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Estudio de un sistema de depuración natural para el tratamiento de aguas residuales industriales de la cervecería mozambiqueña

Study of a natural purification system for the treatment of industrial wastewater from the mozambican brewery

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Resumen: El sistema híbrido de humedales artificiales es una tecnología que actualmente se utiliza en varios países del mundo para depurar aguas residuales industriales. La hibridación tiene como objetivo el acoplamiento en serie como forma de responder a la falta de capacidad de eliminación total. La incapacidad de un sistema unitario para eliminar un parámetro determinado puede ser compensada por el otro sistema acoplado. Cabe señalar que el sistema de humedales artificiales tiene una mayor eficiencia de purificación en lugares con altas temperaturas debido al poder calorífico que obliga a la excitación de los microorganismos a realizar sus actividades en el proceso de descomposición de la materia orgánica, lo que lo convierte en un sistema viable para Mozambique, que tiene un clima predominantemente cálido.

Palabras clave: Sistema de purificación, humedales artificiales híbridos, aguas residuales industriales.

Abstract. The hybrid constructed wetland system is a technology that is currently being used in several countries around the world to purify industrial wastewater. Hybridisation is aimed at serial coupling as a way of responding to a lack of total removal capacity; the inability of a unitary system to remove a given parameter can be compensated for by the other coupled system. It should be noted that the Constructed Wetlands system has a higher purification efficiency in places with high temperatures due to the calorific power that forces the excitation of microorganisms to carry out their activities in the process of decomposing organic matter, making it a viable system for Mozambique, which has a predominantly hot climate. In terms of construction and handling, it does not entail significant costs compared to conventional technologies and is environmentally friendly.

Keywords: Purification system, hybrid constructed wetlands, industrial wastewater.

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Introducción

The most important component of human existence and industrial operations is water, which is currently seriously threatened by dangerous contaminants caused by both human activity and natural processes [1]. However, water pollution has always been a major concern, as it directly affects human health [2].

The main drivers of the degradation of groundwater quality as well as surface water are recognised as industrialisation, population growth and inadequate waste management practices [3]. Urban and industrial wastewater discharges continue to be a major source of pollution worldwide [1], [4]. There are two primary sources of contaminants in wastewater: (i) natural sources, most notably volcanic activity, soil erosion and rock weathering, and (ii) dispersion of mineral contaminants through anthropogenic activities, waste disposal sites, urban runoff, mining, printed circuit board manufacture, agricultural activities, treatment and electroplating of metal surfaces, fuel burning, textile dyes, semiconductor manufacture, etc. [5].

The wastewater produced by the different economic sectors is characterised by great variations in terms of composition and concentration, as well as by various levels of water consumption and, therefore, by the different flow rates of the wastewater produced [6]. The safe and controlled disposal of wastewater has become increasingly important due to the strict regulatory requirements of each country and the regulations imposed by environmental protection agencies on the quality of effluents [4], [7].

One of humanity's current concerns is reconciling environmental protection with industrial production, particularly when it comes to discharging waste into water bodies without prior treatment, which has increased the demand for renewable energy sources [8].

In view of the issues jeopardising water quality and the possibility of environmental contamination, various wastewater treatment technologies have been adopted. It should be noted to increase the efficiency of contaminant removal, a treatment system is required that aims to reduce the levels of contamination present in wastewater to minimise the impact of the discharge on the environment [7], [9].

Wastewater treatment systems can be divided into two groups: Intensive or conventional systems. These are systems that require considerable energy to operate (electromechanical equipment) and use small areas of land per equivalent inhabitant (for example: activated sludge and percolation beds). Extensive or natural systems. These are based on natural processes with little or no energy consumption and occupy larger areas of land per equivalent inhabitant (e.g. stabilisation ponds, constructed wetlands and soil treatment systems). [10], [11].

Conventional wastewater treatment processes are challenged by the need to effectively reduce pollutant loads prior to disposal or reuse, since the composition and concentration of contaminants in wastewater change over time, resulting in a variation in the oxidation-reduction potential (ORP) of the afluent [12].

Nature-based solutions, such as constructed wetlands (CW), offer great possibilities for the sustainable use of water, facilitating its treatment and reuse, as well as contributions to climate change adaptation through the utilisation and promotion of vegetation in both urban and rural areas [10], [13].

Wastewater treatment plants (WWTPs), although effective systems for removing pollutants, usually require large capital investments as well as operating and maintenance costs. Constructed wetlands (CWs) stand out as a low-cost treatment method. They effectively remove a wide range of contaminants through a combination of physical, chemical, and biological processes. In addition, compared to conventional WWTPs, they have a lower visual impact and lead to the production of smaller quantities of sewage sludge [2], [14], [15], [16].

The criteria and objectives of the circular economy require opting for technologies and configurations that allow for the recovery of nutrients and other resources contained in wastewater, while at the same time allowing for the reuse or recycling of the water itself for different uses [7].

However, the main objective of this article is to study a natural purification system applicable to the treatment of industrial wastewater from a Mozambican brewery.

I. Materials and Methods

Types of natural wastewater purification system:

Pond systems or stabilisation ponds

They are made up of huge basins, with a high retention time and limited by dykes built with the material of the land itself, in which the water is purified by entirely natural means, through the biological activity of bacteria (anaerobic/aerobic) and algae [8], [17].

Wastewater stabilisation ponds are often used to treat municipal and industrial wastewater in small and remote communities, and can effectively reduce suspended particles, biochemical oxygen demand, coliform bacteria, nutrients, metals and micropollutants [18], [19]. Their efficiency depends on many factors, and it is very difficult to derive a model that considers all the parameters involved in predicting their performance. Therefore, these models should only be used for guidance. Modifications to the physical design of a lagoon, such as dimensions, depth, recirculation, removal of algae from the effluent, among others, can improve the quality of the effluent. In terms of classification, depending on the process by which organic matter is degraded, lagoons can be classified as anaerobic, aerobic, facultative and maturation [10], [20], [21].

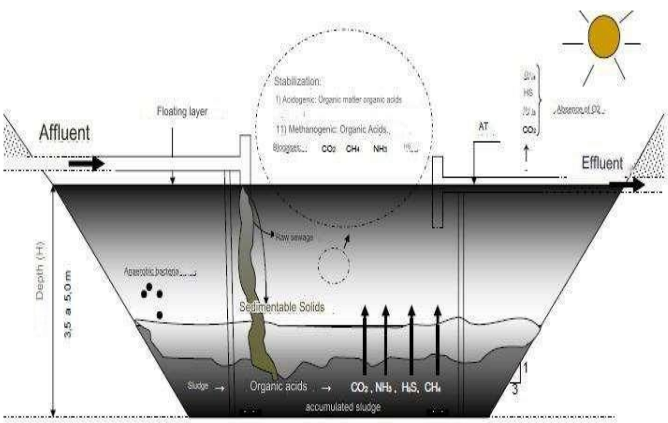
Anaerobic ponds

Anaerobic decomposition processes predominate in the lagoon. It is characterised by the absence of oxygen (free or combined).

They are used to treat wastewater with high organic loads and a high concentration of suspended solids.

Anaerobic lagoons have water column heights of between 2.5 and 5.0 metres.

Figure 1. Schematic representation of the anaerobic lagoon



Note: adapted from C. A. Mendieta-Pino, (2022) [10].

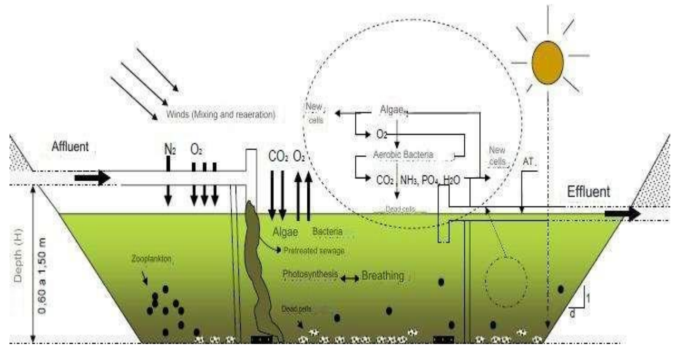
Aerobic lagoons

Aerobic decomposition processes predominate in the lagoon. They are characterised by having dissolved oxygen throughout the liquid mass.

In many larger wastewater treatment systems, anaerobic and aerobic (or facultative, which has both zones) lagoons are used in series to achieve more comprehensive treatment. The anaerobic stage handles the bulk of the organic load, and then the aerobic stage "polishes" the effluent. The aerobic lagoon has water column heights of between 0.30 and 0.45 metres. The removals achieved by this system are: BOD_5 (80 % to 95 %).

Figure 2. Schematic representation of an aerobic stabilisation pond

Note: adapted from C. A. Mendieta-Pino, (2022) [10].

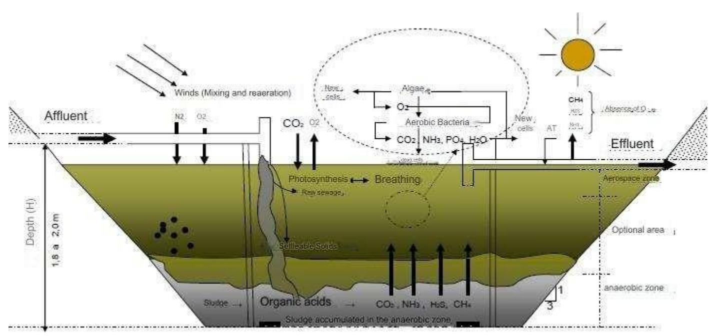


Facultative Lagoon

Soluble and finely particulate BOD is stabilised aerobically by bacteria dispersed in the liquid, while suspended BOD tends to sediment and is stabilised anaerobically by bacteria at the bottom of the pond. The oxygen required by aerobic bacteria is supplied by algae through photosynthesis. Facultative ponds have water column heights of between 1.20 and 2.50 metres.

Figure 3. Representation of how a facultative stabilisation pond works

Note: adapted from C. A. Mendieta-Pino, (2022) [10].



The removals achieved by this system are: BOD5 (80% to 90%); Organic Nitrogen (75% to 95%); Ammoniacal Nitrogen (51% to 82%); Phosphorus (32% to 98%); Faecal Coliforms (99.9%).

Maturation pond

The main purpose of a maturation pond is to remove pathogens. In maturation ponds, adverse environmental conditions prevail for pathogens, such as ultraviolet radiation, high pH, high DO, temperature lower than that of the human body, lack of nutrients and predation by other organisms. Maturation ponds are a post-treatment process aimed at removing BOD and are usually designed as a series of ponds or as a single pond divided by baffles. Their efficiency in removing coliforms is very high.

Technology Constructed wetlands (CWs)

It is considered a secondary or even tertiary treatment used worldwide to treat wastewater from various sources, such as domestic, agricultural, industrial, mining and aquifers, due to its ability to reduce pollutants in wastewater and purify it, hence it has been used in the treatment of effluents since ancient times, specifically in the 1960s [15], [16]. This remedial technology is a low-cost, environmentally friendly sanitation alternative and is recommended for on-site wastewater treatment to meet the required effluent discharge standards [22]. The structure of CWs is designed to simulate the physical, chemical and biological processes that occur in natural wetlands, treating wastewater efficiently [15].

Various types of constructed wetlands differ in their main design characteristics, as well as in the processes responsible for removing pollution. In terms of their hydraulic characteristics, CWs can be classified into surface and subsurface runoff where:

Surface flow constructed wetlands (OFCWs)

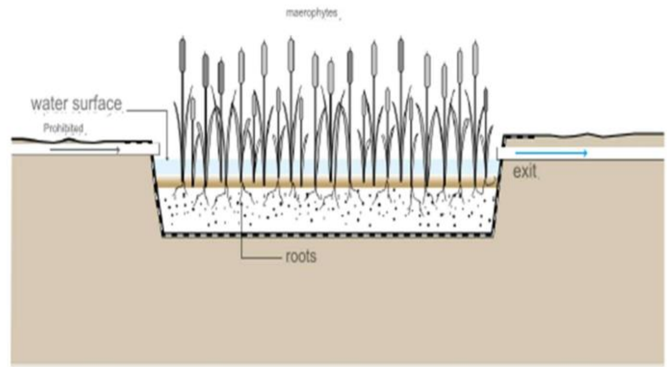
Surface flow wetlands are very similar to natural wetlands; however, with sewage volume in the substrate, they are not very deep [14]. The plants and the substrate are the elements that exert the greatest influence on the efficiency of the system. Plant roots extend into the gaps in the substrate, absorb nutrients (e.g. nitrogen and phosphorus) from the pore wastewater in the CWs to support plant growth and purify the water simultaneously.

The Surface Flow Wetland consists of wetlands where water flows over a free surface with the presence of adapted vegetation. There is one type of surface-flow wetland: free-surface wetlands. These systems are the main choice when it comes to wastewater from urban, agricultural and industrial areas, due to their ability to cope with varying flow rates and depths [23]. Constructed wetland systems can be effective in the treatment of a variety of effluents including textile effluents, dairy effluents, piggery effluents, septic tank dewatering, landfill leachate, inorganic industrial effluents, tannery effluents, among others [17], [23].

It should be noted that the selection of plant species is a key factor; the vegetation must survive the possible toxic effects of wastewater and its chemical variability and, of course, it must adapt to local climatic conditions. The substrates used to build wetlands include soil, sand, gravel, rock and organic materials such as compost, which can also adsorb inorganic ions from water, especially phosphorus ions [19], [22], [24], [25].

Figure 4. Schematic representation of a surface wetland

Note: adapted Vymazal [26].

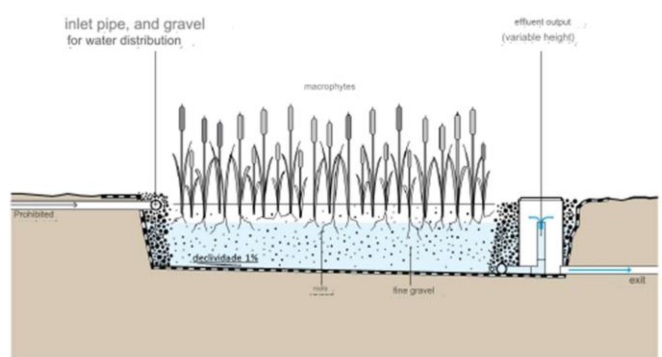


Subsurface flow wetland (SBFW)

Subsurface flow constructed wetlands are divided into two types: horizontal subsurface flow wetland (HSFW) and vertical subsurface flow wetland (VSFW). Where the horizontal subsurface flow constructed wetland consists of gravel or rock beds sealed by an impermeable layer and planted with wetland vegetation. The wastewater is fed at the inlet and flows through the porous medium under the surface of the bed in a more or less horizontal path until it reaches the outlet zone, where it is collected and discharged [26], [27].

Figure 5. Representation of the constructed wetland with horizontal subsurface flow

Note: adapted Vymazal [26].

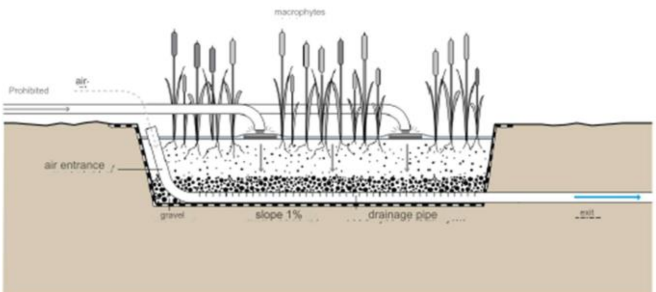


In the wet zone, constructed from vertical subsurface flow, the water is released into the upper/lower layer of the bed, descending/emerging through the soil, passing through a zone of macrophyte roots, until it is finally collected and led to an outlet device. It should be noted that they were originally introduced by Seidel to oxygenate anaerobic septic tank effluents [17], [19], [23].

However, VSFWs have not spread as quickly as HSFWs, probably because of the greater operating and maintenance requirements due to the need to pump wastewater intermittently on the surface of the wetland (Figure 6).

The water is fed in large batches and then the water percolates through the sand medium. The new batch is fed only after all the water has percolated and the bed is free of water [26], [27].

Figure 6. Representation of the Vertical subsurface flow constructed wetland



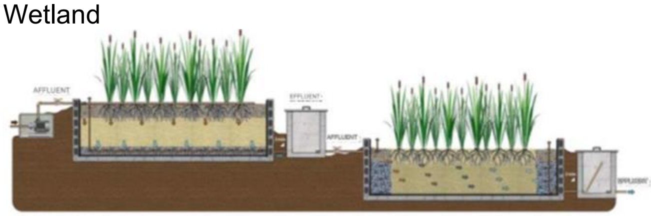
Note: adapted Vymazal [26].

Hybrid Constructed Wetlands (VF-HF CWs)

To improve the efficiency of natural purification systems in constructed wetlands, it is used a hybrid technology for constructed wetlands (VF-HF). For example, France and the UK have been using hybrid vertical flow (VF) and horizontal flow (HF) technology since the 1980s, where the VF-HF system was originally designed by Seidel in the late 1950s and early 1960s, but the use of hybrid systems was then very limited. Today, hybrid constructed wetlands are in operation in many countries around the world and are used especially when the removal of N-ammonia and N-total is required. In addition to sewage, hybrid constructed wetlands have been used to treat a variety of other wastewaters, for example landfill leachate, compost leachate, abattoirs, shrimp and fish aquaculture or wineries [23], [26], [27].

However, proven hybrid systems have shown removal rates of 78% COD, 91% BOD5, 94% NH4-N, 46% NT and 97% TDS. It has been verified that these systems in series can achieve effective wastewater treatment for communities with hot climates [27], [28]. The most common type of configuration, which has been widely used, is composed of a CWs -VF followed by a CWs -HF, achieving good removal of organic matter and solids. [26].

Figure 7. Representation of the Hybrid Constructed Wetland



Note: adapted Vymazal [26].

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Based on various samples taken at the Mozambican brewery and analysed in the laboratory, the following characteristics of the wastewater were obtained:

Table 1. Characterisation of wastewater from the Mozambican brewery

Parameter	Sample Analyses
PH	5.1 - 6.4
Temperature (ºC)	18 - 20
Alkalinity (mg/l)	240 - 265
Conductivity (µS/cm)	2120 - 3480
TDS (mg/l)	2335 - 3246
Turbidity (NTU)	53.42 - 349.92
Phosphate (mg/l)	15.12 - 37.22
Nitrogen (mg/l)	22.03 - 35.09
BOD (mg/l)	1490 - 3241
COD (mg/l)	2670 - 3798

Note: author´s source (2023).

Apos was followed by comparative analyses of the various natural wastewater purification systems (Anaerobic Lagoon, Facultative Lagoon, Maturation Lagoon, Vertical Wetland and Horizontal Wetland), highlighting the relevant aspects for choosing an optimum system in the case of: Efficiency of removal of the various parameters, occupational area, environmentally friendly, local climate, maintenance, total costs inherent in the installation, handling of the optimum natural wastewater purification system.

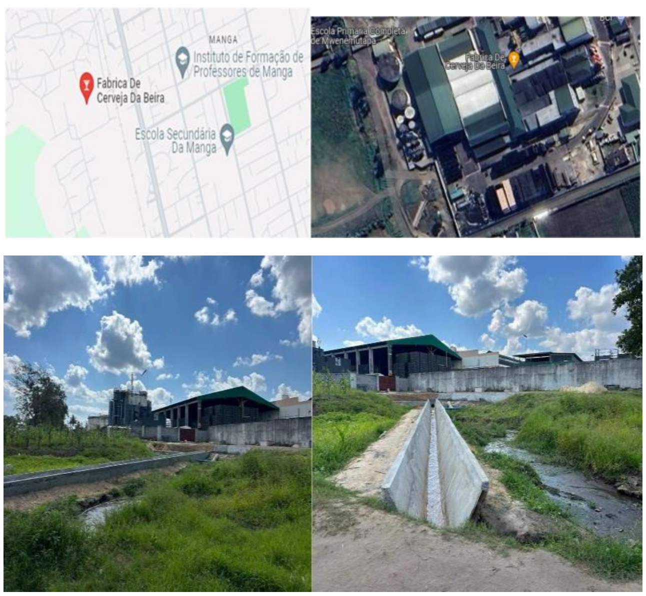
Table 2. Comparison of the efficiency of natural purification systems

Parameters	Reduction (%)				
	Anaerobic lagoon	Lagoon Optional	Lagoon Ripening	Wetlands Vertical	Wetlands Horizontal
Suspended solids	50 – 60	60 – 70	35 – 40	90 – 95	90 – 95

*DBO*5	40 – 50	60 – 80	25 – 40	90 – 95	90 – 95
DQO	40 – 50	55 – 75	15 – 25	80 – 90	80 – 90
NH^+4	–	20 – 60	15 – 50	60 – 70	20 – 25
N total	5 – 10	30 – 60	30 – 60	60 – 75	20 – 30
P total	0 – 5	0 – 30	30 – 45	20 – 30	20 – 30
Coliformes fecais (*UFC*/100 *ml*)	0,2 – 0,5 *u log*	2,2 *u log*	0,7 – 1,3 *u log*	1 – 2 *u log*	1 – 2 *u log*

Note: adapted Mendieta [10].

Figure 8. Characterisation of the project site for the implementation of a natural wastewater purification system at Cervejeira Moçambicana.



Note: author´s source.

The images above illustrate the brewery under study with an extensive open area with the capacity and requirements needed to set up a hybrid constructed wetland. The site is in the city of Beira, in the Manga neighbourhood, which has a tropical climate with an average temperature of 24.6 °C and an average annual rainfall of 1312 mm. The average temperature in February, the hottest month of the year, is 27.7 °C. The average temperature in July is 20.6 °C. This is the lowest average temperature during the year. The driest month - September - has a difference in rainfall of 228 mm compared to the wettest month - February.

Table 3. Average monthly temperatures from 2014 to 2022

	Months					1
	Jan	**Feb**	**Mar**	**Apr**	**May**	**June**
Td	31ºC	31ºC	31ºC	29ºC	26ºC	25ºC
Tn	24ºC	24ºC	24ºC	23ºC	20ºC	18ºC
Pr	240	281.9	205.3	134	37.3	20.8
	Jul	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Td	25ºC	26ºC	28ºC	29ºC	30ºC	31ºC
Tn	18ºC	18ºC	20ºC	22ºC	22ºC	24ºC
Td	74.3	49.5	16.9	61.5	93.7	153

Td: Day temperature. Tn: Night temperature. Pr: Precipitation.

Note: adapted from C. A. Mendieta-Pino, (2022) [10].

Comparative analyses of the use of the built-up wetlands in countries with different climates. temperate and tropical and subtropical countries [29], [17], [18], [19] reported that countries with warmer climates have great potential for implementing this technology, since such temperatures and the flow of sunlight tend to favour the metabolic processes of plants/microorganisms and therefore positively influence the biodegradation of polluting compounds. In addition, studies show that at lower temperatures there is a lower productivity of the microorganisms, i.e. they reduce the rates of biochemical reactions, reducing the treatment results, so it is important to take these variations into account.

This section outlines the criteria for comparatively assessing natural wastewater treatment alternatives. The assessment considers both their environmental impacts and implications, as well as the resources required for their implementation.

Anaerobic ponds

Advantages: simplicity in construction. High BOD and coliform removal efficiency; reduced total operating, energy and maintenance costs.

Disadvantages: the need to occupy large areas; biological activity affected by temperature; generation of bad odours and environmentally unhealthy.

Aerobic lagoon

Advantages: simple construction, minimal maintenance, minimised total costs and efficient removal of pathogenic organisms. The system consumes little energy and has few problems with sludge handling and disposal. In terms of results, it offers treatment equal to or better than some conventional processes.

Disadvantages: requires larger areas than for any other type of treatment, needs an additional source of oxygen to supplement the minimum amount that can be diffused into the surface water, high concentration of total suspended solids in the effluent, dependence on climatological factors such as sunlight and temperature for greater efficiency.

Facultative lagoons

Advantages: low implementation and operating costs. No need for electricity. Ability to absorb sudden increases in hydraulic and organic loads.

Disadvantages: insect proliferation. Evaporation losses. Extensive area required. Environmental and social impact, making it environmentally unhealthy.

Surface flow wetlands

Advantages: ease of construction, low operating and maintenance costs. Minimal sludge production and excellent landscape integration. High removal efficiencies.

Disadvantages: it requires a large area, implying high capital costs. Rodent proliferation and unpleasant odours. Risk of disease transmission due to human and animal exposure, making it unhealthy for the environment.

Vertical subsurface flow wetland

Advantages: easy to build, moderate construction, handling, energy and maintenance costs, low sludge production, low mosquito proliferation and odour generation, high removal capacity and environmentally friendly.

Disadvantages: removal dependent on climate and water characteristics. Wastewater needs to be pre-treated before entering the constructed wetland.

Horizontal subsurface flow wetland

Advantages: easy to build, not too technologically demanding, moderate in terms of construction, handling, energy and maintenance costs, low proliferation of disease-causing insects, high rate of parameter removal and environmentally friendly.

Disadvantages: need to occupy a relatively large area, efficiency dependent on climate in terms of temperature and rainfall, need for pre-treatment of wastewater before it flows into the wetland, deficiency in the oxygenation process implying a reduction in nitrification.

After observing all the comparisons of the systems mentioned above, with emphasis on efficiency rates, the existence of an area behind the industry with the potential for good plant growth and the hot climate of the city where the system was to be implemented, the natural purification system was chosen, namely the Hybrid Constructed Wetland (CWs VF-HF).

Sizing model for the Hybrid Constructed Wetland

As this is a hybrid system, the two constructed wetland systems will be dimensioned: Where we will have the dimensioning of the horizontal flow constructive wetland as well as the vertical flow one.

The following modelling was used to design the Vertical flow constructed wetland: kinetic - hydrodynamic modelling of complete mixing (MC-1st Order +HMC).

Horizontal flow sub-surface wetlands [10] are sized using the first order kinetic equation applicable to piston type reactors. The following modelling was used to design the horizontal flow constructed wetland: kinetic-hydrodynamic modelling of piston flow (MC-1st Order + HFP).

$$A = \frac{Q * (lnC_e - lnC_s)}{Kt * h.n}$$

Equation 1

Where: (A) is the required surface area (m2); (Q) is the affluent flow (m3 /d); (Ce is the affluent concentration in terms of BOD5 (mg/l or g/m3); (Cs) is the effluent concentration in terms of BOD5 (mg/l or g/m3); h is the average depth of the filter (m); (n) is the porosity of the filter material (dimensionless) and Kt a constant which is the product of h and n.

Table 4. Bulletin of the Republic of Mozambique – standards for the emission of liquid effluents by industries.

Parameters	Value	MS
pH	6-9	*
DBO	**30**	*
DQO	**80**	
SST	**15**	*
	10	

NH_4	**10**	
Temperature increase	**<= 3°C**	

Note: adapted from [10]

II. Results and Discussions

Dimensioning the subsurface constructed wetland:

General aspects regarding the sizing of wetlands. To determine the depth, it is followed the ideology of the authors [23], [26], [27], [28] The depth (h) of the wetland should be < =0.40 m for horizontal flow systems and < =0.80 m for vertical systems. The slope inclination should be between 45 and 60° for both.

The length to width ratio (L/W) should be between 2 and 5 for horizontal flow and 1 for vertical flow.

Dimensioning the vertical subsurface constructed wetland:

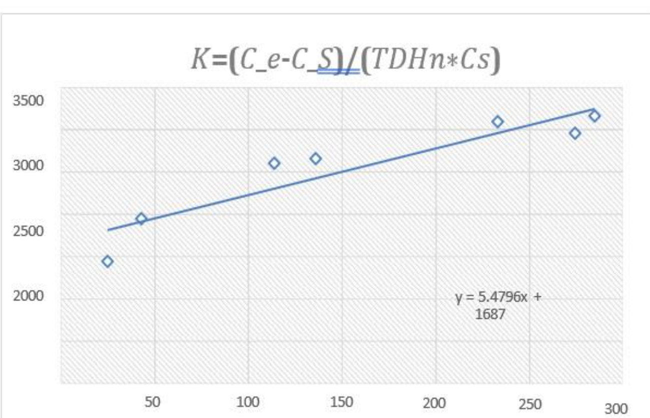
Firstly, the value of K = the pollutant's degradation constant was obtained using data obtained from the Mozambican brewery's wastewater treatment plant.

Table 5: Data collected at the Mozambican brewery's wastewater treatment plant

CODe	2730,8	2670	1490	3040	3241	3170	1998
CODs	64,9	63,5	35,46	72,35	77,13	75,4	47,5
HRTn	2,1	1,8	0,7	3,8	3,7	3,1	0,9

Note: adapted from [10]

Figure 9. Obtaining the K value - the pollutant's degradation constant



Note: author´s source. 1

For a better performance, a good activity of the microorganisms influenced by high local temperatures, the value of K can be altered using as a starting point the lowest average temperature of the year, which is 20.6°C. It's important to note that the rate at which microorganisms degrade organic matter is directly proportional to temperature. During warmer periods, the K value (representing the degradation rate constant) will increase, which in turn boosts the microorganisms' activity and their speed of degradation.

$$K_T = K_{20°C} * 1{,}06^{T-20} = 5{,}4796 * 1{,}06^{20{,}6-20} = 5{,}7 d^{-1}$$

Equation 2

Using equation 3 and the BOD value obtained from the results of the samples taken at the Mozambican brewery and analysed in the laboratory, in this case the highest, with the BOD value recommended by the Mozambican standard for industrial liquid effluent emission standards and the K value, it was possible to find the system's hydraulic detention time:

After obtaining the hydraulic detention time (18.8 d) and knowing the peak flow (Q=78.3), the system volume was calculated.

$$onde\ V = TDHn * Q = 18{,}8 * 78{,}3 = 1472\ m^3$$

$$V = A * H$$

$$A = \frac{V}{H} = \frac{1472}{0{,}8} = 1840\ m^2$$

$$A = C * L$$

$$A = L * l$$

$$1840 = L^2, L = 43\ m\ e\ C = 43\ m$$

Equation 3

It is known that the length/width ratio (L/W) must be 1. L=W Dimensioning the horizontal subsurface constructed wetland.

The filter material to be used is gravel with a filter medium porosity of 45%. Where n will be 0.45. The value of h will be 0.40 m.

$$A = \frac{Q * (lnC_e - lnC_s)}{Kt * h.n} = \frac{78{,}3 * (ln3241 - ln30)}{5{,}7 * 0{,}40 * 0{,}45} = \frac{366{,}6}{1{,}026} = 357{,}3m^2$$

Equation 4

Knowing that the length/width ratio (L/W) must be between 2 and 5 for horizontal flow and adopted for piston flow [27, 28], C = 3*l.

$$A = C * L = 3 * L * L$$

$$357,3 = 3L^2$$

$$L = \frac{357,3}{3} = j119,1 = 11\,m$$

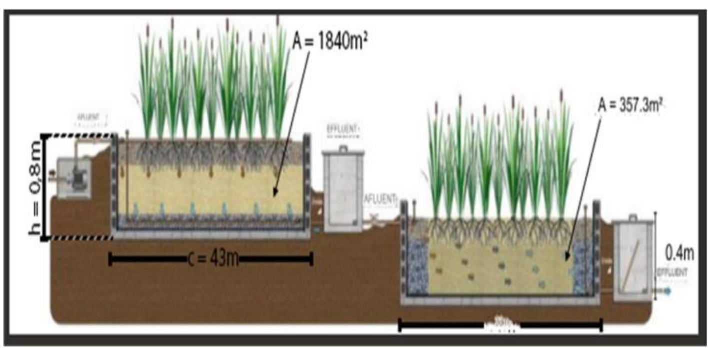
$$C = 3 * L = 3 * 11 = 33\,m$$

$$V = C * L * H = 33 * 11 * 0,4 = 145,2\,m^3$$

Equation 5

Schematic representation of the Hybrid Constructive Wetlands system proposed for a brewery in Mozambique.

Figure 10. Representation with dimensional details



Note: author´s source (2024).

Given the characteristics of the wastewater produced at the Mozambican brewery under study, the proposed system, following the dimensions, could be an optimum system for natural wastewater purification. Hybrid constructed wetlands have evolved considerably as technology has developed. There is a growing need to provide more efficient types of treatment, with lower operating and construction costs, and less environmental impact. Where the Hybrid Constructed Wetlands system requires a better option, several countries have adopted the system in reference to the removal of various parameters in industrial wastewater, with more emphasis on water that has a more complex characteristic in its composition. [30], [31].

The study area has the spatial capacity to build a hybrid wetland.

III. Conclusions

When exploring natural wastewater purification systems discussed in this article, constructed wetlands emerged as the preferred solution. Among the various types, hybrid constructed wetlands (combining vertical and horizontal subsurface flows) were particularly highlighted, alongside surface flow constructed wetlands. This preference stems from analyses and studies conducted at the study site, which revealed an extensive vacant and green area nearby. However, the presence of many houses in the vicinity creates conditions unsuitable for implementing surface wetlands. This is primarily due to their tendency to their ability to release odours originating from the process of degradation of organic matter. It is also considered that the surface system has led to the proliferation of malaria-causing mosquitoes. It is well known that the African continent, and Mozambique in particular, is vulnerable to this disease [27].

When sizing wetlands, it is important to check the local climate, with emphasis on the parameter's temperature and rainfall. Where temperature has a direct influence on the activities of microorganisms in the process of degrading organic matter, rainfall can increase the volume of water in the system and hinder the expected efficiency.

The Mozambican standard for effluent emission standards recommends that the system should be more efficient in removing the 4 main parameters due to the level of danger and indication of the water. The parameters are PH, BOD, TSS and E-Coliforms. Due to the characteristics of the wastewater from the Mozambican brewery, it does not present a hazardous level of E-coliforms due to its production origin. With regard to the other parameters, studies carried out by various authors, articles and projects have shown that the hybrid constructive wetlands system has a high capacity for reducing the parameters.

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