewater treatment systems for domestic water. Therefore, the subsequent level of compression of the biofilter is based on knowledge of instrumental techniques for determining and processing sanitary water through the biofilter medium. Ultimately, the learning outcome is to understand the operation of the biofilter as a means of processing wastewater and to provide a better understanding of the instrumental techniques for determining its disposal yield.

According to Mainardis et al. [1], wastewater treatment technologies follow a predetermined sequence and objectives, namely primary treatment, secondary treatment and tertiary treatment. Thus, primary treatment aims to remove coarse solid particles and reduce the concentration of suspended solid material present in domestic sewage using the principles of physical or physico-chemical processes. Secondary treatment aims to reduce dissolved solids and very small, suspended solids.

Secondary treatments include biological processes that can be aerobic, when they use micro-organisms that need dissolved oxygen in the liquid medium, and anaerobic, which use micro-organisms that don't need dissolved oxygen in the liquid medium and are used in domestic sewage with a high organic load [1].

Tertiary treatment, on the other hand, aims to reduce pathogenic bacteria and finally remove organic matter, nitrogen, phosphorus, and other elements that have escaped from the previous stages and is applied when domestic sewage is discharged into receiving water bodies or for water reuse.

Organic and/or biological filters, more technically known as biofilters, are devices that form part of the class of secondary and tertiary treatment technologies made up of organic filter materials capable of removing solutes and retaining solids that are by-products of human, agricultural and industrial activities. It is a technology that stands out due to the abundance of organic filter media, low acquisition costs and the possibility of composting once used, which is why it can be built to serve most of the population in a decentralized way, does not require a lot of operational engineering and design [9,10]. Biofilters are also suitable for treating effluents containing odorous gases with H2S concentrations below 1.0 g/m3 (approximately 687 ppm) or with concentrations of nitrogen and phosphorus, such as effluents containing manure and urine. [11,12].

Biofilters can be classified into three main types:

i) Unstructured biofilter with bottom filling;
ii) Structured biofilter without bottom filling;
iii) Prefabricated biofilter

Table 1
Input and output parameters of our system.

Parameters	Sample	Filter 1	Filter 2	Filter 3	Exit
Temp (^{0}C)	27.33	29,5	26.35	24	22,25
pH	8.28	7.49	7.32	6.97	6.94
Cond (mS/Cm)	0.4466	0.4966	0.3160	0.3082	0.2162
TSS (mg/L)	5	3	2.5	0.5	0
OD (mg O_2/L)	6.9	6.4	6.4	6.6	6.1
BOD_5 (mg O_2/L)	201	110	70	62	57
COD (mg O_2/L)	420	180	123	113	106
Turbidity (UNT)	108	85.5	59.6	26.5	10.5
Apparent Colour (UC)	666	255	134	55.5	33.6

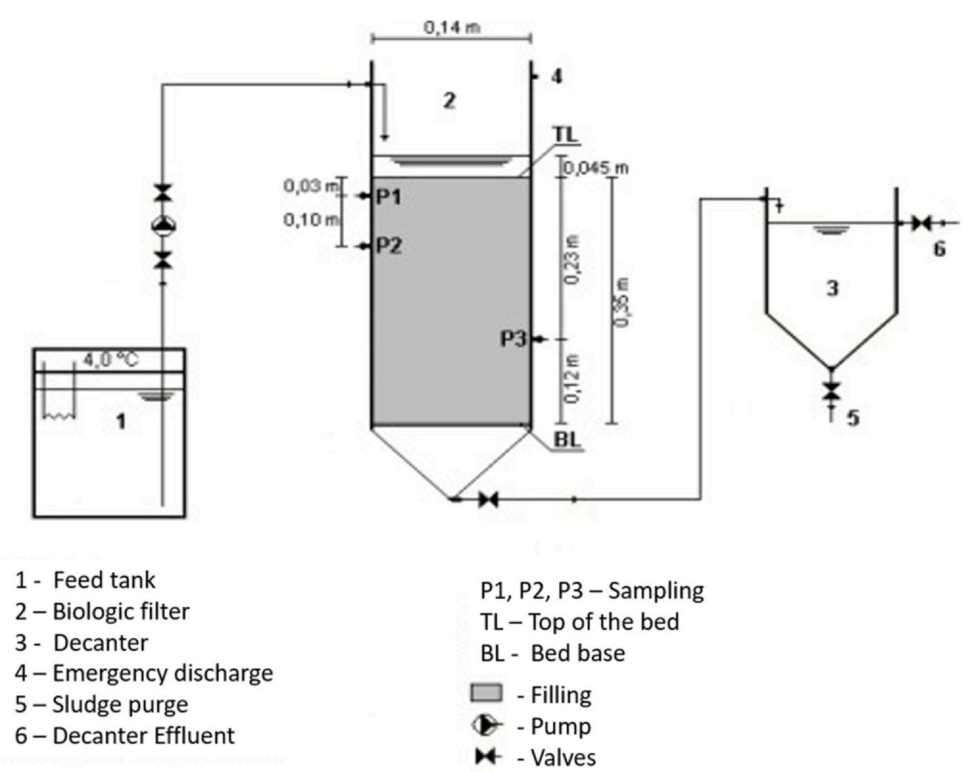

Fig. 1. Schematic of a conventional bio-filter (Source: Author).

Fig. 2. Filter elements.

In general, all biofilters are made up of the following parts or elements:

i) Sewage inlet pipe and
ii) Exhaust pipework and exhaust system;
iii) False bottom;
iv) Bottom drainage system;
v) Support structure of the medium.
vi) Medium support;
vii) Media irrigation system

The filter selected in this study works as a downflow anaerobic/factory reactor with a drowned bed and is therefore part of the secondary treatment equipment class. Its construction makes it easy to remove excess sludge - which may eventually appear over time - but the risk of clogging the bed is reduced because part of the sludge formed inside it is gradually dragged by the effluent to the main outlet where the treated effluent is located [13–19].

The objective of this study was to provide the university community (professors and engineering students) with the technical procedures to build a system to treat domestic sewage from sinks and bathrooms or kitchens, through a home-made biofilter using sand and gravel, concerned with physical and biological processes. However, the technology will benefit the low-income population who do not have conventional sanitation systems, or anyone interested in installing decentralized sanitation systems in peri-urban or rural communities. For this proposal, the work consisted of treating black water from the kitchen of one of the canteens and the toilet of UNIZAMBEZE-FCT (Zambezi University - Faculty of Science and Technology). Physical, chemical, and microbiological parameters of the water treated by the biofilters were analyzed.

2. Material and methods

Recyclable materials and low-cost products were used to build the biofilter and domestic water treatment system, which consisted of four twenty-litre buckets. Three of these buckets formed the body of the filter and the other bucket was used to transport domestic (black) water collected from the kitchen sink to the system located next to the laboratory block. The material used to fill the filters consisted of: gravel (maximum diameter 19 mm), pebbles (maximum diameter 9.5 mm), sand, nylon mesh and a "rough pipe" or "conduit". Filter 1 (top) was filled with two layers of 10 cm each, one of 19 mm gravel and one of sand. Filter 2 (intermediate) was filled with a layer of pebbles and a layer of sand, each 10 centimeters long. The sand was sieved through 18 mesh 10 sieves for filter 1 and 8 mesh sieves for filter 2. In filter 3, the two grain sizes of gravel and sand were mixed and the same thickness was applied to the layers [20–24].

At the top of filter 1 is a reusable bag in the form of a net, designed to contain the coarser materials that make up domestic sewage, serving as a preliminary treatment for the sewage. In the top layer of filter 2 (intermediate), there is a "fishing net", handmade from nylon line, this material is resistant and difficult to degrade when disposed of in the environment, in the filter, it will serve as a holder of coarser materials. In filter 3, the difference is that its top layer contains waste materials from the construction industry, such as "smooth or rough isogril pipe", a piece of material used to install power lines in homes, which has been cut into small pieces to serve as a medium for decomposing microorganisms to adhere to. Each filter contains a tap connected to a 20 mm perforated pipe (drainage pipe), located inside the bottom of the bucket, to collect individual samples for analysis as shown in Fig. 1[25–27].

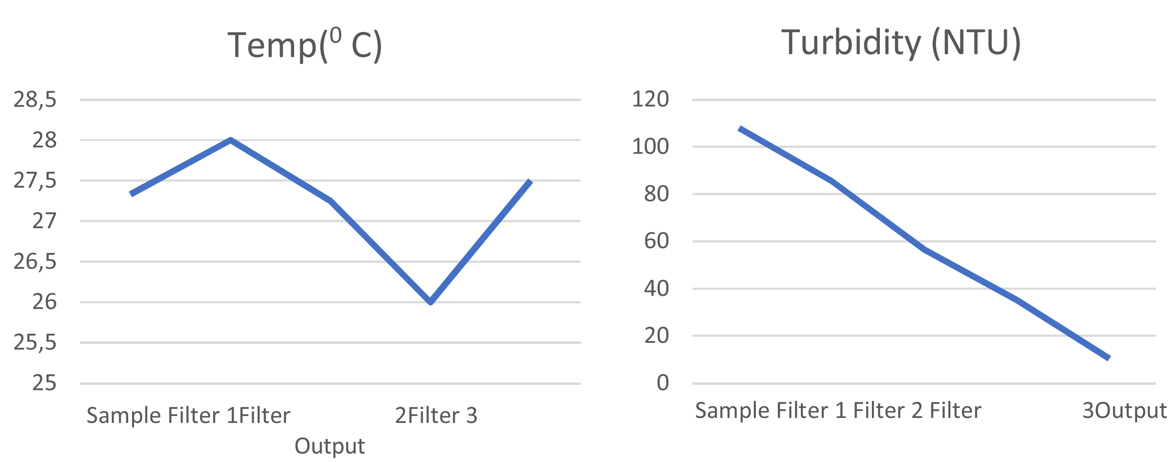

Fig. 3. Temperature and turbidity analyses.

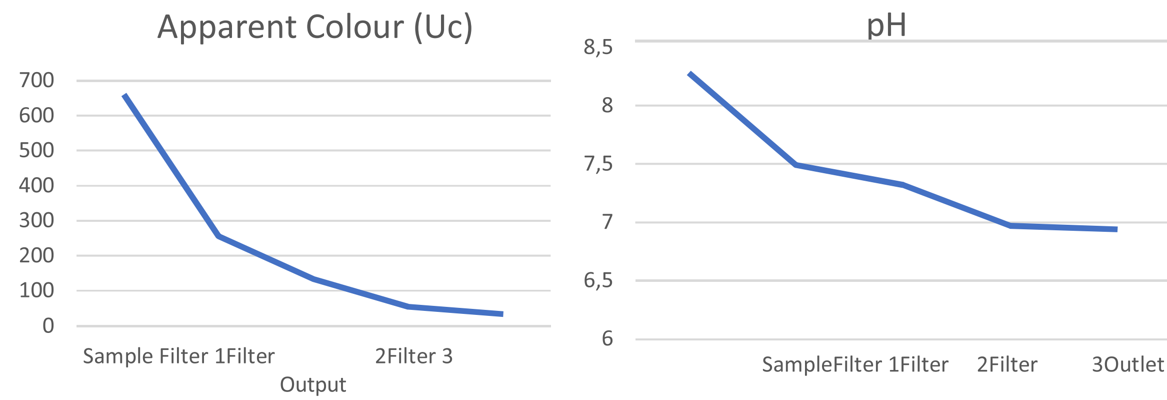

Fig. 4. Apparent colour and pH.

Each filter contains a tap connected to a 20 mm perforated pipe (drainpipe), located inside the bottom of the bucket, to take individual samples for analyses.

The analyses of the physical, chemical and microbiological parameters were carried out in the Water Analysis Laboratory, located on the main campus of unizambeze-FCT, where the following parameters were analyzed beforehand and in each filter phase of our system: Temperature (°C) samples; pH (Hydrogen Potential); Electrical Conductivity (mS/cm); Sedimentable Solids (mg/L); Dissolved Oxygen (OD in mg O_2/L L; Biochemical Oxygen Demand (BOD_5 in mg O_2/L); Turbidity (UNT); Apparent Colour (UC); nitrogen (N), phosphorus (P); sodium (Na) and potassium (K), and are presented in the table below [8]. Table 1.

3. Results

The system built and assembled to treat domestic sewage, as shown in Fig. 2, made up of filters and pipes made from recycled material and low cost, proved to be easy for the students to assimilate, since it can be built even at home and since it proved to be a viable solution in communities or for people on low incomes. As for its operation, it proved to be promising, although some aspects of its size could be adjusted depending on the flow patterns or production of domestic sewage.

Analyzing the parameters of the samples at the inlet and outlet, in the case of temperature it was found that the values remained approximate in the samples between 29.8 °C and 22.25 °C, with an increase in temperature between the raw black water sample (Before treatment) and the treated water sample from the F3 filter in all the analyses. This effect is attributed to the ambient temperature and the biological reactions taking place inside the filter, such as the respiration process of aerobic bacteria that release energy into the environment.

As for turbidity, the filter system showed great efficiency in removing solid particles, with turbidity units gradually decreasing in all filters. Fig 3.

This data can be analyzed in the graphs.

The graphs below show that there was a high removal of colour units (CU) in the system samples, proving that the system operates with the capacity to retain dissolved substances and colloidal particles in suspension, significantly reducing this parameter. Fig 4.

The system was satisfactory in reducing the pH of the black water, as shown in the graph. In all the analyses, the pH value remained in the neutral range between 6.5 and 7.5 after passing through the filters. These values are considered optimum for agricultural irrigation, as well as for final disposal in land and water resources, with an acceptable pH between 5.0 and 9.0 to guarantee the quality of this resource. Fig 5.

According to the electrical conductivity values shown in the graph, it can be seen that the three filters following the initial analyses saw a decrease in conductivity values.

Dissolved oxygen began to be measured from Filter 1 to Filter 2, where it showed constant values, but in Filter 3 the data was satisfactory, with values of 6.4 + /- 0.3 mg/L, after passing through the 3rd filter. This represents the almost anaerobic environment in which the filter found itself, with DO values dropping to zero, extinguishing the aerobic microorganisms and leaving the facultative ones. However, for chemical analyses such as BOD and COD for our experiment, reliable results would be obtained if the samples were analyzed over at least a 15-day time interval, because it would be necessary to wait for chemical processes to start taking place in the reactors. Therefore, for our experiment, we have no way of making the chemical analyses reliable. We only emphasized the treatment of physical parameters. Fig 6.

The analyses show that after passing the black water through filters 2 and 3, the treated water samples did not show any settleable solids. There is a need for a settling tank in the filters due to the granulometry of the sediments, as we are using sand filters.

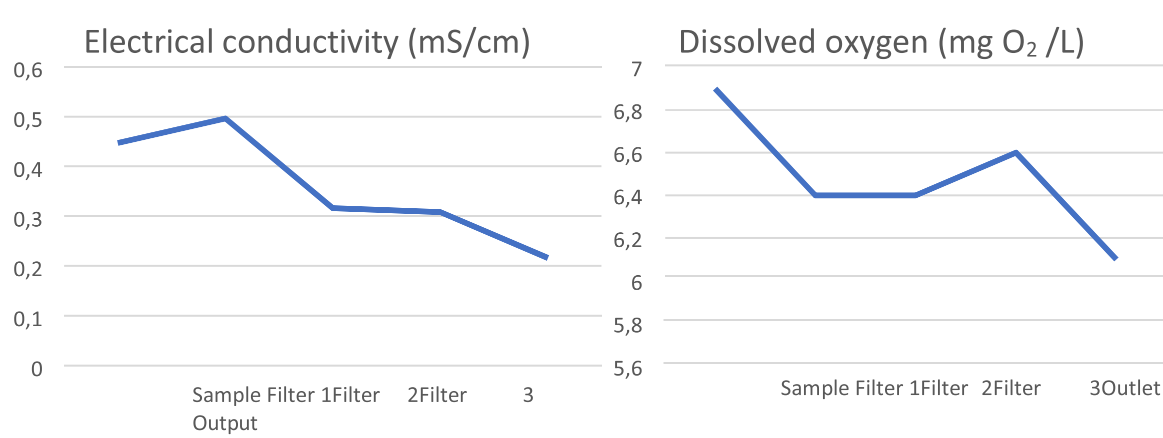

Fig. 5. Conductivity and OD.

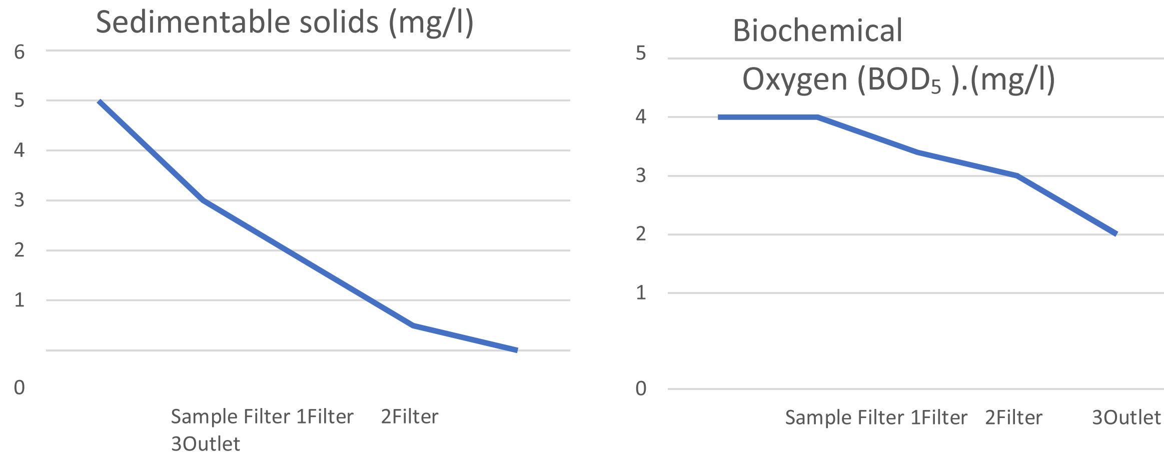

Fig. 6. Settled Solids and BOD5.

In the case of BOD values in domestic wastewater, after passing through the filters they are around 70% and 80% of the total value. When comparing the BOD values of the raw water samples, it can be seen that there is no variation in dissolved oxygen levels, due to the time taken to analyse the water, which was the same number of days, since the microorganisms capable of oxidising the organic matter present in the sewage had not yet been created[5], and this water does not yet have the characteristics of drinking water, but it can be used for other purposes such as irrigation, washing employees' cars, etc.

$$Bio \quad filter \quad efficiency^{5}\%EEE = \frac{Piin - Poot}{Pii} x100\% \tag{1}$$

4. Conclusions and recommendations

The treatment system consisting of filters to treat black water from Unizambeze operated satisfactorily and efficiently to remove turbidity, colour and settleable solids. The parameters pH, turbidity, chlorination, temperature, and electrical conductivity showed acceptable levels for discharge into receiving bodies and domestic use, but the chemical parameters such as BOD and COD did not give satisfactory results. However, it is recommended that the samples be analyzed at 15-day intervals to effectively determine how the chemical characteristics vary in domestic biofilters, which can also be used to treat sanitation water in suburban areas.

Maintenance of Filter 1 is recommended to remove solids that clog the pores of the gravel and sand layer. After each treatment. It is recommended that 3 centimeters of the gravel layer be removed for washing and that 3 to 5 centimeters of the sand layer be scraped with new disinfected material, because filter 1 receives the raw black water. For the other filters, cleaning is suggested once or twice a month or when problems with blockages and reduced flow appear. It is also suggested that the system be fitted with a grease trap to reduce the amount of fat and food waste that leads to problems with clogging the filters, and inspection boxes for sedimentation of solids. Therefore, the aim of this work was to present a simple, efficient, and low-cost methodology in a didactic way to students and the urban community for treating black water and also to present the procedures for maintaining the system.

When implementing these biofilters to also treat sewage in communities, it requires areas or houses with larger areas to facilitate connections to small downflow pits and not for areas with 15/20 type plots as is the case in some neighborhoods in the city of Beira, since the soils are mostly mud and with a very high-water table which makes it easy to fill.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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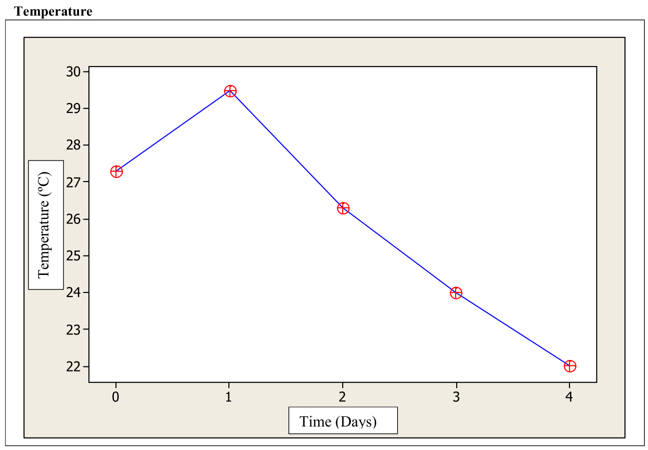
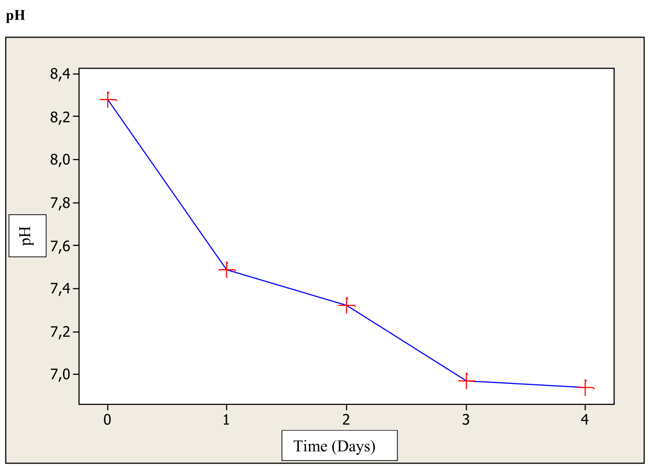
Annexe

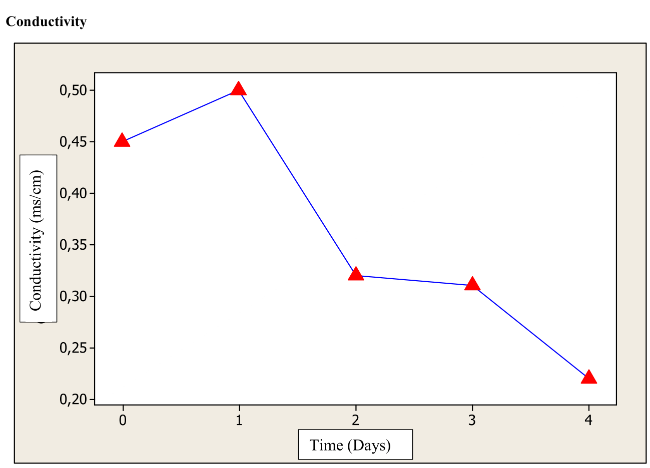
Temperature



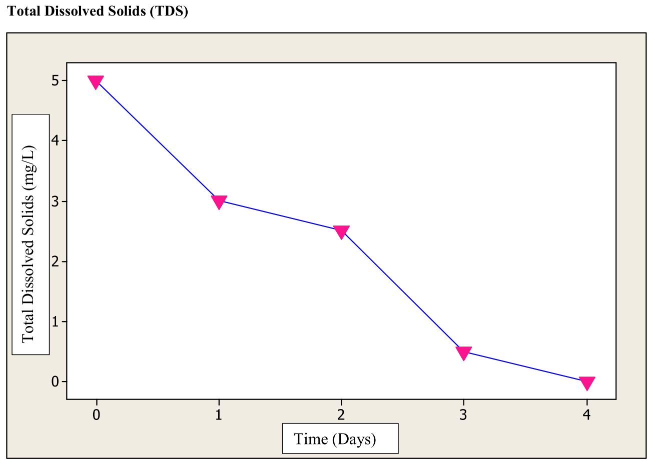
pH



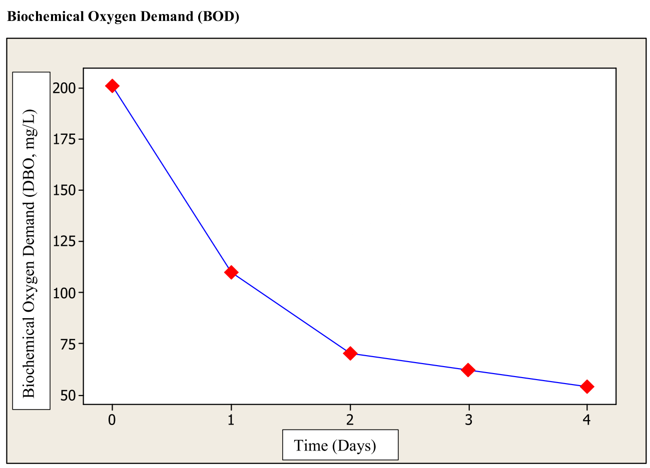
Conductivity



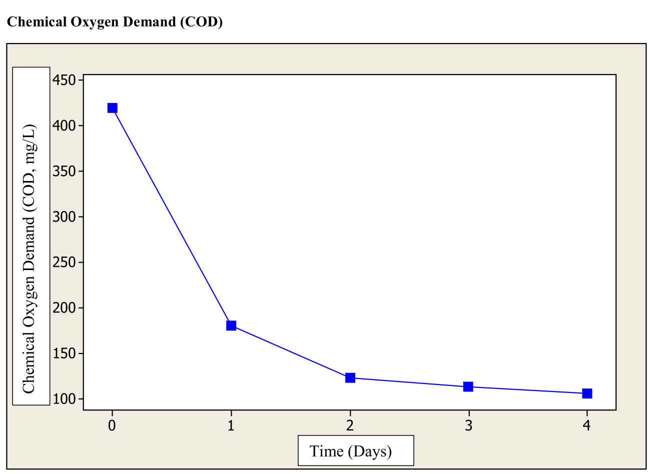
Total Dissolved Solids (TDS)



Biochemical Oxygen Demand (BOD)



Chemical Oxygen Demand (COD)



Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.dwt.2024.100266.

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