Faculty of Graduate Studies
Master Program in Water and Environmental Sciences

M.Sc. Thesis

Effectiveness of Constructed Wetlands for Post-treatment of Mixed Wastewaters from Poultry Slaughterhouse and Olive Mill

كفاءة الأراضي النباتية الرطبة المصطنعة في معالجة لاحقة لمياه صرف مختلطة من مسلخ دواجن ومعصرة زيتون

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This thesis was prepared under the supervision Prof. Dr.-Eng. Rashed Al-Sa`ed and has been approved by all members of the Examination Committee.

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Date of Defense: January 11, 2021

The finding, interpretations, and conclusions expressed in this study do not necessary express the views of Birzeit University, the views of individual members of the M.Sc. committee or the views of their respective employers.

DEDICATION

I dedicate my work

To whom I belong,

To my family,

To my parents,

Ahmad Faqeeh, Eitedal Faqeeh,

To my soul mate, my sister Haneen Faqeeh,

To my lovely husband Hussain Bazzar,

To my sweet daughter Zaina,

To my best friends, for the help, support and encouragement they provided, all the way long.

Abstract

The quality standards of treated wastewater have become more stringent in recent times, which led to high costs and energy that are required to reduce pollution loads from municipal wastewater. Constructed wetlands (CWs), an alternative to mechanized wastewater treatment technologies, have lower capital expenditures with low annual running costs (low energy and personal demands). A pilot system of vertical flow constructed wetlands (CWs) planted with *Phragmites australis* species was installed and operated after two UASB reactors at Birzeit University campus, Palestine. The study aimed at investigating the efficacy the pilot CWs system as a post treatment stage of anaerobically pretreated mixed industrial wastewater from poultry slaughterhouse and olive mill under variable mixtures. For a period of 6 months (May-October, 2020), the CWs pilot system (four beds with 3 m^2 each) was monitored at average loading rates for COD (64.6-145 g/(m^2.d) and for TKN (21.4-34.4 g /(m^2.d). Further, the potential of heavy metals accumulation in CWs vegetation was assessed. We argue that nature-based solutions are environmentally sound options for high quality effluent reclamation that comply with Palestinian technical regulations for effluent reuse in agricultural irrigation purposes. The results of the research will lead to closing the gap in circular bioeconomy pertinent to efficient use of water recycling in beneficial uses, thus a contribution in achieving the water-food-energy-security in Palestine. The findings of this research study included the following:

- The constructed wetland system, under investigation, showed a good performance in the removal of organic and inorganic pollutants in agrifood industrial effluents (COD, TSS, TKN, heavy metals, and total phenols).
- The purification efficacy of CWs for mixed industrial water from olive presses and poultry slaughterhouses was satisfactory with high removal percentages (95% - 99%).
- The constructed wetland system achieved average removal rates for COD (33.2-67.7 g/(m^2.d) and for TKN (10.5-21.2 g /(m^2.d).
- In a semi-arid country, the constructed wetlands produced treated water of high quality with the possibility of water reuse in landscape and agricultural irrigation.

Anaerobically pre-treated agrifood industrial wastewaters (poultry slaughterhouse and olive mill press) were successfully treated, over a period of six months (May-October 2020), using a pilot scale constructed wetland system. Optimizing the system operation and long-term investigations warrant further exploration to ensure compliance of treated water with local reuse standards and ensure safe disposal into receiving environment.

الملخص

في العقود الأخيرة، أصبحت معايير جودة المياه لمعالجة مياه الصرف الصحي أكثر صرامة، مما أدى إلى زيادة التكاليف والطاقة اللازمة للحد من الملوثات. يعتبر استيعاب الأراضي الرطبة المصطنعة بديلاً منخفض التكلفة ومنخفض الطاقة للمعالجة التقليدية لمياه الصرف من الدرجة الثالثة حيث يتم تصريف مياه الصرف البلدية المعالجة الى البيئية المستقبلة من أراضي زراعية او مياه سطحية في فلسطين.

تم إنشاء ومراقبة عمل نظام تجريبي لأراضي رطبة مصطنعة ذات تدفق عمودي (CWs) مزروعة بنبات *Phragmites australis*، بعد تشغيل مفاعلين UASB في حرم جامعة بيرزيت، فلسطين. هدفت الدراسة الى التحقق من فعالية نظام الأراضي النباتية الرطبة المصطنعة، كمرحلة لاحقة في معالجة مياه الصرف الصناعي المختلطة من مسلخ دواجن ومعصرة زيتون، بعد خضوعها لمعالجة لاهوائية مسبقة، تحت نسب خلط متغيرة. لمدة 6 أشهر (مايو – أكتوبر، 2020)، تم رصد النظام التجريبي CWs (أربعة أحواض، 3 م^2 لكل منهما) بمتوسط معدلات يومية للأحمال العضوية (145–64.6 COD جم / م^2) و 34.4– 21.4 TKN جم / م^2).

تم إجراء تحليل فعالية إزالة الملوثات العضوية وغير العضوية بما في ذلك البوليفينول وبعض المعادن الثقيلة المنتقاة. علاوة على ذلك، تم تقييم إمكانية تراكم المعادن الثقيلة في الغطاء النباتي لنظام CWs. نزعم أن حلول أنظمة المعالجة الحيوية القائمة على الطبيعة هي خيارات سليمة بيئياً لشحذ جودة المياه المعالجة الى جودة نوعية عالية تتوافق مع التعليمات الفنية الفلسطينية الخاصة بتدوير المياه المعالجة لأغراض الري الزراعي. تساعد نتائج البحث في سد الفجوة في الاقتصاد الدائري فيما يخص الاستخدام الفعال في تدوير المياه المعالجة في استخدامات متعددة ومفيدة، وبالتالي مساهمة في تحقيق الأمن المائي–الطاقة–الغذائي في فلسطين.

- أظهر نظام الأراضي الرطبة المصطنعة نتائج إزالة جيدة للمعادن الثقيلة والفينول، و TSSو VSSو COD
- كانت معدلات إزالة وتنقية المياه الصناعية المختلطة من معاصر الزيتون ومسالخ الدواجن مرضية ومعدلات عالية تراوحت بين 95٪ و99٪. حيث حقق النظام معالجة مرتفعة للملوثات العضوية بمتوسط معدلات ازالة يومية لـ (67.7–33.2 COD جم / م^2) و 21.2– 10.5 TKNجم / م^2).
- الحصول على مصدر جديد للمياه وهو المياه المعالجة من خلال نظام الأراضي الرطبة المصطنعة وإمكانية استخدامه في قطاع الزراعة والري.

تمت معالجة ناجحة، على مدى ستة أشهر (نيسان–تشرين اول 2020)، لمياه صرف صحي من صناعات غذائية–زراعية (مسلخ دواجن ومعصرة زيتون)، المعالجة مسبقًا لاهوائيا، باستخدام نظام تجريبي لأراضي رطبة مصطنعة. يتطلب تحسين تشغيل النظام والتحقيقات طويلة الأجل مزيدًا من الاستكشاف لضمان امتثال المياه المعالجة لمعايير إعادة الاستخدام المحلية وضمان التخلص الآمن في البيئة المستقبلة.

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List of Abbreviations

BOD	Biochemical Oxygen Demand
Cd	Cadmium
COD	Chemical Oxidant Demand
Cr	Chromium
Cu	Copper
FAO	Ministry of Environmental Affair
HRT	Hydraulic Retention Time
IEMS	Integrated Environmental Management Strategy
MEnA	Ministry of Environmental Affair
MOA	Ministry of Agriculture
MWW	Municipal Wastewater
ND	Non-detected
OLR	Organic Loading Rate
OMW	Olive Mill Wastewater
PADUCO	Palestinian-Dutch Academic Cooperation Program
Pb	Lead
PH	Negative log of the activity of the hydrogen ion
SRT	Sludge Retention Time
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TSS	Total Suspended Solid
UASB	Up Flow Anaerobic Sludge Reactor
VSS	Volatile Suspended Solids
WSRC	Water Sector Regulatory Council
WWT	Wastewater Treatment
Zn	Zinc

Chapter 1 Introduction

1.1 Background

Despite the idea about water appears to be abundant, Water is a defined and life-supporting resource, and shouldn't be lost after being used in any manufacturing, or household, or agricultural processes, because it has serious consequences on both the nature and human healthiness.

Sewage water is destroyed directly in the valleys without undergoing primary treatment, which leads to damage and negative effects on both human health and nature. Despite the possibility of using water that undergoes primary treatment for irrigation and agriculture, and it is an ideal form for the exploitation of treated wastewater, therefore certain standards of primary treatment of wastewater must be provided by municipalities before it is destroyed and used as a new water source.

The primary treatment methods of industrial water must be followed to reduce the loads of organic and inorganic materials and reduce their impact on wastewater treatment plants, and besides that, this water can be used either for agriculture or for the irrigation of ornamental plants and the exploitation of organic gas resulting from treatment. Agri-food industrial discharges from slaughterhouses and olive mills exert huge pollution loads in wastewater treatment plants. The composition of pollution loads contain large amount of inorganic and organic materials as well as emergent chemicals including polyphenols and heavy metals. Sustainable treatment technologies entail unit operations for energy recover and reclamation of treated effluents for agricultural reuse.

This research study explores the feasibility of nature-based solutions for the reclamation of anaerobically pretreated industrial wastewater and suitability of reclaimed water for agricultural irrigation. The results obtained shall provide science based data to enable the industrial sector and policy makers opt installing environmentally sound and economically feasible technologies for industrial wastewater management.

In this study, a mixture of two different agrifood industrial wastewaters with unique characteristics, first UASB anaerobically pre-treated, formed the main inlet for posttreatment:

- Wastewater from a poultry slaughterhouse: High contents in lipids and particulate organic matter.
- Olive mill wastewater [OMWW; Zibar] from a nearby olive mill press: High organic content of volatile, soluble and slowly biodegradable COD fractions (total phenols).

Therefore, such type of agrifood industrial wastewaters should be treated efficiently prior to connection to the public sewerage network or discharge into receiving environment to ensure the safe disposal and beneficial uses.

1.2 Problem Statement

The Palestinian authorities invested capital expenditures that aimed to improve the quality of water resources to raise the level of wastewater by focusing on developing the level of public water treatment facilities. So the Palestinian government enacted selective laws and regulations for the owners of factories and groups producing wastewater. The national rules and regulations specify pollution loads limits for organic rich industrial wastewater, which often are connected to the public sewer networks without preliminary treatment. This practice, lead to an increase in the organic and inorganic pollution loads in sewage works and caused negative impacts on the environment and public health.

This research study investigated the efficacy of constructed wetlands, a nature-based solution, as a post-treatment stage of anaerobically pretreated mixed industrial wastewater from poultry slaughterhouse and olive mill under variable mixing ratios. The main research questions behind the current study were the following:

1. How efficient constructed wetlands in reduction of organic and inorganic pollution loads in comparison to waste stabilization ponds?
2. Are constructed wetlands feasible for industrial effluents post-treatment?
3. Will the treated effluent of nature-based technologies meet the national guidelines for agricultural irrigation?

1.3 Research Objectives

The research objectives are the following:

1. Determine the effectiveness of a pilot system of constructed wetlands in polishing the quality of anaerobically pretreated industrial wastewater.
2. Identify the impacts of phenols and heavy metals on CWs vegetation and overall efficiency in pollution reduction, a phytoremediation option.
3. Explore how efficient nature-based technologies as post-treatment systems for industrial wastewater reclamation.

Chapter 2 Literature Review

2.1 Introduction

The wording “wastewater” indicates to any type of water that has been used and/or contaminated with waste products. Wastewater consists of around 99% water, and only 1% mix from suspended and dissolved biological solids, cleaners, and chemicals. Municipal wastewater treating or sewage treating; that type of wastewater that includes household waste liquid from toilets, showers, tanks and so forth that is through away of via sewers, is a process of taking pollutants off from wastewater and domestic sewage that comprise of physical, chemical, and biological process to reduced organic, inorganic and biological contaminants (Zhang, 2012).

Throughout a person's life, water has been a source of life and a source of the end of life. Water is a common and widely available natural resource, and sufficient quantities of water to meet the human need and meet the basic needs are a major condition for survival, development and health. With the progress and development of development and the increase in the population of the earth, the demand for water will rise in a direct way. Despite the human understanding of the vitality of water for development and its vitality as a fundamental role in meeting the needs and requirements of man. Man has continued to consume excessive water as an inexhaustible source. Therefore, water planners expect that in different parts of the world within two decades the abundance of pure water will be less than the average human needs. The water source for diverse applications is mostly streams or aquifers. Discharge of untreated wastewater of various types including agricultural drainage and stormwater runoff are behind pollution of receiving water bodies. In many countries, a large ratio of this polluted water discharged into the environment with small or no treatment. With the increasing requested for water, not only must large quantities of clean water be provided, but natural water sources depend on them are provided to mitigate the contaminated water that is discharged, which doubles the availability of fresh water. In many parts of the world, there is widespread lack, gradual demolition, and increased pollution of freshwater resources (Vigneswaran and Sundaravadivel, 2019).

2.2 Wastewater Reuse and Reclamation

Water reuse (also known as water recycling or water reclamation) works to recover water from a variety of sources and then treat it and reuse it for beneficial purposes such as agriculture and irrigation, potable water supply, groundwater replenishment, industrial processes, and environmental restoration. Water reuse can provide alternatives to the existing water supply and use to enhance water security, sustainability and resilience (Demortain, 2020).

Water reuse can be divided into: striped or unstriped, unstriped water pointed to situation in which the water depend on water used before in large scale , for example on unstriped water reuse occurs when communities withdraw their water supplies from rivers (Demortain, 2020). While the Planned water reuse refers to water systems designed with the goal of usefully reusing recycled water supplies. Often times, societies strive to improve their overall water use by reusing water to the maximum extent possible within the community, before returning the water to the environment. Examples of planned reuse include agricultural and landscaping irrigation, industrial process water, drinking water supply, and groundwater supply management (Demortain, 2020). The planning of using treated water needs to determining quantity and quality of the produced wastewater. The goodness of water used for irrigation will affect the yield, product, product quality and soil properties. In specific, salinity and boron are important, but also suspended solids, nutrient contents and biological parameters, like BOD5 infectious bacteria, parasites, and viruses, can be connect for the effluent reuse.

On the other hand the collected wastewater quantity will impact the management planning, tanks facilities and economic feasibility (Afifi, 2006).

Definition of the term sanitation (FAO) for the United Nations, “The consumed or used water of a society or manufactory is around 99 percent of most wastewater water, and only one percent is solid waste. Consequence, a natural lack of water can be conquering by using water purification. Sewage water is the preferred non-traditional water source, because it rises due to population increasing. Wastewater needs must be treated, disposed of in order to preserve the environment. Reuse of wastewater will help in the quality of the environment, at the same time, time of unrelenting pressure on natural and natural water sources (Vigneswaran and Sundaravadivel, 2004).

The use of wastewater to irrigate crops is becoming increasingly popular (Ayres et al., 1996), as more developed technologies are used for water conservation, the quality of treated water can surpassed normal drinking water quality (Zhang, 2012), also because almost all detectable contaminants can be removed from wastewater, making it suitable for every use; despite original pollution levels, all wastewater types can be reused if they undergo appropriate reclamation treatments (Levy et al., 2010).

The fruitful advancement of wastewater reuse has the cozy associations with the establishment of wastewater treatment plant, incorporated water asset the executives, monetary and monetary examination and public acknowledgment. Since the extra treatment of wastewater past auxiliary treatment and establishment of pipeline networks for reuse are required, costly capital expense is a significant issue of wastewater reuse usage (Asano et al., 2007).

Integrated water resources management (IWRM) entails water recycling, reuse and reclamation, which all call for deep understanding of the sources, types and water pollution impacts (Diagram 1). In addition, identify building capacity in water and wastewater treatment to ensure requirements for adequate water quality destined for recycling and reuse, and the technological and socio-economic considerations that affect demand management practices on water supply services (Asano et al., 2007).

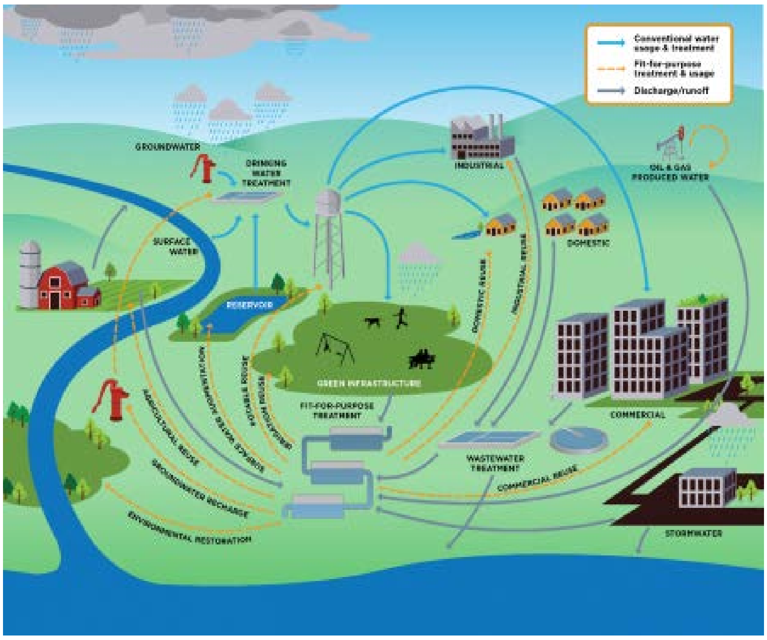


Diagram 1: IWRM water resources and applications (Source)

Diagram 1 illustrated the concept of IWR including diverse water resources and different selective water uses and applications:

- Agricultural applications and irrigation.
- Landscape use (recreational parks, forestry and golf courses).
- Domestic and municipal water services.
- Industrial uses including mining, energy, refineries, and mills firms.
- Recycling at household's level such as toilet greywater flushing.
- Municipal uses for dust control at construction sites and streets cleaning.
- Recycling in ready-made concrete and other commercial purposes.
- Water for nature including flows for storage, stream and aquifer recharge.

The reuse of treated wastewater regularly excessively advantages for poor people. It should be joined with methodologies to forestall or moderate wellbeing chances from microbes, weighty metals, insecticide, and endocrinal misbehaver and natural harm from hefty metals and saltiness. Long haul institutional coordination among water, horticultural, natural, and specialist organizations and end clients is a prerequisite for water reuse speculations to pay off (Birzeit University, IWES).

Guidelines for Wastewater Reuse in the Gaza Strip, Palestine

In the Gaza Strip, the approval of wastewater for its non-potable uses has become one of the most important priorities. Recently, this requires developing national guidelines. Environment and the preservation of public health are of the most basic concerns. Hence, Afifi (2006) suggested that water reuse in Gaza must be managed and controlled according to national reclamation rules to ensure public health and environment protection. In his study (Afifi, 2006) underlined that reuse of treated wastewater in Gaza Strip necessitates source separation, and advanced treatment, and capacity promotion. Treated water use in planned aquifer recharge could reduce saline water intrusion from coastal areas into groundwater.

The water reuse regulations entail following principles:

1. Economic and financial principles
2. Water is certifiably not a typical business item yet a scant regular asset which should be secured, safeguarded and treated correspondingly and should be given as a fundamental need by providing safe water to all buyers. One of the significant segments for wastewater reuse is wastewater levy charge and the motivations should be given to advance the far and wide reuse. What's more, request and supply the executives for treated wastewater must considered.
3. Environmental Principles Exercises identified with the reuse of wastewater should be arranged and executed with due respect for all their ecological ramifications, including the security of spring from contamination and over abuse. In addition, the short-and long haul

impacts of the reuse of wastewater should be observed so the enhancements can be supported and negative effects limited.

4. Institutional and management principles: The function of the capable specialists and all official bodies at all levels should be obviously characterized and the territories of duty formally settled. The structure and arrangement of the wastewater reuse the executives should be planned so as to encourage the contribution by the capable specialists at various levels with support of private area inclusion. Likewise, limit working for all foundations for treated wastewater reuse must be conceived and middle person bodies, for example, affiliation, NGP and nearby chambers must be improved.

Regional wastewater reuse

In most of the Mediterranean regions, there is a 70-80% increase in demand for agricultural irrigation water sources (Angelakis et al., 1999). The advantages that encourage the reuse of wastewater as a complementary source of water resources in the agricultural field have been recognized. Some countries, such as Jordan, Tunisia, Egypt, Cyprus, Malta, Italy, and Spain, are seriously giving up on wastewater reclamation. The reuse of this wastewater in Saudi Arabia is constant and has led to reducing the percentage of pollution and providing a source of water to effectively irrigate landscapes and ornamental trees (Al-A’ama and Nakhla, 1995).

In the Occupied Palestinian Territory, wastewater reuse is part of the National Water Management Strategy. Different projects aimed to liaise the agricultural land for treated water irrigation. According to Afifi (2006), the annual flow of wastewater into Israel in 1994 reached about 293 MCM, of which 232 MCM are treated (79%) and 194 MCM are reused (66%).

Limitation of wastewater reuse in Palestine

There are still many challenges and problems that must be overcome in order to reuse wastewater (treated water). The future reuse projects will be approved in the fields of various activities and better management and control of reuse operations based on the level of need and demand for water. Economic and financial feasibility of water reuse applications requires to be best assessed. Methodological sides need also moreover research, along with utilized research for specific applications. Teaching, information, and practicing of farmers and extension services also play an important role in promoting these practices aiming to achieve higher agricultural production without negative impacts on the nature. In Palestine, the use of treated wastewater has become more difficult than realistic, due to the scarcity and limitations of documented information related to the quality and quantity of wastewater in the current situation and the lack of a clear reuse system and policy. This is in addition to the treatment needs and wastewater quality for specific and different reuse purposes (Afifi, 2006).

2.2.1Wastewater treatment

One of the most important aspects of monitoring and controlling pollutions wastewater treatment (States, 1998). Wastewater treatment have spurred processes in water reclamation and reuse, due to the increased demands on freshwater and the environmental worries about discharging of wastewater into ecosystems, and the high cost and technology requests for its control and handling (Zhang, 2012).

Treating sewage water and minimizing the percentage of irregularities and pollutants in it is called purification of sewage water, as it is treated before reaching the environment and into the water in the ground (groundwater).

Due to the dearth of clean, pure water in nature, the difference between polluted water and pure water is the presence of the percentage of impurities and pollutants in the water (Ambulkar, 2020).

Wastewater treatment as a water use since it is so interconnected with different employments of water. A significant part of the water utilized by homes, ventures, and business should be treated before it is delivered back to the environment (Cressler, 2020).

The significant point of wastewater treatment is to eliminate however much of the suspended solids as could reasonably be expected before the leftover water, called effluent, is released back to the nature. As strong material rots, it goes through oxygen, which is required by the plants and creatures living in the water. "Essential treatment" eliminates around 60% of suspended solids from wastewater. This treatment likewise includes circulating air through (working up) the wastewater, to return oxygen to. Auxiliary treatment eliminates in excess of 90% of suspended solids (Cressler, 2020).

2.2.2 Overview of (waste) water Management in Palestine

In Palestine, groundwater is one of the most inexhaustible water assets that can be accessed and used. The volume of groundwater that can be reached in the West Bank is estimated at (580-830) million cubic meters per year, with the Palestinians approaching it today about 15-20%. Despite the water shortage, recently a 'red line' has been crossed, as polluted water has saturated these water sources, such as springs and groundwater springs (Figure 5.1). In some areas disturbing signs have been taken into account about groundwater pollution with high concentrations of chloride (400 mg / l), sodium (200 mg / l), potassium (35 mg / l) and nitrates (250 mg / l) in both the West Bank and the Gaza sector. The current management of water and environmental facilities in Palestine is unsustainable and calls for urgent programs for wastewater management including water reuse facilities (Mahmoud et al., 2008). In

Palestine, domestic sewage is collected and stored in cesspits, where urban centers have central sewerage networks for municipal wastewater associated with modern wastewater treatment facilities. In rural areas and refugee camps, black wastewater is collected in cesspools, while greywater is discharged into open channels (photo 1). Illicit industrial must be controlled and municipal by-laws enforces to manage municipal and industrial wastewater effluents (photo 2).

Photo 1: Sewerage pipe replacing open channel in Jalazoun Refugee Camp (Mahmoud et al., 2008).

In many cases, collected industrial liquid waste from various industrial sites and discharged into nearby seasonal streams without prior treatment (photo 2).

Photo 2: Raw industrial sewage disposal in Wadi Zaimer (Mahmoud et al., 2008)

Approximately 65% of the population of Palestine (West Bank) is not provided with a sewage network service, and they mainly resort to cesspits, and the sewage networks serve 35% of population, where about 6% of the population are served by wastewater treatment plants (Mahmoud, personal communication). At the beginning of the nineties, treatment plants in Ramallah, Tulkarm, and Jenin in particular underwent development and improvement, as they consisted of the oxidation lagoon technology (photo 3).

Photo 3: Ramallah oxidation pond system for municipal wastewater treatment

However, it does not work efficiently and well, so it does not achieve any better treatment than the basic treatment, in addition to those stations there are three other treatment plants. The first system is a basin system located in the city of Hebron and has not been used or operated since its establishment and establishment. This is due to the conflicts and disputes between the Hebron municipality and the Israeli occupation. In 1980, the second system was established on the campus of Birzeit University, consisting of a contact stabilization system and serving 4,500 employees and students (photo 4). It was working with excellent efficiency though, and the operating expenses were very high due to increased operational costs for energy by the aeration system. Reclaimed water produced from the central sewage treatment on BZU campus follows the zero-liquid discharge principle. In addition to reclaimed water use for landscape irrigation, rainwater is collected and stored for use during summer season (Al-Sa`ed and Zimmo, 2004). The third system was built as extended aeration system (photo 5) and started in operation by 2000 to serve 50000 capitants in Al-Bireh City. This wastewater treatment plant has been supported financially and technical extensions by the German government.

Photo 4: Birzeit water recovery facility through contact stabilization system

Photo 5: Al-Bireh extended aeration system for wastewater treatment

Diagram 2 depicts the current practices in wastewater management in Palestine. The total volume of domestic wastewater generated was 114.36 MCM, and about 32.5 MCM partially treated and raw wastewaters are being discharged into the Mediterranean Sea. While Israeli Practices, about 14.97 MCM of the Palestinian wastewater is dealt with or mostly treated in five Israeli treatment plants and solely reused in the Israel's horticultural area Israel charges the Palestinian National Authority 1.5 - 2 NIS for the treatment of one cubic meter of wastewater Israel regularly doesn't concede improvement ventures in sterilization area in Area C (Water and Environment Research Department (WERD), Database 2015).

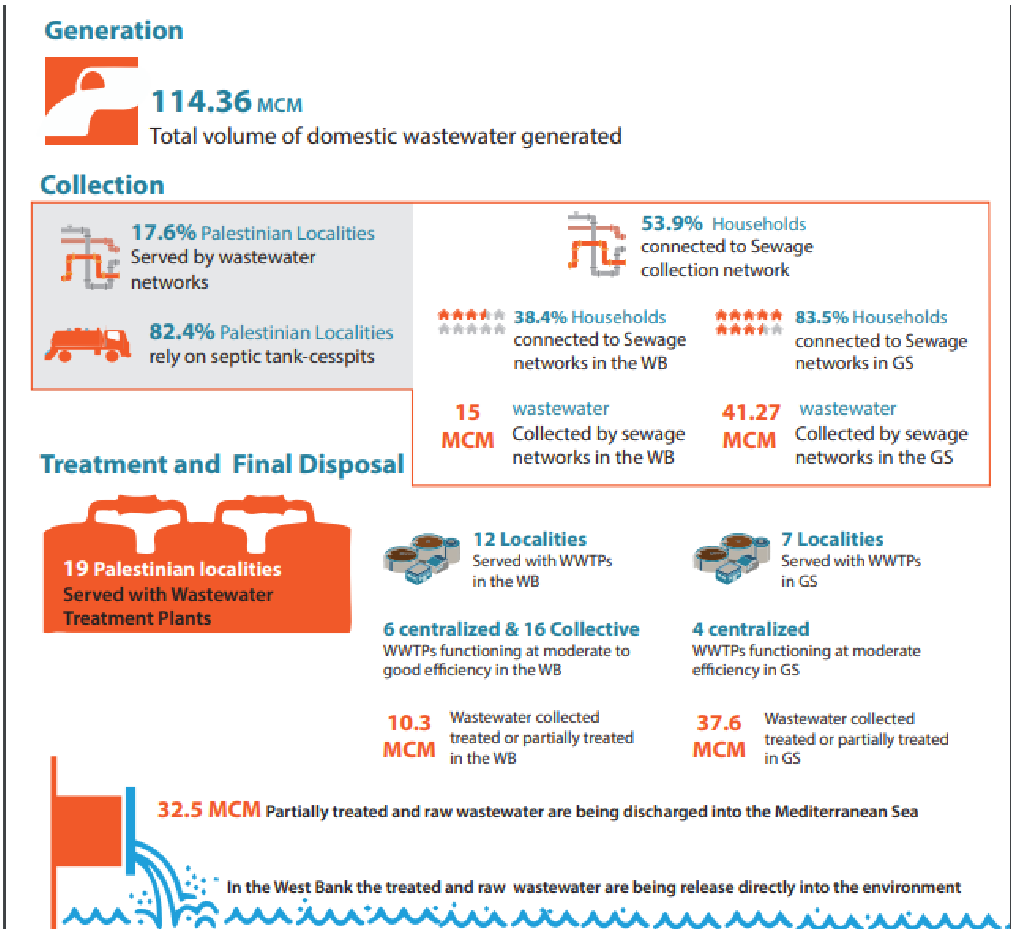


Diagram 2: Current wastewater management practices in Palestine (source).

There are two basic steps of wastewater from primary and secondary waste. In the primary step, magnetic materials it is allowed to settle and removed from the sewage. While secondary step use biological processes for additional wastewater purification. Sometimes, these stages they are combined into a single operation (States, 1998). These stages aim to remove materials from raw wastewater, such as fats, oils, sand, gravel, stones, larger settle able solids, and floating materials (Levy et al., 2010).

Human wellbeing and climate are primarily influenced by the immediate removal of mechanical and human effluents into regular assets with no treatment. Sewage treatment is important to lessen the harmfulness of sewage and keep a protected and sound climate, just as advance human government assistance. Also, the Sewage contains a gigantic measure of natural issues which are poisonous. Microorganisms are generally utilized in the sewage treatment plant for eliminating this harmful natural issue. So this image clarifies the stages or cycle of wastewater (Sewage Treatment Process).

Wastewater treatment plant (WWTP) comprises of two phases:

- Primary Treatment

  It includes the evacuation of enormous or little estimated segments in the wastewater through actual cycles.

- Biological Treatment:

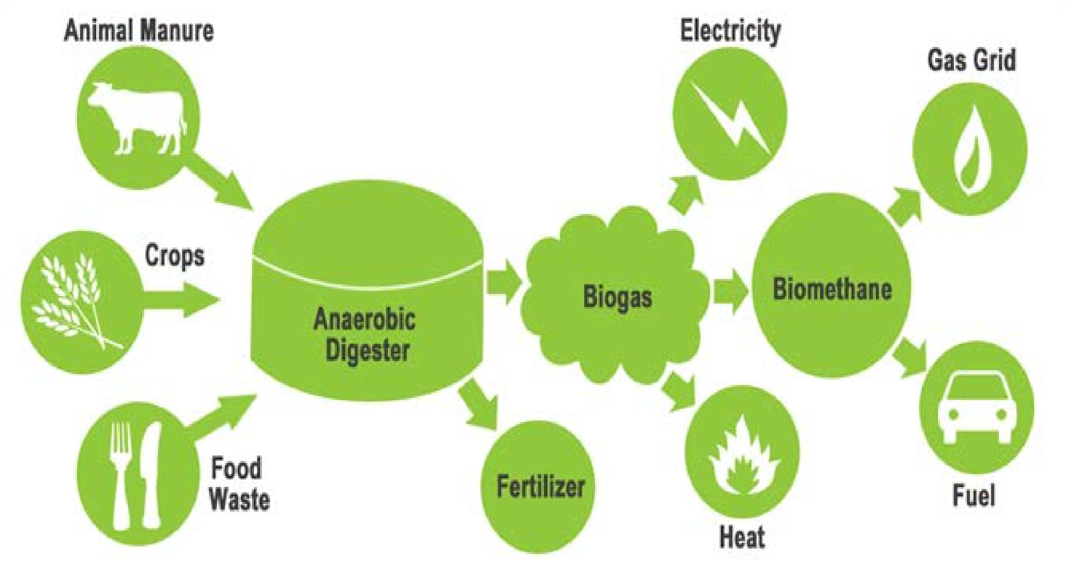
Oxygen consuming microorganisms are vaccinated into the sewage treatment plant. These microorganisms use the natural segments of the sewage and lessen the poisonousness. This can be estimated by BOD (Biological oxygen demand).

After the natural treatment, the ooze is siphoned from the treatment plant into an enormous tank. This huge tank comprises of anaerobic microscopic organisms which lead to the absorption of slop. During assimilation, biogas is created and it is utilized as a fuel source. Henceforth, Sewage treatment plant plan and sewage the board assume an essential part in the upkeep of human government assistance.

Energy generation

Microorganisms which are associated with the creation of energy are called microbial power modules. Microbial power modules are utilized to create an assortment of fuel sources like biogas and power. Agrarian waste, compost, and homegrown squanders are utilized as crude materials for the age of biogas. Biogas age is done in the huge solid tank which is known as a biogas plant (byjus, 2020).

Biomasses (Biowastes) are gathered at the biogas plant and the slurry is taken care of. Biomasses are wealthy in natural issue. A portion of the microorganisms can become anaerobically inside the biogas plant. These microorganisms can process the biomasses which are available in the slurry and sewage. During assimilation, an immense measure of combination of gases is delivered inside the tank. The combination of these gases is known as the biogas. Biogas is eliminated from the biogas plant through a different source (byjus, 2020).



Microbial energy components are additionally used to produce power from wastewater. Microbial energy units use the natural issue from the wastewater treatment plant. During absorption, natural issues are changed over into the basic particle and delivery the carbon dioxide and electrons. Those electrons are consumed by the anode and utilized as the wellspring of power.

2.2.3 Anaerobic pretreatment of high strength industrial wastewater

Anaerobic treatment is an power producing process, which is technically simple and comparatively cheap cost technology which needs less power, area and produces less surplus sludge in comparison to the traditional aerobic treatment technologies (Evren et al., 2011).

Anaerobic pretreatment of high strength industrial wastewater (slaughterhouse, olive mill, and dairy) contributes to reducing risks and impact on treatment plants and water bodies (Mahmoud et al., 2008). Initial results reported by Diab (2019) revealed that COD effluent from the UASB pilot system treating raw poultry wastewater revealed a technically feasible alternative, considering a post-treatment stage for biological nutrient removal and hygienic issues. Post-treatment of an aerobically pretreated municipal wastewater warrants further deep studies. Nature-based biotechnologies including constructed wetlands and waste stabilization ponds are low-cost and environmentally friendly systems, which will be explored in this study.

The utilization of anaerobic innovations for wastewater treatment goes back more than 100 years. The primary whole scale use of anaerobic sewage treatment was in a reactor taking after the septic tank in the 1860's, and was designated "Mouras Automatic Scavenger". A short time later, the mechanical advancement continued by means of presenting the anaerobic channel in 1880's, the anaerobic cross breed framework in around 1890 or 1891 by W. D. Scott Moncrieff and the septic tank in 1895 by Donald Cameron. The flow of these septic tanks were regularly dark and hostile, and have high measures of solids, which will in general stop up the contact beds that were frequently utilized for ensuing treatment. Thus, Harry W. Clark at Lawrence, Massachusetts, proposed in 1899 to tackle this issue by processing the slop without help from anyone else in a different tank. This was the primary move towards discrete ooze assimilation. In 1905, Karl Imhoff presented the Imhoff tank, which comprised of a pioneer situated over a capacity tank for absorption of settled slime. At that point, anaerobic advancements were begun to be moved from treatment of wastewaters to the treatment of settled slop. The Imhoff tank was not the total arrangement as it was tall, and the assimilation chamber must be associated personally with the sedimentation tank. Thereafter, endeavors started with independent assimilation of slop which was effective by and by in

1927 when the Ruhrverband in Essen Rellinghausen introduced the main warmed ooze digester. In the 1950's, the significance of the muck maintenance idea for decreasing the reactor size started to be perceived (McCarty, 2001).

One of the significant triumphs in the improvement of anaerobic wastewater treatment was the presentation of high-rate reactors in which biomass maintenance and fluid maintenance are uncoupled (Lettinga et al., 2001). The acceleration of energy costs in the 1970's and the impressive expenses of the development, support and activity of high-impact frameworks brought about consideration of anaerobic high-rate frameworks as far as examination and application.

The accomplishment of the anaerobic high–rate frameworks is because of the chance utilization of a generally high stacking rate, while keeping up long SRT at moderately short HRT because of slime immobilization. In these frameworks, wastewater moves through the anaerobic ooze where purging happens through complex bio - physical - substance interrelated cycles. Natural issue is changed over into biogas (essentially methane which is a helpful final result and carbon dioxide) and slime. The fundamental concept listing main pros and contras of high rate upflow anaerobic sludge blanket (UASB) systems are summarized in Table 1.

Table 1: Main pros and contras of UASB systems

Advantages	Disadvantage
-A generous sparing in operational expenses as no energy is needed for air circulation; on the opposite energy is created as methane gas, which can be used for warming or power creation. Thus, it couples the corruption of natural materials from waste to the creation of energy.	-Need for post treatment, contingent upon the prerequisites for emanating guidelines. -No involvement in full-scale application at low/moderate temperatures. -Significant measure of delivered biogas (CH_4) and H_2S stays emanating particularly for low strength wastewater (sewage).

Table 1 (*continue*): Main pros and contras of UASB systems

Advantages	Disadvantage
-The cycle can deal with high water driven and natural stacking rates. Consequently, the applied advancements are somewhat smaller and diminish the volume of post treatment stages. -The innovations are straightforward in development and activity; therefore they are minimal effort advancements. -The frameworks can be applied all over the place and at any scale as meager if any power is needed, empowering a decentralized application. This extraordinary advantage mirrors the frameworks adaptability, other than the way that the decentralized mode prompts critical reserve funds in the speculation expenses of sewerage frameworks. -The overabundance slop creation is low. Likewise, the ooze is all around balanced out and effectively dewatered because of high solids maintenance time (SRT). In this way, the slime doesn't need broad exorbitant post treatment. -The important supplements (N and P) are preserved which give high potential for crop water system and hydroponics. -Practical for a wide scope of waste and wastewaters, for example complex in creation, an exceptionally low and extremely high strength, low and high temperatures.	- Created CH4 during anaerobic sewage treatment is frequently not used for energy creation.

Based on literature analysis (Lettinga et al., 1993; Schellinkhout, 1993; Zeeman and Lettinga, 1999; Foresti, 2001; Gijzen, 2001; Lettinga, 2001), Table (1) illustrates the advantages and drawbacks of anaerobic sewage treatment using the UASB technology.

2.2.4 Operating costs for wastewater treatment

The nature of wastewater decide the necessary treatment level and related expenses, and that is by three significant factors, for example, Quality, Quantity and Location; of the source that influences the costs identified with transport of wastewater from the source to the recovery plant and afterward to the last reuse objective (Ayres et al., 1996).

Most of the Energy needed in wastewater treatment Because of the emission of water from the source, During the stage of introducing air into the waste during aerobic treatment, and upon completion of the treatment of solid materials, they are used again as fertilizer, or burned, or left to settle in landfills, and the production of energy depends on the amount of production of these materials, the energy increases with its production (IRENA, 2015).

About 3% of electricity is being used in the process of wastewater treatment, as energy input is needed during wastewater treatment, either for its collection, treatment and discharge (IRENA, 2015). And there is a failure or abandonment of wastewater treatment plants economically in developing countries. Due to the weakness to provide the necessary permanent power material. despite the immense potential for energy production from wastewater itself (WERF, 2011).

Operating Costs per m3 of Wastewater in Palestine

- This pointer (indicator) was determined for specialist organizations who give wastewater administrations to their clients; 9 SPs out of the 15 comprehensive Jericho which began giving wastewater administrations in mid-2014 (Water Sector Regulation Council, 2015).

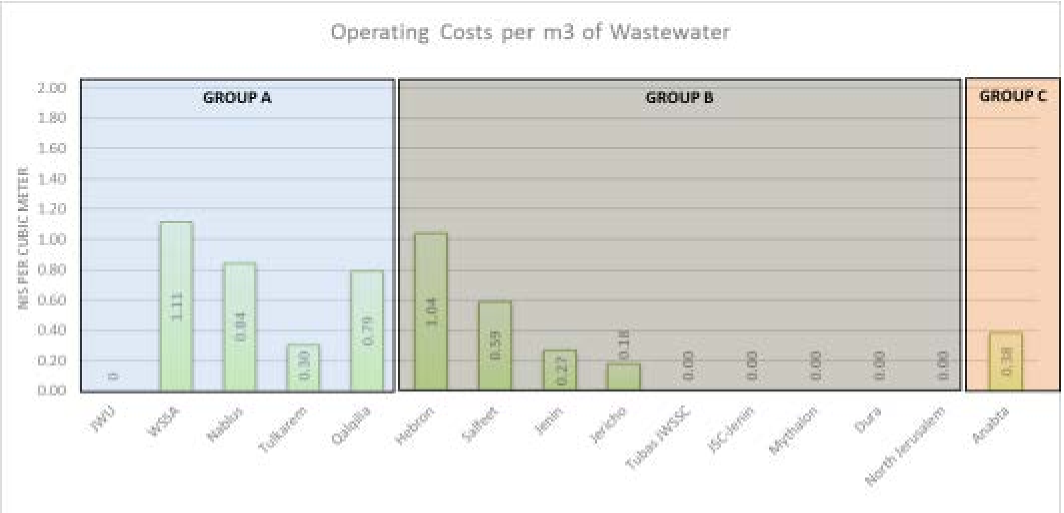


Figure 1: Operating Costs per m3 of Wastewater – West Bank

This figures show that the top operating expenditures of wastewater were for WSSA and Hebron with working rate of 1.11 and 1.04 NIS/m3 respectively, and the lowest wastewater operating expenditures were reported for Tulkarm and Jericho with 0.25 and 0.18 NIS/m3 sequentially.

Figure 2: Operating Costs per m3 of Wastewater – Gaza-sector

This figures show Operating Costs per m3 of Wastewater in Gaza-Strip, It has been shown that the costs of caring for workers and water services are not separated by the suppliers, and this is one of the main problems in knowing and calculating operating expenses for caring for workers. Service providers are encouraged to record the expenses of sanitation activities at an independent cost center. This contributes to assisting in setting appropriate tariffs for wastewater services, whose objectives include covering the expenses of each service.

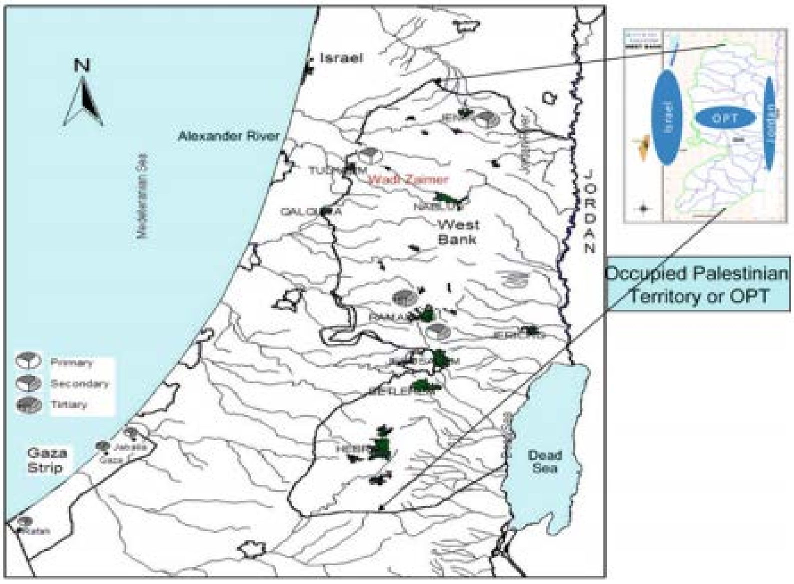
2.2.5 Purification of wastewater treatment

Considering the high-energy costs and increased operating costs required in wastewater treatment lately, an increased focus towards finding alternative strategies and techniques for their purification (Tu et al., 2010).

Most treatments plants were built to clean wastewater, to later discharge into receiving water to reuse. In the past, normal process of water cleaning starts; when sewage was dumped into waterways,, where small organisms and bacteria in the water consumed the sewage and other organic matter, turning it into new bacterial cells; carbon dioxide and other products (States, 1998).

As of now, the Involved Palestinian Region (Pick) has eight huge metropolitan WWTPs including very nearly 300 on location treatment plants. These wastewater treatment offices (WWTFs) serve chiefly metropolitan networks covering a roughly 1.5 million populace same (PE), where the ebb and flow all out populace of the Pick is marginally in excess of 3,000,000. The innovation type applied for treatment measures is customary utilizing the enacted muck framework with its cycle changes. The majority of old WWTPs do not work quite well, with emanating quality surpassing the endorsed public gushing guidelines. This is expected to over-burdening, yet it can regularly be the aftereffect of the different elements related with inappropriate actual plan, flawed development and inadequate policy framework (Al-Sa`ed, 2017).

Report made by Al-Sa`ed and Al-Hindi (2009) uncovered that about 20% of the complete populace that are served by focal sewer networks dwell in metropolitan networks and the wastewater is released into occasional Channels. Among these significant Channels in the West Bank are Aqueduct Mugata (Jenin area), Watercourse Zaimer (NablusTulkarm locale), Aqueduct Zhor (Qalqilia region), Watercourse An-Nar (Hebron region), Channel Mahbas (Ramallah region), and Channel Al-Qilt (Jerusalem and Jericho regions). About 33% of the yearly gathered metropolitan wastewater (73.7 mcm/year) from Palestinian people group is being treated in Israeli WWTPs. The treated effluent from this Palestinian wastewater is then much further recovered for different applications inside Israel (not to serve the Pick), predominantly for unlimited rural water system and water for nature purposes, for instance, waterway recovery and scene entertainment (Al-Sa`ed and Al-Hindi, 2009). In the Pick territories, a large portion of the current WWTPs are not working great, e.g., the three failing WWTPs in Jenin, Tulkarm and Ramallah and the nonoperation one for Hebron. This is without referencing the WWTP in the Gaza Strip that is confronting similar issues, however more intense, since it directly affects the water assets put away in the delicate topographical structure fundamentally made out of sandstone arrangements that portray the zone (PWA, 2002). The wastewater gushing is streaming into little watercourses in the Select, with the most noticeably awful circumstances found in Jabalia, Gaza, and Rafah since their issues are not just the way that the WWTPs are not working admirably, however the release of the effluents and its use (Waco-Euroconsult, 1995).



Map 1 Location of Palestinian WWTPs and receiving surface water bodies.

2.2.6 Natural treatment systems: an ideal solution for municipal wastewater treatment

Natural treatment systems (NTS) are Eco technologies intended to treat water or recover corrupted locales. Treatment wetlands are a center Eco technology that have entered the standard of enormous civil activities for tertiary wastewater treatment, water recovery, water supply pretreatment and storm water the board (Jacobs, 2017).

The motivation behind normal treatment frameworks is the re-foundation of upset environments and their supportability for advantages to human and nature. The working of regular treatment frameworks on biological standards and their maintainability as far as minimal effort, low energy utilization, and low mechanical innovation is exceptionally attractive (Cai, et al., 2017).

According to Stefanakis (2018), nature-based technologies are characterized by low operating costs, low requirements for maintenance, energy, and ease of operation. These facts made natural treatment systems an ideal solution for municipal wastewater treatment (Puigagut et al., 2007). Energy requirements in terms of electricity/grid power in order to reach effective treatment in wetlands that are constructed compared to other treatment technologies are low, as in most cases electricity is required only to pump wastewater in cases where gravity cannot be applied to it. The reason for the lower requirements for electricity is due to the support of natural environment and natural energies (Kadlec and Wallace, 2009).

2.2.7 Alternative techniques for purification of wastewater treatment

Since biological wastewater treatment systems aren't convenient to solve all the problems associated with emerging pollutants, new concepts need to be developed, and more cost-effective and sustainability convenient treatment technologies (Donde, 2017).

Electrolytic wastewater treatment is more efficient to produce high quality water than both biological and chemical treatment. Biological treatments are not sufficient because they have some disadvantages, such as they need a long time for treatment; require large land area for treatment, and the problem of how to dispose sludge produced by the treatments. In another hand the electrochemical handling process could be used as an alternative technology to reduced the pollutant from waste water and toxemic material (Chopra et al., 2011).

A results study of Richmond (1998) in New South Ribs, show a huge scope pilot plant was situated close to Richmond (New South Grains) on which had a long term concentrate on seven plots accepting auxiliary treated waste was directed. The point was to test minimal effort, low support, and energy effective strategies. Treatment capability of amphibian macrophytes (enormous sea-going plants) in one or the other normal or built frameworks was evaluated. It was set up in 1983. Saprophyte and two control channels without plants (1 vast water, 1 rock) with measurements 100 m by 4 m, 0.5 m profound were utilized with an application pace of 0.1 - 1.8 ML/ha (Million liters/ha?) every day.

In the untamed water locale of channels algal blossoms obstructed the downstream interface, altogether lessening emanating stream. Rock filled saprophyte channels - suspended solids and Body were viably taken out - fast drop in levels over the initial 10 to 20 m were expected to sifting and sedimentation inside the rock. Nitrogen (N) expulsion was poor because of moderate advancement of nitrifying microscopic organism's populaces down and dirty. N evacuation happened with 5 to 10 days maintenance time. Just restricted aggregation of oxidized nitrification - if oxygen can be moved by means of plant roots into the channel frameworks, at that point nitrification and DE nitrification will promptly follow. Little phosphorus (P) evacuation. Rock control equivalent expulsion of Body, N, P. Recommends separating and sedimentation of particulate issue was a critical supplement evacuation component. Rock based sea-going saprophyte frameworks had a high vanish pace of fecal coliforms – Blend of sedimentation and normal cease to exist, enhanced by bright radiation.

2.3 Olive mills wastewater treatment

Olive oil is delivered from olive trees, every olive tree producing in some place in the range of 15 and 40 kg of olives annual. Overall olive oil creation for the year 2002 was 2 546 306 t, delivered from around 750 million profitable olive trees, most of which are in th south European area. Only south European nations bring about 97% of the absolute olive oil creation, while European Association (EU) nations produce 80–84%. The greatest olive oil-creating nation is Spain (890 100 t in 2002), at that point Italy (614 950 t), Greece (402 703 t) and Turkey (168 700 t), trailed by Tunisia, Portugal, Morocco and Algeria. Outside the Mediterranean bowl, olives are developed in the Center East, the USA, Argentina and Australia (Leontopoulos, Skenderidis, & Vagelas,2020).

Olive oil is created from olives in olive plants either by the irregular shove technique or by the persistent separator strategy. There are around 25 000 olive factories global. Wastewater emerging from olive handling is one of the most grounded industrial effluents, with compound oxygen interest (COD) estimations of up to 220 g/L and comparing bio-synthetic oxygen interest (Body) estimations of up to 100 g L−1. The wastewater arising from the milling measure adds up to 0.5–1.5m 3 per 1000 kg of olives relying upon the cycle. The intermittent cycle delivers less yet more thought wastewater (0.5–1m3per 1000 kg) than the c separator cycle (1–1.5m 3per 1000 kg).3–5 The attributes of olive plant wastewater are variant, contingent upon numerous entertainers, for example, strategy for extraction, type and development of olives, area of cause, climatic conditions and related development/preparing strategies. Other than its solid natural substance (BOD 535 – 110 g/L, COD 45 – 170 g/L, suspended solids (SS) 1 – 9 g/L). Olive mills wastewater (OMW) contains high concentrations of unmanageable mixes, for example, lignin and tannins which give it a trademark dim shading (52 270–180 000 mg L−1Pt-Co units). But, above all, it contains phenolic mixes and long-chain unsaturated fats which are harmful to microorganisms and plant (Paixao and Anselmo, 2002).

Olive plant wastewater (OMW) emerges from the creation of olive oil in olive factories. It is created occasionally by countless little olive plants dissipated all through the olive oil-delivering nations. OMW has an exceptionally high natural burden, obstinate in nature and with an extreme measure of poisonousness/phytotoxicity - related mixes. A few physicochemical, natural and joined cycles have been inspected for the therapy of OMW, bringing about impressive natural burden and harmfulness decrease. Organic cycles, high-impact and anaerobic, incorporating anaerobic co-absorption with different effluents and fertilizing the soil, are overwhelming in the treatment of OMW. Progressed oxidation measures have pulled in a lot of consideration inferable from the solid oxidation capability of the specialists utilized, which can bring about a serious level of treatment (Paraskeva and Diamadopoulos, 2006).

About 750 million productive olive tree's international, 98% are in the Mediterranean area, where more than 97% of olive oil is produced. All this urged for safe disposal of large amounts of wastes produced during olive oil production (Oreopoulou and Russ, 2007).

The organic content is mainly composed of polyphenols, carbohydrates, sugars, nitro-chloric compounds and oil, which are substances worth recovering. Since pollution control the distribution of vegetation of water on agricultural soil and in the surface waters, which isn't acceptable because of a very high secondary pollution effect on water, so many pollution disposal methods were used, such as aerobic and anaerobic treatment.

2.4 Composition of agrifood industrial discharges

Various Mediterranean nations experience the severe effects of shortage and limited access to available water resources, which experienced overexploitation and quality degradation. many Italian communities have recently confronted the negative effect of pollution discharges aiming at improving water quality in coastal areas. Especially, in Apulia Area (South-Eastern Italy), water deficiency affected seriously the economy in local communities, generally dependent on horticulture. In addition, the agrarian coastal zone regions of Apulia District experienced the harsh effects of increased seawater intrusion into groundwater aquifers. This was explained by uncontrolled groundwater withdrawals to satisfy diverse water demands (Libutti and Monteleone, 2012). Therefore, policymaker are forced to search for non-conventional water sources and integrate this into water governance policies.

Few research studies (Qadir et al., 2007, Pedrero et al., 2010) tackled management of municipal wastewater treatment und applied treated water to match the increasing agricultural water demand in irrigation purposes. However, increased population associated by increased water demands, depleted water sources and ineffective water and sanitation services, climate change, ageing infrastructure and limited funding increased annual stress on limited water resources. Promotion of environmental sustainability and control of wastewater discharges to receiving water bodies will contribute to improvements in upgrade and expansion of water and wastewater reclamation facilities (Pedrero et al., 2010, Agrafioti and Diamadopoulos, 2012). Moreover, reclaimed water use improves soil properties supplemented with nutrients (P: N: P elements), in addition to reduction in pollution loads discharged into aquatic environment (Meli et al., 2002, Rusan et al., 2007). Application of treated water in crops irrigation can improve the growth development and increase the production yields (Kiziloglu et al., 2008, Bedbabis et al., 2010) on one side, on the other side it can equally improve the economic value and market competiveness of treated water irrigated crops (Bedbabis et al., 2010, Paranychianakis et al., 2006). Water user associations should monitor the water quality of treated water supplied to ensure compliance with national rules and guidelines pertinent to reclaimed water use in irrigation (Pedrero et al., 2010). Sustainable water reuse schemes include wise selection of water reuse categories; proper water quality criteria for the destined reuse considering local regulations and guidelines, as well as feasible design of treatment processes that achieve the required effluent quality with reduced health and environmental risks (Qadir et al., 2007).

Reducing the capital and operational expenditures of WWTPs and water reuse facilities leads to increased efficiency of water recycling and reuse in beneficial applications. However, application of cleaner production in the industrial sector would lead to pollution loads reductions, removal of sanitary parameters, salts, heavy metals, pathogenic microorganisms. Compliance with reuse standards for agricultural irrigation reduces soil and groundwater pollution, improves produce quality and productivity, and reduces energy demand for groundwater pumping and transport, thus closing the loop of water-energy-food security (Khan et al., 2008). Among the emergent challenges pertinent to reclaimed water use in irrigation is coping with the guidelines for pathogenic bacteria and emergent viruses (Rubino and Lonigro, 2008,). This is crucial to reduce the risks of widespread of water-borne diseases resulting from uncontrolled water use of poor quality (Toze, 2006).

Since the agri-food industries are the most represented with sectors such as dairies, oil mills, sugar factories, slaughterhouses(Noukeu et al., 2016), and provide a singular opportunity to explore biological effects of contamination. As many plant species can be classified in a pollution context according to their dominance in the environment (Noukeu et al., 2019). So the composition of agri-food industrial discharges varies depending on the industrial processes and the demand for water used in various production phases. However, they usually contain high levels of organic matter and nutrients, usually measured by the demand for biochemical oxygen (BOD), chemical oxygen demand (COD), total organic carbon (TOC), total suspended solids (TSS), and nitrogen Kidney (TN) and phosphorous (TP) (Dobleand Kumar 2005). Because of the rapid industries of the last two centuries, huge quantities of wastewater have been produced with the progress of the industry, especially the agri-food industry; new components were added to the lines of industrial wastewater, which led to the presence of problems that constantly needed treatment (Doble and Kumar 2005).

2.5 Composition of slaughterhouse wastes

Slaughterhouses are a significant wellspring of water contamination and GHG emanations, particularly in the creating scene. Explicit guidelines for abattoirs frequently don't exist or are inadequately checked and authorized, with wastewater regularly staying untreated and entering neighborhood streams and water sources. This speaks to a prompt ecological issue, influencing the advancement of oceanic life. Likewise, slaughterhouse squander frequently conveys zoonotic illnesses, creature sicknesses that can be moved to people (Orisakwe, 2011).

Treating effluents with regular strategies adequately lessens water contamination, however prompts expanded emanations of methane and carbon dioxide. The group along these lines set out to locate an elective methodology that would limit the carbon impression of the activity. Anaerobic fixed-film reactors were created to treat agro-mechanical waste and produce biogas. With the assistance of an adjusted type of this innovation, slaughterhouse waste could be transformed into clean family cooking gas, just as natural manure. This methodology offers at any rate three vital favorable circumstances. To start with, it limits water contamination from slaughterhouse squander. Second, it essentially decreases the GHG emanations created by the slaughterhouse and the treatment of its waste. Third, it makes important biogas items. Through biogas deal, the undertaking can turn out to be monetarily self-practical, yet transform into a productive venture too (Orisakwe, 2011).

The complex composition of slaughterhouse wastes makes it highly harmful worldwide, as it contains proteins, fats and organic substances along with the materials used in cleaning of disinfectants, detergents and veterinary drugs (Tritt et al, 1992). Therefore, wastewater treatment and disposal in slaughterhouses and meat processing plants is a public health and hygiene necessity (Debik and Coskun, 2009; Irshad and Sharma, 2015).Severe environmental and economic impacts are formed due to illegal discharges to valleys and sewage networks (Al-Saeed, 2010; Sulaiman, 2010; Al-Darawsheh, 2014).

The research studies by Wang et al., (2006), and Mahmoud et al., (2008) underlined that slaughterhouse wastewater contained metabolic by-products several organic and inorganic substances. Those could include organics, lipids, abdominal and bowel contents and blood) form cow, pigs and sheep with 66.0%, 52.0%, and 68.0% of animal live weight. Over 50.0% of the animal by-outputs are not suitable for human or animal consuming due to the physical and chemical characteristics.

2.6 Wetland and stabilization ponds systems

Constructed wetlands (CW) and waste adjustment lakes (WSP) are two mainstream techniques for common (i.e., non-electromechanical) wastewater treatment that are utilized in practically all pieces of the world. Notwithstanding, there is little data accessible (or, at any rate, promptly accessible) to help a wastewater treatment configuration engineer choose which of these two cycles is probably going to be the more proper in some random circumstance as the CW writing essentially says that CW are fantastic, and the WSP writing says the equivalent for WSP (Mara, 2005).

Waste stabilization ponds (WSPs) are open bowls encased by earthen dikes, and at times completely or halfway fixed with concrete or manufactured geofabrics. They utilize characteristic cycles to treat homegrown wastewater, septage, and slime, just as creature or mechanical squanders. They can be utilized in concentrated or semi-brought together sewerage frameworks, serving urban areas or towns; they can likewise be utilized as on location frameworks serving a solitary element (e.g., parkway rest region, public venue, and so forth) (Ayres, et al., 1993).

WSPs are much of the time utilized in blend with other sterilization advancements. The most widely recognized sorts of WSPs are anaerobic lakes, facultative lakes, development lakes, circulated air through lakes, and high-rate algal lakes (HRAPs). These lakes vary regarding their capacity in the general wastewater treatment framework. The principle capacity of anaerobic, facultative and circulated air through lakes is the evacuation of carbon-containing natural issue, while the fundamental capacity of development lakes is the expulsion of microbes. HRAPs were created to streamline the effectiveness of natural issue expulsion while at the same time considering the recuperation of broke up supplements that become joined into the algal biomass. These distinctive lake types are recognized from one another by their profundity, water powered and natural stacking rates, and by whether they utilize automated hardware for blending or air circulation. As a rule, anaerobic lakes are most profound (≥3.0 m) and are utilized first in arrangement; facultative lakes are shallower (1.5 – 3.0 m) and might be utilized first or second in arrangement (after anaerobic lakes);

development lakes are shallowest (≤1.5 m), and are utilized toward the end in arrangement. Circulated air through lakes might be utilized anyplace in a progression of lakes, and HRAPs are regularly utilized in without anyone else or among anaerobic and development lakes. For more data about the plan of WSP frameworks, allude to Shilton (2006) or Mara (2003). Figure 2 represents various sorts of lakes and one schematic of a regular WSP framework plan with three distinct kinds of lakes (anaerobic, facultative, and development) working in arrangement (Ayres, et al., 1996).

The WSPs consisted of three compartments in series, an anaerobic (AP), a facultative (FP) and a maturation (MP) pond (Ho et al., 2018), while constructed wetlands (CWs) are engineering systems that are built and designed to take advantage of and benefit from vital operations, In addition, the soil, vegetation and microbial communities to which it is linked all help and contribute to industrial wastewater treatment (Vymazal, and Kröpfelová, 2009; Stefanakis, 2018).

Artificial CWs have been considered cost effective methods for wastewater treatment, that's been prepared to exploit the chemical, physical, and biological treatment process which happens in wetland, and provides a decrease in organic material, total suspended solids, nutrients, and disease-causing organisms. Also CWs provide public benefits such as: research experimenter and entertainment uses (Zhang, 2012).

Up to nowadays there is no fixed method to design ponds and wetlands for phosphorus removal, considering phosphorus removal is one of the most difficult things to be achieved in stabilization pond systems (WSPs) and wetland (Powell et al., 2008). This can be attributed to the absence of clear mechanisms to completely remove phosphorus from a stabilization pond or a wetland system (Gratziou & Chalatsi, 2017). According to Pycha, & Lopez (2015).This removal Process depends on the phosphorus form in the sewage. Phosphorus (P) in wastewater totally appears in the form of phosphates; including organic phosphates, inorganic phosphates, polyphosphates and orthophosphate (Gratziou & Chalatsi, 2017).

According to Gratziou and Chalatsi, (2017) “In wastewater, the organic phosphorus is about one fifth of the total phosphorus (TP). At the outlet of WSPs, the organic P is approximately one third of TP and the inorganic P is two-thirds of TP. Orthophosphates are available for biological metabolism without further analysis. Usually, polyphosphates undergo hydrolysis and are converted to orthophosphate form. This process is usually very slow (Lenntech, 2015). Inorganic P is easily consumed by aquatic organisms. Some organisms are capable of storing the excess of phosphorus in the form of poly- phosphates for future use. Simultaneously, a part of the organic phosphates constantly disappears in sediments; it is trapped in an insoluble form of precipitate (Pycha and Lopez, 2015). The removed phosphorus from the water column has to be stored somewhere else and the main mechanisms that occur in phosphorus removal depend on the phosphorus form in the sewage. In a WSP system, phosphorus removal is associated with precipitation, sedimentation and hiring of the algal biomass. Since the alkalinity increases during daylight hours, the phosphate is incorporated to TSS and precipitates off wastewater (Pycha and Lopez, 2015)

2.7 Constructed wetlands

Non-point sources of nitrogen and phosphorous discharged into streams due to urban expansion and extensive agriculture escalated eutrophication process in watercourses. Started in Europe, constructed wetlands (CWs) applications have been installed to serve metropolitan sewerage facilities. Forbes et al., (2004), who studies CWs in more details, reported that widespread of CWs to different societies started mid of 80's.

Engineered constructed wetlands are applied for modern wastewater treatment, agricultural drainage, stormwater runoff, domestic, industrial and municipal waste streams (Dou, 2017).

Similarly, CWs are installed to remove nutrients behind excessive growth of algal blooms in stagnant surface water bodies (Rousseau et al., 2004). Well-designed CWs have been used in corrosive mine wastewater, stormwater runoff, urban wastewater, agricultural drainage and animals husbandry and slaughterhouse discharges. Sa`at (2006) reported on the role of CWs in controlling pollution loads including TSS, nitrogen, phosphorus, and microbial pathogens in wastewater.

Points of interest and impediments of Developed Wetland Framework Built wetlands are intended to exploit a significant number of the equivalent measures that happen in regular wetlands inside a more controlled climate. Points of interest of built wetlands include:

- Site area adaptability,
- No change of regular wetlands,
- Cycle security under changing ecological conditions,

Well designed and operated vertical flow constructed wetlands (VFCWs) could effectively applied for municipal wastewater water pretreatment with treated effluent complying with national standards pertaining to toxic substance and pathogens removal. Subsurface flow constructed wetlands have numerous crucial advantages over natural wetlands (Hoffmann and Winker, 2011).

In the work published by Plamondon et al., (2006), the efficacy of horizontal subsurface flow constructed wetlands (HSSFCWs) was not affected by low ambient temperatures. This was due to operational flow mode where water feed was kept under the media bed of medium thickness, thus avoiding cooling or freezing the water flow path.

As onsite treatment systems, Basham (2003) explored pros and contras of using constructed wetlands (CWs) as a feasible alternative for wastewater treatment. He underlined the low capital and operational expenditures for sewage transport through long sewerage mains, inexpensive unit operations, low energy and minimal uncontrolled effluent discharge into surrounding environment.

The application of constructed wetlands for black wastewater treatment may give a straightforward technical solution and an economic value indicator in reducing health and environmental risks, increased sanitation services, and improved community development (Niyonzima, 2007). According to Hoffmann and Winker (2011), planted vegetation in constructed wetlands posed no shading effect on the top media surface, and ensured treatment of black wastewater stream). Reasoning for this, Free water surface constructed wetlands (FWSCW) harbor a wide range of microorganisms including bacteria, protozoa, algae, fungi, and nematodes. (Niyonzima, 2007). However, CWs have one main constrain regarding high specific land area requirements for establishment (2-10 m^2 per inhabitant). The specific aerial demand varies depending on flow configuration, climatological conditions, and pretreatment and vegetation type, and effluent requirements. Stefanakis and Tsihrintzis (2009) concluded that constructed wetlands installation for municipal wastewater treatment in urban areas is not financially feasible, where economy and environment are in conflict.

2.7.1 Types and elements design of constructed wetlands

Constructed wetlands (CWs), manmade designed, are engineered nature-based technology for pollution control and reduction in domestic, municipal and industrial wastewater effluents. Considering the inflow pattern Niyonzima (2007) classified CWs into horizontal (free) water or surface flow and vertical subsurface flow (Fig. 2.1).

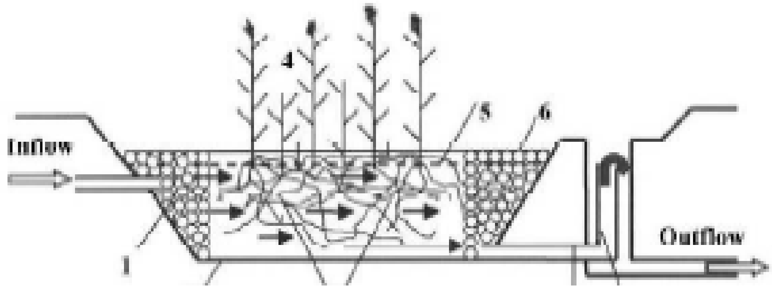


Figure 3 Constructed wetland with horizontal sub-surface flow.

UASB pretreated domestic wastewater contains less oxygen demanding biodegradable COD content and reduced toxic substance (Yamagiwa et al., 2008). Aerobic conditions within the soil media in VFCWs and associated with vegetation roots enhance oxygen transport into soil-plant-microflora. Oxygen provided through the roots and upflow water pattern provide optimal conditions for nitrification process. In their review, Vymazal and Kröpfelová (2009) grouped CWs by the type of the vegetation and flow pattern (free water surface and vertical flow) established with passive aeration conditions (Fig. 2.2).

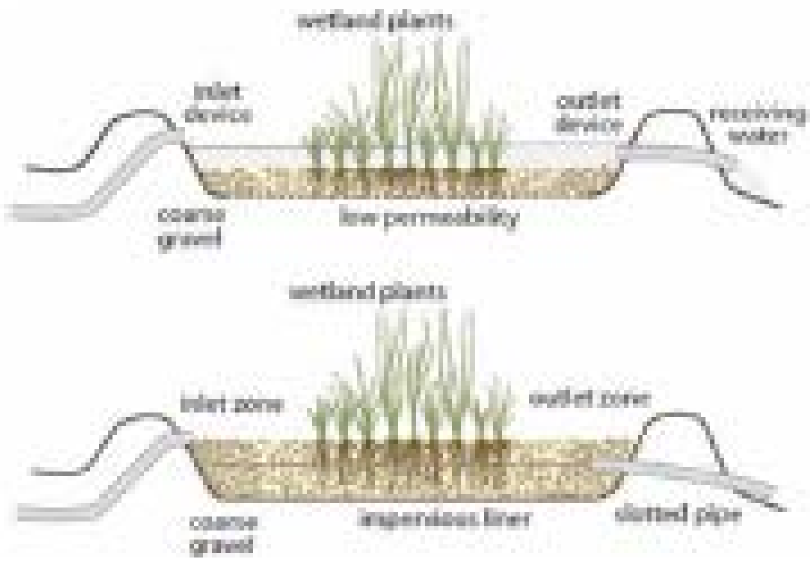


Fig. 4: CWs types: (a) FWS, (b) VF (Vymazal and Kröpfelová, 2009).

2.8 Historical and global applications of constricted wetlands

The application of constructed wetlands goes back to sixties in Germany. The wetland treatment processes entail physical, chemical and microbial activities. Vegetative CWs enhance microbial degradation through oxygen transfer by the roots, where vegetation and microorganisms in the media assimilate nutrients. Natural and constructed wetlands form carbon neutral ecosystems with oxygen production and carbon dioxide consumption through photosynthesis and biomass assimilation. Greenhouse gas reduction achieved by CWs promoted the widespread of CWs installment in Europe, USA and Asia (Hoffmann and Winker, 2011).

Luederitz et al. (2001) looked at the cleaning exhibitions of constructed horizontal flow wetlands (HFW) and vertical flow (VFW) wetlands including a little even stream wetland, a slanted HFW, bigger HFW, a defined vertical flow wetland and un-stratified VFW. Luederitz et al. (2001) reported that both HFW and VFWs eliminated over 90% of organic pollution loads and acceptable levels in nutrients removals (N and P). Control of nitrogen and phosphorus was achieved after a pretreatment stage. HFWs were less effective in nutrient removal due adsorption of phosphorus on particulate and natural organic matter. Chazarenc et al. (2003) studied six SSF constructed wetlands under variable flow patterns and hydraulic retention time (HRT). They found that HRT and flow pattern in the CWs played a major role in efficacy of organic and nutrients removal.

Ghrabi et al. (2011) investigated the efficiency of wastewater treatment plants in Tunisia for a quarter of a year. WWTPs entailed Imhoff tank, HSSFCW, subsurface vertical stream CW and level stream CW. The treatment effectiveness for SSFCW reached 85.4% for BOD, 42.7 % for COD, with lower removal percentage for nitrogen (7.1%) and 38.08 % for the removal of phosphorus.

Chazarenc et al. (2003) studied the impact of HRT in SSFCW using different flow patterns. They found that water flow in the subsurface flow caused more oxygen in the constructed media through down and upflow velocities. Planted CWs developed healthy environmental microcosm within the water surface and rhizosphere zone. Though planned water uses, evapotranspiration is more advantageous and appears to improve soil structure and effectiveness of treatment.

Zurita et al., (2009) examined four wetland treatment systems including two subsurface wetlands (horizontal and vertical flow wetlands) for domestic wastewater treatment. The research group (Zurita et al., 2009) concluded that vertical subsurface flow CWs were more efficient compared to HFCs for most of pollutants. The normal removal percentage were reported as 80% for BOD and COD, 50.6% for TKN, 72.2% for NH4. Nitrate and complete suspended solids (TSS) were reduced at higher percentages in the HSS flow CWs (NO3 = 47.7% and TSS = 82%). A recent review published by Nivala et al., (2020) reported on advances in design, installation, operation and maintenance of large scale aerated constructed wetlands.

2.9 Correlation of SF with VF constructed wetlands

Larger surface area of horizontal flow constructed wetlands made increment the water misfortune because of evapotranspiration. Vertical flow beds are desirable over horizontal flow bottoms since they have an unsaturated top layer in the bed and a more limited maintenance time than horizontal flow beds (Hoffmann and Winker, 2011).

2.9.1 Favorable circumstances of VFCW

Vertical flow constructed wetlands (VFCW) can accomplish good oxygenation capacity through passive infiltration and void spaces in the media, thus improves the environmental process conditions for wastewater treatment. Provision of oxygen is crucial for the microbial activities in aerobic organic and nitrification. Aerobic conditions enhance heterotrophic activity for pollutant oxidation. These environmental conditions in CWs are feasible for domestic and municipal wastewater treatment. Stefanakis and Tsihrintzis (2009) reported on VFCWs treating municipal sewage with high BOD_5 (95%) removal and 90% for nitrogen and with only about 50% efficacy in total phosphorous removal.

2.9.2 Detriments of VFCW

Low levels of phosphorous removal rates in natural constructed wetlands (Stefanakis and Tsihrintzis, 2009) were reported due to insufficient hydraulic retention times (reduced contact time between biomass and substrate). The regular energy consumption reported for constructed wetlands range from 10 to 20 kWh/PE*year, reaching secondary treatment. For tertiary treatment, 50-100 kWh/PE*year are consumed. Considering the planned treatment objectives, energy could vary depending on the treatment technology opted for. As a rule, developed wetlands have demonstrated to be extremely effective in controlling the COD content (>90%), suspended solids (>90%) and pathogens (3-4 log units). However, with less capacity in nutrient removals (TKN 40-60% and total phosphate 20-40%) as reported by Stefanakis and Tsihrintzis (2009).

2.10 Examination of subsurface stream built wetlands with lakes

Lakes are hard to incorporate in metropolitan regions because of their vast water surface, mosquitoes and scent. Then again, lakes are simpler to plan and develop furthermore; they needn't bother with a material and have lower principle expenses for huge scope plants. Constructed wetlands have essentially lower activity and upkeep expenses contrasted with high-tech and increased development impacts associated with energy consumption and logistics.

According to Hoffman and Winkler (2011), large urban treatment systems serving 10000 inhabitants could be a feasible alternative using constructed wetlands conditional that land is accessible economically. Lakes have lower capital expenditure compared with constructed wetlands.

CHAPTER 3 Materials and Methods

3.1 Materials

In this study, a mixture of two different agrifood industrial wastewaters with unique characteristics, first UASB anaerobically pre-treated, formed the main inlet for posttreatment:

- Wastewater from a poultry slaughterhouse: High contents in lipids and particulate organic matter.
- Olive mill wastewater [OMWW; Zibar] from a nearby olive mill press: High organic content of volatile, soluble and slowly biodegradable COD fractions (total phenols).

Therefore, such type of agrifood industrial wastewaters should be treated efficiently prior to connection to the public sewerage network or discharge into receiving environment to ensure the safe disposal and beneficial uses.

Frequent sampling and characterization of the anaerobically pretreated mixed industrial wastewater entailed testing of physical and chemical parameters. Those included pH, temperature, dissolved oxygen, biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), ammonium-N (NH_4-N), nitrate-N (NO_3-N), total phosphorus (TP). Selective heavy metals (Zn, Fe, Mn, Cu, Ni, Pb, and Cr) were measured in the inlet and outlet of CWs and vegetation samples (stems and leaves) from the constructed wetlands. All samples will be prepared and analyzed according to APHA (2005).

3.2 Methodology

(1) Research Type

This research, an applied study, was performed using a pilot scale system of vertical flow constructed wetlands (CWs), installed on the campus of Birzeit University, Palestine.

(2) Aims and Group Samples

Slaughterhouse holders, olive manufactory holders, municipalities, water and environmental foundation

(3) Research Tools/ equipment: secondary treatment, Basins constructed wetland.

(4) Research method of analysis: System monitoring and process control, sampling and lab analysis at Birzeit University Testing Laboratory Center.

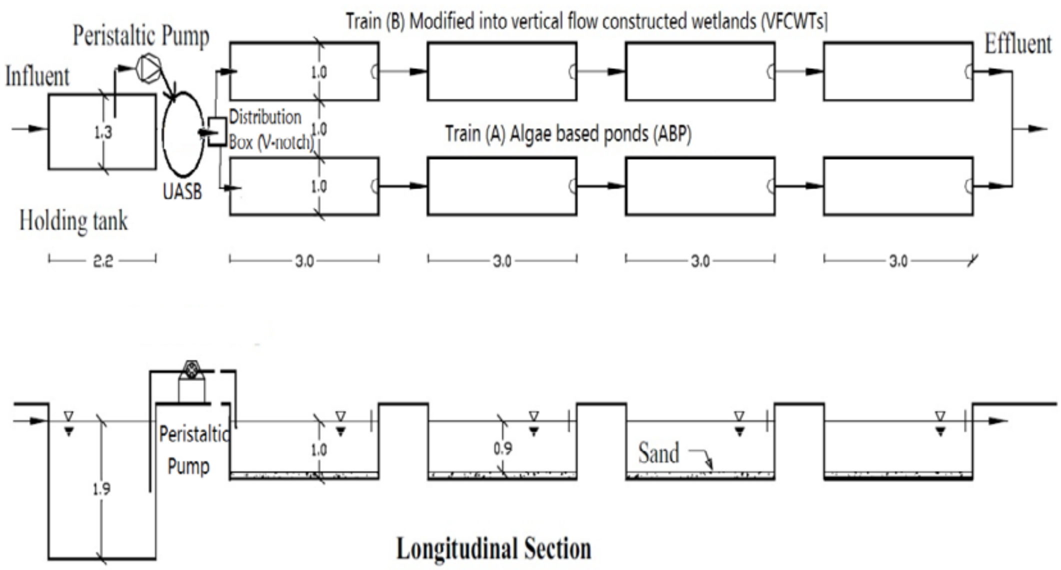


Fig (5) Vertical flow constructed wetlands (Train B).

The Duckweed based ponds [Train A] was not operated as of the following reasons:

- Insufficient flow rate feeding the CWs due to high organic content of the industrial effluents and avoid overloading the UASB reactor.
- COVID-19 delayed the installment of the second UASB to ensure hydraulic load for the CWs.

3.3 Water Sampling and Analysis

The industrial effluents from a slaughterhouse in Birzeit town and nearby olive oil mill presses were collected and transported by a truck to BZU campus. Then a mixture of variable ratios was prepared before fed to an equalization tank (5 m^3). Using peristaltic pumps, the UASB reactors were fed with mixed and equalized industrial mixture for pretreatment. This mixture was pretreated anaerobically using two UASB reactors (Najajra, 2020).

- Water samples were taken from the inlet and outlet of each constructed wetland cell. The CWs system, four built cells in series, was operated in a vertical flow mode. Each the of the CWs cells, constructed in series, has an area of 3 m^2 with a volume of 2.5 m^3 (in total 12 m^2 and about 10 m^3). All CWs cells were planted with common reed (*Phragmites australis*) in gravel, where roots play a key role in purifying the incoming anaerobically pretreated wastewater. The *Phragmites australis* species (*P. australis*) seedlings were collected from Misilya large-scale constructed wetlands (CWs), treating domestic wastewater from a small rural community in Jenin district (PWA, 2016). Based on published literature (El-Khateeb et al., 2008; Kadlec and Wallace, 2009; Hoffmann and Winker, 2011) a number of 3-5 seedlings were planted in each cell of the pilot system at Birzeit University.

- During study period (May-October 2020), grab samples (after the start-up stage) were collected from the inlet and outlet of constructed wetland beds (CW1, CW2 and CW4) and analyzed for TSS, COD, TKN, heavy metals and total phenols according to the APHA Standard Methods (APHA, 2005). Water samples, collected using plastic bottles between 9:00 AM and 12:00 PM, and stored at four (4) ºC until lab testing.

3.4 Pilot UASB-Constructed Wetlands: operation and control

Figure 6 shows the pilot system working with one reactor (UASB 1), and then another (UASB 2) was put into operation to investigate the impacts of variable operational parameters. Transported from a poultry slaughterhouse, fresh slaughterhouse wastewater was mixed with olive mill wastewaters, with intermittent mixing in a balancing tank. Two heavy duty and adjustable variable peristaltic pumps fed the two UASB systems, with the first system operated under low organic loading rate conditions (Najajra, 2020).

Fig (6): Pilot system of constructed wetlands at Birzeit University campus

-The mixing ratio of olive mill wastewater and the margarine was unchanged (fixed), and the variable percentage was due to the average feeding of the two systems (UASB1 and UASB2) The flow for UASB1 was 166 l / day, and the flow rate for (UASB2) was 230 l / day.

- 500 liters of wastewater for slaughterhouses and 16 liters of sewage water were added to olive presses in July and mixed together

- 5016 liters of wastewater of olive presses were added to the tank and mixed with the previous mixture at the beginning of August.

-500 liters of slaughterhouse water and 16 liters of sewage water were added to olive presses at the end of August 2020. As stated before, having the UASB installed as a pretreatment stage for the agrifood industrial mixture, the anaerobically pretreated effluent formed the influent for the constructed wetland system.

3.4.1 Hydraulic Retention Time (HRT)

- During June, the wastewater flow was 0.166 m^3/day.

Hydraulic Retention Time = $volume/flow$

HRT = 3m^3 *4/0.166 m^3/day

= 72 day, which is too long.

July and August 2020, the wastewater flow was increased to 0.6 m^3/day

HRT= $volume/flow$

HRT= 12 m^3/0.6 m^3/day; equals 20 day

- During September, the flow was 0.7 m^3/day.

Hydraulic Retention Time = $volume/flow$

HRT = 3m^3 * 4/0.7 m^3/day; which equals 17 day

At first, the flow was few because of the high evaporation resulting that the water did not reach to third and fourth CW ponds to have sampling done (Fig. 7). So a second UASB was installed, the flow increased starting from July, August and September 2020.

Fig (7): Sampling procedure of the inlet and CWs 4 ponds under study

3.4.2 Organic Surface Loading Rates (SLR_{COD} and SLR_{TKN})

The CWs pilot system was operated at variable hydraulic and organic surface loading rates for COD and TKN (SLR_{COD} and SLR_{TKN}). The detailed operational conditions are summarized in Annex 2 and 3.

3.4.3 Scope, Challenges and Limitations

To the best of our knowledge, this study is the first of its kind to use a pilot CWs system for the treatment of agrifood industrial effluents under variable hydraulic and organic surface loading rated. Published literature (e.g. Brix and Arias, 2005; Molle et al., 2005; Kadlec and Wallace, 2009; Konnerup et al., 2009; Almasi et al., 2011; Abed et al., 2016) accumulated a bulk of knowledge on using CWs for domestic and municipal wastewater treatment. Only few studies were found on using CWs for individual industrial wastewater (e,g, Vymazal, 2009; Vymazal and Kröpfelová (2009); Kato et al., 2010; Dan et al., 2011).

Annex 4 shows the sampled vegetation (plant parts) of *P. australis* species for lab analysis to measure the potential of CWs for heavy metals accumulation. Shoots, stems and leaves were taken, grinded and preserved for lab analysis, as the apparatus was under maintenance and COVID-19 pandemic delayed the repair.

Chapter 4 – Results and Discussion

4.1 General

This chapter presents the results on the performance of the constructed wetlands (CWs) pilot system, consisted of four CW beds in series, over the study period (May and October 2020). The UASB effluent formed the influent for the CWs. Grab water samples, taken from constructed wetlands (CW1, CW2, and CW4), were analyzed for physical and chemical parameters.

4.2 UASB effluent characteristics

4.2.1 UASB effluent physical parameters

The pH value (6.5-8.5), reflecting the chemical characteristics of in UASB effluent, feeding the CWs play a key role in the biological activities carried by the vegetation and soil microbial communities (Metcalf, 2003). According to Abed et al. (2016), who considered that pH of the UASB outlet (pH = 8) has no significant impacts on bench-scale constructed wetlands treating domestic wastewater.

The pH level measured including those reported by Najarja (2020) for the UASB pretreated mixed industrial wastewater varied from 6.90 to 7.70. These pH values are within the favorable range for microbial activities, so the inlet pH was not adjusted.

The acidity of the water flowing from the UASB effluent, which forms the influent for the pilot constructed wetlands system was in the normal range for treatment.

The water temperature was affected by the ambient temperature of the local weather conditions, which varied between 25 and 35 °C during the study period.

4.3 Constructed Wetlands Performance

4.3.1 COD removal efficiency

The overall assessment for CWs capacity to reduce organic pollution loads for anaerobically pretreated mixed industrial wastewater reflected a wide variation (17-80%) after the start-up phase in May 2020. Figure 8 shows the variations in removal efficiency for the CW beds during June until July 2020 at variable hydraulic and organic loads. Detailed results on the removal percentages and mass removal rates (g COD/m^2.d) can be found in Annex 2.

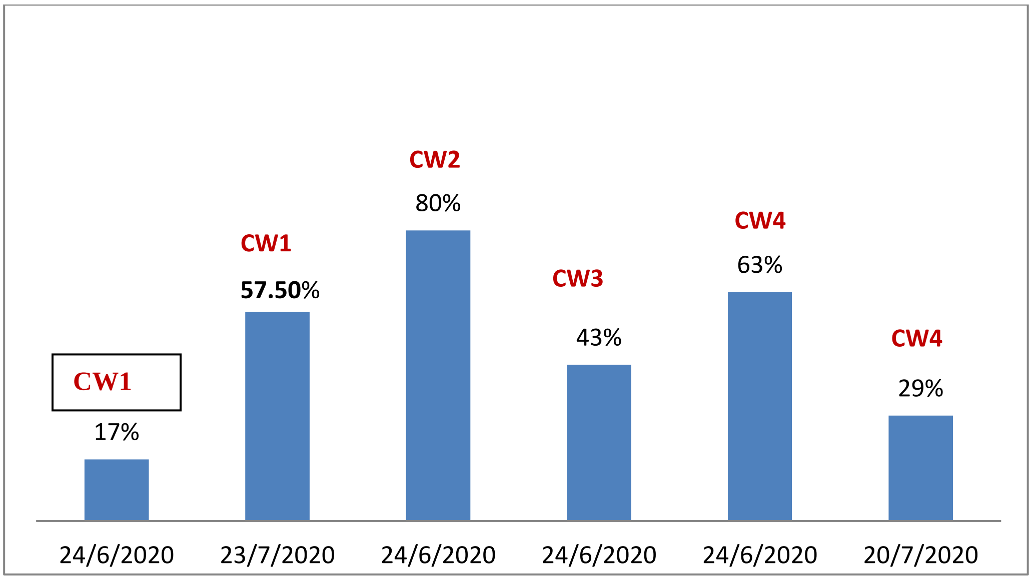


Fig (8): COD Removal Efficiency in constructed wetland system VS time

At average loading rates for COD (64.6-145 g/(m^2.d), the removal efficiency for COD in the four CWs ponds (beds) is depicted in Figure 8. A summary for the results is as follows:

-COD removal efficiency range for CW system (17-80%), Average value (48.1 %).

- The effectiveness of COD removal efficiency differs from one basin to another depending on the flow rate, which varies from date to date and on HRT.

- On date 24/6/2020, the readings of COD removal efficiency were different for the four ponds, although the sample was taken at the same time (CW1, 17%), (CW2, 80%), (CW3, 43%) and (CW4, 63%).

4.3.2 Total Kjeldahl Nitrogen

The constructed wetlands (CW1 and CW2), showed different removal efficiencies for total Kjeldahl nitrogen (TKN). Figures 9 and 10 present the data on TKN in the inlet and outlet of CWs including the removal percentages in both CWs with time. In this study, CWs were operated and monitored at average loading rates for TKN (21.4-34.4 g /(m^2.d). More ddetailed results on the removal percentages and mass removal rates (g TKN/m^2.d) for the overall system can be found in Annex 3.

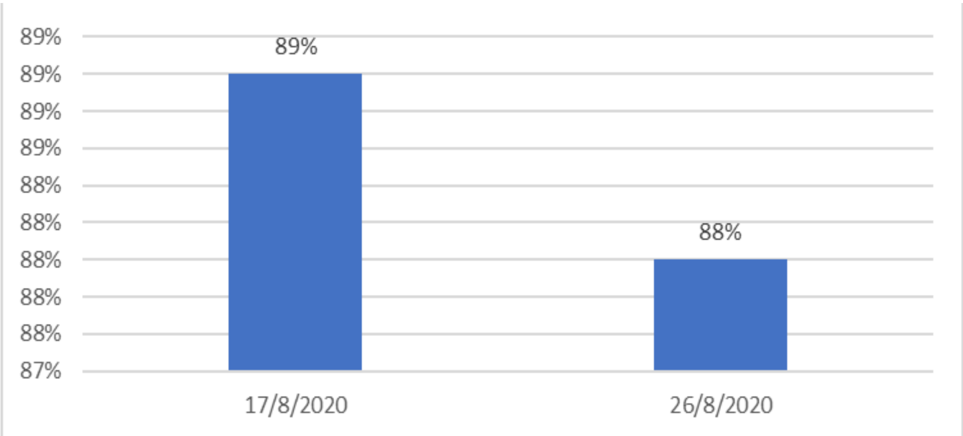


Fig (9): TKN removal percentage in CW1 with time

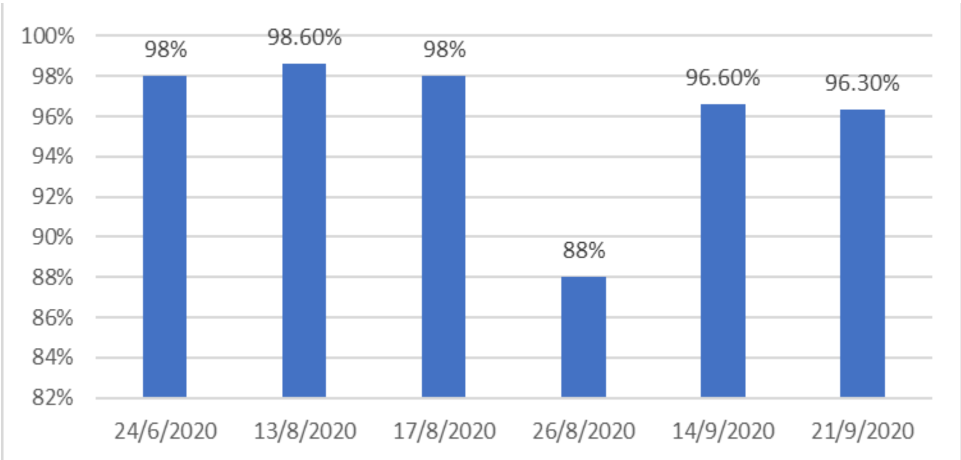


Fig (10): TKN removal efficiency in CW2 with time

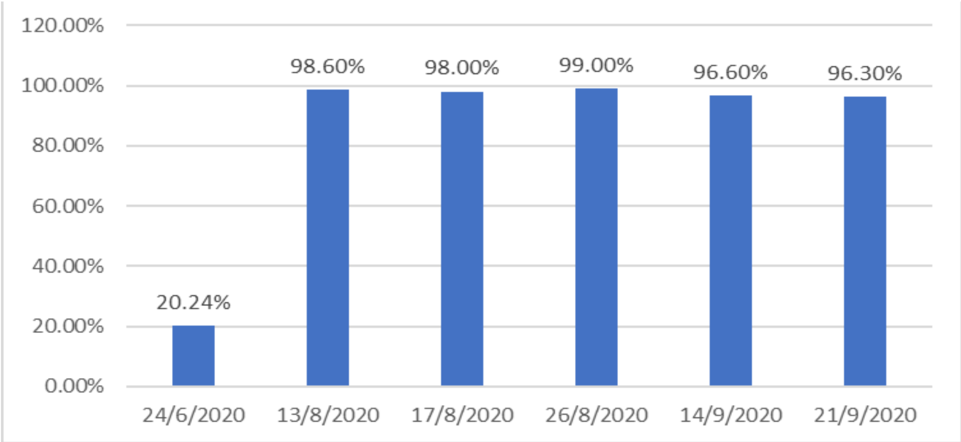


Fig (11): TKN removal percentage in CW4 with time

Figure 11 illustrates the CWs efficacy in TKN removal, listed below:

TKN was partially removed in CW1 and was no difference between the two samples in TKN removes. The TKN removal efficiency range in CW2 is (88-98.6%), Average value (95.9%). TKN removal efficiency range in CW4 is (20-98.9%), Average value (84.7%). TKN removal efficiency range in constructed wetland (all CW beds) is (20-99%), Average value (83.8%). Kato et al., (2010) reported similar achieved nitrogen removal rate in CWs systems treating dairy and swine wastewater.

4.3.3 VSS removal percentage

The CWs under investigation showed excellent reductions in VSS content. CW number 2 reflected slight difference during different hydraulic loads (Fig. 12 and 13). The removal efficacy reached 99% in the VSS reduction.

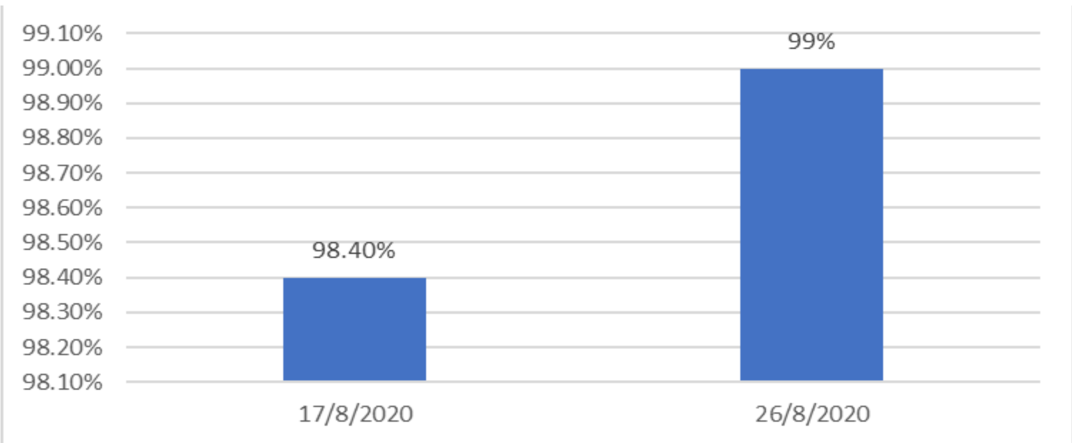


Fig (12): VSS removal percentage in CW1 with time

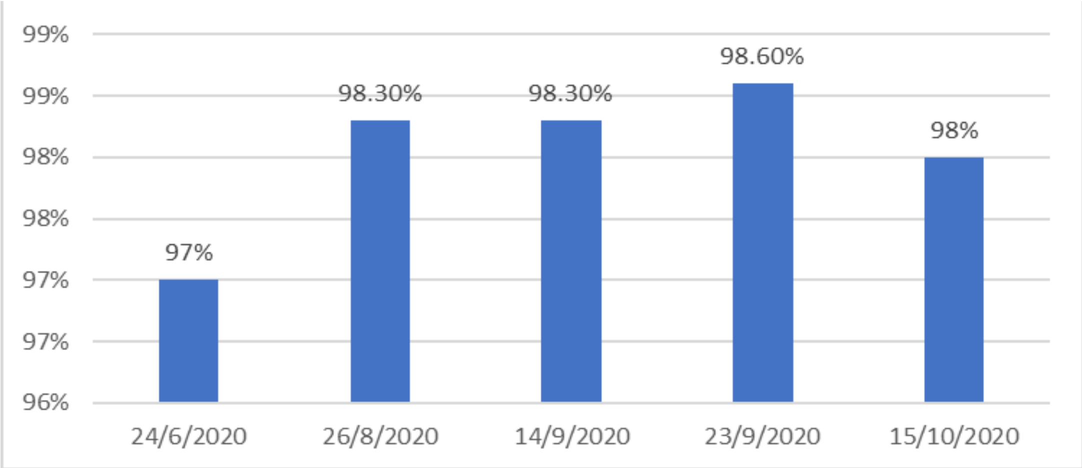


Fig (13): VSS removal percentage in CW2 with time

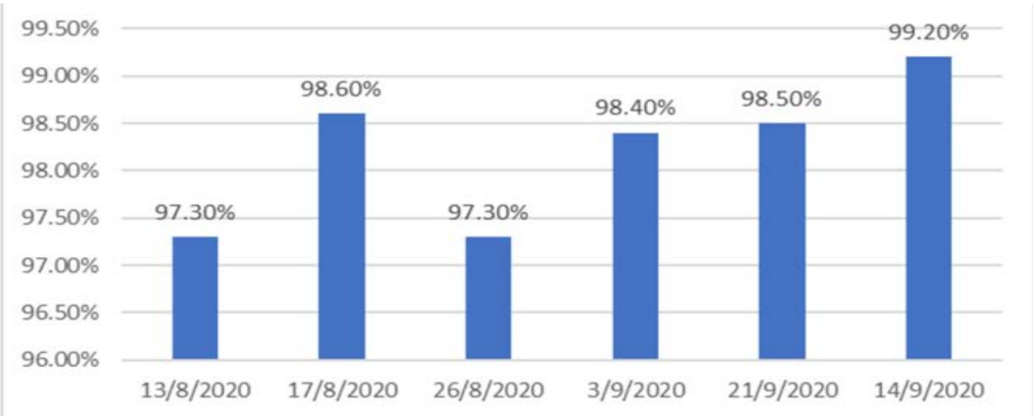


Fig (14): VSS removal percentage in CW4 with time

The variation in removal efficacy (Fig. 14) for VSS reduction in CW4 during the study period shows the following tendency:

- VSS removal efficiency in CW1and was no different there between the two samples in VSS removes. The removal efficiency of CW2 for VSS ranged between 97 and 98.6% with an average value of 98%.
- VSS removal efficiency range in CW4 is (97.3-99.2%), Average value (98. %).
- VSS removal efficiency range in constructed wetland (all beds) is (97-99.2%), Average value (98.2%).

4.3.4 Constructed wetlands performance in TSS reduction

During the study period (June-October, 2020), the removal performance for the total suspended solids (TSS) in CW1 is depicted in Figures 15 and 16 for CW2.

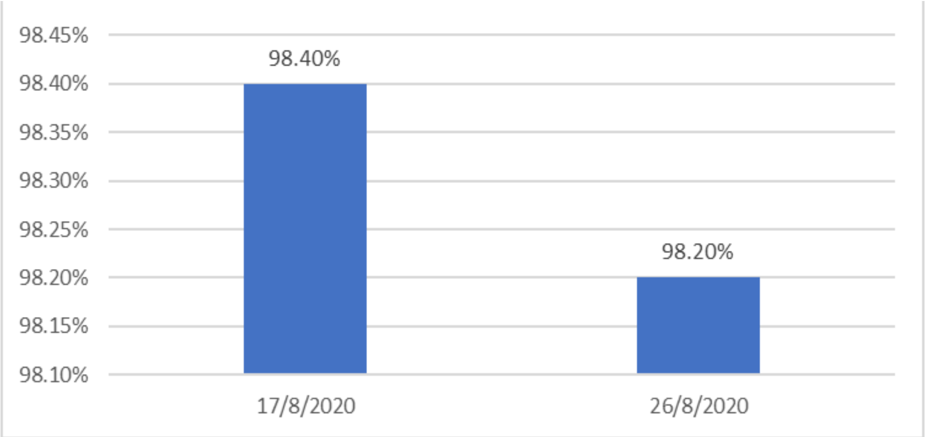


Fig (15): TSS removal percentage in CW1 with time

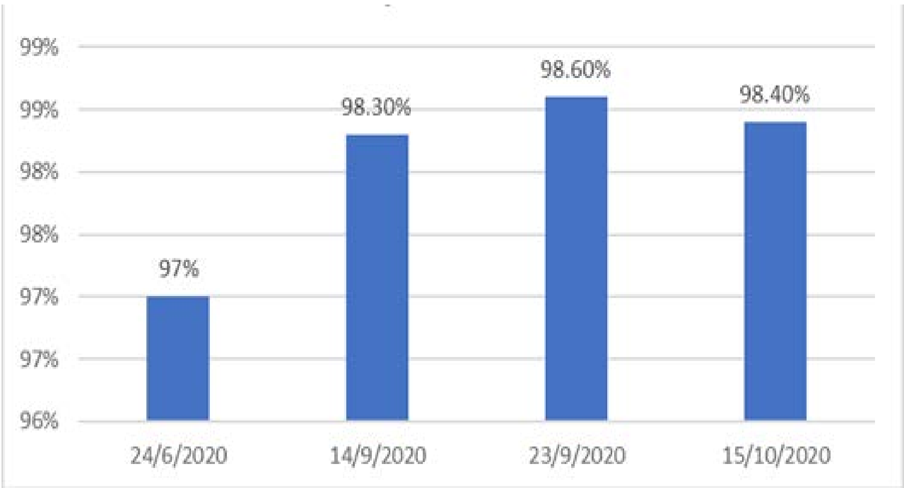


Fig (16): TSS removal percentage in CW2 with time

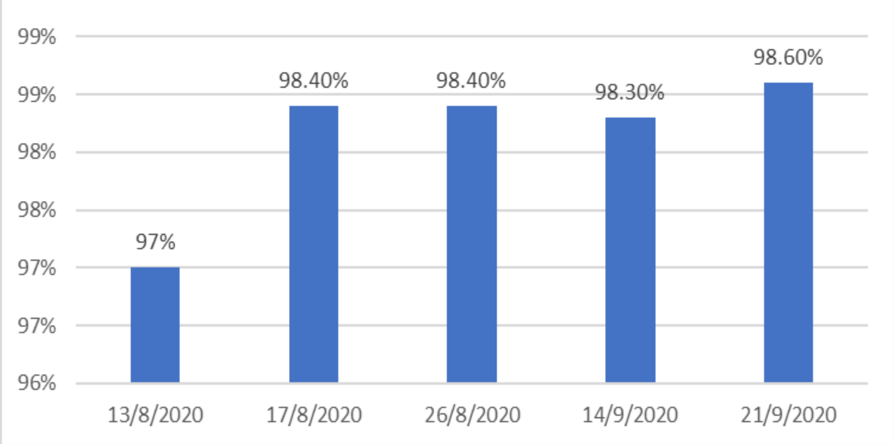


Fig (17): TSS removal percentage in CW4 with time

The data in Figure (17) entails the followings facts:

- TSS removal efficiency in pond#1and was no different there between the two samples in TSS removes; the average value is (98%)
- TSS removal efficiency range in pond#2 is (97.2-98.6%), Average value (98%).
- VSS removal efficiency range in pond#4 is (97.3-98.6%), Average value (98. %).
- VSS removal efficiency range in constructed wetland (all ponds) is (97-99.2%), Average value (98.2%).

There was no different in VSS removal efficiency between constructed wetland ponds, high efficiency removal for each one.

4.3.5 Heavy metals removal efficiency

Figures 18-20 depict the removal efficiency in percentages for selective heavy metals (HMs). The HMs included testing for zinc, chromium, copper, lead, and cadmium in water samples. The and phenol for each pond from the four ponds in constructed wetland system

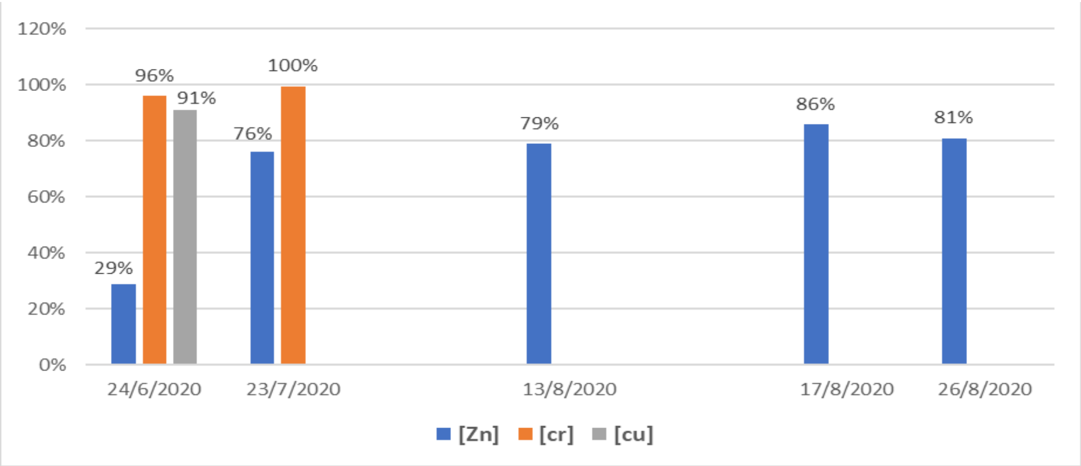


Fig (18): Zinc, chromium and cupper removal efficiency in CW1 with time

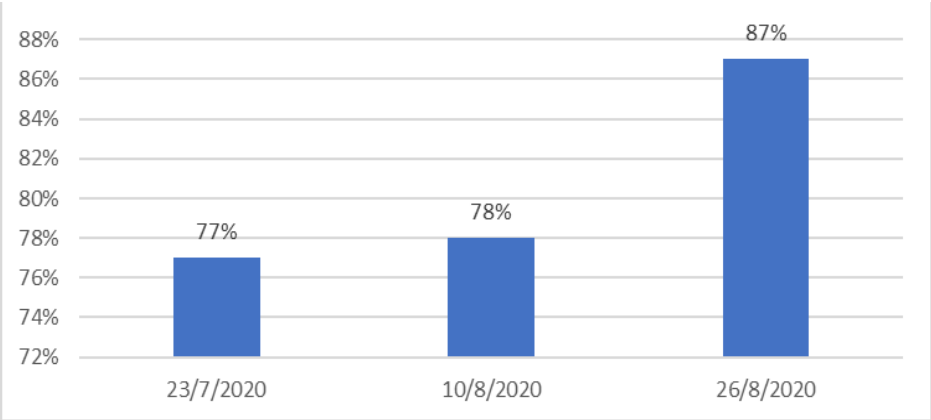


Fig (19): Zinc, chromium and copper removal efficiency in CW2 with time

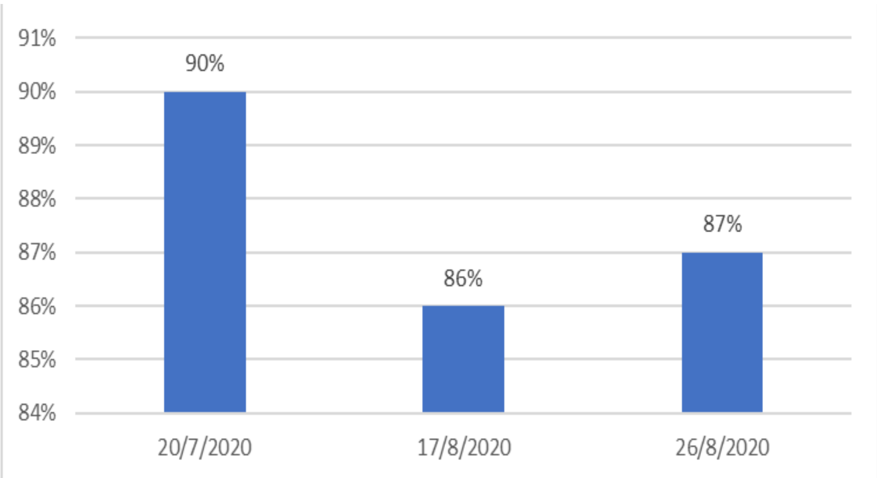


Fig (20): Zinc, chromium and copper removal efficiency in CW4 with time

Removal efficiency for heavy metals results are scale and represented in charts above.

- CW1 outlet: The removal efficiency for zinc, chromium and copper in water samples taken on 24/9/2020 was 29%, 96%, and 91%, respectively. On 23/7/2020, the removal efficiency for zinc and chromium was 76% and 100%.

On 13/8/2020, 17/8/2020 and 26/8/2020 the removal efficiency for zinc was 79%, 86%nd 81% respectively. The chromium and copper was does not exist.

- CW2 outlet: Water sample taken during July and August (23/7/2020, 10/8/2020 and 26/8/2020) revealed a removal efficiency for zinc of 77%, 78%nd 87%, respectively. Neither chromium and nor copper was detected.
- CW4 outlet: Water samples (20/7/2020, 17/8/2020 and 26/8/2020) showed a removal efficiency for zinc of 90%, 86%nd 87%, respectively. Cr and Cu were not detected.
- The efficiency of heavy metals removal in all the pond samples is close to the samples that were taken on the same date and their difference was slight, and the efficiency of removing heavy metals may increase all that we went to the basins respectively.
- Zinc removal efficiency range for constructed wetland system is (29-90%), Average value (77.8 %). Chromium removal efficiency rang for constructed wetland is (96-100%), Average value (98%). Copper removal efficiency reached 91%.

4.3.6 Phenol

Since olive mills were not working during the study investigation (May-October 2020), old OMW stored in BZU Lab refrigerator from last year, was co-mixed with the poultry slaughterhouse wastewater. It is worth mentioning, that results on total phenols revealed trace contents in the inlet of the CWs. Therefore, results on total phenol impacts and removal in both the UASB and CWs were erratic and not to compare with published literature (Najajra, 2020).

Chapter 5 Conclusions and Recommendations

5.1 Conclusions

The present study indicated that the CWs pilot system planted with *Phragmites australis* species is a promising solution for polishing UASB pre-treated mixed effluents from poultry slaughterhouse and olive mill press to levels complying with local discharge regulations.

- Preceded by two UASB reactors, vertical flow constructed wetlands (four in series operated beds), were eeffective in removing TSS, COD, TKN and heavy metals from the mixed agrifood industrial effluents.
- Heat waves with temperatures ranging between 25 and 35 (June to August) induced high evapotranspiration rates in the beds of the constructed wetlands (CWs).
  - The purification efficacy of CWs for mixed industrial water from olive presses and poultry slaughterhouses was satisfactory with high removal percentages (95% - 99%). The average removal rates achieved were for COD (33.2-67.7 g/(m^2.d) and for TKN (10.5-21.2 g /(m^2.d).
- The results for constructed wetland system shown high removal efficiency for chromium (98%) and copper (91%).
- Based on the results obtained, the constructed wetlands (CWs) are efficient as posttreatment for the anaerobically pretreated mixed agrifood industrial wastewater (olive mills and slaughterhouses). The quality of treated water from the CWs pilot system allows further for multi-beneficial water reuses including landscape and agricultural irrigation.

5.2 Recommendation

Based on the results obtained from the research study described in this M.Sc. thesis, the following aspects deserve attention and require further investigations:

- The effectiveness of CWs in the reduction of organic pollution loads from industrial effluents requires confirmation under variable organic loading rates and variable mixing rates during the winter season. .
- To optimize the nutrient removals (nitrogen and phosphor) the CWs pilot used in this research study, intermittent feed and effluent recirculation could improve effluent quality, thus warrants further studies.
- Considering rural areas as the source of agrifood industrial liquid streams from olive mills, dairies and slaughterhouses, installing UASB reactors at current large-scale CWs is recommended as a feasible pretreatment option for the treatment of seasonal organic-rich agrifood industrial effluents.
- Long-term research studies are needed, if existing CWs are scaled-up by UASB systems, where operation optimization and biogas utilization are of crucial importance.

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Annex 1: Photos from the Lab and study area

Overview of the pilot UASB-constructed wetlands system

Last three beds of the four beds in series of the pilot CWs installed at Birzeit University


Photo of the constructed wetland basin cultivated with common reeds


Water sampling from outlet of constructed wetland (CW2)


Water sampling for analysis

Final outlet from the constructed wetlands

Water samples collected from various beds of the constructed wetlands

Discussion round on work progress and system monitoring at Birzeit University

Annex 2: Sampling and COD lab analysis for the inlet and outlet of constructed wetlands*)

Determination of COD removal rates (g COD/m^2.d)

Constructed wetlands Bed Number	Date	COD inlet (mg/l)	Loading Rate g COD/(m^2.d)	COD outlet (mg/l)	COD removal (g/m^3)	Flow (m^3/d) (m^3/d)	Surface Area (m^2)	Removal Rate g COD/(m^2.d)
CW1	24-06-20	1020	73.4	846	174	0.216	3	12.528
CW1	23-07-20	1540	110.9	653	887	0.216	3	63.864
CW1	17-08-20	1150	197.8	890	260	0.516	3	44.72
CW1	26-08-20	1150	197.8	280	870	0.516	3	149.64
Average [June-August]		1215	145	667	548	0.366	3	67.7
CW2	24-06-20	846	60.9	536	310	0.216	3	22.32
CW2	10-08-20	1080	185.8	424	656	0.516	3	112.832
CW2	14-09-20	818	140.7	590	228	0.516	3	39.216
CW2	23-09-20	818	140.7	510	308	0.516	3	52.976
Average [June-September]		890.5	132.0	515.0	375.5	0.441	3	56.8
CW4	24-06-20	580	41.8	390	190	0.216	3	13.68
CW4	20-07-20	1250	215.0	1126	124	0.516	3	21.328
CW4	10-08-20	424	72.9	210	214	0.516	3	36.808
CW4	17-08-20	424	72.9	163	261	0.516	3	44.892
CW4	26-08-20	490	35.3	280	210	0.216	3	15.12
CW4	14-09-20	450	77.4	240	210	0.516	3	36.12
Average [June-September]		447.0	64.6	223.3	223.8	0.441	3	33.2

*) *The constructed wetlands pilot consists of four (4) cells arranged in series (CW1, CW2, CW3, and CW4)*

Annex 3: Sampling and TKN lab analysis for the inlet and outlet of constructed wetlands*)

Determination of TKN removal rates (g TKN/m^2.d)

Constructed wetlands Basin Number	Date	TKN inlet (mg/l)	Loading Rate g TKN/(m^2.d)	TKN outlet (mg/l)	TKN removal (g/m^3)	Flow (m^3/d)	Surface Area (m^2)	Removal Rate g TKN/(m^2.d)
CW1	24-06-20	381	27.4	179	202	0.216	3	14.5
CW1	17-08-20	230	16.6	183	47	0.216	3	3.4
CW1	26-08-20	470	80.8	205	265	0.516	3	45.6
Average [June-August]		360	41.6	189.0	171.2	0.316	3	21.2
CW2	24-06-20	179	30.8	96	83	0.516	3	14.3
CW2	10-08-20	192	13.8	76	116	0.216	3	8.4
CW2	26-08-20	235	40.4	45	190	0.516	3	32.7
CW2	14-09-20	300	51.6	186	114	0.516	3	19.6
CW2	23-09-20	220	37.8	191	29	0.516	3	5.0
Average [June-September]		225	43.3	118.8	106.4	0.456	3	16.0
CW4	24-06-20	82	5.9	21	61	0.216	3	4.4
CW4	10-08-20	65	11.2	23	42	0.516	3	7.2
CW4	17-08-20	90	15.5	24	66	0.516	3	11.4
CW4	26-08-20	45	7.7	15	30	0.516	3	5.2
CW4	03-09-20	160	11.5	65	95	0.216	3	6.8
CW4	14-09-20	186	32.0	62	124	0.516	3	21.3
CW4	21-09-20	121	20.8	22	99	0.516	3	17.0
Average [June-September]		107	21.4	33.1	73.9	0.430	3	10.5

*) *The constructed wetlands pilot consists of four (4) cells arranged in series (CW1, CW2, CW3, and CW4)*

Annex 4: Vegetation samples for heavy metals analysis (phytoremediation)