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*Wastewater treatment by planted macrophytes filters
in parallel and in series*

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Resume

Resume

Wastewater treatment is a crucial process to ensure the protection of the environment and public health. Planted filters, also known as constructed wetlands (CWs) represent a pioneering approach to wastewater treatment, leveraging the natural processes of wetland ecosystems to purify water. This technique involves the use of planted macrophytes, such as *Phragmites australis* and *Cyperus papyrus*, which are instrumental in removing contaminants through physical, chemical, and biological interactions. Unlike conventional treatment methods, CWs offer a sustainable and cost-effective solution, minimizing energy consumption and chemical usage. The importance of this technology lies in its ability to address the growing demand for efficient wastewater management, particularly in regions with limited access to conventional infrastructure. By utilizing macrophytes' natural filtration capabilities, CWs not only enhance water quality but also contribute to ecological conservation and the restoration of wetland habitats. This study aims to evaluate the efficiency of constructed wetlands (CWs) for treating wastewater through the use of planted macrophytes, specifically *Phragmites australis* (common reed) and *Cyperus papyrus* (papyrus), arranged in series and parallel configurations. The experiment showed the effectiveness of *Phragmites* plant and *Cyperus* plant in filtering sewage water, whether the macrophytes filters are planted in series or in parallel. The removal percentage of NH_4^+ reached 61.76% in A, B and A+B basins, the removal percentage of BOD_5 reached 69.48 in AB and BA basins, the removal percentage of COD reached 5.77 in A, B and A+B basins, and the removal of conductivity reached 75.67 in AB and BA basins. The results obtained indicate that the activity ratio is balanced in both cases. In the case of sequential filter planting, the results showed more effective performance for some parameters compared to parallel filter planting, and vice versa. This proves the effectiveness of both methods, whether used individually or together, as well as the effectiveness of *Cyperus papyrus* and *Phragmites australis* in removing pollutants from wastewater.

Keywords: Constructed Wetlands, Wastewater Treatment, *Phragmites australis*, *Cyperus papyrus*, Series and Parallel Filters, Macrophytes.

Resume

Résumé

Le traitement des eaux usées est un processus crucial pour assurer la protection de l'environnement et de la santé publique. Les filtres plantés, également connus sous le nom de zones humides construites (ZHC), représentent une approche innovante du traitement des eaux usées, exploitant les processus naturels des écosystèmes de zones humides pour purifier l'eau. Cette technique implique l'utilisation de macrophytes plantés, tels que *Phragmites australis* et *Cyperus papyrus*, qui jouent un rôle essentiel dans l'élimination des contaminants par le biais d'interactions physiques, chimiques et biologiques. Contrairement aux méthodes de traitement conventionnelles, les ZHC offrent une solution durable et économique, minimisant la consommation d'énergie et l'utilisation de produits chimiques. L'importance de cette technologie réside dans sa capacité à répondre à la demande croissante de gestion efficace des eaux usées, en particulier dans les régions ayant un accès limité aux infrastructures conventionnelles. En utilisant les capacités de filtration naturelle des macrophytes, les ZHC améliorent non seulement la qualité de l'eau, mais contribuent également à la conservation écologique et à la restauration des habitats des zones humides. Cette étude vise à évaluer l'efficacité des zones humides construites (ZHC) pour le traitement des eaux usées grâce à l'utilisation de macrophytes plantés, spécifiquement *Phragmites australis* (roseau commun) et *Cyperus papyrus* (papyrus), disposés en configurations série et parallèle. L'expérience a montré l'efficacité des plantes *Phragmites* et *Cyperus* pour filtrer les eaux usées, que les filtres de macrophytes soient plantés en série ou en parallèle. Le pourcentage d'élimination de NH_4^+ a atteint 61,76% dans les bassins A, B et A+B, le pourcentage d'élimination de la DBO5 a atteint 69,48% dans les bassins AB et BA, le pourcentage d'élimination de la DCO a atteint 5,77% dans les bassins A, B et A+B, et l'élimination de la conductivité a atteint 75,67% dans les bassins AB et BA. Les résultats obtenus indiquent que le rapport d'activité est équilibré dans les deux cas. Dans le cas de la plantation de filtres séquentiels, les résultats ont montré une performance plus efficace pour certains paramètres par rapport à la plantation de filtres parallèles, et vice versa. Cela prouve l'efficacité des deux méthodes, qu'elles soient utilisées individuellement ou ensemble, ainsi que l'efficacité de *Cyperus papyrus* et *Phragmites australis* pour éliminer les polluants des eaux usées.

Mots-clés : Zones Humides Construites, Traitement des Eaux Usées, *Phragmites australis*, *Cyperus papyrus*, Filtres en Série et en Parallèle, Macrophytes.

Resume

ملخص

معالجة مياه الصرف الصحي هي عملية حيوية لضمان حماية البيئة والصحة العامة. تمثل المرشحات المزروعة، والمعروفة أيضًا بالأراضي الرطبة المُنشأة (CWs)، نهجًا رائدًا في معالجة مياه الصرف الصحي، حيث تستفيد من العمليات الطبيعية للنظم البيئية للأراضي الرطبة لتنقية المياه. تتضمن هذه التقنية استخدام النباتات المائية المزروعة، مثل نبات القصب الشائع (*Phragmites australis*) ونبات البردي (*Cyperus papyrus*)، التي تلعب دورًا رئيسيًا في إزالة الملوثات من خلال التفاعلات الفيزيائية والكيميائية والبيولوجية. على عكس طرق المعالجة التقليدية، توفر الأراضي الرطبة المُنشأة حلاً مستدامًا وفعالًا من حيث التكلفة، حيث تقلل من استهلاك الطاقة واستخدام المواد الكيميائية. تكمن أهمية هذه التقنية في قدرتها على تلبية الطلب المتزايد على إدارة مياه الصرف الصحي بكفاءة، خاصة في المناطق التي تفتقر إلى البنية التحتية التقليدية. من خلال الاستفادة من قدرات الترشيح الطبيعية للنباتات المائية، لا تساهم الأراضي الرطبة المُنشأة في تحسين جودة المياه فحسب، بل تسهم أيضًا في الحفاظ على البيئة واستعادة موائل الأراضي الرطبة. تهدف هذه الدراسة إلى تقييم كفاءة الأراضي الرطبة المُنشأة في معالجة مياه الصرف الصحي باستخدام النباتات المائية المزروعة، وتحديدًا نبات القصب الشائع (*Phragmites australis*) ونبات البردي (*Cyperus papyrus*)، مرتبة في تكوينات متسلسلة ومتوازية. أظهرت التجربة فعالية نبات البوص ونبات البردي في ترشيح مياه الصرف الصحي، سواء كانت المرشحات المزروعة مرتبة بشكل متسلسل أو متوازي. بلغت نسبة إزالة الأمونيوم (NH_4^+) 61.76% في الأحواض (A, B, A+B)، وبلغت نسبة إزالة الأكسجين الحيوي المطلوب (BOD_5) 69.48% في الأحواض (AB) و(BA)، وبلغت نسبة إزالة الأكسجين الكيميائي المطلوب (COD) 5.77% في الأحواض (A, B, A+B)، وبلغت نسبة إزالة التوصيلية الكهربائية 75.67% في الأحواض (AB) و(BA). تشير النتائج المحصل عليها إلى أن نسبة الفعالية متوازنة في كلتا الحالتين. في حالة زراعة المرشحات بشكل متسلسل، أظهرت النتائج أداءً أكثر فعالية لبعض المعايير مقارنة بزراعة المرشحات بشكل متوازي، والعكس صحيح. يثبت ذلك فعالية كلا الطريقتين، سواء تم استخدامهما بشكل فردي أو معًا، وكذلك فعالية نبات البردي نبات القصب الشائع في إزالة الملوثات من مياه الصرف الصحي.

الكلمات المفتاحية:

الأراضي الرطبة المُنشأة، معالجة مياه الصرف الصحي، القصب الشائع (*Phragmites australis*)، البردي (*Cyperus papyrus*)، المرشحات على التوالي والمتوازية، النباتات المائية.

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Acronymslist

PO_3^{4-}	Orthophosphate
NO_2^-	Nitrite
NH_4^+	Ammonium
COD	Chemical oxygen demand
BOD_5	Biochemical oxygen demand after 5 days
pH	Potential hydrogen
CWs	Constructed wetlands

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General introduction

General introduction

The treatment of wastewater is a critical environmental and public health issue, necessitating effective, sustainable, and adaptable solutions. Among various treatment technologies, the use of planted filters, also known as constructed wetlands, has garnered considerable attention for their ecological and economic benefits. Planted filters utilize vegetation, soil, and microbial interactions to remove contaminants from wastewater. The deployment of these systems can be configured in series or parallel, each offering unique advantages and applications (**Vymazal, 2011**).

In a series configuration, wastewater passes sequentially through multiple treatment stages, each designed to target specific pollutants. This stepwise approach enhances the overall treatment efficiency, as each stage can be optimized for particular physical, chemical, or biological processes. Conversely, a parallel configuration distributes wastewater across multiple independent filters simultaneously, allowing for increased treatment capacity and redundancy. This setup is particularly advantageous for handling large volumes of wastewater or providing consistent treatment under varying flow conditions (**Kadlec and Wallace, 2009**).

Both configurations leverage the natural processes of phytoremediation, where plants play a crucial role in the uptake, transformation, and stabilization of pollutants. The choice between series and parallel configurations depends on site-specific conditions, treatment goals, and resource availability (**Wu.het et al., 2015**). By integrating these natural systems into wastewater management strategies, communities can achieve sustainable water quality improvements while supporting biodiversity and reducing operational costs (**Garcia et al., 2010**).

Ultimately, the problem centers on developing a comprehensive framework for the design, implementation, and optimization of planted filters in series and parallel configurations. This framework must consider the intricate balance between treatment efficacy, cost-effectiveness, ecological impact, and adaptability to changing environmental and operational conditions (**Ghosh and Gopal, 2010**).

How can we design and optimize constructed wetland systems to maximize their efficiency and sustainability while addressing the diverse needs of different communities and environmental conditions.

Chapter 1: Bibliographic synthesis

1. Introduction:

Wastewater is water whose physical, chemical or biological properties have been altered by the introduction of certain substances, making it unsafe for certain uses such as drinking water. Humans' daily activities mainly rely on water, thus introducing "waste" into the water. Substances include body waste (feces and urine), shampoo, hair, leftover food, grease, laundry detergent, fabric softener, toilet paper, chemicals, detergents, household cleaners, dirt and microorganisms (bacteria), which may cause people to get sick and harming the environment. It is known that most of the water supplied ends up as wastewater, so its treatment is very important. Wastewater treatment is the process and technology used to remove most of the contaminants from wastewater to ensure a healthy environment and good public health. Wastewaters come from various domestic uses of water. They are mainly carriers of organic pollution. They are divided into household water, originating from bathrooms and kitchens, and are generally loaded with detergents, fats, solvents, organic debris, etc. And "black water"; these are toilet flushes, loaded with various nitrogenous organic materials and fecal germs (**Gomella and Guerree, 1978**).

In Algeria, the daily pollution produced by a person using 150 to 200 liters of water is estimated to be:

1. from 70 to 90 g of suspended matter
2. from 60 to 70 g of organic matter
3. from 15 to 17 g of nitrogenous matter
4. 4 g of phosphorus
5. Several billion germs per 100 ml. (**Gomella and Guerree, 1978**).

2. Industrial waters:

According to **Metahri (2012)**, they are very different from domestic wastewater. Their characteristics vary from one industry to another. In addition to organic, nitrogenous, or phosphorus materials, they are loaded with various organic and metallic chemical substances. Depending on their industrial origin, they may also contain:

1. Fats (agri-food industries...).
2. Hydrocarbons (refineries).
3. Metals (surface treatments, metallurgy).
4. Acids, bases, and various chemicals (various chemical industries, tanneries).
5. Hot water (cooling circuits of thermal power plants).

Bibliographic synthesis

6. Radioactive materials (nuclear power plants, radioactive waste treatment).

Before being discharged into collection networks, industrial wastewater must undergo treatment. They are only mixed with domestic wastewater when they no longer pose a danger to the collection networks and do not disrupt the operation of purification plants.

3. Components of domestic water:

According to **Henze and Ledin (2002)**, the strength and composition of the domestic wastewater changes on hourly, daily and seasonal basis, with the average strength dependent on per capita water usage, habits, diet, living standard and lifestyle. The main reason is variation in water usage in households. Households in developed countries use more water than those in developing countries. Wastewater components can be divided into different main groups as shown in Table1. They can adversely affect aquatic life if discharged into the environment.

Table 1: Components present in domestic wastewater (**Henze and Ledin, 2002**).

Component	Of special interest	Enviromental effect
Microorganisms	Pathogenic bacteria, virus and worms eggs	Risk when bathing and eating shellfish
Biodegradable organic materials	Oxygen depletion in rivers and lakes	Fish death, odours
Other organic materials	Detergents, pesticides, fat, oil and grease, colouring, solvents, phenols, cyanide	Toxic effect, aesthetic inconveniences, bioaccumulation in the food chain
Nutrients	Nitrogen, phosphorus, ammonium	Eutrophication, oxygen depletion, toxic effect
Metals	Hg, Pb, Cd, Cr, Cu, Ni	Toxic effect, bioaccumulation
Other inorganic materials	Acids, for example hydrogen sulphide, bases	Corrosion, toxic effect
Thermal effects	Hot water	Changing living conditions for flora and fauna
Odour (and taste)	Hydrogen sulphide	Aesthetic inconveniences, toxic effect
Radioactivity		Toxic effect, accumulation

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3.1 Physically:

Domestic wastewater is usually characterized by a gray color, musty odor and has a solid content of about 0.1%. The solid material is a mixture of feces, food particles, toilet paper, grease, oil, soap, salts, metals, detergents, sand and grit. The solids can be suspended (about 30%) as well as dissolved (about 70%). Dissolved solids can be precipitated by chemical and biological processes. From a physical point of view, the suspended solids can lead to the development of sludge deposits and anaerobic conditions when discharged into the receiving Environment (**Henze and Ledín, 2002**).

3.2 Chemically:

Wastewater is composed of organic (70%) and inorganic (30%) compounds as well as various gasses. Organic compounds consist primarily of carbohydrates (25 %), proteins (65 %) and fats (10 %), which reflects the diet of the people. Inorganic components may consist of heavy metals, nitrogen, phosphorus, pH, sulfur, chlorides, alkalinity, toxic compounds, etc. However, since wastewater contains a higher portion of dissolved solids than suspended, about 85 to 90% of the total inorganic component is dissolved and about 55 to 60% of the total organic compound is dissolved. Gasses commonly dissolved in wastewater are hydrogen sulfide, methane, ammonia, oxygen, carbon dioxide and nitrogen. The first three gasses result from the decomposition of organic matter present in the wastewater (**Henze and Ledín, 2002**).

3.3 Biologically:

wastewater contains various microorganisms but the ones that are of concern are those classified as Protista, plants, and animals. The category of Protista includes bacteria, fungi, protozoa, and algae. Plants include ferns, mosses, seed plants and liverworts. Invertebrates and vertebrates are included in the animal category. In terms of wastewater treatment, the most important category are the Protista, especially the bacteria, algae, and protozoa. Also, wastewater contains many pathogenic organisms which generally originate from humans who are infected with disease or who are carriers of a particular disease. Typically, the concentration of fecal coliforms found in raw wastewater is about several hundred thousand to tens of million per 100 ml of sample (**Henze and Ledín, 2002**).

4. Pollution parameters and discharge standards:

The use of water generates a new product called effluent or wastewater, including urban wastewater (ERU) and industrial wastewater (ERI).

4.1 Pollution parameters:

Urban wastewater (ERU): According to **Morin (2017)**, urban wastewater (ERU) includes domestic wastewater, sewage, and runoff. The composition and characteristics of urban wastewater are relatively consistent compared to industrial wastewater.

1 - Suspended solids (SS)

2 - Biochemical oxygen demand (BOD)

3 - Chemical oxygen demand (COD)

4 - Nitrogen and phosphorus levels are also significant parameters due to eutrophication issues.

5 - Microorganisms excreted with fecal matter, classified into bacteria, viruses, protozoa, and helminths.

Industrial wastewater (ERI): Wastewater discharged after manufacturing processes or cleaning. **Morin (2017)** outlined the Major pollutants in industrial wastewater in the following points:

1- Toxic metals

2- Organic toxins

3- Colored matter

4- Oils and fats

5- Salts

4.2 Wastewater treatment parameters:

Wastewaters are characterized by several parameters. Two categories of parameters are distinguished: physical and chemical.

4.2.1 Physical parameters:

4.2.1.1 Temperature:

It plays an important role in the solubility of salts and gasses. Since it determines the rate and speed of degradation reactions, it also allows for the correction of analysis parameters whose values are linked to temperature (conductivity, pH, O₂). An increase in temperature decreases the solubility of gasses; this phenomenon is significant in the case of O₂, which implies an insufficient reserve of O₂ (**Haoua, 2007**).

4.2.1.2 Suspended solids (SS):

According to **Haoua(2007)**, these are materials that are neither soluble nor colloidal. They can be considered as an intermediary between mineral particles such as sand or coal dust and mineral particles of a mucilaginous type.

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4.2.1.3 Chemical parameters:

pH (Hydrogen Potential): This parameter indicates the acidity or alkalinity of water. pH reflects the concentration of H⁺ ions in water, indicating the balance between acid and base. Its role is crucial for the growth of microorganisms; this growth will be directly affected when pH is below 5 or above 8 (Haoua, 2007).

Biochemical Oxygen Demand (BOD₅): It characterizes the oxygen consumption (mg/L) by purifying bacteria, meaning the amount of oxygen needed by living microorganisms to oxidize and stabilize organic matter in wastewater. The measurement conditions involve incubation at 20°C and in darkness. The complete process duration is three weeks (BOD₂₁), but this duration is very long. It represents the concentration of biodegradable matter. By convention, the BOD value obtained is for five days of incubation, noted as BOD₅ (Sadik, 2017).

Chemical Oxygen Demand (COD): This is the measurement of the amount of oxygen needed, which corresponds to the quantity of oxidizable matter per unit of oxygen contained in an effluent. It represents most of the organic compounds (detergents, fecal matter). It is measured by the oxygen consumption of a solution of potassium dichromate in sulfuric acid in the presence of silver sulfate and mercury II sulfate (chloride complexant), heated for 2 hours (Mekhalif, 2009).

Table 02: The limits of pollution parameters in wastewater effluents.

Type of unitary networks	Suspended solids (in mg/l)	Dissolved organic carbon	Biochemical Oxygen Demand (BOD ₅)
Effluents from separate networks	152--670	114--570	48--270
Combined sewer overflows	34--640	28--320	13--40
Treated water	35	125	25

5. Discharge water standards:

The standard is represented by a number that sets an upper limit not to be exceeded or a lower limit to be respected.

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5.1 International standards :

The respective international standards for wastewater according to the World Health Organization (WHO).

Table 03 : International discharge standards.

Characteristics	Standards used (WHO)
pH	6.5-8.5
BOD ₅	<30 mg/l
COD	<90 mg/l
SS	<20 mg/l
NH ⁴⁺	<0.5mg/l
NO ²⁻	1 mg/l
NO ³⁻	<1 mg/l
PO ⁴	<2 mg/l
Temperature	<30 C
Color	Colorless
Odor	Odorless

5.2 Algerian standards :

The discharge standards for industrial effluents result from Law No. 83-17 of July 16, 1983, concerning the water code, Ordinance No. 96-13 of June 15, 1996, amending and supplementing Law No. 83-17, Executive Decree No. 93-160 of July 10, 1993, regulating the discharge of liquid effluents from industries, and Executive Decree No. 06-141 of April 19, 2006, of the Algerian Democratic Republic defining the maximum permissible values for industrial liquid effluent discharge (**Algeria Official Journal, Jul 19,1983**).

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Table 04: Algerian standards for liquid effluent discharge.

Parameters	Units	Limit Values
Temperature	C	30
pH	–	6.5-8.5
BOD ₅	mg/l	30
COD	mg/l	120
SS	mg/l	35
Total Nitrogen	mg/l	30
Total Phosphorus	mg/l	10
Furfural	mg/l	50
Hydrocarbons	mg/l	10
Lead	mg/l	0.5
Iron	mg/l	3
Mercury	mg/l	0.01
Copper	mg/l	0.5
Zinc	mg/l	3

6. Wastewater treatment:

Basically, wastewater treatment is a simple process of converting wastewater into bilge water, which is then released into the environment. This wastewater contains contaminants such as chemicals, bacteria, and other toxins. The main reason for treatment is to treat this water to an acceptable level where it can be safely returned to the environment. Wastewater treatment is also the process of removing impurities and other contaminants from wastewater using advanced equipment and methods. As the word suggests, purifying raw wastewater is a process. This happens gradually until the final stage when the water is released into the river.

Wastewater treatment typically involves several steps to remove contaminants and pollutants before the treated water is discharged back into the environment. The specific steps can vary depending on the type of wastewater and the treatment plant's design. Here are some common wastewater treatment steps according to Water Environment Federation:

6.1 Preliminary treatment :

This step involves the removal of large objects, such as sticks, rags, and debris, through screening and grit removal processes (WEF, 2014).

6.2 Primary treatment :

In this step, solid particles are settled out of the wastewater using sedimentation tanks. The settled solids, known as sludge, are removed for further treatment (WEF, 2014).

6.3 Secondary treatment:

Secondary treatment involves the biological degradation of organic matter in the wastewater by microorganisms. This can be achieved through processes like activated sludge, trickling filters, or rotating biological contactors (WEF, 2014).

6.4 Tertiary treatment:

Tertiary treatment is a final polishing step that further removes remaining contaminants, such as nutrients (nitrogen and phosphorus), pathogens, and trace chemicals. This can include processes like filtration, disinfection, and advanced oxidation (WEF, 2014).

6.5 Sludge treatment:

Sludge generated during the treatment process is typically treated separately to reduce its volume, stabilize it, and remove pathogens before disposal or reuse (WEF, 2014).

7. The objectives of wastewater treatment:

The purpose of treating wastewater is to remove contaminants and pollutants to protect public health and the environment. Treatment processes are designed to reduce the levels of biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total nitrogen (TN), and total phosphorus (TP), as well as other harmful pathogens, metals, and organic compounds. By removing these contaminants, treated wastewater can be recycled for non-potable purposes such as irrigation, industrial processes, and toilet flushing, thereby reducing demand on freshwater sources and conserving the environment (Asadi, 2018). We can summarize the objectives of wastewater treatment in the following points:

7.1 Removal of pollutants :

Wastewater treatment involves the removal of physical, chemical, and biological pollutants from the water to ensure that contaminants are not discharged into the environment. This helps to protect aquatic ecosystems and prevent harm to human health (Tchobanoglous *et al.*, 2013).

7.2 Pathogen removal :

Wastewater treatment processes help to remove pathogens such as bacteria, viruses, and parasites that can cause waterborne diseases. Disinfection methods like chlorination or UV treatment are used to kill or inactivate these harmful microorganisms (Tchobanoglous *et al.*, 2013).

7.3 Nutrient removal:

Wastewater treatment facilities typically aim to remove excess nutrients like nitrogen and phosphorus, which can lead to eutrophication in water bodies. Nutrient removal helps to prevent algal blooms and improve water quality (Tchobanoglous et al., 2013).

7.4 Compliance with regulations:

Treating wastewater is essential to comply with environmental regulations and discharge permits set by regulatory agencies. Meeting these standards ensures that wastewater is treated to acceptable levels before being discharged into receiving water (Metcalf and Tchobanoglous, 2014).

7.5 Protection of public health:

Proper wastewater treatment safeguards public health by preventing the spread of waterborne diseases and reducing exposure to harmful substances. Treated water that meets quality standards can be safely released into the environment or reused without posing health risks (Tchobanoglous et al., 2013).

7.6 Minimize odors :

The treatment process can help reduce unpleasant odors associated with untreated wastewater (Tchobanoglous et al., 2013).

7.7 Supporting sustainable water management :

Wastewater treatment can help to conserve water resources by reducing the demand for freshwater and preventing the depletion of water supplies (Tchobanoglous et al., 2013).

7.8 Chemical contamination :

Treated wastewater may contain various chemical contaminants such as pharmaceuticals, heavy metals, and organic compounds that are not completely removed during the treatment process. Reusing this water can lead to the accumulation of these chemicals in soil, crops, and groundwater, posing risks to human health and the environment (Effendi et al., 2017).

8. Comparison :

The processing of wastewater is crucial for safeguarding the well-being of urban and rural communities. Beyond protecting the environment and public health by preventing diseases, wastewater treatment also facilitates its reuse in agriculture and industry. This latter purpose is gaining prominence, leading to ongoing advancements in treatment techniques and facilities. In addition to conventional methods like primary and secondary treatments,

efforts are being made to develop tertiary treatments to eliminate harmful substances further. While traditional individual sanitation systems are expensive and often inadequate, an eco-friendly and cost-effective alternative exists in the form of Phyto purification.

9. Wastewater treatment with constructed wetlands:

Currently, significant attention is being given in Europe and America to the purification of urban and industrial wastewater using planted filter beds with macrophytes (Phyto Purification). Phyto Purification refers to the purification of wastewater in the presence of plants. It can be achieved through various systems characterized by the slow flow of water under controlled conditions through vegetative environments, promoting natural purification through processes such as aeration, sedimentation, absorption, and metabolization by microorganisms and flora. Phyto Purification systems are used for purifying water from different sources and with different characteristics (**Himour and Guendouz, 2017**). Phyto Purification is particularly advantageous for small, dispersed communities and developing countries. The main objective of this chapter is to provide an overview of wastewater purification using planted filter beds with macrophytes, as well as the different types of planted filters and the most commonly used plants in this technique (**Himour and Guendouz, 2017**).

10. Constructed wetlands:

Wetlands have been used around the world for hundreds of years for informal water treatment. Our ancestors noticed that black water passing through wetlands comes out in a much cleaner state. There is archaeological evidence that the Chinese used this knowledge to their advantage as early as 2000 BC. Already in the 17th century, Parisians spread sewage and sludge, which were collected in simple garbage cans in the center of the city, to clean it in the suburban countryside. However, this characteristic of wetlands was not studied until the 1950s. This leads to the development of more densely constructed wetlands (Fig.01) designed to remove certain levels of pollutants. This work was initially carried out by Seidel (1960) at the Max Planck Institute and later with Kickuth (1970) at the University of Gottingen. Later they worked separately, in fact as rivals. Their work raised the profile of treatment wetlands worldwide, and since then we have seen a dramatic advance in the application of wetland construction technology worldwide. From the beginning, treatment wetlands have been proposed for tertiary, secondary and primary treatment of urban areas. waste water and is strongly associated with the green agenda, "nice to have", almost a

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curiosity. However, technology has advanced by leaps and bounds over the past 20 years, and a wide variety of constructed wetlands have been developed to handle high loads of sewage or sludge from many domestic and industrial sources. At the same time, we have seen an increased awareness of human impact on the global environment, particularly in relation to global sustainability and, more recently, climate change. This has led to the perception and value of constructed wetland treatment systems changing from a curious water treatment system to a very suitable water treatment solution for our times, as they consume no or little energy, low maintenance, low carbon footprint, biodiversity and sustainability and continuity (US EPA, 1995).

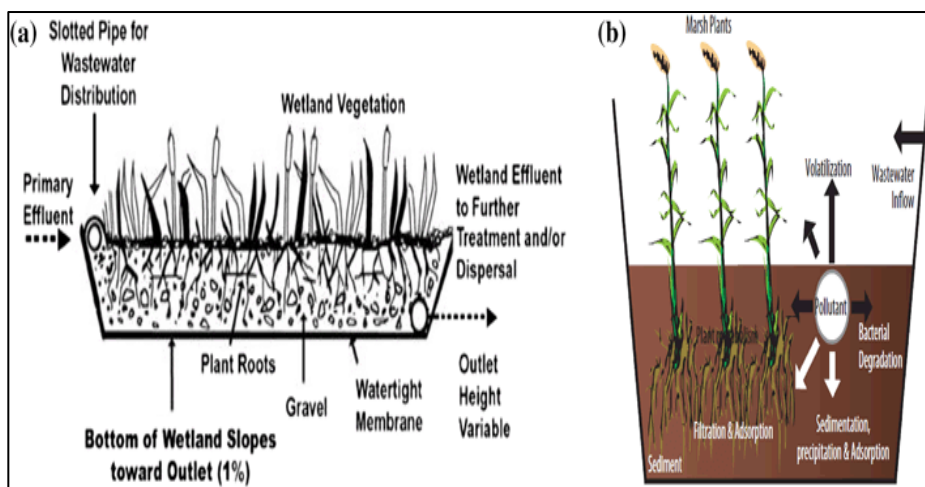


Figure 01: Constructed wetland working and pollutant removal mechanisms (Advances in Health and Environment Safety, 2020)

11. Basics form:

A constructed wetland is basically a pit filled with organic or inorganic particles in which reeds are planted. They are usually covered with rubber (butyl) or plastic (HDPE) to keep out polluted water and thus protect the groundwater and adjacent bottom. Clay-based materials can also be used to seal constructed wetlands, providing a more natural option. Wastewater can enter the system as a continuous flow or in controlled batches. Wastewater can move either horizontally across or vertically up or down through the environment, depending on the treatment requirements. Microbial degradation or treatment of contaminants is the primary treatment method and is carried out by bacterial communities that grow as biofilms on the surface of the particle carrier (Kadlec and Wallace, 2009).

12. Type of constructed wetlands for wastewater treatment:

Constructed wetlands can be classified based on a variety of design parameters, but the three most important are hydrology (water surface flow and subsurface flow),

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macrophyte growth form (emergent, submerged, free-floating, and floating leaved plants), and flow path. Different types of CWs can be integrated (known as hybrid or combined systems) to take advantage of the unique benefits of each system. To provide more effective removal of ammonia and total nitrogen (N), during the 1990s and 2000s, an upgraded design strategy blended vertical and horizontal flow CWs to achieve higher treatment efficiency (Vymazal, 2011).

13. Constructed wetlands with surface flow (SF):

Also known as free water surface CWs, have open water and various plant types (Kadlec and Wallace, 2009). The shallow water level, low flow velocity, and presence of plant stalks and litter regulate water flow and improve water filtration, especially in long, narrow channels (Crites *et al.* 2005). The most prevalent uses for SF CWs are for tertiary treatment of municipal wastewater, stormwater runoff, and mine drainage waters (Kadlec and Knight, 1996; Kadlec and Wallace, 2008). SF CWs are good for all climates (Fig.02), especially the far north (Mander and Jenssen, 2003).

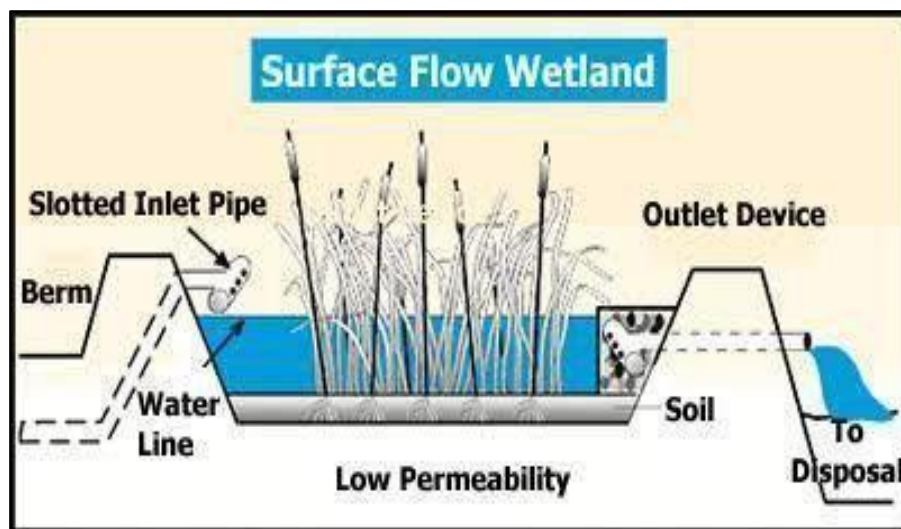


Figure 02: Constructed wetland with surface flow (WATER ONLINE, 2020).

14. Constructed wetlands with subsurface flow:

In horizontal subsurface flow constructed wetlands (HSSF CWs), wastewater enters the inlet and slowly flows through the porous medium beneath the surface of an emergent vegetation-covered bed to the outlet, where it is collected before exiting via a water level control structure, during passage, the wastewater interacts with a network of aerobic, anoxic, and anaerobic zones. The majority of the bed is anoxic/anaerobic due to the beds' persistent saturation. The aerobic zones form around roots and rhizomes that leak oxygen into the

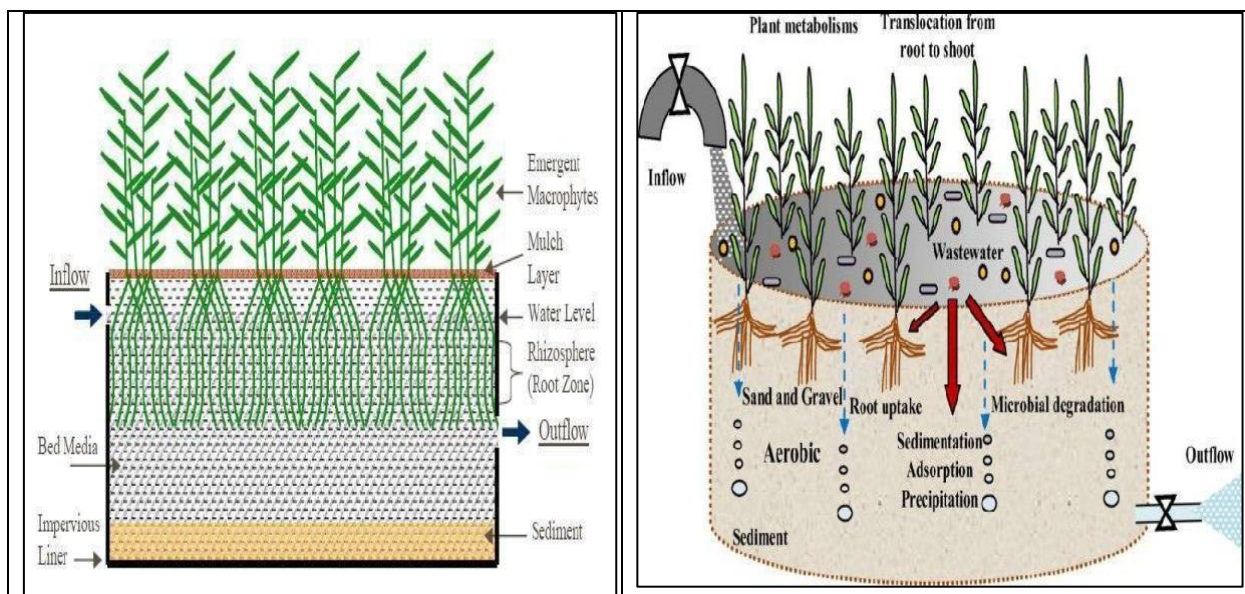
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substrate. A liner is typically used to seal HSSF CWs and prevent seepage while also ensuring controlled outflow (Vymazalet *et al.*, 1998).

A liner (Fig. 1.a) is typically used to seal HSSF CWs and prevent seepage while also ensuring controlled outflow. HSSF CWs are typically employed for secondary treatment of municipal wastewater, but numerous other uses have been documented in the literature (Vymazal and Kröpfelova, 2008). The oxygen transport capacity in these systems is insufficient to enable aerobic decomposition, consequently, anaerobic processes play a major role in HSSF CWs (Vymazal and Kröpfelova, 2008). Some HSSF CWs, with the ability to insulate the bed surface, can operate in cooler temperatures than SF systems (Mander and Jensen, 2003).

Vertical subsurface flow (Fig.1.b) constructed wetlands (VSSF CWs) are made up of a flat bed of graded gravel covered with sand and seeded with macrophytes. VSSF CWs are fed by enormous intermittent wastewater flows that flood the bed's surface before percolating down through it and being collected by a drainage network at the bottom. The bed drains fully, allowing air to fill the bed. Thus, VSSF CWs enhance oxygen transfer into the bed, resulting in nitrified (high NO_3^-) effluent (Cooper, 2005). As a result, VSSF CWs do not provide optimal conditions for denitrification to complete conversion to gaseous nitrogen forms, which ultimately escape into the atmosphere (Vymazal, 2011).

Recently developed tidal ("fill and drain") flow systems ensure improved contact between wastewater and microorganisms growing in the media. This considerably improves the purifying procedure (Vymazal, 2011).



a/ Horizontal subsurface flow.

b/ Vertical subsurface flow

Figure 03: Horizontal and Vertical subsurface flow

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(Environmental Science and Pollution Research, 2020).

15. Hybrid Wetlands:

Various CWs can be coupled to increase removal efficiency, particularly for nitrogen. The design is divided into two stages: many parallel vertical flow (VF) beds and two or three horizontal flow (HF) beds in succession (VSSF-HSSF system). The VSSF wetland is meant to remove organics and suspended solids while also promoting nitrification, whereas the HSSF wetland denitrifies and removes more organics and suspended solids (Vymazal, 2011).

Another configuration is an HSSF-VSSF system. A large HSSF bed is installed first to remove organics and suspended solids while also promoting denitrification. An intermittently loaded tiny VF bed is used to remove more organics and suspended particles, as well as nitrify ammonia into nitrate. To maximize total nitrogen removal, the nitrified effluent from the VF bed must be returned to a sedimentation tank (Vymazal, 2011). VSSF-HSSF and HSSF-VSSF CWs are the most popular hybrid systems (Fig.04), however any type of CW can be mixed to improve treatment efficiency (Vymazal, 2007).

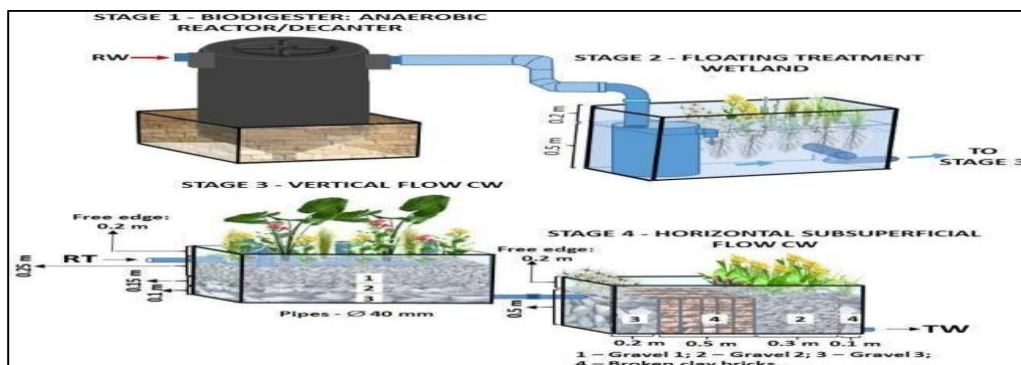


Figure 04: Hybrid constructed wetlands for wastewater treatment (Ecological Engineering, 2020).

16. The innovation of planted filters technologies:

On November 23rd, planted filter technology was invented with the introduction of two flow modes for different systems. Surface flow utilizes floating macrophytes like water hyacinth and duckweed, as well as macrophytes with floating leaves such as Indian lotus and yellow water lily, along with emergent macrophytes. The effluent passes from one basin to another via overflow in this mode. Subsurface flow, on the other hand, utilizes emergent macrophytes like reed, bulrush, and bamboo. This flow mode is associated with horizontal flow planted filters operating at saturation and vertical flow filters operating at unsaturation. The focus of this study is on planted filters using emergent macrophytes. The development

of wastewater treatment processes using planted filters began in Germany in the 1960s by Dr. Kathe Seidel, with the Max Planck Institute Process or Krefeld System, consisting of two vertical flow stages followed by horizontal flow stages. Kickuth (1970) continued this work from 1970 onwards. To enhance the system, Dr. Seidel combined a first stage vertical flow filter planted with *Phragmites australis* with a horizontal flow bed plan (**Bernier, 2001**).

17. The different varieties of planted filters:

Depending on the direction of water flow within the bed, the following are distinguished:

- Planted filters with vertical flow, where the first stage can receive raw wastewater, thus eliminating the need for sludge management since they mineralize on the bed.
- Horizontal flow filters are typically placed downstream of vertical flow beds, primarily for tertiary treatment to remove nitrogen and phosphorus.

Various configurations combining these two types of filters exist worldwide. Systems composed of vertical flow filters in multiple stages in series or vertical flow filters in two stages associated with a horizontal flow filter are encountered for better removal of nitrogen and phosphorus in cases of discharge into environments sensitive to eutrophication. There are also combinations by associating the two types of beds with a possibility of recirculation for optimal nitrogen removal by denitrification (**Vymazal, 2005; Brix et al., 1997**).

18. Operating principles of the filters:

The purification is carried out according to the principle of mainly aerobic biological purification in fine to coarse granular media. There is no regular renewal or washing of the filter bed to remove the biological sludge produced within the filters. However, sludge produced upstream of the filters (on the filters or in a sedimentation device) must be evacuated (**Crites, 2005**). Two types of planted filters are distinguished, according to the direction of vertical flow filters and horizontal flow filters.

Planted filter stations are generally an assembly of beds in parallel and/or in series. The purifying activity of the soil adds to that initially developing in the mineral filter bed. A trend towards improved efficiency with the aging of the installation is observed at this site (**Crites, 2005**).

19. Vertical flow plant filters:

Wastewater treatment plants with vertical flow reed bed filters are often composed of at least two stages in series, each consisting of two or three filters in parallel operating alternately. The objective of this alternation is to minimize filter clogging through the mineralization, during resting phases, of accumulated organic matter. The required rest time for the first stage is approximately twice the operating time, leading to 3 beds in parallel. For the second stage, the rest and operating times are equivalent: thus, 2 beds are sufficient. Rotation typically occurs every 3-4 days. The filters in the first stage are exclusively made up of various types of gravel, where aeration phenomena by diffusion are significantly higher than in sand (**Mander, 2003**).

The main purification mechanisms rely on the combination of several aerobic processes, which occur successively on the two treatment stages in series.

Vertical flow filters are surface-fed, and the effluent percolates vertically through the substrate. The effluent undergoes an initial filtration stage allowing for physical retention of suspended matter at the surface of the first-stage filters, resulting in the accumulation of sludge on the surface (**Mander, 2003**).

Biological degradation of dissolved matter is carried out by aerobic bacterial biomass attached to the unsaturated support and the accumulated surface deposit layer (**Molle et al., 2003**).

The oxygenation capacity is such that the first-stage filters mainly contribute to the degradation of the carbonaceous fraction, with partial nitrification also noted. The second stage then refines the degradation of the carbonaceous fraction and completes nitrification depending on oxygenation conditions, temperature, and pH (**Molle et al., 2003**). In order to optimize this oxygenation and the use of the entire biological reactor that is the filter, each batch must be evenly distributed over the entire surface of the bed.

Aerobic conditions do not allow for denitrification in these devices. Additionally, phosphorus removal is not achievable due to the low adsorption capacities of mainly siliceous materials and the negligible assimilation by plants, given the applied loads. Unless specifically arranged, decontamination is almost negligible due to the short residence times of effluents in the system (**Molle et al., 2003**).

The necessary limitation to prevent biomass development in the filter beds and avoid clogging is achieved through self-oxidation during resting phases. This is why vertical planted filter devices consist of multiple rows, three in the first stage and two in the second, in parallel and fed alternately (**Molle et al., 2003**).

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The role of reeds on the first-stage vertical flow is mainly mechanical (Fig. 05). The dense development of reed stems originating from rhizome nodes (underground stems) and piercing the superficial deposit layer creates pathways that extend to the entire root system and from there to the draining layer of the filters, thus preventing clogging even in the case of raw domestic wastewater input, i.e., without prior settling (**Molle *et al.*,2003**).

Experience gained over fifteen years in Gensac la Pallue reveals that in the shade of reeds and under adequate humidity, microbial biomass develops within the organic deposits retained on the infiltration bed. This biomass contributes to the mineralization of organic matter to an extent of around 65% by mass compared to the received flux. This results in a soil that accumulates at a rate of about fifteen mm per year and also serves as a biofilter, maintaining good permeability (**Molle *et al.*, 2003**).

The purifying activity of the soil adds to that initially developing in the mineral filter bed. A trend towards improved efficiency with the aging of the installation is observed at this site (**Molle *et al.*, 2003**).

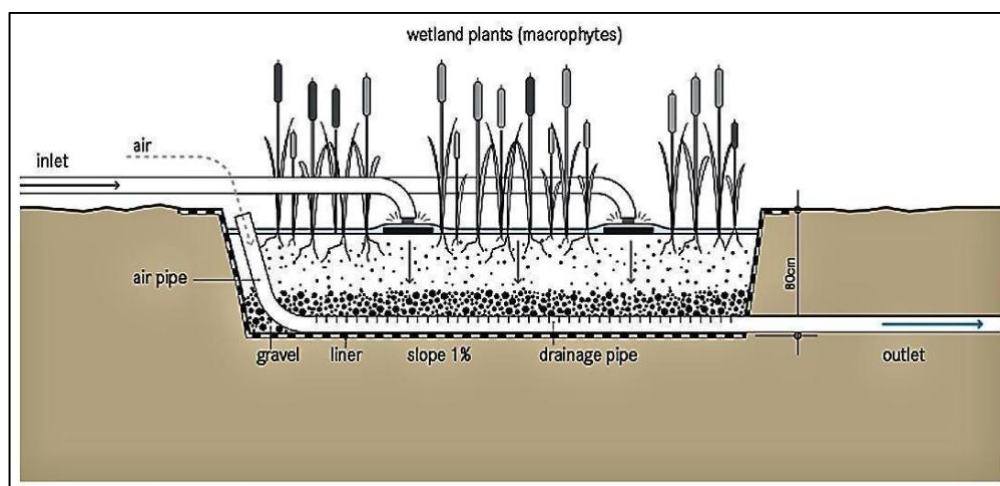


Figure 05: Vertical flow constructed wetlands (SSWM,2020)

20. Horizontal flow plant filters: (Fig. 06)

On the other hand, they are completely saturated with water by an outlet siphon system allowing for water level adjustment in the basin. Gabion distribution structures at the inlet and outlet of the filter enable a relatively uniform distribution and recovery of water. More prone to clogging than vertical flow filters, horizontal filters must be fed with water previously cleared of suspended matter. This can be achieved either through a settling-digesting tank or a septic tank placed upstream, or by a first stage of vertical flow planted filtration. Dissolved matter is degraded in the filtration bed by the bacterial biomass attached to the support (**Molle *et al.*,2004**). The water level at the outlet of the horizontal filter

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depends on the evolution of the permeability of the filtration bed over time and the variation of hydraulic loads. It is adjustable by a height adjustment system throughout the filter (**Molle *et al.*,2004**).

Aeration results solely from inputs from plant roots and gaseous diffusion in the unsaturated superficial part. The oxygen supply per unit area is therefore much lower than for vertical flow filters, and consequently, the effective surfaces used are larger. This surface area must be adjusted according to the objectives assigned to the horizontal filter, taking into account the reductions achieved in the upstream equipment (**Molle *et al.*,2004**).

The relatively low oxygen supply limits the growth of heterotrophic and autotrophic aerobic bacteria and, consequently, the degradation of carbonaceous matter and especially the oxidation of nitrogen compounds. However, anaerobic and aero-anaerobic mechanisms occur at the roots of macrophytes (rhizosphere effect) and contribute to the degradation of carbonaceous matter and the transformation of reduced forms of nitrogen (**Molle *et al.*,2004**).

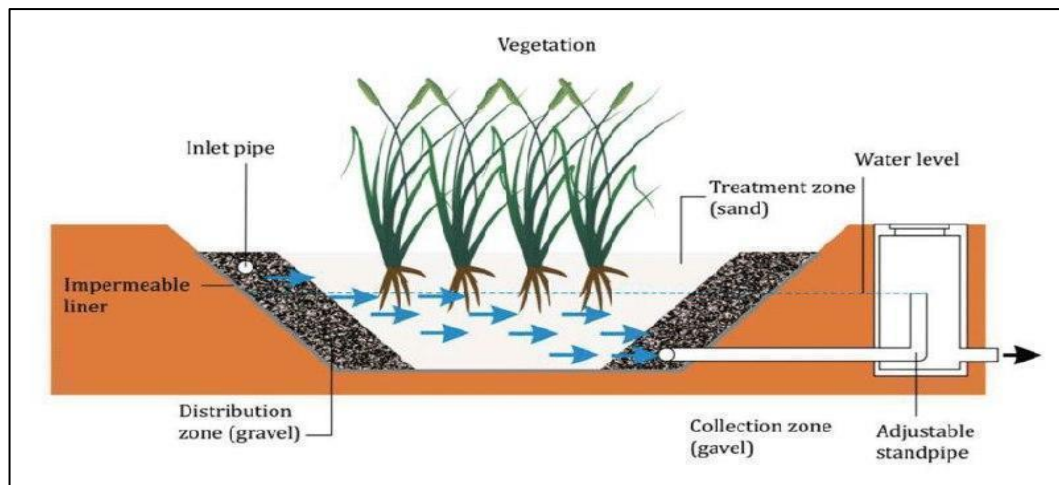


Figure 06: Horizontal flow planted filters (Suwartanti, 2024).

21. Planted macrophyte filters:

The treatment of wastewater through planted filters (or artificial marshes) using macrophytes (Fig 07) is inspired by natural processes occurring in wetland areas among plants, soil, microorganisms (primarily bacteria), and certain invertebrates (insects, worms, larvae). They operate within a more or less controlled environment since the choice of materials, plants, applied hydraulic loads, site, and water flow mode are selected based on expected performance criteria and the fate of the treated water. This process, which is increasingly widespread worldwide, can treat both urban wastewater (domestic and industrial) and stormwater. It has the advantage of being accessible in terms of

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implementation and operating costs, especially as it does not require energy input, (**Vymazal and Lenka, 2008**).

The macrophytes used in various countries vary but commonly include *Phragmites australis*, *Typha latifolia*, *Sparganium erectum*, *Iris pseudacorus*, *Carex acutiformis*, and *Phalaris arundinacea*. However, *Phragmites australis* and *Typha latifolia* are consistently favored according to Brix cited by Vymazal and Lenka (2008). In India, *Phragmites karka* and *Typha latifolia* are used for wastewater treatment, while in China, *Phragmites australis*, *Cyperus malaccensis*, and *Lepironia articulata* are commonly utilized. Central and South America use *Zizaniopsis bonariensis*, *Echinochloa polystachia*, and *Pennisetum purpureum* in planted filters. The configuration of these filters is determined based on the quality objectives for the receiving environment in all cases (**Vymazal and Lenka, 2008**).



Figure07: Planted macrophytes filters in constructed wetland (Wikiwater, 2019).

22. The role of macrophytes:

Beyond their aesthetic aspect and mechanical role (crucial on the first stage of vertical filters, macrophytes indirectly contribute to the degradation of organic matter from the raw effluent.

Root and rhizome growth helps maintain or regulate the initial hydraulic conductivity. The fine granularity of the substrate (sand or gravel) and the significant input of organic matter favor filter clogging. Root growth limits these risks by forming tubular pores along the developing roots. However, one should not rely on an improvement in the hydraulic conductivity of the original material (**Haberl and Perfler, 1990**).

Small amounts of oxygen from the aerial parts are released at the root tips of plants regardless of the type of filter they are rooted in. These contributions are always low. In vertical filters, the oxygen fraction brought in is negligible compared to the inputs by

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diffusion and convection already mentioned. In horizontal filters, however, while the contribution from plants is low, it is probably the main source of oxygen. The active surfaces must be adapted to potential oxygen inputs and are therefore larger in the case of horizontal filters (**Haberl and Perfler,1990**).

Root development increases the attachment surface for microorganism growth and precipitation reactions. To this increased active surface, there is also likely a poorly documented factor of stimulation of activity, diversity, and density of microorganisms, involved in various ways in purification processes. This is a well-known concept in agronomy and can be summarized as follows: "a planted soil is biologically richer and more active than a bare soil", sometimes referred to as the "rhizosphere effect". Root tissues and their exudates likely provide more welcoming niches for microorganisms than inert mineral substrates (**Haberl and Perfler,1990**).

Plant metabolism (nutrient assimilation) influences treatment to varying degrees depending on the surfaces involved. While nutrient assimilation is negligible for vertical flow planted filters (less than 1% of the incoming load for phosphorus), the larger surfaces in horizontal filters may lead to withdrawals that can be reasonably considered in balances, but which should however be around 5% for nitrogen and significantly less for phosphorus. All these elements are not directly exportable into harvestable biomass but are also bound in the root system whose long-term fate, i.e., over fifteen years, has not yet been extensively studied (**Haberl and Perfler,1990**). However, plant evapotranspiration can have a significant impact on water balances for large unit areas involved. Leaf cover preserves the filter surfaces from drying out in summer. It also provides shading that allows bacteria to thrive, thereby contributing to the mineralization of organic matter. Summer evapotranspiration leads to a significant decrease in outgoing volume. In winter, it mitigates the negative impact of low temperatures in cold climates (**Haberl and Perfler,1990**).

In a more general sense, the filter medium, thanks to the presence of roots, harbors a wide variety of species (bacteria, protozoa, invertebrates) whose presence closely depends on the organic load and oxygen renewal conditions. All these organisms also participate, as predators, in reducing fecal bacteria populations, but reductions also depend on residence times (**Haberl and Perfler,1990**).

23. Classification of *Cyperus papyrus*:

The classification was conducted by *Saunders et al (2007)*:

Kingdom: Plantae

Phylum :Streptophyta

Class :Equisetopsida

Subclass :Magnoliidae

Order : Poales

Family : Cyperaceae

Genus : *Cyperus*

Species : *Cyperus papyrus*

Subspecies *Cyperus papyrus* subsp *papyrus*



Figure 08: Photography of *Cyperus Papyrus* plant(Arbustes,2019)

24. The role of *Cyperus papyrus* in wastewater treatment:

Cyperus papyrus, a species of papyrus plant, has been recognized for its viability in wastewater treatment inside developed wetlands. Inquiry has appeared that *Cyperus papyrus* has the capacity to expel overwhelming metals, pharmaceuticals, and pathogenic microscopic organisms from wastewater, making it an important plant for phytoremediation forms (*Mareriet al.,2021*). Moreover, *Cyperus papyrus* has been found to be more compelling in holding strong poisons compared to other plant species (*Mareriet al., 2021*). Ponders have moreover highlighted the part of *Cyperus papyrus* within the evacuation of overwhelming metals such as copper, lead, zinc, and press from water frameworks, displaying its potential as a water quality marker and a phytoremediation specialist (*Kyambadde et al., 2004*).

Moreover, *Cyperus papyrus* has been considered in comparison with other plant species like *Miscanthidiumviolaceum* for wastewater treatment in tropical climates, illustrating its viability in supplement expulsion and by and large refinement forms (*Mareriet*

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al., 2021). The flexibility of *Cyperus papyrus* in built wetlands has been explored, appearing that the plant can flourish in unused situations and contribute to the treatment of residential wastewater (**Baryaet al., 2022**).

In conclusion, *Cyperus papyrus* plays a vital part in wastewater treatment inside developed wetlands by successfully evacuating toxins, overwhelming metals, and pathogens from water frameworks. Its capacity to hold strong pollutants and heavy metals, and its versatility to diverse situations, makes *Cyperus papyrus* a profitable plant for phytoremediation forms in wastewater treatment.

25. Classification of *Phragmites* :

this classification was conducted by **Corolla and Kupper (2019)**:

Kingdom: Plantae

Phylum: Magnoliophyta

Class: Liliopsida

Order: Cyperales

Family: Poaceae

Genus: *Phragmites*

Species: *P. australis*

Subspecies: *P. australis*



Figure 09 : Photography of *Phragmites australis* plant (Personal photography).

26. The role of *Phragmites* in wastewater treatment:

Phragmites australis, commonly known as the common reed, plays a noteworthy part in wastewater treatment inside developed wetlands. Ponders have appeared that *Phragmites australis* has the capacity to filter wastewater by amassing supplements, overwhelming metals, and micropollutants, this macrophyte is as often as possible utilized in built wetlands due to its tall supplement maintenance capacity (*Gracia et al., 2019*). Inquiry has highlighted

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the importance of *Phragmites australis* within the expulsion of nitrogen, phosphorus, boron, and chromium from mechanical wastewater (*García et al., 2019*).

The productivity of *Phragmites australis* in wastewater treatment is credited to its biomass assignment and supplement amassing capabilities (*Garcia et al.,2019*). Moreover, *Phragmites australis* has been found to upgrade the decontamination proficiency of sand channel beds in built wetlands, permitting for the improvement of biofilms that encourage move forward treatment forms (*Garcia et al.,2019*). In general, *Phragmites australis* illustrates a surprising capacity to contribute to the treatment of different sorts of wastewater by viably expelling contaminants and upgrading the by and large decontamination prepared inside built wetlands.

27. The CO- Performance of *Phragmites Australis* and *Cyperus Papyrus* in the treatment of wastewater by vertical and horizontal flow constructed wetlands:

A study by **Ahmed and Arora (2020)** found that using *Cyperus papyrus* was more effective than using *Phragmites australis* in the grey water treatment. The removal efficiency using *Phragmites australis* had no value as high as *Cyperus papyrus* or 19.51%. The ability of Total Suspended Solids (TSS) using the constructed wetland was 59.62% higher with *Cyperus papyrus* than with *Phragmites australis*. The removal process of phosphate using *Cyperus papyrus* showed efficiency as 65% while using *Phragmites australis* showed as 50%. Similar conditions were observed in the removal process of nitrogen (**Ahmedand Arora, 2020**).

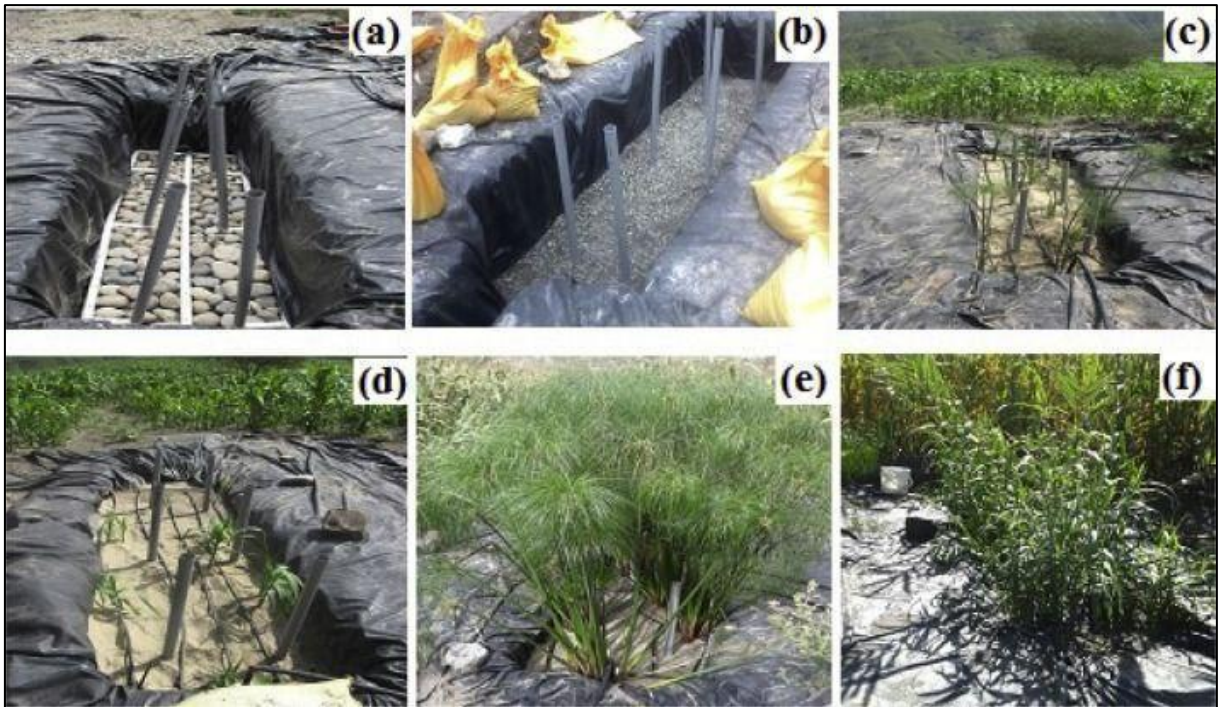


Figure 10: Cooperation of *Phragmites* and *Cyperus papyrus* in wastewater treatment
(International soil and water conservation research, 2019)

28. Conclusion:

In conclusion, macrophytes filters plants are a promising and sustainable solution for wastewater treatment, particularly in developing countries. The technology of constructed wetlands, which involves the use of macrophytes in horizontal and vertical flow systems, has been shown to be cost-effective and environmentally friendly. Macrophytes provide good conditions for filtration, phytoremediation, and provide a large surface area for adhered microbial growth, which can remove contaminants such as organic matter, nutrients, and heavy metals from wastewater.

The choice of plant species is crucial in constructing efficient wetlands, as different species have varying abilities to tolerate and remove contaminants. For example, *Typha domingensis* has been shown to have a high pollutant removal efficiency from wastewater, while *Cyperusprolifer* has been found to be the most suitable indigenous wetland plant for electricity production and COD, ammonia, and phosphate removal among three species.

The mechanisms for removing contaminants in constructed wetlands include biological nitrification-denitrification and uptake from plants, as well as physical effects brought about by the presence of the plants, such as filtration and prevention of resuspension of sediment. These mechanisms work together to provide a comprehensive and sustainable solution for wastewater treatment.

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In summary, the use of macrophytes filters plants in constructed wetlands is a promising and sustainable solution for wastewater treatment, providing a cost-effective and environmentally friendly alternative to traditional wastewater treatment methods. The choice of plant species and the mechanisms for removing contaminants are crucial factors in constructing efficient wetlands, and further research is needed to optimize these factors for different wastewater treatment scenarios.

Chapter 2
Material and Methods

Material and methods

II. Materials and methods:

1. Presentation of the studied region:

1.1. Geographical location:

Skikda province is located in the Northeastern part of the country (Fig. 01). it covers an area of 4,118 km² and is bordered:

1. To the north, by the Mediterranean Sea.
2. To the east, by Annaba province.
3. To the south, by Constantine, Mila, and Guelma provinces.
4. To the west, by Jijel province.



Figure 01: Situation card shows the geographical location of Skikda-Algeria (Ghennaï,2022).

1.2. The raw water:

We have obtained a sample of domestic wastewater from the Stora region (Fig. 02).



Figure 02: The discharge of domestic wastewater from the Stora region (Personal photography).

Material and methods

1.3. Climate:

The province belongs to the humid and subhumid bioclimatic domains, with a mild and temperate climate along the coast and a colder climate inland. The humid zone covers the mountainous western area as well as the eastern and southern peaks. The subhumid domain prevails over 4/5 of the province's territory with precipitation ranging from 1000 to 1500 mm/year. Under maritime influence, temperatures are mild in winter (11°C in January) and warm in summer (24°C in August) along the coast, where temperature variations are low. Inland, winters are less mild (9°C) and summers are hotter (27°C), with more pronounced temperature variations (ANIREF, 2020).

1.4. Hydraulic resources:

The province's dense hydraulic network is due to the moisture of the climate, the slopes, and the presence of low-permeability terrain, which promotes runoff at the expense of infiltration. The hydraulic potential of the province consists of three (03) types of water resources: surface water, groundwater, and springs (ANIREF, 2020).

1.5. Groundwater resources:

Groundwater resources (wells and boreholes) with a volume estimated at 87,115 hm³ are located in the alluvial aquifers of the province's rivers, namely El Kébir, SafSaf, Guebli, Bibi côtier, Fil-Fila, and the coastal river of Bougaroun (ANIREF, 2020).

1.6. Surface water resources:

The significant rainfall and mountainous relief of the province contribute to its hydrology. However, despite having several watersheds, the dense hydrological network sees a significant amount of water lost to the sea each year due to a lack of mobilization means. Infrastructure such as the Zerdazas, Bekkouche Lakhdar, Oum Toub, and Béni Zid dams with a total capacity of 290,667 hm³, along with two desalination stations, allowed for the exploitation of 93,177 hm³ of water in 2020. However, the capacity of hill reservoirs (13 in total) is only approximately 01.41 hm³, resulting in significant losses for the province, whose water needs are increasing (ANIREF, 2020).

To address the water resource storage, several initiatives have been undertaken to make it more available; including:

- A seawater desalination plant with a capacity of 100,000 m³/day providing potable water to various areas such as Skikda, Fil fila, Hammadi Krouma, El Hadaiek, Béni Béchir, Ramdane Djamel, Salah Bouchaour, El Harrouch, MedjezEdchiche, and the Skikda petrochemical zone (ANIREF, 2020).

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➤ The transfer and rehabilitation of the La Marsa monobloc seawater desalination station with a capacity of 5000 m³/day, aimed at enhancing and improving the provision of potable water for a total estimated population of over 216,500 inhabitants (ANIREF, 2020).

1.7.Processing Station:

This experiment was conducted at the University 20 Août 1955 - Skikda, the department of Agronomic Sciences has two glass greenhouses (Fig.03). These greenhouses are equipped with specific equipment that creates a microclimate inside these educational greenhouses.



Figure 03: Pedagogic greenhouse (Personal photography).

1.8.The materials used:

In this experiment, we used the following materials:

1.8.1. The pillar:

1. Pebbles are collected and sieved to obtain pebbles of varying diameters.
2. The pebbles are divided into three groups according to their diameter.
3. They are washed thoroughly to remove clay, salts, organic materials, waste, grease, and adhering metals. After that, they are spread out to dry, and finally stored in boxes.

Thus, they are ready for use in an easy-to-handle manner. The figure 04 below shows the properties of the packaging materials.

Material and methods



Figure 04: Pebbles arranged by size (Personal photography).

1.8.2. The basins:

In order to conduct this experiment, we used basins with a cylindrical shape made of plastic with a diameter of 30 cm and a capacity of 5 liters (Fig. 05).



Figure 05: Plastic basins with a capacity of 5 liters (Personal photography).

1.8.3. The PVC tube:

The plastic tube, 25 cm in length, has several holes and is placed vertically in the filter basin to ensure ventilation and facilitate the measurement of physical and chemical standards.

The tube is secured by installing several layers of stacked pebbles of varying diameters (from largest to smallest) (Fig. 06).



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Figure 06: Perforated ventilation PVC tube (Personal photography).

1.8.4. The faucet:

A plastic faucet is placed at the bottom of the basin to drain the water (Fig. 07).



Figure 07: Plastic faucet of 10mm diameter (Personal photography).

1.9.Plants selection:

Choosing the plants we want to cultivate involves five important criteria:

1. Adaptation to local climatic conditions and growth cycle length.
2. Growth rate.
3. Ease of obtaining.
4. Transporting.
5. The plant's efficiency.

Our experiment primarily depends on *Cyperus papyrus* that is a plant of the sedge family and it's a type of aquatic perennial herb commonly known as "paper Reed".

Also from the family Poaceae, there is a plant species belonging to the genus *Phragmites*, which is the second type, a reed plant. These are particularly characterized by very active root systems capable of withstanding harsh conditions.

We obtained these plants (Fig. 08) from the University 20 Août 1955 - Skikda gardens and from the National Observatory of the Environment and Sustainable Development (ONEDD).

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Figure 08: *Phragmites australis* and *Cyperus papyrus* (Personal photography).
a/ *Phragmites australis*, b/ *Cyperus papyrus*.

1.10. Work method inside the station:

1.10.1. Plants preparation:

Papyrus and *Phragmites* plants were brought at an intermediate stage of growth and placed in a water basin, cleaned, with water changed periodically to ensure plant adaptation and root growth enhancement, ensuring smooth workflow. The first stage for plants before commencing work.

1.10.2. Basins preparation stage:

For this task, we used five identical cylindrical basins with a diameter of 40 cm. In each basin (Fig. 09), a plastic faucet was placed, located 5 cm above the basin's bottom. Additionally, we installed a PVC tube in each basin for ventilation and easy sampling.

Material and methods



Figure 09: Plastic basins (Personal photography).


1.10.3. Filling the containers and planting:

We fill the basins with gravel from bottom to top according to their diameter, placing the largest diameter gravel at the very bottom, followed by medium and then smaller diameter gravel. Meanwhile, as gravel is being added, the plants are also placed (Tab. 01).

The plants were placed in the basins in two ways: the first method involved placing the plants sequentially in four basins, while the second method involved placing the plants in parallel in one basin.

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Table 01:Planting and grafting.

Image	Layers
	First: Large pebbles under the faucet
	Second:Coarsegravel
	Third: Medium gravels + plant
	Fourth: Fine gravels to cover plant roots

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1.11. Watering and sampling:

The basins are supplied with treated domestic wastewater after initial physical treatment.


On the first day, we water each of B1, A1, and A+B, and the sampling from these basins proceeds as follows (Tab. 02) :

1. The first sample is taken after two days.
2. The second sample is taken after seven days.

On the day of taking the second sample, the water in basins B1 and A1 is transferred to basins A2 and B2 respectively in the order (A2 B1) (B2 A1), then the sampling process is repeated only with basins A2 and B2.

Table02: Time and date of irrigation and sampling.

Basins	Irrigation date	Irrigation time	First sampling date	Second sampling date
A1	13/02/2024	11:00:00 AM	15/02/2024	20/02/2024
B1	13/02/2024	11:00:00 AM	15/02/2024	20/02/2024
A+B	13/02/2024	11:00:00 AM	15/02/2024	20/02/2024
A2	20/02/2024	11:00:00 AM	22/02/2024	26/02/2024
B2	20/02/2024	11:00:00 AM	22/02/2024	26/02/2024



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2. Protocol of analysis:

2.1. Activities of the laboratory:

The regional laboratory of the ONEDD center located in Skikda center, ensures the analysis of various physico-chemical parameters. The laboratory controls the physicochemical parameters of seawater, rivers, basins, sources, and industrial discharges, aiming to protect the environment within the framework of sustainable development (Law, 2003). It defines the limit values of industrial liquid effluent discharges (Executive Decree No. 06-141 of April 19, 2006), and sets out the modalities for the application of the additional tax on industrial wastewater (Executive Decree No. 07-300 of September 21, 2007). The analysis of physico-chemical parameters of wastewater was conducted systematically. After preparing the tanks and filling them with wastewater, samples were taken. Both raw water samples and those collected at the outlet of planted filters after each residence period were subjected to thorough analysis in the laboratory. The measured parameters included pH, electrical conductivity, temperature, nitrates, nitrites, orthophosphates, COD, and BOD₅.

2.2. PO₄ Determination:

2.2.1. Analyzed Element:

Determination of phosphorus in environmental and industrial waters.

2.2.2. Scope:

This International Standard is applicable to all types of water, including industrial waters. The scope ranges from 0.005 mg/L to 0.8 mg/L.

2.2.3. Safety Precautions:

Safety goggles and gloves must be worn before handling sulfuric acid, and work should be conducted under a fume hood.

2.2.4. Equipment, Materials, Chemicals, and Reagents:

2.2.4.1. Equipment:

1. Aqua mate Spectrometer
2. SaniClave Autoclave

2.2.4.2. Materials:

1. 50 ml flasks
2. Pipettes : 25 ml, 2.5 ml, 10 ml, 5 ml, 50 ml
3. Borosilicate glass bottles (250 ml)
4. Cuvette: 10 mm or 1 cm

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2.2.4.3. Preparation of standard solutions (total phosphorus/orthophosphate):

Mother solution of Phosphorus 0g/l:

Weigh 4.399 g of (KH_2PO_4), dissolve in a small amount of water until completely dissolved, then make up to one liter to the mark.

Standard solutions of 100 mg/l, 10 mg/l, 5 mg/l:

Standard solutions for the calibration curve are prepared from 5 mg/l: 0.25mg/l, 0.5mg/l, 0.75mg/l, 1 mg/l.

These standard solutions are used in the determination of orthophosphate and total phosphorus.

2.2.5. Sample pretreatment:

Sampling should be done in transparent polyethylene or glass bottles. Analysis should be done within four hours of sampling and filtered before orthophosphate analysis. Total phosphorus sample analysis's not filtered. If the sample is not analyzed on the same day, acidify with sulfuric acid and store in the refrigerator.

2.2.6. Blank solution:

Take a quantity of distilled water and treat it in the same way as the sample:

1. Orthophosphate: 40 ml of distilled water, add 1 ml of ascorbic acid, 2 ml of molybdate solution, let it stand for 25 minutes, analyze at 880nm.
2. Total phosphorus: take 40 ml of distilled water, add 4 ml of $\text{K}_2\text{S}_2\text{O}_8$, heat between 115°C and 120°C for 30 minutes in an autoclave, cool, transfer to a 50 ml flask, neutralize to neutral pH, add 1 ml of ascorbic acid, then 1ml of molybdate solution, let it stand for 30 minutes, measure at 880 nm.

2.2.7. Calibration solution:

Establish the calibration curve from these standards; these concentrations are the same for both orthophosphate and total phosphorus. The standards are analyzed in the same way as the blank.

2.2.8. Orthophosphate determination:

At $\text{pH} < 1$, orthophosphate ions react with molybdate ions to form a complex that can be reduced by ascorbic acid, forming a compound called phosphomolybdate blue (Fig. 10).

1. Sample filtered into a 50 ml flask
2. 1 ml of ascorbic acid
3. 10 g \pm 0.5 g in 100 ml \pm 5 ml H_2O

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4. 1 ml of acid molybdate solution
5. $13 \text{ g} \pm 0.5 \text{ g}$ $(\text{NH}_4)_6 \text{ Mo}_7 \text{ O}_{14} \cdot 4\text{H}_2\text{O}$
6. Make up to $100 \text{ ml} \pm 5 \text{ ml}$ H_2O
7. $0.35 \pm 0.05 \text{ g}$ $\text{K} (\text{SbO}) \text{C}_4\text{H}_4\text{O}_6 \cdot 1/2$
8. Make up to $100 \text{ ml} \pm 5 \text{ ml}$ H_2O
9. Add $300 \text{ ml} + 5 \text{ ml}$ H_2SO_4 (9 mol/L)
10. Make up to $500 \text{ ml} \pm 5 \text{ ml}$ H_2O
11. Add $500 \text{ ml} \pm 5 \text{ ml}$ H_2SO_4 p1.84
12. Let it rest for 25 minutes:
13. Pass through a spectrophotometer at a wavelength of 880 nm.

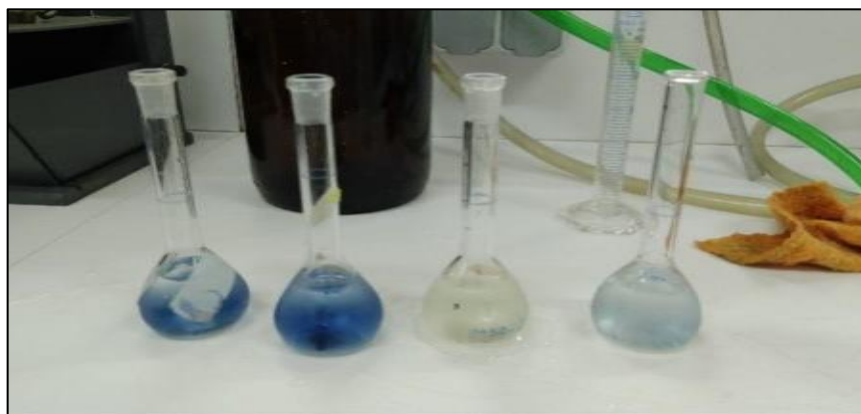


Figure 10: Stages of orthophosphate determination (Personal Photography).

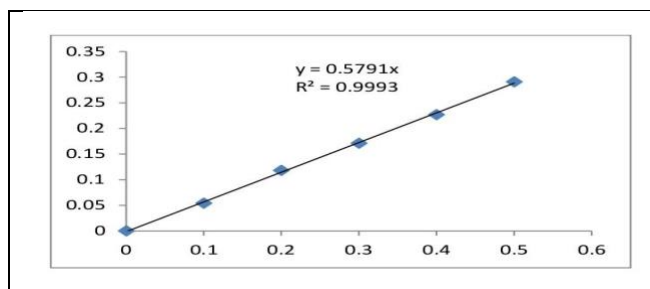
Table02 : Calibration curve and determination of phosphate.

Daughter Solution 1 (mL)	0	2	4	6	8	10
Distilled water	40	38	36	34	32	30
Ascorbic acid	1	1	1	1	1	1
Mixed reaction	2	2	2	2	2	2
Wait for 10 minutes						
PO_4^{3-} (mg/l)	0	0.306	0.612	0.918	1.224	1.530

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Table03: Phosphate calibration curve.

The concentration(mg/L)	A, B, and C (880 nm)
0	0
0.054	0.1
0.118	0.2
0.171	0.3
0.227	0.4
0.291	0.5



2.3. Nitrite determination:

2.3.1. Method of work:

2.3.1.1. Reagents and equipment:

mixed reagent:

1. Dissolve 40 grams of amino-4-benzene sulfonamide ($\text{NH}_2\text{C}_6\text{H}_4\text{SO}_2\text{NH}_2$) in a mixture of phosphoric acid and 500 mL of water.
2. Add 2 grams of N-(naphthyl-1) diamino-1,2 ethane hydrochloride ($\text{C}_{10}\text{H}_7\text{NH}-\text{CH}_2-\text{CH}_2-\text{NH}_2$) and dilute to 1000 mL with distilled water.

Standard nitrite solution at 100 mg/L:

Dissolve 0.5 grams of sodium nitrite (dried at 105°C for at least 2 hours) in 1000 mL of distilled water.

Standard nitrite solution at 1 mg/L:

Using a pipette, take 1 mL of the standard nitrite solution at 100 mg/L, transfer it to a 100 mL flask, and dilute to volume with distilled water. Prepare this solution on the day of use.

2.3.2. Calibration:

In a series of 50 mL volumetric flasks, add the appropriate volumes of the standard nitrite solutions as indicated in the table below. Add distilled water to each flask, then add 1 mL of the mixed reagent and wait for at least 20 minutes. The appearance of pink color indicates the presence of NO_2^- . Finally, measure the absorbance of each standard at a wavelength of 540 nanometers.

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Figure 11: Stages of nitrite determination (Personal Photography).

2.3.3. Preparation procedure:

Take 50 ml of the sample, add 1 ml of the mixed reagent, and wait for less than 20 minutes. The pink color indicates the presence of NO_2 . Finally, measure the absorbance of each standard at a wavelength of 540 nanometers. Results are displayed directly using a UV-V spectrophotometer in mg/L.

Table04: Calibration table (nitrite determination).

Daughter Solution 1 mg/l	0	1	2	5	20	40
Distilled Water (ml)	50	49	48	45	30	10
Mixed solution (ml)	1	1	1	1	1	1
Wait for 20 minutes						
NO_2 -(mg/l)	0	0.02	0.04	0.1	0.4	0.8

2.4. Ammonium determination:

2.4.1. Method of work:

Reagents and equipment:

Color reagent:

1. Dissolve 130 grams of sodium salicylate and 130 grams of trisodium citrate dihydrate in water in a 1000 ml flask.
2. Add 0.97 grams of sodium nitroprusside and dilute to 1000 ml with distilled water.

Sodium dichloroisocyanurate solution:

1. Dissolve 32 grams of sodium hydroxide in 500 mL of water and let it cool to room temperature.

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2. Add 2 grams of moist sodium dichloroisocyanurate and dilute to 1000 ml with distilled water.

Standard ammonium solution at 100 mg/L:

1. Dissolve 0.297 grams of ammonium chloride (dried at 105°C for at least 2 hours) in 1000 ml of distilled water.

Standard ammonium solution at 1 mg/L:

1. Using a pipette, take 1 mL of the standard ammonium solution at 100 mg/L, transfer it to a 100 ml flask, and dilute to volume with distilled water.

2.4.2. Calibration:

In a series of 50 ml volumetric flasks, add the appropriate volumes of the standard ammonium solutions. Add distilled water to each flask. Take 40 ml of each solution, then add 4 mL of the color reagent and 4 mL of sodium dichloroisocyanurate solution. Wait until the color develops. After 60 minutes, measure the absorbance at a wavelength of 655 nanometers using a UV spectrophotometer.

2.4.3. Preparation procedure:

Take 40 ml of the sample for analysis. Add 4 ml of the color reagent and 4 mL of sodium dichloroisocyanurate solution in sequence. Wait until the color develops. After at least 60 minutes, take measurements at a wavelength of 655 nanometers using a UV spectrophotometer.

Table 05: Calibration table (ammonium determination).

Daughter Solution 1 (ml)	0	1	2	3	4	5	25	50
Distilled Water (ml)	50	49	48	47	46	45	25	0
Color Indicator (ml)	4	4	4	4	4	4	4	4
Potassium Ferricyanide Indicator (ml)	4	4	4	4	4	4	4	4
Wait for 60 minutes								
NH ₄ ⁺ (mg/L)	0	0.02	0.04	0.06	0.08	0.1	0.5	1

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2.5. Chemical Oxygen Demand (COD) determination:

The Chemical Oxygen Demand is a measure of the amount of oxygen required for the chemical breakdown of all organic substances present in water, whether they are biodegradable or non-biodegradable. It is measured using spectrophotometric analysis with the following equation:

$$\text{COD} = 336 * \lambda_{254} - 0.95 * R, \text{ where } R = 48.8$$



Figure 12: Chemical Oxygen Demand (COD) Determination (Personal Photography).

2.6. Determination of Biochemical Oxygen Demand (BOD₅):

2.6.1. Analysis parameter:

Biochemical Oxygen Demand is the concentration of dissolved oxygen consumed under defined conditions by the biological oxidation of organic and/or inorganic matter present in water.

2.6.2. Safety precautions:

Laboratory safety measures should be implemented for environmental safety and the safety of laboratory personnel.

2.6.3. Apparatus, equipment, chemicals, and reagents:

2.6.3.1. Apparatus:

1. Adjustable incubator at $20^{\circ}\text{C} \pm 1^{\circ}\text{C}$, type FOC 225 E Refrigerated incubator VELP Scientifica.
2. Oxygen meter of Type WTW-inolab-Oxi 730.
3. Equipment for aeration (air compressor).
4. Refrigerator from 0°C to 4°C .

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5. Magnetic stirrer, type: Magnetic stirrer VELP Scientifica.
6. Analytical balance - Brand: Sartorius - Model: BP221S - Max: 220g-d=0.1mg.

NOTE: Follow the manufacturer's instructions for adjusting instrumental parameters.

2.6.4. Equipment:

1. Volumetric flasks: Capacity 100ml.
2. Graduated pipettes: Capacity 2ml, 5ml, 10ml.
3. Special DBOS flasks: 250ml.
4. Magnetic stir bars.

2.6.5. Reagents and standards:

All commercial reagents used are of ACS quality. Water used for reagent preparation is distilled or demineralized water. Unless otherwise indicated, prepared solutions can be stored indefinitely at room temperature. However, they must be remade if a color change is observed or if a precipitate forms.

1. Sulfuric acid, H_2SO_4 (CAS no 7664-93-9)
2. Ammonium chloride, NH_4Cl (CAS no 12125-02-9)
3. Anhydrous calcium chloride, CaCl_2 (CAS no 10043-52-4)
4. Ferric chloride, $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ (CAS no 10025-77-1)
5. Sodium hydroxide, NaOH (CAS no 1310-73-2)
6. Monobasic potassium phosphate, KH_2PO_4 (CAS no 7778-77-0)
7. Dibasic potassium phosphate, K_2HPO_4 (CAS no 7758-11-4)
8. Dibasic sodium phosphate, $\text{Na}_2\text{HPO}_4 \cdot 7\text{H}_2\text{O}$ (CAS no 7782-85-6)
9. Magnesium sulfate, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ (CAS no 10034-99-8)
10. Sodium sulfite, Na_2SO_3 (CAS no 7757-83-7)
11. 2-chloro-6-(trichloromethyl) pyridine (TCMP) (CAS no 1929-82-4)

NOTE: The use of TCMP mixed with commercially purchased inert substances is preferred.

1. Magnesium sulfate solution: Accurately weigh about 22.5 g of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ and dissolve in about 800 ml of water. Make up to 1,000 ml with water.
2. Calcium chloride solution: Accurately weigh about 27.5 g of anhydrous CaCl_2 and dissolve in about 800 ml of water. Make up to 1,000 ml with water.
3. Ferric chloride solution: Accurately weigh about 0.25 g of $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ and dissolve in about 800 ml of water. Make up to 1,000 ml with water.

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4. Phosphate buffer solution: Accurately weigh about 8.5 g of KH_2PO_4 , 21.75 g of K_2HPO_4 , 33.4 g of $\text{Na}_2\text{HPO}_4 \cdot 7 \text{H}_2\text{O}$, and 1.7 g of NH_4Cl , then dissolve in about 800 ml of water. Make up to 1,000 ml with water. The pH of this buffer should be around 7.2.
5. Sodium sulfite solution: Accurately weigh about 1.575 g of Na_2SO_3 and dissolve in about 800 ml of water. Make up to 1,000 ml with water. This solution is stable for 24 hours.
6. Dilution water: Incubate a pitcher containing distilled water at 20°C overnight. Then add the equivalent of 1 ml/liter of water from each of the following solutions: phosphate buffer solution, magnesium sulfate solution, calcium chloride solution, and ferric chloride solution. Oxygenate this water by bubbling air at high flow rate with an aerator for one hour for a volume of 10 liters or two hours for a volume of 20 liters. This solution must be prepared for each use.

2.6.6. Evaluation and measurement:

2.6.6.1. Measurement procedure:

Preparation of dilution water:

For each liter of dilution water, add respectively 1 ml of the buffer solution, 1 ml of hexahydrated ferric chloride solution, and 1 ml of heptahydrate magnesium sulfate solution. Then, enrich or saturate this solution with oxygen by bubbling air using the air compressor for 10 minutes.

Measurement:

1. Allow the sample to reach room temperature.
2. Adjust its pH between 6 and 8 (if not, neutralize it with HCl or NaOH).
3. Take 10 ml of the sample using graduated pipettes and transfer them into a 100 ml flask, then adjust (dilution of 1/10).
4. Take respectively 7, 15, and 30 ml from the flask of diluted sample and transfer them into the special BOD flasks.
5. Prepare two sets of BOD samples for blanks.
6. Transfer 350 ml of dilution water into a one-liter graduated cylinder, agitate for 20 seconds. Then fill the flasks for blanks and the other flasks containing different dilutions of the sample (7, 15, and 30 ml) respectively. Measure the

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dissolved oxygen in these flasks under agitation. The value indicated by the oxygen meter is BOD.

7. Place the flasks in the incubator at 20°C for 5 days, then measure the BOD₅ for the second time. This value is the BOD₂.

NOTE: The dilution factor varies depending on the nature of the sample (see the standard). Before the BOD analysis, excess water must be removed from the flask lids.

Calculation:

The biochemical oxygen demand, expressed in milligrams of oxygen per liter, is given by the following equation:

$$\text{BOD}_5 = [(\text{BOD}_1 - \text{BOD}_2) \times F \times V_t/V_e] \text{ (mg/l)}$$

Where:

1. BOD₁: Initial concentration of dissolved O₂ (mg/L)
2. BOD₂: Concentration of dissolved O₂ after 5 days (mg/L)
3. V_t: Total volume of the sample
4. V_e: Volume extracted from the sample
5. F: Dilution factor

Measurement conditions:

1. Choose the most significant dilution factor possible.
2. Calibrate the oxygen meter before analysis.

Quality control:

1. Use freshly distilled water.
2. Run the analysis for two blanks.
3. After incubation and analysis, the difference between the results of the blanks should not exceed one (1).
4. Run the analysis for one of the three sample dilutions in duplicate and compare the results.

Detection limit:

1. The detection limit ranges between 3 mg/l and 6,000 mg/l.
2. **Reference:** ISO: 5815 - 1989 (F).
3. Recording and Revision of Standard Operating Procedure.

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Figure 13: BOD incubator VWR (Personal Photography).

2.7. pH Measurement:

2.7.1. Procedure:

1. Calibrate the device.
2. Turn on the pH meter.
3. Rinse the electrode with distilled water.
4. Place a small beaker containing pH 7 solution.
5. Set the meter to the lowest speed.
6. Insert the electrode into the calibration solution.
7. Allow it to stabilize briefly until the device prompts to insert the second calibration solution.
8. Remove the electrode, rinse it thoroughly with distilled water, then insert it into another beaker containing pH 4 or pH 10 solution, depending on the nature of the medium to be measured.
9. Remove the device's electrode and rinse it with distilled water.

2.7.2. pH Measurement method:

1. Take 100 mL of the sample and place it in a beaker.
2. Place a magnetic stirrer inside the beaker with gentle movement.
3. Insert the device's electrode into the beaker.
4. Allow it to stabilize, then read the result directly on the device.

2.8. Electrical conductivity measurement:

2.8.1. Procedure:

1. Insert the electrode into a beaker containing the sample.
2. Rinse the electrode with distilled water.
3. Read the electrical conductivity value directly from the device once it stabilizes.

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2.9. Temperature measurement:

In temperature measurement, we used a multi-parameter analyzer.

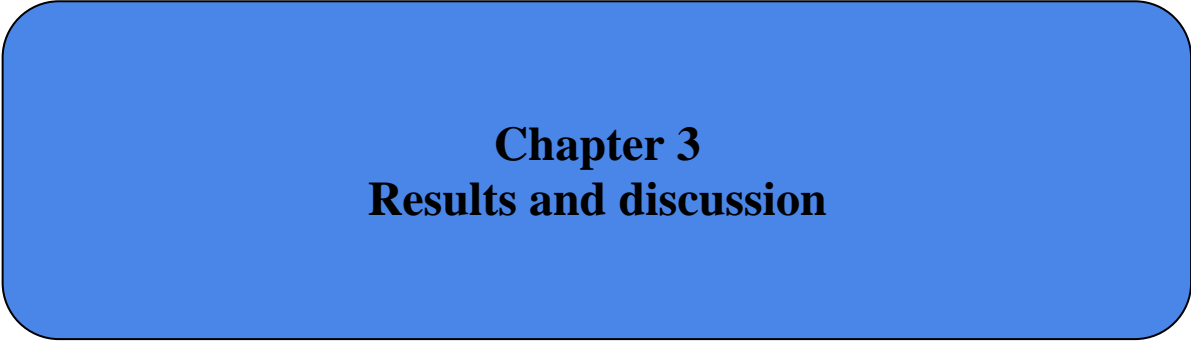
1. Turn on the device.
2. Immerse the device's probe into the sample.
3. Read the temperature directly once it stabilizes on the device.



Figure 14: Ph/OPR, CE meter (multi parameters) ,(Personal Photography).

Conclusion:

In this chapter, we attempted to present the materials and procedures used during this study. Additionally, we aimed to provide a comprehensive overview of the stages conducted, including filling, cultivation, sampling, and taking physical and chemical measurements of wastewater entering and exiting the planted filters.



Chapter 3
Results and discussion

Results and discussion

III. Results and discussion:

1. Wastewater treated with *Phragmites*, *Papyrus*, and their combination:

1.1. Temperature variation :

Based on the graph (Fig.01) the results were quite similar compared with the study of **Okurut (2000)** who found that the aquatic plants cannot decrease the temperature totally due to many factors like microbial activity.

The increase in temperature in wastewater treated with planted filters using *Phragmites* and *Papyrus* is a result of the combined effects of solar radiation absorption, microbial activity, plant metabolism, evapotranspiration, and thermal conductivity within the system. These factors work together to raise the temperature of the wastewater as it passes through the treatment system.

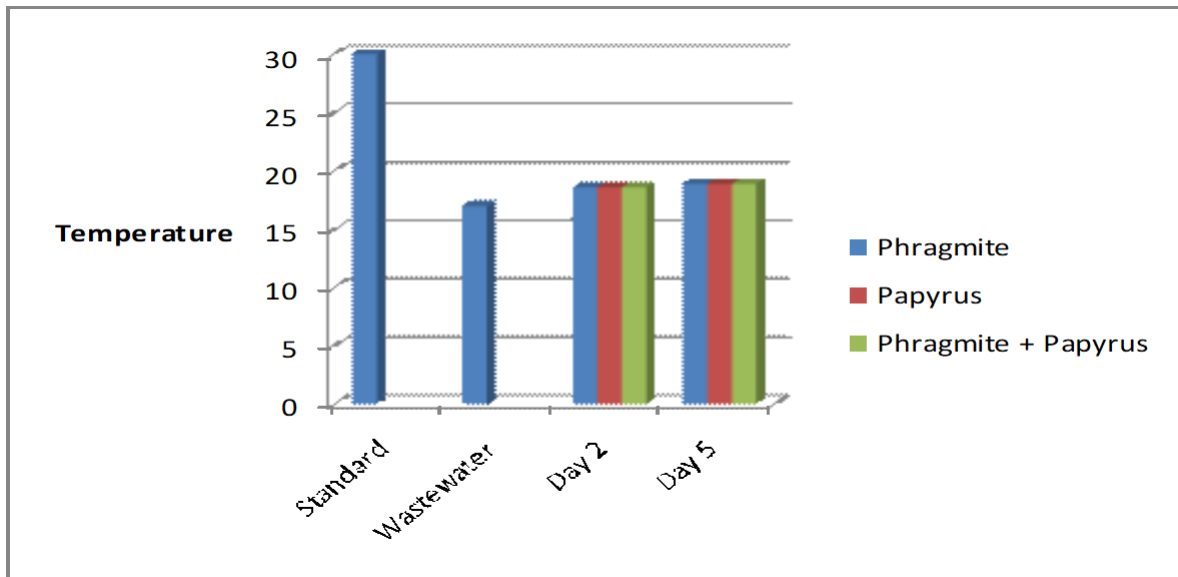


Figure 01 : Graph representing temperature variation.

1.2. COD variation (Chemical Oxygen Demand):

1.2.1. COD quantity in wastewater lower than standard:

The initial COD quantity in the untreated wastewater was mentioned to be a bit less than the standard or expected levels. This could indicate that the organic matter content in the wastewater was relatively lower than typical or expected values.

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1.2.1.1. COD reduction using *Papyrus* and *Phragmites*:

When the wastewater was treated using only *Papyrus* or *Phragmites*, the COD decreased after 7 days (Fig.02). This suggests that the individual plant species were able to remove or degrade the organic matter in the wastewater, thereby reducing the COD.

1.2.1.2. Better COD reduction using the combination of *Papyrus* and *Phragmites*:

When the combination of *Papyrus* and *Phragmites* was used to filtrate the wastewater, the COD reduction was even better compared to using the plants individually. The synergistic effects of the two plant species and their associated microbial communities likely enhanced the overall efficiency of organic matter removal, leading to a more significant decrease in COD.

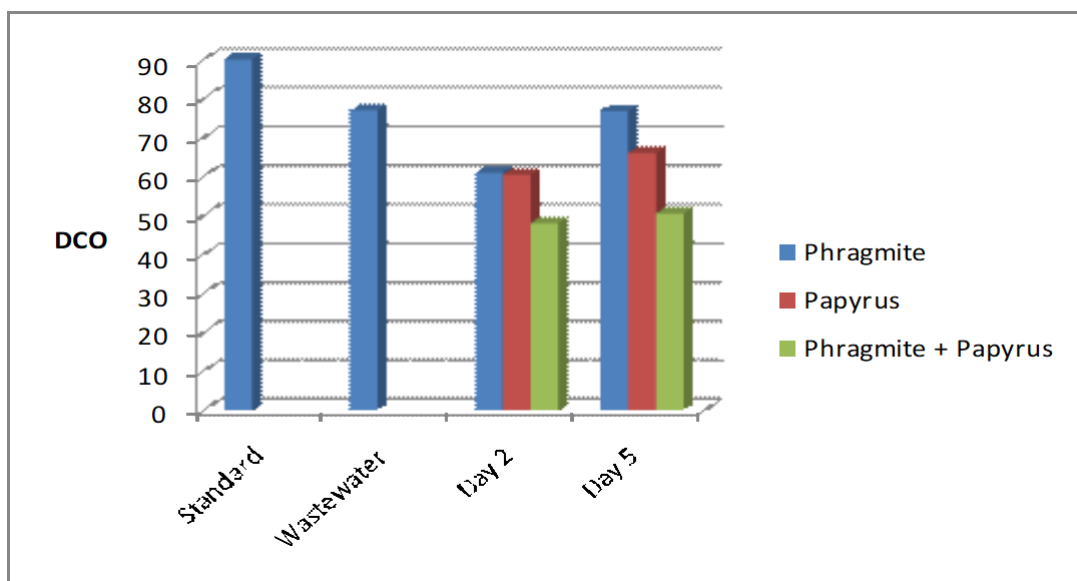
1.2.1.3. Factors contributing to the COD reduction:

The aquatic plants, *Papyrus* and *Phragmites*, can remove organic matter through various mechanisms, such as:

1. Uptake and incorporation of organic compounds into plant biomass.
2. Facilitating the growth of microorganisms that can degrade the organic matter.
3. Providing an environment for adsorption and sedimentation of organic particles.

Regarding the results, the findings on *Phragmites* were close to the results of the research of **Vymazal(2011)** because *Phragmites* work better in high temperatures (more than 28°C).

In summary, the initial wastewater had a COD that was a bit lower than the standard, but the treatment using *Papyrus* and *Phragmites*, either individually or in combination, was able to further reduce the COD levels. The combination of *Papyrus* and *Phragmites* demonstrated better COD reduction compared to using the plants separately, suggesting a more efficient and effective organic matter removal process.



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Figure 02: Graph representing COD variation.

1.2.2. Variation in the PO₄ (phosphate):

Based on the study of **Vymazal(2011)**, the results are in contradiction because he used coconut fibers; coconut fibers are likely to be more effective at absorbing phosphate (PO₄³⁻) from water than pebbles due to their higher surface area, porous structure, and the presence of functional groups that can attract and bind phosphate ions. This makes them a potentially better option for applications such as water filtration or treatment processes aimed at reducing phosphate levels. The explanation of the PO₄ (phosphate) removal dynamics in the wastewater treatment system using *Papyrus* and *Phragmites*:

1.2.2.1. Stable PO₄ at 0.4 mg using *Papyrus* and *Phragmites*:

Papyrus and *Phragmites*, when used together, were able to maintain a stable PO₄ concentration of 0.4 mg in the treated wastewater (Fig. 03).

The combination of these two aquatic plant species likely provided a balanced and efficient system for phosphate removal through various mechanisms like uptake by plants, adsorption, and microbial transformation.

1.2.2.2. Rapid PO₄ removal using the combination of *Phragmites* and *Papyrus*:

When the combination of *Phragmites* and *Papyrus* was used in the filtration process, the PO₄ concentration reached the maximum removal within 2 days (Fig. 03).

The synergistic effects of the two plant species and their associated microbial communities enhanced the overall efficiency of phosphate removal, leading to this rapid decrease in PO₄ levels.

1.2.2.3. Decreased PO₄ removal after 7 days using *Papyrus* alone:

When only *Papyrus* was used in the filtration process, the PO₄ removal efficiency decreased after 7 days (Fig. 03). This could be due to factors such as the saturation of the plant's uptake capacity, changes in the microbial community, or the release of phosphate back into the water during plant senescence or decomposition.

1.2.2.4. Treated wastewater with higher PO₄ than non-treated wastewater:

In some cases, the PO₄ concentration in the treated wastewater was found higher than the non-treated wastewater. This could happen if the plants and microorganisms in the treatment system release or absorb phosphate back into the water, or if the overall removal process is not efficient enough to reduce the PO₄ concentration below the initial level.

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In summary, the combination of *Papyrus* and *Phragmites* demonstrated a stable and efficient PO₄ removal in the wastewater treatment system, reaching the maximum removal within 2 days. However, when using only *Papyrus*, the PO₄ removal decreased after 7 days, and the treated wastewater had a higher PO₄ concentration compared to the non-treated wastewater.

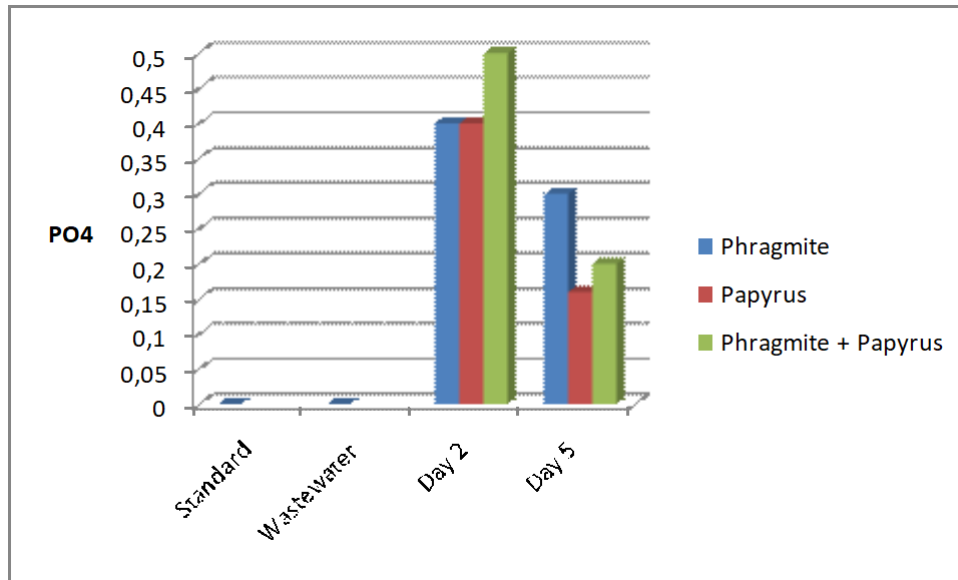


Figure 03 : Graph representing PO₄ variation.

1.2.3. Conductivity variation :

The decrease in conductivity during the treatment of wastewater with planted filters using *Phragmites* and *Papyrus* and their combination can be attributed to several biological and chemical processes. Conductivity in water is a measure of its ability to conduct electric current which is directly related to the concentration of dissolved ions.

1.2.3.1. Initial high conductivity :

Wastewater typically contains a high concentration of dissolved ions such as sodium (Na⁺), potassium (K⁺), calcium (Ca²⁺), magnesium (Mg²⁺), chloride (Cl⁻), sulfate (SO₄²⁻), and nitrate (NO₃⁻). These ions come from various sources, including domestic sewage, industrial effluents, and agricultural runoff.

1.2.3.2. Decreasing conductivity over 7 days :

Ion uptake by plants :

Both *Phragmites* and *Papyrus* plants absorb various nutrients and ions from the wastewater through their root systems. This uptake reduces the concentration of dissolved ions in the water which in turn decreases conductivity.

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Microbial action:

Microbial communities associated with the roots of these plants play a significant role in breaking down organic matter and converting dissolved nutrients into biomass. Processes such as nitrification and denitrification reduce the levels of nitrogen compounds (e.g., NH_4^+ , NO_2^- , NO_3^-) thus lowering the total ionic content.

Precipitation and sedimentation:

Certain ions can form insoluble compounds and precipitate out of the solution. For example, calcium and magnesium can form carbonate or phosphate precipitates. These precipitates settle out of the water column, effectively removing these ions from the dissolved phase and thereby reducing conductivity.

Filtration effect:

The root systems of *Phragmites* and *Papyrus*, along with the soil or substrate they are planted in, act as a natural filter. This filtration process can physically trap and remove particulates and associated ions from the water, further contributing to the reduction in conductivity.

Based on the graph (Fig 04), we found that the results are similar to those of **Rodier *et al.* (2008)**; The combined effect of these processes leads to a significant decrease in the concentration of dissolved ions, resulting in a reduction of conductivity from 15 to 7 over the 7-day treatment period. This demonstrates the effectiveness of using *Phragmites*, *Papyrus*, and their combination in improving the quality of wastewater by reducing its ionic content.

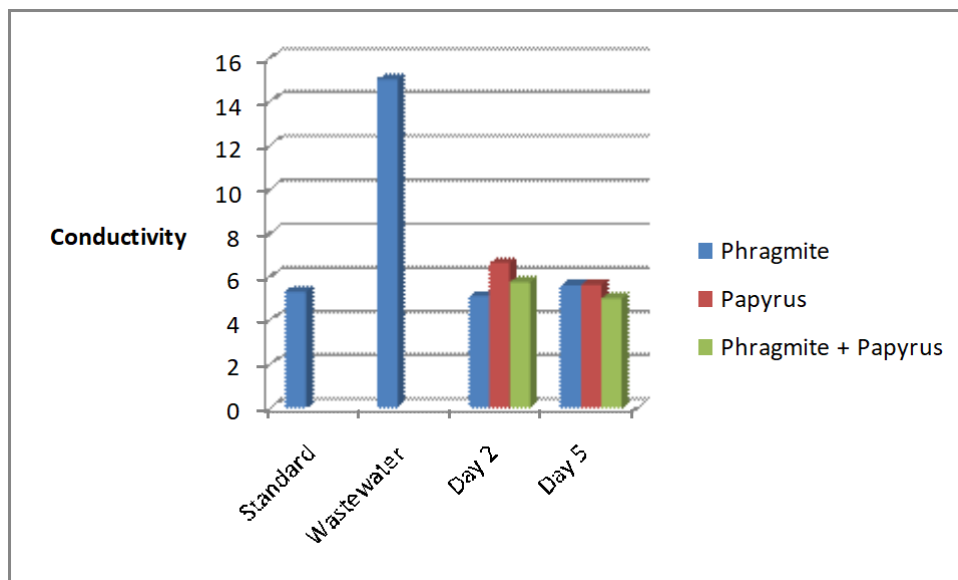


Figure 04 : Graph representing conductivity variation.

1.2.4. Variation in Biological Oxygen Demand (BOD):

Results and discussion

Using *Papyrus*, *Phragmites*, and their combination can be intriguing and complex.

1.2.4.1. Initial decrease in BOD (First 2 Days):

***Papyrus*:** There is a slight decrease in BOD. *Papyrus* plants are known to uptake nutrients and some organic matter from the wastewater. However, their efficiency in reducing BOD in the initial days might not be very high due to their specific uptake rates and microbial activity associated with them.

***Phragmites*:** There is a significant reduction in BOD. *Phragmites* are highly efficient in reducing BOD due to their robust root systems which promote microbial activity that breaks down organic matter more effectively.

Combination of *Phragmites* and *Papyrus*: The combination leads to a near disappearance of BOD. This synergistic effect likely comes from the enhanced microbial diversity and increased surface area for microbial colonization provided by both plants, leading to more efficient degradation of organic matter.

1.2.4.2. Increase in BOD by *Papyrus*:

After the initial reduction, there's an observed increase in BOD when using *Papyrus* alone. This can be attributed to release of organic compounds; *Papyrus* might release organic exudates into the water as part of its metabolic processes, which can temporarily increase the BOD. Also, the initial microbial community might not be fully established or might be releasing intermediate compounds that increase BOD. Any dying plant material can also contribute to an increase in organic content, thus raising BOD levels.

1.2.4.3. Subsequent decrease in BOD (Days 5-7):

***Phragmites* and combination treatment:** Both treatments show a reduction in BOD, nearing the original levels. The microbial communities associated with *Phragmites* and the combination of both plants become more stable and effective over time, and the results confirm the study of **Effendi(2018)** about the effective role of *Phragmites* in wastewater filtration.

***Papyrus* Alone:** Based on the graph (Fig. 05) the results were comparable with the research of **Smith (2018)**; While there's a decrease, it's not as significant as with *Phragmites*. This indicates that *Papyrus* alone might not support as rapid or thorough a microbial degradation process compared to *Phragmites* or their combination.

1.2.4.4. Final BOD levels (after 7 days):

***Papyrus*:** The BOD level is higher than the untreated wastewater due to the factors mentioned above (e.g., organic exudates, slower microbial establishment).

Results and discussion

***Phragmites* and combination:** The BOD levels are nearly the same as the untreated wastewater, indicating that these setups have achieved a balance where the microbial degradation processes are effectively maintaining the BOD at a stable level.

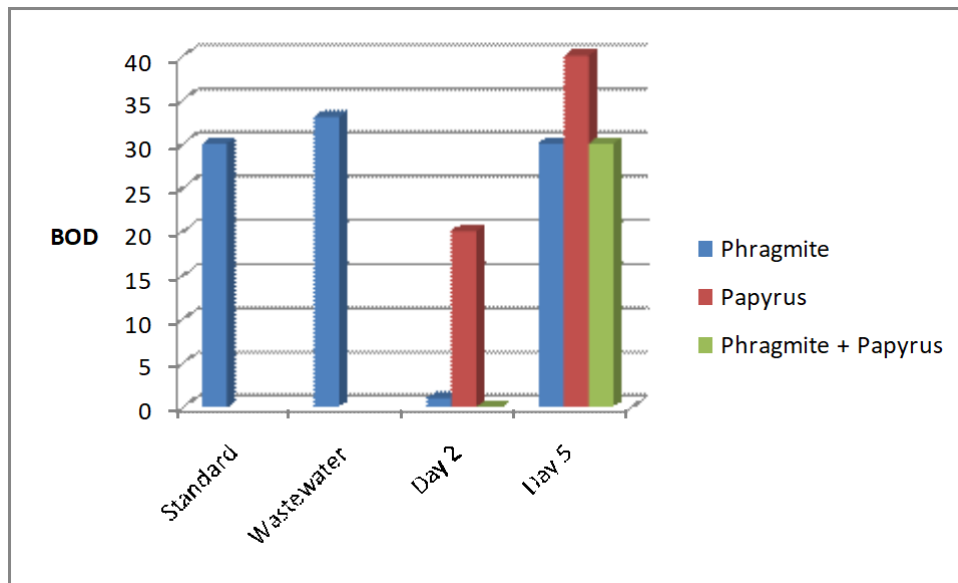


Figure 05 : Graph representing BOD variation.

1.2.5. NH_4^+ variation (ammonium) :

Using a combination of *Papyrus* and *Phragmites* was effective and it gave better results which were comparable with the study of **Wiesman (2007)**, who proved that both *Phragmite* and *Papyrus* plants can initially absorb NH_4^+ directly through their roots, leading to a slight decrease in ammonium levels. The root systems can also provide surfaces for microbial communities that start to process NH_4^+ . The variation in NH_4^+ can be understood by examining the biological and chemical processes involved in the treatment.

First 2 Days: *Phragmites*, *Papyrus*, and their combination led to a slight decrease in NH_4^+ through initial uptake and beginning nitrification. Next 5 Days; Significant reduction in NH_4^+ due to enhanced nitrification, increased microbial activity, and plant uptake. Elevated NH_4^+ in untreated wastewater is due to sources like organic matter and industrial/agricultural inputs, which exceed international standards without any treatment (Fig. 06).

This sequence of events explains the gradual and then substantial decrease in NH_4^+ levels in the treated wastewater, highlighting the effectiveness of using *Phragmites*, *Papyrus*, and their combination in reducing ammonium concentrations.

Results and discussion

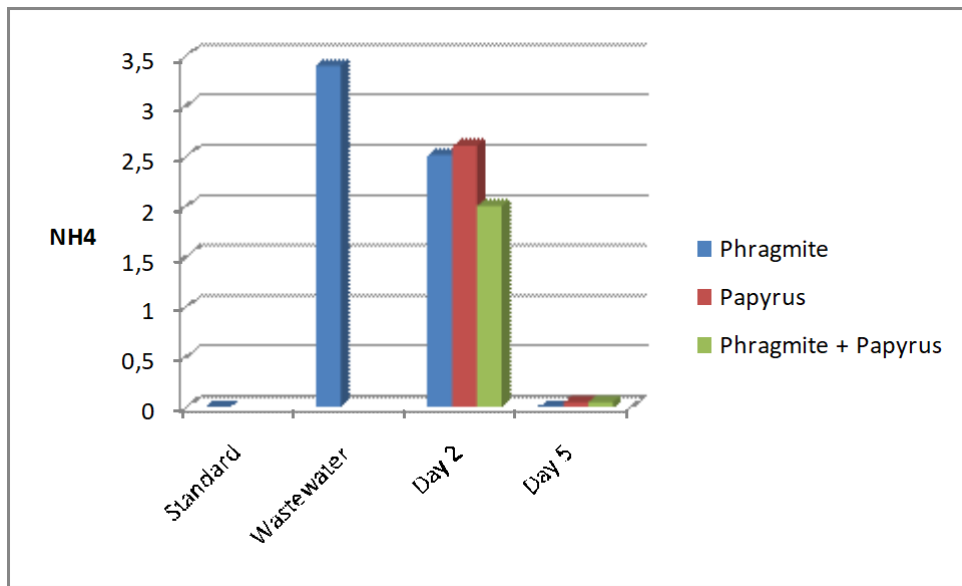


Figure 06 : Graph representing NH₄ variation.

1.2.6. NO₂⁻ variation (nitrite):

Based on the study of Liu *et al.*, (2008), the results were quite similar, the only difference is the number of days of the experimentation, so the effectiveness of *Phragmites* increases with the number of days. The initial increase in NO₂⁻ with *Phragmites* Only (First 2 Days).

1.2.6.1. Nitrification process:

Phragmites (common reed) can enhance the activity of nitrifying bacteria, which convert ammonia (NH₃) to nitrite (NO₂⁻) and then to nitrate (NO₃⁻). In the initial phase, there might be a rapid conversion of ammonia to nitrite, leading to a temporary increase in NO₂⁻ levels.

1.2.6.2. Inadequated denitrification :

Denitrification, which converts nitrite and nitrate to nitrogen gas (N₂), may not be fully active early on, resulting in the accumulation of nitrite.

Decreasing NO₂⁻ with papyrus and combination treatments (after 2 days)

Role of papyrus:

Cyperus papyrus can support both nitrification and denitrification processes. The root systems of *Papyrus* create anoxic (low oxygen) zones that are conducive to denitrifying bacteria, which convert nitrites to nitrogen gas, thereby reducing NO₂⁻ levels.

Enhanced biological activity:

The combination of *Papyrus* and *Phragmites* likely provides a more balanced environment, supporting both nitrifying and denitrifying bacteria. This synergy can lead to a more efficient overall nitrogen removal process, reducing NO₂⁻ levels more effectively.

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Overall changes in NO_2^- levels (7 days):

Initially, there is an increase in NO_2^- due to active nitrification and a lag in denitrification. Over time, as denitrifying bacteria populations increase and conditions stabilize, NO_2^- levels begin to decrease.

By the end of 7 days, the combined treatment with *Papyrus* and *Phragmites* creates a stable environment where both nitrification and denitrification are balanced, leading to a decrease in NO_2^- levels. NO_2^- Levels relative to International Standards

The NO_2^- levels in the untreated wastewater were already below international standards, indicating that the raw wastewater had relatively low nitrite content. After Treatment; despite the initial increase with *Phragmites* alone, the final levels after 7 days of combined treatment are expected to be lower than at the start, due to effective denitrification.

First 2 days; *Phragmites* alone increases NO_2^- due to rapid nitrification. After 2 days: *Papyrus* and the combination treatment promote denitrification, reducing NO_2^- .

7 Days later; A balanced microbial environment with *Papyrus* and *Phragmites* leads to decreased NO_2^- levels. This sequence of events explains the fluctuations and eventual decrease in NO_2^- levels in the treated wastewater.

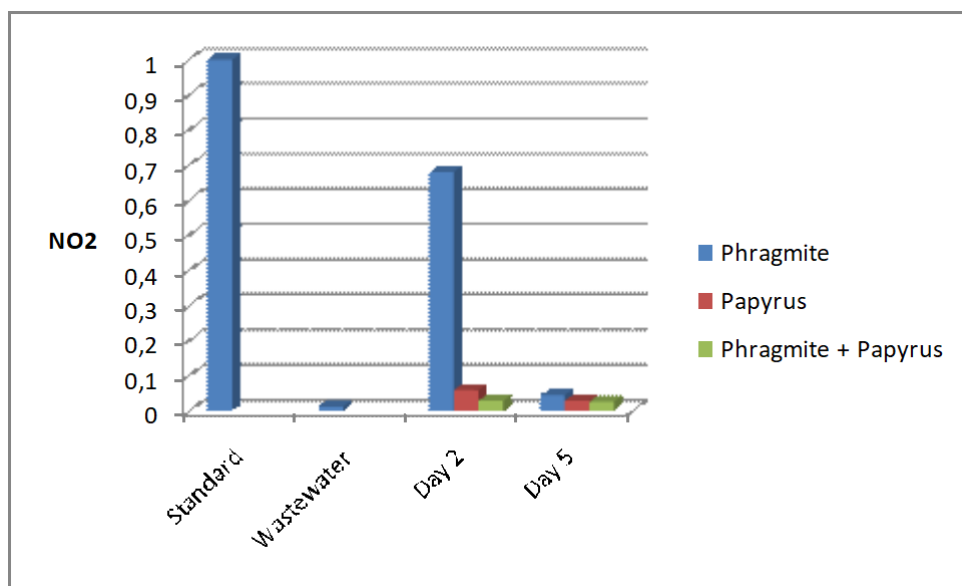


Figure 07: Graph representing NO_2 variation.

1.2.7. pH variation:

Based on the graph (Fig. 07) the results were approachable with the study of **Degrément (2005)**, it proved that there are several factors that control the variation in pH such as plant characteristics; *Cyperus papyrus* and *Phragmites australis* are both emergent macrophytes commonly used in constructed wetlands for wastewater treatment. These plants have different physiological characteristics that can affect pH variation. For example, *Papyrus* has a higher

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transpiration rate, which can lead to a higher pH in the rhizosphere due to increased oxygen availability.

The composition of the wastewater being treated can also influence pH variation. Different contaminants and organic matter in the wastewater can undergo various chemical reactions, affecting pH levels. Additionally, the presence of certain ions, such as ammonium (NH_4^+) or carbonate, can also influence pH levels in the treatment system. The design and operation of the treatment system can also impact pH variation. Factors such as hydraulic retention time, flow rate, and aeration can affect the pH dynamics within the system.

The presence of oxygen in the rhizosphere can promote aerobic conditions and higher pH levels, while anoxic conditions can lead to lower pH levels. pH can also be influenced by the buffering capacity of the substrate used in the planted filters. Different substrates can have varying abilities to maintain pH stability. Within a 14-day period can vary depending on several factors. While the specific pH changes within this timeframe may not be explicitly mentioned in the search results, we can provide some general information about pH in wastewater treatment and the potential effects of planted filters.

1.2.7.1. pH in Wastewater treatment:

The pH of wastewater can vary depending on its source and composition. It may range from acidic to alkaline. Wastewater often contains substances that can act as buffers, helping to maintain the pH within a certain range. In wastewater treatment processes, pH adjustment may be necessary to optimize the efficiency of various treatment steps. This can be achieved by adding chemicals to raise or lower the pH.

1.2.7.2. Effects of planted filters (*Phragmites* and *Papyrus*):

Planted filters, such as *Phragmites* and *Papyrus*, can uptake nutrients and contaminants from the wastewater. This uptake process may influence the pH of the surrounding water. Planted filters provide a habitat for various microorganisms, including bacteria and fungi. These microorganisms can contribute to the breakdown of organic matter and nutrient cycling, potentially affecting pH levels. Plants in the filters release oxygen through their roots, which can promote aerobic conditions and influence pH levels. The pH of untreated wastewater may already be alkaline due to the presence of certain industrial or domestic substances. During the treatment process with *Papyrus* and *Phragmites*, biological activity and chemical processes occur that can slightly alter the pH (Fig. 08). These plants can absorb nutrients and contaminants, leading to minor changes in the water chemistry. The slight increase in pH

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observed at the end of the treatment is likely due to the removal of acidic substances and the release of basic compounds from the plant matter, which maintains or slightly raises the alkaline pH.

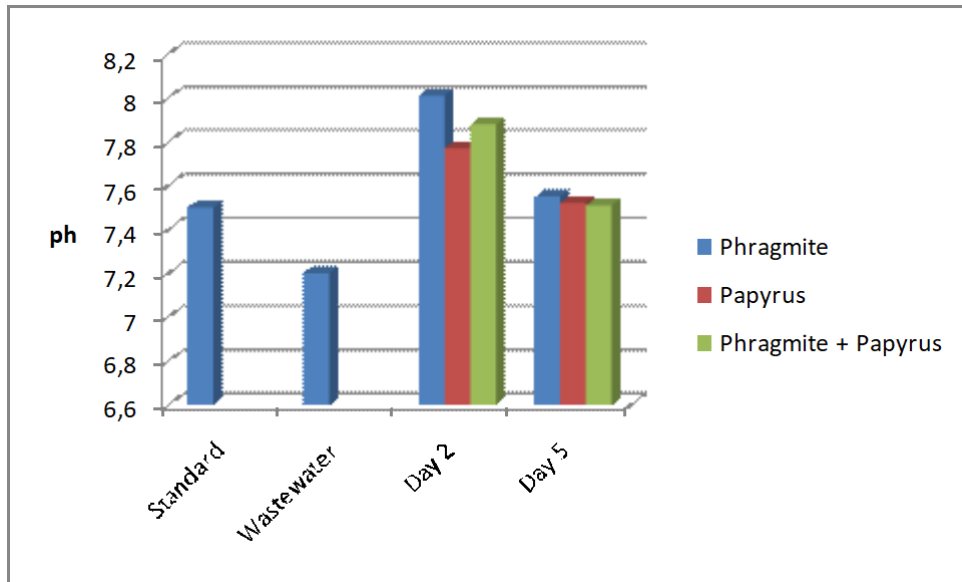


Figure 08 : Graph representing pH variation.

2. Wastewater treated with *Papyrus* and filtered by *Phragmite*:

2.1. Temperature variation:

Based on the graph (Fig. 09) the results were quite similar compared with the study of Okurut (2000) who found that the aquatic plants cannot decrease the temperature totally due to many factors like microbial activity.

2.1.1. Non-Treated wastewater temperature:

Below Standard; this could be due to the initial conditions of the wastewater, which might be cooler due to environmental factors or the nature of the inflow sources.

2.1.2. Temperature after *Papyrus* filtration:

Slight Decrease; *Papyrus* plants can provide shading and evapotranspiration effects, slightly cooling the water as it passes through the filtration system.

2.1.3. Temperature after *Phragmites* Filtration:

Further Decrease; when the *papyrus*-filtered wastewater is further filtered by *Phragmites*, the combined effects of increased shading, higher evapotranspiration, and potentially more extensive root systems can cause an additional slight cooling.

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2.1.4. Return to normal temperature:

Stabilization; As the treated water exits the filtration systems and equilibrates with the ambient environment, it returns to the standard temperature. This stabilization can be due to the cessation of active cooling effects and the water reaching thermal equilibrium with its surroundings.

In summary, the initial cooling effects from *Papyrus* and *Phragmites* are temporary and localized, with the temperature normalizing once the water re-equilibrates with the environmental conditions.

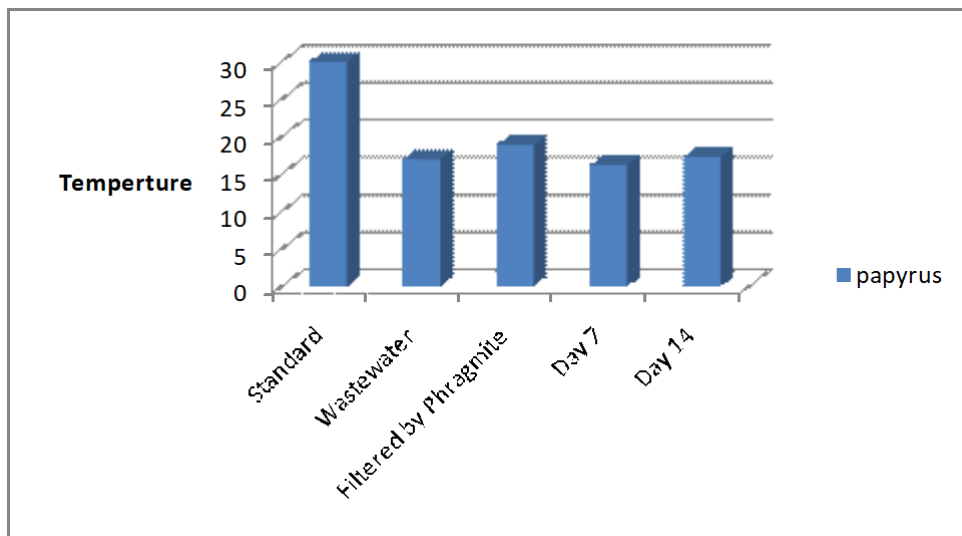


Figure 09 : Graph representing temperature variation of wastewater treated with *Papyrus* and filtered by *Phragmite*.

2.2. BOD variation (Biological Oxygen Demand):

2.2.1. Non-treated wastewater BOD:

Slightly Above Standard; the initial BOD of the untreated wastewater is higher than the standard due to the presence of organic pollutants and contaminants typical in raw wastewater.

2.2.2. BOD after *Papyrus* filtration:

Returns to Standard; *Papyrus* plants help reduce BOD by absorbing nutrients and promoting microbial activity that breaks down organic matter, bringing the BOD back to standard levels.

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2.2.3. BOD after *Phragmites* filtration:

Based on the graph (Fig.10) the results were comparable to the study of Okurut (2000) comparing the performance of *Cyperus Papyrus* and *Typha* for the removal of heavy metals, roxithromycin and pathogenic bacteria from wastewater, this study compared the efficiency of *Cyperus Papyrus* and *Typha* in removing BOD among other pollutants from wastewater. The results showed that *Papyrus* had a greater capacity in removing BOD with efficiency of 80.69%.

Reaches lowest level; when the papyrus-filtered wastewater is further treated by *Phragmites*, the BOD reaches its lowest level. This significant reduction can be attributed to enhanced microbial activity; *Phragmites* have a robust root system that supports diverse and effective microbial communities, which further degrade any remaining organic matter. The combined treatment with both *Papyrus* and *Phragmites* creates a more effective filtration system, maximizing the reduction of BOD.

In summary, the BOD initially decreases to standard levels after *Papyrus* filtration and then reaches its lowest level after further filtration by *Phragmites* due to enhanced microbial activity and the synergistic effects of the combined plant treatment.

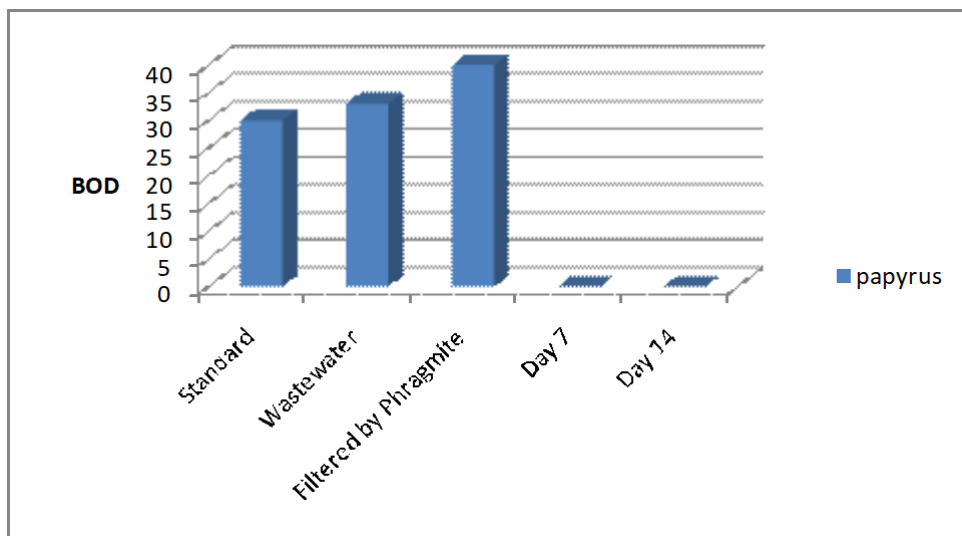


Figure 10 : Graph representing BOD variation of wastewater treated with *Papyrus* and filtered by *Phragmite*.

2.3.COD variation (Chemical Oxygen Demand):

2.3.1. Non-Treated wastewater COD:

Slightly Below Standard; the initial COD of the untreated wastewater is slightly less than the standard, possibly due to a lower concentration of oxidizable organic and inorganic materials in the raw wastewater compared to typical standards.

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2.3.2. COD after *Papyrus* and *Phragmites* filtration:

When the wastewater is filtered first by *Papyrus* and then by *Phragmites*, the COD initially stabilizes. These plants help to remove some organic and inorganic materials, bringing the COD closer to a stable level.

2.3.3. COD After 7 days of treatment:

Regarding the results (Fig.11), the findings on *Phragmites* were approachable to the results of the research of **Boutin et al., (2003)**; the COD of untreated wastewater is slightly below standard, stabilizes after initial filtration by *Papyrus* and *Phragmites*, but increases above the initial level after 7 days due to the release of organic compounds, microbial metabolism, and accumulation of soluble organics.

Increases above initial level; after 7 days, the COD increases to levels higher than in the non-treated wastewater. This increase can be attributed to release of organic compounds, both *Papyrus* and *Phragmites* may release organic exudates and decaying plant matter into the water, contributing to higher COD.

Microbial activity can produce intermediate compounds that are still oxidizable, thus increasing COD. Over time, the breakdown of complex organic matter into simpler, soluble organics that are more easily measured by COD tests can result in higher COD readings.

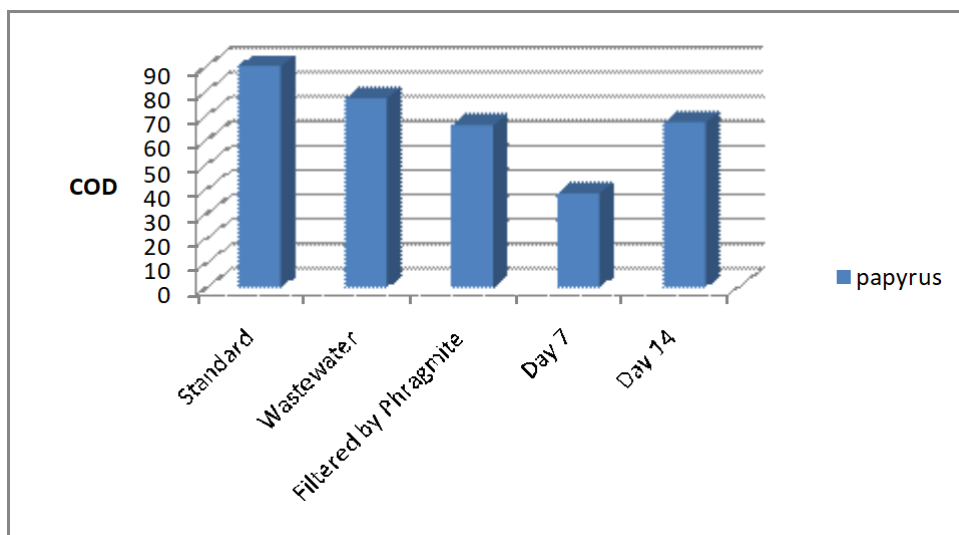


Figure 11 : Graph representing COD variation of wastewater treated with *Papyrus* and filtered by *Phragmite*.

2.4.Variation in phosphate (PO_4):

Based on the study of **Vymazal (2011)** the results are in contradiction because he used coconut fibers; coconut fibers are likely to be more effective at absorbing phosphate (PO_4^{3-})

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from water than pebbles due to their higher surface area, porous structure, and the presence of functional groups that can attract and bind phosphate ions. This makes them a potentially better option for applications such as water filtration or treatment processes aimed at reducing phosphate levels.

2.4.1. Non-treated wastewater PO₄:

Nearly 0 (Same as Standard); The initial PO₄ concentration in the untreated wastewater is very low, similar to the standard, possibly due to low levels of phosphorus in the raw wastewater.

2.4.2. PO₄ after *Papyrus* and *Phragmites* filtration:

Slight Increase; when the wastewater is filtered first by *Papyrus* and then by *Phragmites*, there is a slight increase in PO₄. This could be due to the release of phosphate from the plants or the breakdown of organic matter containing phosphorus (Fig.12).

2.4.3. PO₄ after 2 days of treatment:

High Increase; after 2 days, the PO₄ levels increase significantly. This spike can be attributed to release from plant material; both *Papyrus* and *Phragmites* may release more phosphate as they begin to break down or through metabolic processes. Microbial decomposition of organic matter can release phosphate into the water.

2.4.4. PO₄ after 7 days of treatment:

Returns to Level after *Papyrus Filtration*; the PO₄ levels decrease back to the levels observed after the initial *Papyrus* filtration. This reduction can be attributed to stabilization; the system may reach a new equilibrium where the rate of phosphate release and uptake by plants and microbes balances out. Also, *Phragmites* may reabsorb some of the released phosphate as they continue to grow and stabilize.

In summary, the PO₄ in untreated wastewater is nearly 0, increases slightly after *Papyrus* and *Phragmites* filtration, peaks after 2 days due to release from plants and microbial activity, and then decreases back to earlier levels as the system stabilizes and plants reabsorb phosphate.

Results and discussion

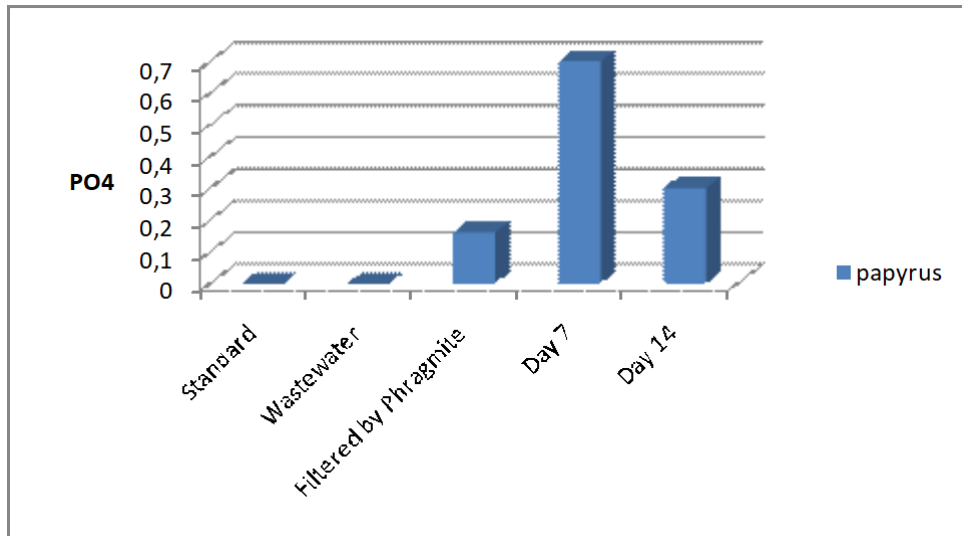


Figure 12 : Graph representing PO₄ variation of wastewater treated with *Papyrus* and filtered by *Phragmite*.

2.5.Variation in ammonium (NH₄):

2.5.1. Non-Treated wastewater NH₄:

Higher Than Standard; the initial NH₄ concentration in untreated wastewater is higher than the standard due to the presence of organic waste and nitrogenous compounds typical in raw wastewater.

2.5.2. NH₄ after *Papyrus* and *Phragmites* filtration:

Nearly Disappears; when the wastewater is first filtered by *Papyrus* and then by *Phragmites*, the NH₄ levels significantly decrease. This reduction can be attributed to plant uptake; both *Papyrus* and *Phragmites* absorb ammonium for their growth. Microorganisms in the root zones of these plants convert NH₄ into other nitrogen forms through nitrification.

2.5.3. NH₄ at the end of treatment:

Using a combination of *Papyrus* and *Phragmites* was effective and it gave better results (Fig.13) which were comparable with the study of **Wiesman(2007)** who proved that both *Phragmite* and *Papyrus* plants can initially absorb NH₄⁺ directly through their roots, leading to a slight decrease in ammonium levels. The root systems can also provide surfaces for microbial communities that start to process NH₄⁺.

By the end of the treatment, NH₄ levels increase slightly. This could be due to decomposition of organic matter might release small amounts of NH₄ back into the water and some microbial activity might convert other nitrogen forms back to NH₄ under certain conditions.

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In summary, the NH_4 in untreated wastewater is higher than the standard, nearly disappears after filtration by *Papyrus* and *Phragmites* due to plant uptake and microbial activity, and then increases slightly at the end of the treatment due to release from decomposing organic matter and microbial processes.

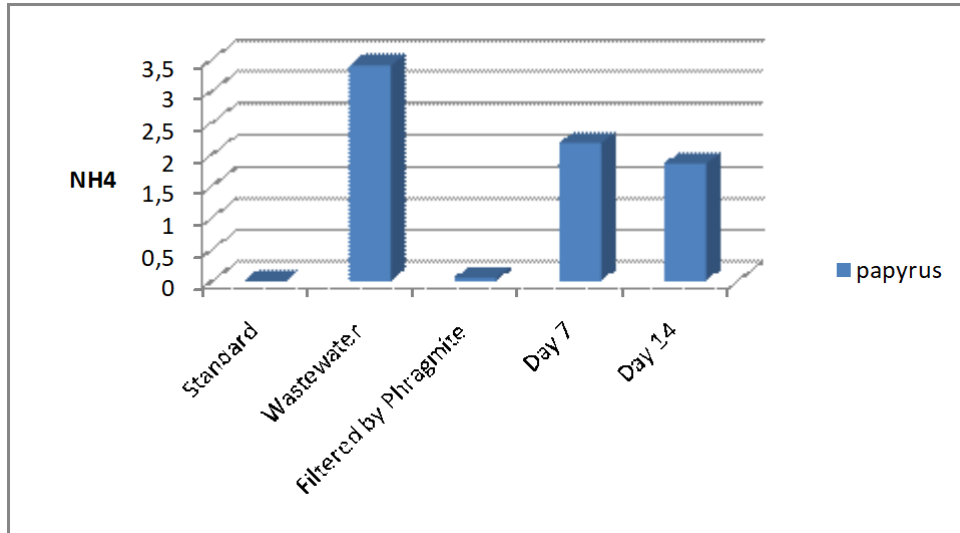


Figure 13 : Graph representing NH_4 variation of wastewater treated with *Papyrus* and filtered by *Phragmite*.

2.6. Variation in nitrite (NO_2^-):

2.6.1. Non-treated wastewater NO_2^- :

Lower Than Standard; the initial NO_2^- concentration in untreated wastewater is lower than the standard. This could be due to the rapid conversion of nitrite to nitrate (NO_3^-) in the presence of oxygen or due to less nitrite being present initially.

2.6.2. NO_2^- after *Papyrus* and *Phragmites* filtration:

Nearly Disappears; when the wastewater is filtered first by *Papyrus* and then by *Phragmites*, the NO_2^- levels significantly decrease. This reduction can be attributed to microorganisms in the root zones of these plants convert NO_2^- to NO_3^- through nitrification or to nitrogen gas (N_2) through denitrification. Plants may also absorb nitrite, albeit less commonly compared to ammonium and nitrate.

2.6.3. NO_2^- at the end of treatment:

By the end of the treatment, NO_2^- levels increase slightly (Fig.14). This could be due to intermediate step in Nitrogen cycle; during the complex nitrogen cycle, some microbial processes might temporarily produce NO_2^- as an intermediate product. Fluctuations in oxygen levels or microbial population dynamics can lead to transient increases in NO_2^- .

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Based on the study of **Liu *et al.* (2008)**, the results were comparable, so the NO_2^- in non-treated wastewater is lower than the standard, nearly disappears after filtration by *Papyrus* and *Phragmites* due to effective microbial conversion, and then slightly increases at the end of the treatment likely due to transient microbial processes and intermediate steps in the nitrogen cycle.

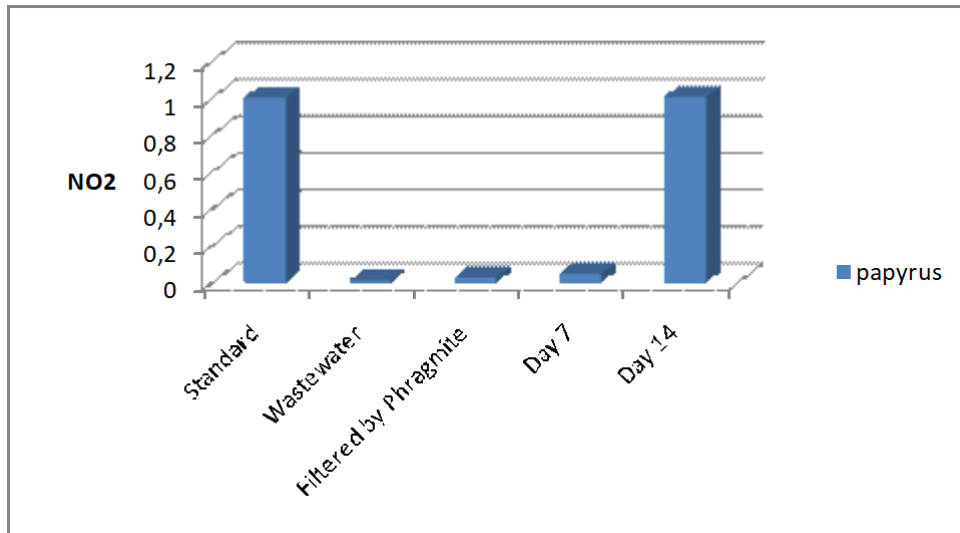


Figure 14 : Graph representing NO_2 variation of wastewater treated with *Papyrus* and filtered by *Phragmite*.

2.7.Variation in pH:

Based on the graph (Fig. 15) the results were approachable with the study of **Degrément (2005)**, it proved that there are several factors that control the variation in pH such as *Cyperus papyrus* and *Phragmites australis* are both emergent macrophytes commonly used in constructed wetlands for wastewater treatment. These plants have different physiological characteristics that can affect pH variation. The composition of the wastewater being treated can also influence pH variation. Different contaminants and organic matter in the wastewater can undergo various chemical reactions, affecting pH levels. Additionally, the presence of certain ions, such as ammonium (NH_4^+) or carbonate, can also influence pH levels in the treatment system. The design and operation of the treatment system can also impact pH variation. Factors such as hydraulic retention time, flow rate, and aeration can affect the pH dynamics within the system. The presence of oxygen in the rhizosphere can promote aerobic conditions and higher pH levels, while anoxic conditions can lead to lower pH levels .

The pH of untreated wastewater is slightly less than the standard but still alkaline, it indicates that the water has some acidic contaminants that haven't fully neutralized the overall alkaline nature. During the treatment process with phragmites, these plants can help reduce contaminants and possibly release some basic substances, slightly increasing the pH. When the

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already filtered wastewater is further treated with papyrus, similar processes occur, maintaining or slightly further increasing the alkaline pH. Both plants contribute to stabilizing and slightly adjusting the pH by their biological and chemical interactions with the wastewater contaminants.

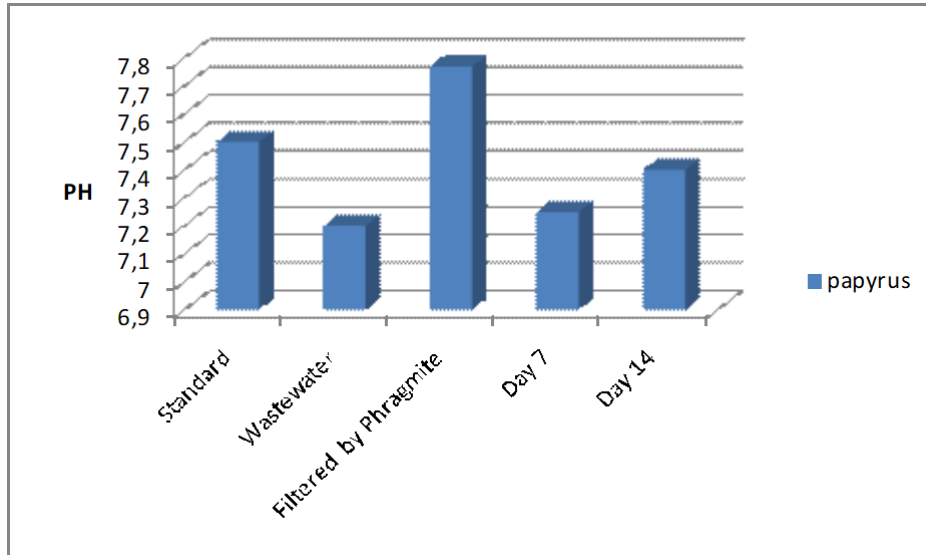


Figure 15 : Graph representing pH variation of wastewater treated with *Papyrus* and filtered by *Phragmite*.

2.8. The Variation in conductivity:

The conductivity of untreated wastewater is extremely high due to the high concentration of dissolved ions from pollutants. When this wastewater is first filtered using phragmites, many of these ions are absorbed or broken down, causing the conductivity to stabilize to levels similar to the standard.

Based on the graph (Fig. 16), we found that the results are similar to those of **Rodier *et al.* (2008)**; during the subsequent treatment with papyrus, over the span of 7 days, the plant continues to remove additional dissolved ions, leading to a slight decrease in conductivity after 2 days. By the end of the treatment period, the conductivity stabilizes again to the standard level, as *Papyrus* further reduces the ion concentration, ensuring the water quality meets the desired standard.

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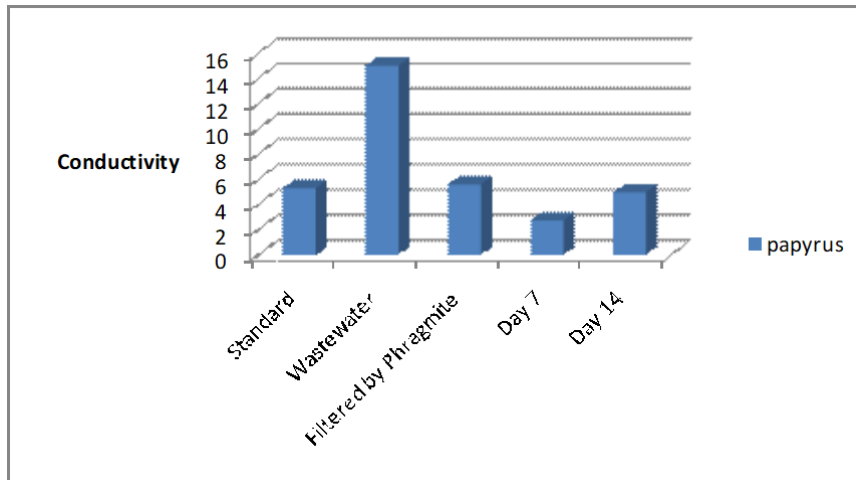


Figure 16 : Graph representing conductivity variation of wastewater treated with *Papyrus* and filtered by *Phragmite*.

3. Wastewater treated with *Phragmite* and filtered by *Papyrus*:

3.1. Temperature variation:

3.1.1. Non-treated wastewater temperature:

The initial temperature of untreated wastewater is lower than the standard. This could be due to the source of the wastewater being cooler (e.g., groundwater, or cooler ambient conditions).

3.1.2. Temperature after *Papyrus* and *Phragmites* filtration:

When the wastewater is filtered first by *Phragmites* and then by *Papyrus*, the temperature stabilizes. This stabilization can be attributed to thermal equilibrium; the water temperature adjusts to the ambient temperature of the treatment environment and the thermal properties of the plants and soil. Both *Papyrus* and *Phragmites* can also moderate temperature fluctuations through shading and evapotranspiration processes.

3.1.3. Temperature by the end of treatment:

Based on the graph (Fig.17) the results were quite similar compared with the study of **Okurut (2000)** who found that the aquatic plants cannot decrease the temperature totally due to many factors like microbial activity. By the end of the treatment, the temperature remains stable due to the ongoing influence of the treatment environment and plant processes.

In summary, the temperature of non-treated wastewater is lower than the standard, stabilizes after filtration by *Phragmites* and *Papyrus* due to thermal equilibrium and plant influence, and remains stable to the end of the treatment.

Results and discussion

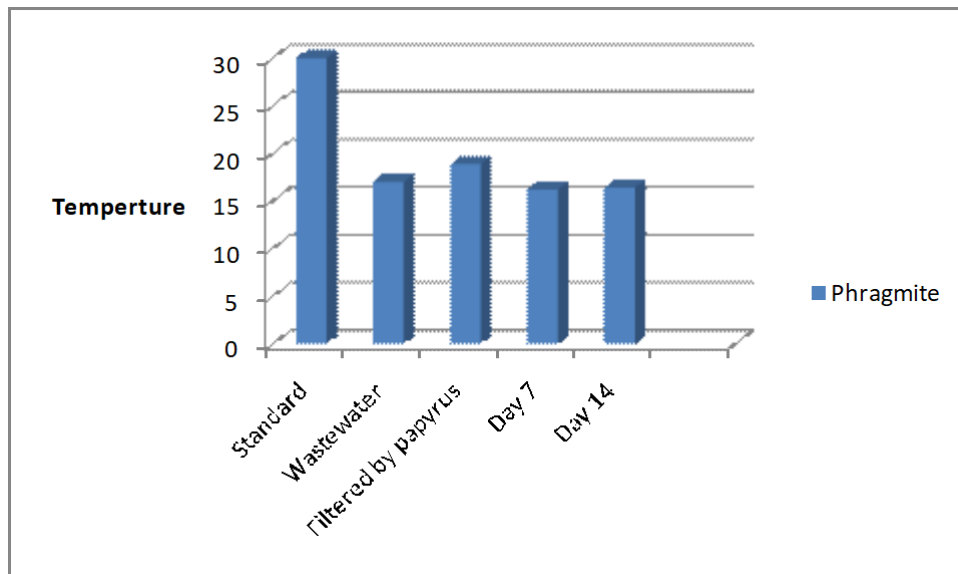


Figure 17 : Graph representing temperature variation of wastewater treated with *Phragmites* And filtered by *Papyrus*.

3.2.BOD variation in (Biochemical Oxygen Demand):

3.2.1. Non-treated wastewater BOD:

The initial BOD of untreated wastewater is higher than the standard, indicating a higher concentration of biodegradable organic matter that requires oxygen for microbial decomposition.

3.2.2. BOD after *Papyrus* and *Phragmites* filtration:

When the wastewater is filtered first by *Phragmites* and then by *Papyrus*, the BOD increases significantly (Fig.18) and those results were in contradiction with the study of **Okurut (2000)**, this study compared the efficiency of *Cyperus papyrus* and *Typha* in removing BOD among other pollutants from wastewater. The results showed that *Papyrus* had a greater capacity in removing BOD with efficiency of 80.69%. This can be attributed to the filtration process might initially release additional biodegradable organic compounds from the plant material or soil into the water. Increased microbial activity in the root zones of these plants might temporarily raise the BOD as microbes break down organic matter.

3.2.3. BOD by the end of treatment:

By the end of the treatment, the BOD significantly decreases. This reduction can be attributed to microorganisms continuing to decompose the organic matter effectively over time, reducing the BOD. *Papyrus* and *Phragmites* further absorb and filter out organic materials, leading to a substantial decrease in BOD.

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In summary, the BOD of non-treated wastewater is higher than the standard, increases significantly after initial filtration by *Phragmites* and *Papyrus* due to the release of organic matter and microbial activity, and then nearly disappears by the end of the treatment due to effective microbial degradation and plant uptake.

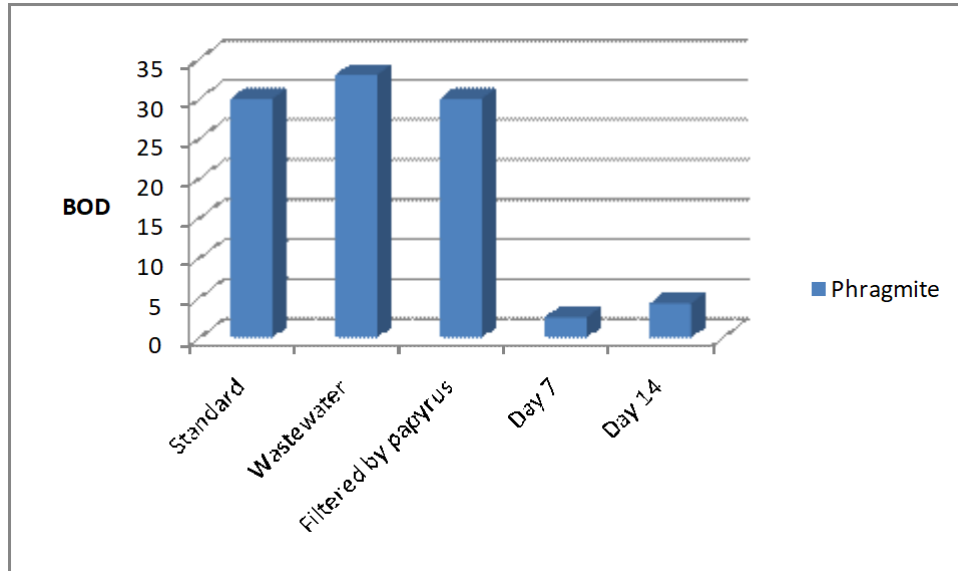


Figure 18: Graph representing BOD variation of wastewater treated with *Phragmites* And filtered by *Papyrus*.

3.3.Variation in phosphate (PO₄):

Based on the study of **Vymazal (2011)** the results are in contradiction because he used coconut fibers; coconut fibers are likely to be more effective at absorbing phosphate (PO₄³⁻) from water than pebbles due to their higher surface area, porous structure, and the presence of functional groups that can attract and bind phosphate ions. This makes them a potentially better option for applications such as water filtration or treatment processes aimed at reducing phosphate levels.

When filtered by *Papyrus* can be explained by the filtration capabilities of the different plant species and the treatment process. Here is an explanation of the observed changes; non-treated wastewater typically contains phosphate levels that are similar to the standard, which is nearly 0.

When the non-treated wastewater is filtered by *Phragmites*, there is a slight decrease in phosphate levels. *Phragmites*, also known as common reed, is a common plant used in constructed wetlands for wastewater treatment. It has the ability to remove pollutants, including phosphates, from the water. After the wastewater has been filtered by *Phragmites*, it is further filtered by *Papyrus*. *Papyrus* is another plant commonly used in constructed wetlands for

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wastewater treatment. It has been found to be effective in removing pollutants, including phosphates, from the water.

Interestingly, there is a significant increase in phosphate levels within 2 days of the treatment when filtered by *Papyrus* (Fig.19). This could be due to the release of phosphate from the plant material or the breakdown of organic matter in the wastewater.

After the initial increase, the phosphate levels stabilize at the end of the treatment process. This suggests that the *Papyrus*, along with the previous filtration by *Phragmites*, effectively removes and retains phosphates from the wastewater, leading to a reduction in phosphate levels over time.

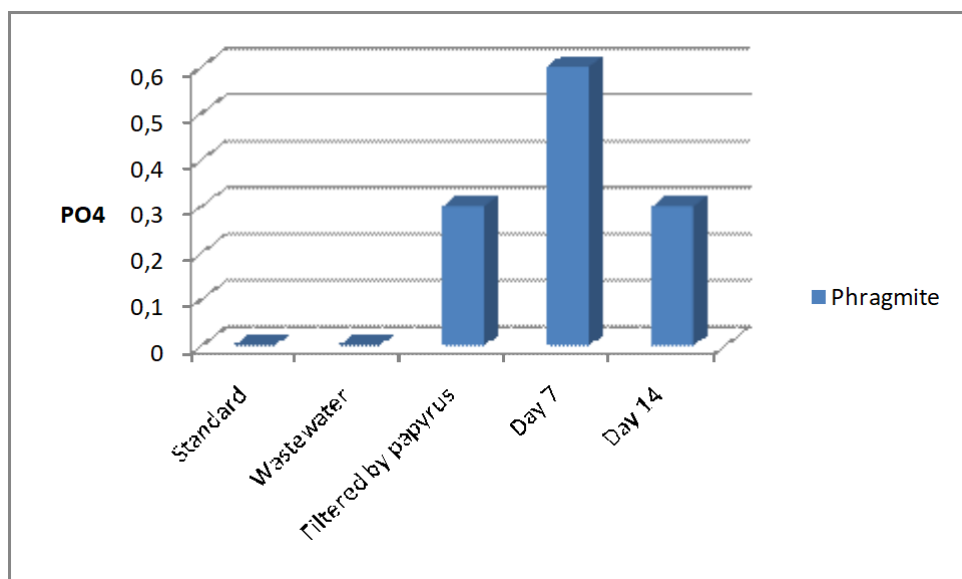


Figure 19 : Graph representing PO₄ variation of wastewater treated with *Phragmites* And filtered by *Papyrus*.

3.4.NH₄ variation (ammonium):

Using a combination of *Papyrus* and *Phragmites* was effective and it gave better results (Fig.20) which were comparable with the study of **Wiesman (2007)** who proved that both *Phragmite* and *Papyrus* plants can initially absorb NH₄⁺ directly through their roots, leading to a slight decrease in ammonium levels. The root systems can also provide surfaces for microbial communities that start to process NH₄⁺.

The high levels of NH₄ (ammonium) in non-treated wastewater can be attributed to various factors, including the presence of organic matter, proteins, urea, and other compounds that contribute to the production of ammonia during the breakdown process. When wastewater is not treated, these compounds are not effectively removed, leading to elevated ammonia

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levels. However, when the non-treated wastewater is filtered by *Papyrus*, the NH_4 levels nearly disappear. This can be explained by the filtration process, which helps to remove suspended solids, organic matter, and other contaminants that contribute to the high ammonia levels. *Papyrus* is known for its ability to effectively filter and purify water, removing impurities and pollutants.

By filtering the already filtered wastewater by *Phragmites* using *Papyrus*, the treatment process is further enhanced. *Phragmites* can help stabilize the wastewater by absorbing excess nutrients and promoting the growth of beneficial bacteria that aid in the breakdown of organic matter. The combination of *Phragmites* and *Papyrus* filtration helps to improve the overall quality of the wastewater and reduce ammonia levels.

In summary, the high NH_4 levels in non-treated wastewater can be significantly reduced when filtered by *Papyrus*, especially when combined with *Phragmites* filtration. However, it is essential to implement a comprehensive treatment process that includes additional steps like nitrification to fully address ammonia levels and meet standard requirements.

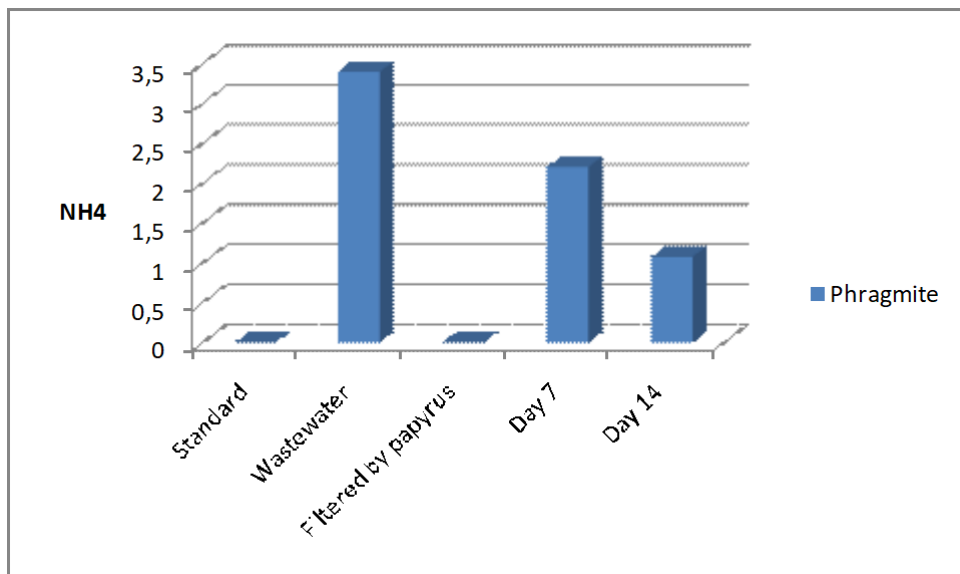


Figure 20 : Graph representing NH_4 variation of wastewater treated with *Phragmites* And filtered by *Papyrus*.

3.5. NO_2^- variation (Nitrite):

The NO_2^- concentration in non-treated wastewater is typically high due to the presence of organic matter and other pollutants. However, when wastewater is treated using *Papyrus*, the NO_2^- concentration decreases significantly (Fig.21).then it increased and those results in the

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graph were similar to the study of **Koné (2010)**; that confirmed that the increase in NO_2^- levels after treatment with planted filters is primarily due to the enhanced nitrification process facilitated by plant-microbe interactions, the creation of micro-aerobic zones by plant roots, and possibly incomplete nitrification due to insufficient hydraulic retention time or other environmental factors. Understanding these dynamics can help in optimizing the design and operation of planted filter systems for more effective wastewater treatment.

There are several reasons for this reduction; *Papyrus* has a high surface area and can absorb pollutants, including NO_2^- , from the wastewater. This reduces the concentration of NO_2^- in the water. *Papyrus* provides a habitat for microorganisms that can break down organic matter and pollutants, including NO_2^- , in the wastewater. This biological treatment can lead to a reduction in NO_2^- concentration. When wastewater is filtered through *Papyrus*, the suspended solids and other pollutants settle at the bottom, leaving cleaner water with a lower NO_2^- concentration.

The standard for NO_2^- in treated wastewater is typically set at a low level (nearly 0) to ensure that the water is safe for release into the environment. When wastewater is filtered through papyrus, the NO_2^- concentration can decrease significantly, meeting the standard at the end of the treatment.

In summary, the NO_2^- concentration in non-treated wastewater is high due to the presence of organic matter and other pollutants. Treating wastewater using papyrus can significantly reduce the NO_2^- concentration, meeting the standard set for treated wastewater.

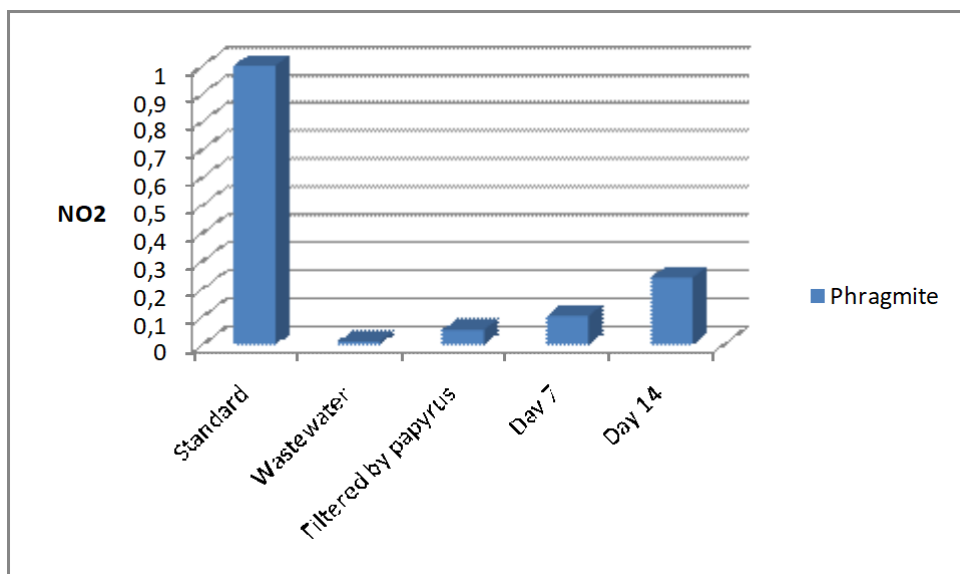


Figure 21 : Graph representing NO_2 variation of wastewater treated with *Phragmites* And filtered by *Papyrus*.

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3.6. The changes in COD (Chemical Oxygen Demand):

Regarding the results (Fig.22), the findings on *Phragmites* were approachable to the results of the research of **Boutin et al.(2003)**; the fluctuations in COD levels throughout the treatment process reflect the dynamic nature of pollutant removal and transformation in the constructed wetlands. Each plant species and treatment stage can influence the COD levels differently, leading to variations in the overall COD concentration of the treated wastewater.

The variation in COD (Chemical Oxygen Demand) levels during the treatment process of wastewater can be explained by the different stages of filtration and treatment by the wetland plants. Initially, the COD of the untreated wastewater is slightly below the standard level. This could be due to the presence of certain contaminants that contribute to the COD levels.

When the wastewater is filtered by *Phragmites*, the COD decreases slightly. *Phragmites Australis* is known for its ability to remove pollutants and contaminants from water, which could lead to a reduction in COD levels.

Subsequently, when the already filtered wastewater by *Phragmites* is further treated by *Cyperus Papyrus*, there might be a slight increase in COD levels. This could be due to the release of certain organic compounds during the treatment process, which might temporarily elevate the COD levels.

Towards the end of the treatment process, the overall COD levels might increase slightly. This increase could be influenced by the breakdown of organic matter by microbial activity or other processes occurring in the wetland system.

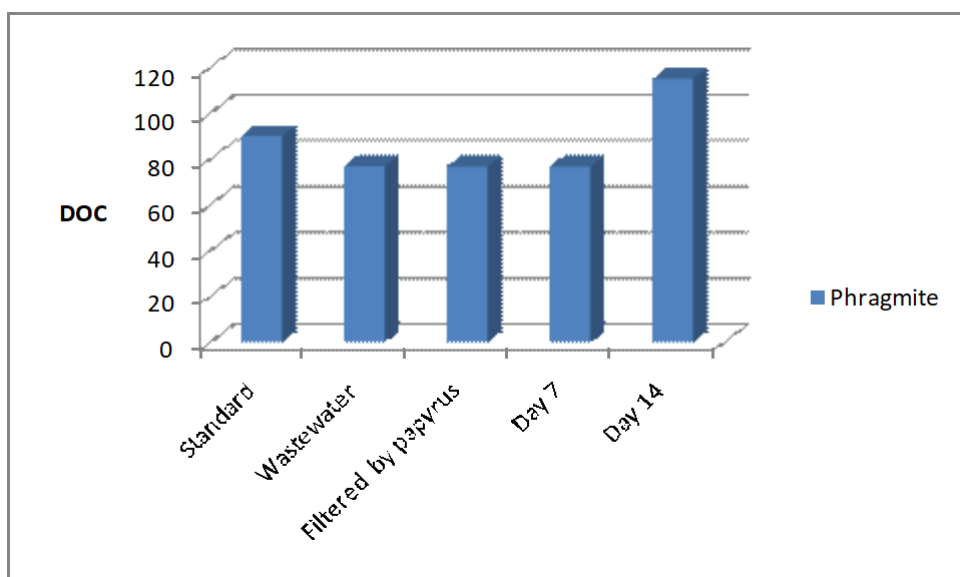


Figure 22: Graph representing DOC variation of wastewater treated with *Phragmites* and filtered by *Papyrus*.

3.7. Variation in pH:

Based on the graph (Fig. 23) the results were approachable with the study of **Degrément (2005)**, it proved that there are several factors that control the variation in pH such as *Cyperus papyrus* and *Phragmites australis* are both emergent macrophytes commonly used in constructed wetlands for wastewater treatment.

These plants have different physiological characteristics that can affect pH variation. For example, *Papyrus* has a higher transpiration rate, which can lead to a higher pH in the rhizosphere due to increased oxygen availability.

The composition of the wastewater being treated can also influence pH variation. Different contaminants and organic matter in the wastewater can undergo various chemical reactions, affecting pH levels. Additionally, the presence of certain ions, such as ammonium (NH_4^+) or carbonate, can also influence pH levels in the treatment system.

The design and operation of the treatment system can impact pH variation. Factors such as hydraulic retention time, flow rate, and aeration can affect the pH dynamics within the system. The presence of oxygen in the rhizosphere can promote aerobic conditions and higher pH levels, while anoxic conditions can lead to lower pH levels.

When the pH of untreated wastewater is slightly less than the standard but still alkaline, it suggests the presence of some acidic components that haven't significantly neutralized its overall alkaline nature. When this wastewater is first filtered using papyrus, the plant's biological activity helps to remove some contaminants, slightly stabilizing the pH but keeping it alkaline. When the already filtered wastewater is then treated with *Phragmites*, additional contaminants are removed, and basic compounds may be released by the plant. This further treatment with *Phragmites* can lead to a slight increase in pH, maintaining or slightly enhancing its alkaline condition by the end of the process.

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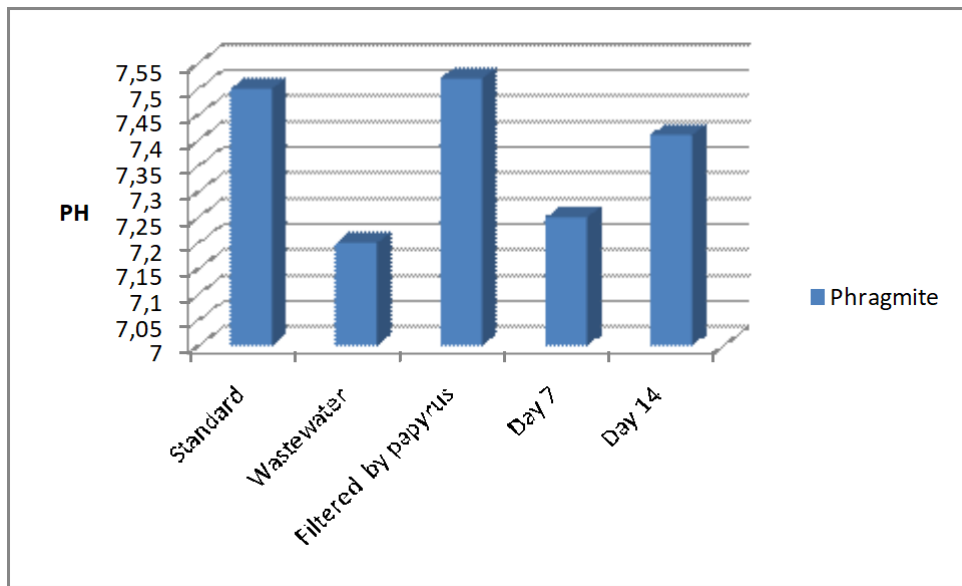


Figure 23 : Graph representing temperature variation of wastewater treated with *Phragmites* And filtered by *Papyrus*.

3.8.Variation in conductivity:

The conductivity of untreated wastewater is extremely high due to the presence of a large amount of dissolved ions from various pollutants. When this wastewater is first filtered using *Papyrus*, many of these ions are absorbed or broken down, causing the conductivity to stabilize to levels similar to the standard.

Based on the graph (Fig.24), we found that the results are similar to those of **Rodier *et al.*, (2008)**; when the already filtered wastewater is then treated with *Phragmites*, further removal of ions occurs, leading to a slight additional decrease in conductivity after 2 days. By the end of the treatment with *Phragmites*, the conductivity stabilizes again to the standard level as the plant effectively reduces the remaining dissolved ions, ensuring the water quality meets the desired standard.

Results and discussion

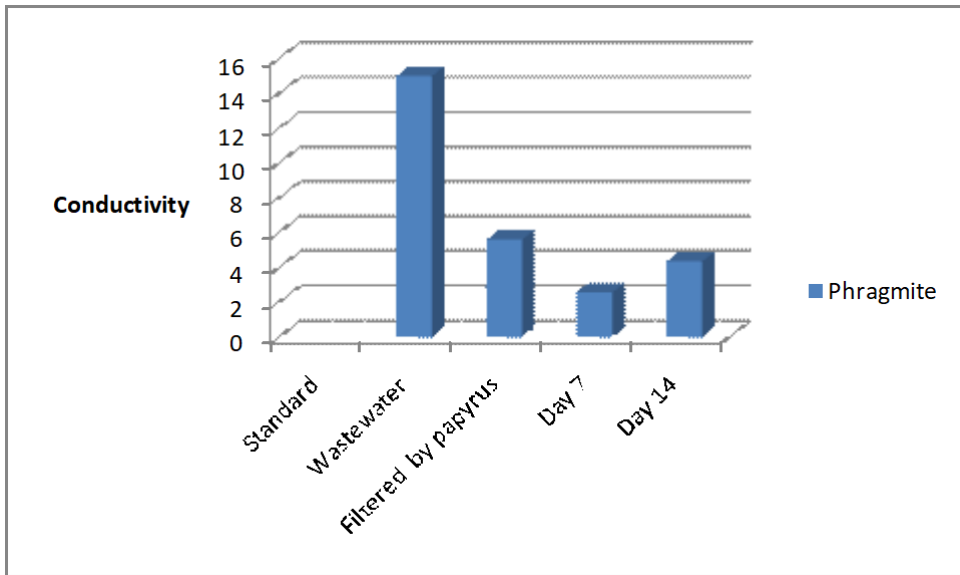


Figure 24 : Graph representing conductivity variation of wastewater treated with *Phragmites* And filtered by *Papyrus*.

4. Conclusion:

In this chapter, we compared the results of treating wastewater using planted filters, specifically *phragmites* and *papyrus*, both in series and in parallel with The international standards. The results were quite similar and encouraging for using the technique of constructed wetlands regardless of the method employed to treat wastewater and achieve better outcomes.

Conclusion

General conclusion

Conclusion

General conclusion

Planted filters, also known as constructed wetlands, are an effective and sustainable technology for the treatment of wastewater. These systems utilize the natural ability of aquatic plants to absorb and degrade pollutants, providing a low-energy, low-maintenance approach to wastewater remediation. Planted filters can be designed in various configurations, and can be optimized for specific wastewater characteristics and treatment goals. This nature-based solution offers an environmentally friendly alternative to traditional wastewater treatment methods, making it a promising technology for communities and industries seeking to improve their water management practices.

Given this, we set up experimental tanks containing *Papyrus* and reed plants to assess their effectiveness over a 14-day trial from 02/13/24 till 02/26/24

The experiment showed the effectiveness of *Phragmites* plant and *Cyperus* plant in filtering sewage water, whether the macrophytes filters are planted in series or in parallel. The removal percentage of NH_4^+ reached **61.76%** in A, B, A+B basins, the removal percentage of BOD_5 reached **69.48** in (AB) and (BA) basins, the removal percentage of COD reached **5.77** in A, B, A+B basins, and the removal of conductivity reached **75.67** in AB and BA basins.

The results obtained indicate that the activity ratio is balanced in both cases. In the case of sequential filter planting, the results showed more effective performance for some parameters compared to parallel filter planting, and vice versa. This proves the effectiveness of both methods, whether used individually or together, as well as the effectiveness of *Cyperus papyrus* and *Phragmites australis* in removing pollutants from wastewater.

The effectiveness of these results is not limited only to the plants or the filter's planting method, whether sequential or parallel, but is also related to the type of pollutants in the wastewater specific to each region.

Overall, the results of this study contribute to the growing body of knowledge on the use of constructed wetlands and planted macrophyte filters for wastewater treatment. The insights gained from this research can inform the design and implementation of similar systems in various contexts, ultimately promoting the adoption of more sustainable and eco-friendly wastewater management practices.

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Bibliographic References

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3. Décret exécutif n° 93-160 du 10 Juillet 1993 réglementant les rejets d'effluents liquides des industriels (Decree No. 93-160)
4. Décret exécutif n° 06-141 du 19 avril 2006 de la République algérienne démocratique définissant les valeurs limites des rejets d'effluents liquides industriels (Decree No. 06-141)

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