Faculty of Graduate Studies
Master Program in Water and Environmental Engineering

M.Sc. Thesis

Comparative Assessment of Pilot Scale Ecotechnologies for Wastewater Treatment and Effluent Reuse of from a Poultry Slaughterhouse

تقييم مقارن لتكنولوجيات بيئية على نطاق تجريبي لمعالجة وإعادة استخدام مياه الصرف الصحي من مسلخ دواجن

Submitted By:

Mohammad Hussin (1195080)

Supervisor:

Prof. Dr.-Eng. Rashed Al-Sa`ed

June 2021

Examination Committee Approval

Comparative Assessment of Pilot Scale Ecotechnologies for Wastewater Treatment and Effluent Reuse of from a Poultry Slaughterhouse

تقييم مقارن لتكنولوجيات بيئية على نطاق تجريبي لمعالجة وإعادة استخدام مياه الصرف الصحي من مسلخ دواجن

Submitted by:

Mohammad Hussin

(1195080)

This Thesis was prepared under the supervision of Prof. Dr.-Eng. Rashed Al-Sa'ed and has been approved by all members of the examination committee

Prof. Dr.-Eng. Rashed Al-Sa'ed (Chairman of the committee) Signature Dr. Al-Sa'ed

Dr. Maher Abu-Madi (Member) Signature

Dr. Omar Zimmo (Member) Signature. Omar Zimmo

Date of Defense: 02.06.2021

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

DEDICATION

I dedicate this research to my wonderful loving parents, mother and father, who always encouraged me to succeed. To my life partner, for her encouragement and motivation to sustain success and creativity throughout my thesis works. To my supervisor, brothers, friends, and to everyone, who gave me a hand, I wish a better future for all,

I dedicate my work

Acknowledgments

Foremost, I would like to express my sincere gratitude to my advisor Prof. Rashed Al-Sa`ed for the continuous support of my Master thesis, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my MSc thesis. I would like to thank Dr. Maher Abu-Madi and Dr. Omar Zimmo, members of the examination committee, for their insightful comments, and the hard questions they raised during the defense.

My sincere thanks also go to Birzeit University Testing Laboratories for helping me conduct the required tests in the research.

I acknowledge the financial support provided by the Dutch Government to carry out thesis works through the DUPC2 (MENARA project) and PADUCO2 (INWA project) Programs.

Last but not the least, I would like to thank my family, my wife, relatives and friends for supporting me throughout this journey and strengthened my determination to bring it to light.

Contents

List of Tables

List of Figures

List of Abbreviations

BOD	Biochemical Oxygen Demand
COD	Chemical Oxidant Demand
FAO	Food and Agriculture Organization
HRT	Hydraulic Retention Time
IEMS	Integrated Environmental Management Strategy
MWW	Municipal Wastewater
OLR	Organic Loading Rate
pH	Negative log of the activity of the hydrogen ion
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TSS	Total Suspended Solid
UASB	Up Flow Anaerobic Sludge Reactor
WWT	Wastewater Treatment
WSPs	Waste stabilization ponds
vfCWs	Vertical flow constructed wetlands

Abstract

Cleaner production and pollution prevention from the agri-food industries firms require huge capital and annual operating expenses due to the installation of conventional and advanced treatment techniques. Consequently, Palestinian policy and decision makers are facing great challenges in imposing and implementing laws and legislations related to pollutants resulting from industrial activities. Discharges of Untreated industrial wastewater leads to environmental deterioration and public sewerage networks, if directly discharged into nearby streams or illegally connected to public sewer network. In the event that it is disposed of in the public network without treatment, treatment plants experience troubleshooting and noncompliance with effluent guidelines. Direct discharge into streams Without prior treatment, poses a great risk of contamination to soil, surface water and seepage into groundwater. In Palestine, there are more than 35 slaughterhouses currently in operation, including: 21 slaughterhouses for sheep and cows, and 14 slaughterhouses for poultry. Several slaughterhouses in Palestine drain their wastewater into the sewage network without primary treatment, and some of them drain it directly into wadis. This wastewater usually contains high levels of organic matter and nutrients such as COD (5,000 - 15,000 mg / L).

This study attempts to solve the problem by establishing and monitoring the effectiveness of two pilot nature-based systems: the first is for constructed wetlands (CWs) cultivated with Phragmites australis, and the second system is duckweed-based waste stabilization ponds(dWSPs). Installed on Birzeit university campus, Palestine, both systems were used as post-treatment stage for anaerobically pre-treatment industrial wastewater using UASB reactors. For a period of four months (November 2020 to March 2021) the two pilot systems, vfCWs and dWSPs (four ponds, 3 m^3 each) were monitored fed by an average daily rates of organic loads COD (58-187 g / m^2) and TKN (6.1-21.5 g / m^2).

The efficacy of both pilot systems was evaluated for the removal of organic pollution (COD) and nitrogen removal rates in liquid line and in the vegetation samples (vfCWs) and algae samples (dWSPs).

The results obtained showed satisfactory results for both systems under study. At an average surface organic loading of 106 g COD/m^2.d, constructed wetlands revealed removal efficiencies for COD, TSS, TKN, PO4 were 83%, 80%, 70%, 66%, respectively. The removal efficiencies for dWSPs were COD, TSS, TKN, PO4, 79%, 72%, 74% and 68%, respectively, at the same average organic loading (COD 106g / m^2).

Improving the operation of the two systems and long-term investigations require further exploration to ensure that the treated water complies with local reuse standards and to ensure safe disposal into the receiving environment. Nature-based biological treatment systems are environmentally sound options to polish the quality of treated water to a high standard that complies with Palestinian technical rules for recycling in agricultural irrigation purpose. The results of the research help to bridge the gap in the circular economy problem with regard to the effective use of treated water for various useful purposes, and thus contribute to maintaining water-food energy security in Palestine.

The research results provide technical assistance to Palestinian policy makers to integrate nature-based solutions as possible treatment alternative for poultry slaughterhouse wastewater. As green infrastructure, both vfCWs and dWSPs proved low capital and operational expenditures, and offer environmental and economic benefits pertinent to improving environmental and public health and lowering wastewater treatment costs at slaughterhouses.

الخلاصة

يتطلب منع التلوث والتصريفات الصناعية من الصناعات الغذائية الزراعية ارتفاع رأس المال ونفقات التشغيل السنوية بسبب تركيب تقنيات المعالجة التقليدية والمتقدمة.وبالتالي أصبحت التشريعات والقوانين البيئة الفلسطينية تواجه تحديات كبيرة في فرض وتطبيق قوانين وتشريعات خاصة بالملوثات الناتجة عن الأنشطة الصناعية، حيث أن تصريف المياه العادمة "الصناعية" غير المعالجة يؤدي إلى تدهور البيئة، سواء كانت طريقة التخلص منها عن طريق ضخها بشكل مباشر الى مجاري الاودية او داخل شبكة التصريف، ففي حالة التخلص منها في الشبكة العامة دون معالجة، فإن محطات المعالجة سوف تتعطل، وفي حال ضخها مباشرة الى مجاري الاودية والسيول دون معالجة فإن ذلك يترتب عليه خطر كبير على تلوث المياه الجوفية. ففي فلسطين يوجد أكثر من 35 مسلخ قيد التشغيل حاليا، منها: 21 مسلخ للخراف والابقار، و14 مسلخ للدواجن. تقوم عدة مسالخ في فلسطين بتصريف المياه العادمة الخاصة بها إلى شبكة الصرف الصحي دون معالجة أولية، ومنها ما يقوم بتصريفها إلى الأودية بشكل مباشرة. عادة ما تحتوي هذه المياه العادمة على مستويات عالية من المواد العضوية والعناصر الغذائية مثل COD (5,000 – 15,000 ملغم / لتر).

تحاول هذه الدراسة إلى حل المشكلة عن طريق إنشاء ومراقبة فعالية عمل نظامين تجريبين: الأول لأراضي رطبة مصطنعة ذات تدفق عمودي (CWs) مزروعة بنبات *Phragmites australis* ، والثاني برك التثبيت باستخدام الطحلب البطي، كمرحلة لاحقة في معالجة مياه الصرف الصناعي بعد خضوعها لمعالجة لاهوائية مسبقة عن طريق تشغيل مفاعلين UASB في حرم جامعة بيرزيت، فلسطين. لمدة أربع شهور (نوفمبر 2020 الى مارس 2021) تم رصد كلا من النظامين التجريبين vfCWs

و dWSPs (أربع أحواض، 3 م^3 لكل منهما) بمتوسط معدلات يومية للأحمال العضوية (COD 58–187 جم / م^2) و TKN 6.1–21.5 جم / م^2).

تم اجراء تحليل فعالية ازالة الملوثات العضوية في كلا النظامين، وتحليل تراكم النيتروجين في النباتات والطحلب البطي. نزعم أن أن حلول أنظمة المعالجة الحيوية القائمة على الطبيعة هي خيارات سليمة بيئياً لرفع 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 مشكلة الاقتصاد الدائري فيما يخص الاستخدام الفعال للمياه المعالجة في أغراض مختلفة ومفيدة، وبالتالي المساهمة في الحفاظ على الأمن المائي- الغذائي – الطاقة في فلسطين.

أظهرت نتائج البحث نتائج مرضية في كلا النظامين، حيث بلغت كفاءة الازالة لنظام الاراضي الرطبة لكل من COD، TSS، TKN، PO_4، 83%، 80%، 70%، 66% على التوالي، وبمتوسط تحميل عضوي (106 جم COD/ م^2)، أما معدلات كفاءة الازالة لنظام برك التثبيت المعتمدة على الطحلب البطي لكل من COD، TSS، TKN، PO4، 79%، 72%، 74%، 68% على التوالي بمتوسط تحميل عضوي (106 CODجم/ م^2). كانت كفاءة الازالة في بعض المراحل واعدة ومستوفاة لمعايير الري الفلسطينية.

يتطلب تحسين تشغيل النظامين والتحقيقات طويلة الأجل مزيدًا من الاستكشاف لضمان امتثال المياه المعالجة لمعايير إعادة الاستخدام المحلية وضمان التخلص الآمن في البيئة المستقبلة. كما يمكن أن تساعد هذه النتائج واضعي السياسات والمشرعين في القانون المائي في فلسطين على اعتماد النظاميين البيئين لمعالجة مياه المسالخ. وفي النهاية يتمتع النظامين بتكاليف تشغيلية قليلة، ويعود كل منهما بفوائد بيئية واقتصادية ذات صلة بخفض التدهور البيئي الحالي وتقليل نفقات مياه الصرف الصحي في المسالخ.

Chapter 1: introduction

1.1 Background

Slaughterhouse is one of the largest industries in Palestine and a big quantity of wastewater is generated by this industry. Slaughterhouse wastewater is very harmful to the environment. The groundwater is contaminated by effluent discharge from slaughterhouse wastewater (Sangodoyin and Agbawhe 1992). This study will study and evaluate two pilot scale systems using ecotechnologies for the treatment of poultry wastewater to achieve high percentages reduction in organic load and suspended solids, before coming in the sewer network and the WWTP (if any) to reduce sewer fouling. The stabilization ponds and constructed wetlands technologies will be used to feed them by slaughterhouse to produce reclaimed water complying with Palestinian regulations.

Slaughterhouse wastewater has many characteristics, which are caused problem to treating industrial wastewater in Palestine. The one of characteristics is chemical oxygen demand (COD), this industrial wastewater contains a high strength pollution load, so COD in slaughterhouse wastewater ranges between 5000-7000 mg/l (Bustillo et al 2015). Suspended solids (SS) also are high concentrations in slaughterhouse wastewater, including pieces of manure, fat, hair, grease, feathers, flesh, grit, and undigested feed (Bull et al. 1982). Moreover, microorganisms (pathogenic and non-pathogenic), detergents, disinfectants, organics, stomach and intestinal mucus are observed in slaughterhouse wastewater (Masse and Masse, 2000; Debik and Coskun, 2009). As well as nutrients, color, turbidity, disinfectant and pharmaceuticals for veterinary purposes (Tritt and Schuchardt, 1992).

In this study, two different sanitation technologies will be used, duckweed-based waste stabilization ponds and vertical flow constructed wetlands to compare between them. According to Stefanakis (2018), nature-based technologies are characterized by low requirements for maintenance, energy, ease of operation and low operating costs. These are optimal solution as natural treatment systems for municipal wastewater treatment (Puigagut et al., 2007). In wetlands and DWSPs, energy requirements in terms of electricity/grid power in order to reach effective treatment is less than with other systems, the demand on electricity in each system is important only to pump wastewater in cases where gravity cannot be applied to it. Therefore, the reason for reduced requirements for electricity is due to the support of natural environment and natural energies (Kadlec and Wallace, 2009).

Literature expressed that regular frameworks for successful wastewater treatment are accessible in three significant classifications: wetland (e.g., natural marshes, free water surface constructed wetland, subsurface flow wetland), aquatic pond (e.g., algae-based waste stabilization pond, duckweed-based waste stabilization pond, hyacinth pond) and terrestrial including the soil aquifer treatment (Zimmo et al., 2000; Crites et al., 2006). The regular arrangement of wastewater treatment utilizing aquatic macrophytes, for example, duckweed has as of now gain consideration. The characteristics of duckweeds are high productivity, high protein content, nutrients supplement take-up, simple dealing with, harvesting and handling (Oron et al., 1984; Oron et al., 1986; Hammouda et al., 1995; Zimmo et al., 2002). Roman and Brennan (2019) reported that the protein ratio of duckweed grown on wastewater did not improve with increased nitrogen content in the wastewater feed, but rather was dependent on adequate system management and chemical and microbiological interactions in the pilot scale system.

In Palestine, there are many environmental problems, the most important of which is the industrial wastewater problem. The industrial sector in Palestine did not invest in installing wastewater treatment systems due to poor financial procedures and a reluctance to apply local water regulations. The industrial sector worked to increase financial benefits at the expense of the environment and public health. Currently, most of the wastewater treatment plants in

Palestine are designed for domestic wastewater from commercial residential areas and commercial sites. All industrial discharges in Palestinian urban centers (such as the cities of Nablus, Jericho, Tira, and Hebron) are either collected centrally in the sewage networks or are discharged on site in the reception environment without prior treatment.

Treating Industrial wastewater faces many challenges in Palestine; some of the challenges are listed below:

1. High strength pollution load in Industrial wastewater (Slaughterhouse; COD: 5,000.0-16,000.0 mg/l) (Bustillo et al 2015).
2. Random spreading of factories and industrial businesses.
3. Lack of investments in in-house treatment or even pretreatment inside the factories; lack of CIP (in house wastewater treatment plants).
4. Hard to separate domestic from industrial wastewater due to the lack of industrial zones; No separate industrial sewer network thus, No specialized industrial wastewater treatment plants
5. Not all industries are covered with the sewer network; some industries directly discharge its industrial Effluent to Wadi.
6. Lack of legislations and regulations that forces the factories to take actions regarding the discharged wastewater.

1.2 Slaughterhouse wastewater

The organic and nutrient concentration in Slaughterhouse wastewater is very high because of it contains suspended solids, blood, protein and fat, so, if directly discharged without being treated this leads to high contamination effect on water bodies. The quantity of water consumed per slaughtered animal varies differently according to the animal type and the process employed in each industry, the greater part of this amount is released as wastewater, with amounts from 400 to 3,100 litter for each butchered creature (Saddoud and Sayadi, 2007).

Degradable organic matter is present in high amounts in slaughterhouse wastewater, mostly proteins and fats and adequate concentrations of nutrients for biological growth. (Masse and Massé, 2005; Al-Mutairi, 2006), it also contains high total suspended solids (TSS) grease, hair, feather, flesh, manure, grit and undigested feed (Asselin et al. 2008).

Slaughterhouse wastewater contains high amount of biodegradable organic so biological processes are widely used for treated it. In this study, the nature-based biological treatment systems are selected especially aerobic treatment such that constructed wetlands and waste stabilization ponds which is more appealing contrasted with physical and chemical treatment choices in light of its lower treatment costs.

1.3 Problem statement

In Palestine, there are many slaughterhouses that operate on a daily basis and in large quantities, thus generating large quantities of wastewater that contains organic and inorganic loads and pathogens, and is discharged without prior treatment, which pose a great threat to the environment and health. And because most of the wastewater treatment plants in Palestine were not designed to receive industrial water, an environmental solution had to be found for slaughterhouse water.

This research study investigates a secondary treatment to complement the primary treatment of the Upflow anaerobic Sludge Blanket system (UASB), where work will be done on the design, operation and control of two aerobic treatment systems: vertical-flow constructed wetlands and duckweed-based waste stabilization ponds. Secondly, Besides, the cleaner creation guideline will be applied to investigate water and contamination decreases in a chose slaughterhouse in Al-Bireh/Ramallah area. We contend that the treatment efficiency of the aerobic pilot framework will deliver an effluent quality gathering the Palestinian guidelines for the release of industrial wastewater into sewer networks. The outcomes got will give plan rules to a full-scale WWTP.

1.4 Research Objectives

The main goal of this study is to study the feasibility of vertical flow constructed wetlands, and duckweed-based stabilization ponds, at pilot-scale, for the reduction of organics and nutrients from poultry wastewater. The specific objectives include:

1. Monitor and assess the efficacy of two pilot-scale ecotechnologies at variable hydraulic and organic loading rates for poultry wastewater treatment and effluent reuse.
2. Determine the optimal design conditions for adequate nature-based systems using vfCWs and dWSPs for discharge into ground water.

1.5 Research Questions

1. What is the quality of reclaimed water from both constructed wetlands and wastewater stabilization ponds?
2. What is the optimal organic load for each system to achieve adequate reclaimed water quality suitable for agricultural irrigation?

1.6 Hypothesis

The prevailing semi-arid climatic conditions and the design parameters play a crucial role in the efficacy of both systems understudy. However, we argue that the vegetation in constructed wetlands will achieve more than duckweed-based stabilization ponds pertinent to the removal rates of organics, nutrients and pathogens.

1.7 Thesis Outline

This research thesis consists of five chapters:

Chapter One: Introduction

This chapter presents the introductory background that introduces for the following contents of the research; it recognizes the scope and level of intervention of the research. Moreover, it clearly identifies the problem statements, goals and systematically itemized on research theme and context.

Chapter Two: Literature review

This section gives an outline of the nearby and worldwide slaughterhouses wastewater treatment rehearses and existing information. It likewise distinguishes the significant hypotheses with respect to the SWW, and gathering, assessing and breaking down the distributions identified with the examination questions; this section additionally investigates, blends, and basically assesses the past related exploration concentrates to give a reasonable image of the condition of information on SWW treatment.

Chapter Three: Materials and methods

This part clarifies the materials that were utilized to direct the examination notwithstanding the procedure that was followed to lead this exploration. The schedule presents the exercises that have been finished and the time of every action. Notwithstanding the phases of framework plan and the computations that have been embraced to play out the important estimations to investigate the outcomes.

Chapter Four: Results and discussions

This section represents the results obtained by analyzing the experimental flow/effluent samples on a systemic scale dWSPs and vfCWs, in addition to the records taken from the site measurements and monitoring and evaluation of the system and then discussing the results obtained after analyzing the achieved data.

Chapter Five: Conclusions and Recommendations

The end part momentarily checks the capacity of the examination to accomplish its objectives. It likewise gives an overall approach structure of techniques, for advancing outcomes and strategies for future investigations and if there should arise an occurrence of applying the dWSPs and vfCWs frameworks in a full scale, by distinguishing the preconditions to start such turn of events, through a concise conversation for the speculation thoughts and suggestions for strategy making.

Chapter 2: Literature Review

2.1 Introduction

Recently, fresh water resources are being polluted due to high population growth and lack of a suitable sanitation system (US EPA, 2004). Therefore, wastewater treatment has become serious for improving human life. Moreover, the stringent standards imposed by states to discharge wastewater worldwide and the shortage of freshwater resources have led to a rearrangement of wastewater treatment goals from direct disposal to recycling and reuse. For this reason, a high level of treatment must be achieved in order to maintain a safe and sustainable environment. (World Bank Group, 2007).

Last decade, there was a large consumption of fresh water by meat processing and therefore producing bigger quantities wastewater (SWW) for a purpose of animals slaughtering**,** facilities cleaning and meat processing plants (MPPs). This industry consumes one-third of the total freshwater consumed by the food and drinkables industry (Mekonnen and Hoekstra, 2012; Gerbens-Leenes et al., 2013).

2.2 Slaughterhouse Wastewater Characteristics

The poultry slaughterhouse wastewater is a one type of wastewater, which is high polluted with blood, microorganisms (pathogenic and non-pathogenic), detergents, disinfectants, organics, stomach and intestinal mucus (Masse and Masse, 2000; Debik and Coskun, 2009). Moreover, it contains heavy metals, nutrients, color, turbidity, disinfectant and pharmaceuticals for veterinary purposes (Tritt and Schuchardt, 1992). These pollutants can cause huge damage to water sources.

There are some parameters to evaluate quality of SWW such that biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN), total organic carbon (TOC), fecal coliform (FC). Table 2.1 shows the parameters, which are commonly used for SWW characterization.

Table 0-1: slaughterhouse wastewater General characteristics

SWW Parameter	Value (mg/l)
BOD_5	150 — 4635
COD	500 — 15,900
TN	50 — 841
TOC	70 — 1200
TSS	270 — 6400
pH	4.90 — 8.10

Adapted from: Bustillo-Lecompte and Mehrvar, 2015.

2.3 Slaughterhouse wastewater regulations and guidelines

Around the world, SWW treatment has become a regulatory requirement, as it has been classified as one of the most harmful industrial wastes as it can cause river pollution and groundwater pollution (US EPA, 2004). Because of the spread of poultry slaughterhouses around the world dramatically and the amount of wastewater effluent of these factories became in need of instructions and legislations dealing with wastewater emerging. Table 2.2 lists different legislations and standards that governing the SWW discharging to water bodies

Table 0-2: different standards of authorities worldwide for slaughterhouse wastewater effluent discharge

Parameter (mg/l)	Palestinian standards (Ground water recharge)	Palestinian standards (discharge to sewer network)	Canada	Australia	United Sates	World Bank	European Union
BOD5	60.0	500.0	5.0-30.0	6.0-10.0	26.0	30.0	25.0
COD	200.0	2000.0	***	3*BOD	***	125.0	125.0
TSS	50.0	500.0	5.0-30.0	10-15.0	30.0	50	35.0

TN	50.0	60.0	1.0	0.1-15.0	8.0	10.0	10.0

Source: Adapted from: Environment Canada (2012), (CEC, 1991), US EPA (2004), ANZECC (2000), World Bank (2007), Palestinian Standards Institution (PS, 2010), Ministry of Environmental Affairs (MEA, 2001)

2.4 Slaughterhouse wastewater treatment

Development of agricultural sector and rapid industrialization has produced a big amount of wastewater and discharges its untreated SWW effluents into water bodies. A suitable wastewater treatment is needed before been discharged into the water body, to avoid negative impact on environment due to high organic strength and degradation such as eutrophication and spreading of water borne diseases (Akpor and Muchie, 2011). However, the appropriate disposal and treatment systems are needed to recovery by-product like nutrients and fertilizer.

The SWW treatment contains many stages: preliminary, primary, secondary and tertiary treatment in some cases when reuse is considered. This research is focusing on secondary treatment which contains biological treatment. Biological treatment is divided into two parts: aerobic and anaerobic. On other hand, there are some technologies that combine among physical, chemical, and biological mechanisms to remove various contaminants or improve the water quality (Vymazal, 2011; Saeed and Sun, 2012).

Because of the shortage of spotless, pure water in nature, the distinction between dirtied water and pure water is the presence of the level of contaminations and toxins in the water. (Ambulkar, 2020). Wastewater treatment for a water use because it is very interconnected with different uses of water. A large portion of the water used by homes, enterprises and businesses must be treated before being returned to the environment. (Cressler, 2020).

If the term "wastewater treatment" is confusing, you might think of it as "wastewater treatment". Nature has an amazing ability to deal with small amounts of waste water and pollution, but nature will be powerless in front of billions of gallons of wastewater if it is not treated. It is produced daily before it is re-released into the environment. So, treatment plants reduce pollutants in wastewater to a level that nature can handle. An important point in wastewater treatment is to get rid of as much suspended solids as can reasonably be expected before the remaining water, called effluents, is returned to nature. The "basic treatment" removes about 60% of suspended solids from wastewater. (Cressler, 2020).

2.5 Wetland and stabilization ponds systems

At present, there are growing issues that associated with water environment including water shortage, water degradation and pollution of water resources worldwide. Moreover, the condition is becoming more complex and serious due to the effects of the large population and the increase in demand for various industries and thus the exacerbation of environmentally friendly activity, especially in developing countries (Vymazal, 2011; Wu et al., 2014). In most case historically, conventional treatment technologies have been used successfully for water pollution in most countries (Li et al., 2014). However, these technologies such as activated sludge process, membrane bioreactors and membrane bioreactor (MBR) are very expansive, high energy requirement and high amount sludge production (Grégorio and Eric, 2019). Thus, the selecting low-cost and efficient alternative technologies for wastewater treatment is considered. For this purpose, vfCWTs and dWSPs are two of natural treatment system that are considered in this research.

Waste stabilization ponds (WSPs) are open ponds constructed from concrete walls or earthen embankments that are anchored entirely or midway with concrete or fabricated geotextiles. The waste stabilization ponds (WSPs) offer less affordable and valid elective way to deal with costly biomechanical frameworks of wastewater treatment particularly in tropical and subtropical districts (Moazzam et al, 2009). The (Asano et al., 1996) show that the treated wastewater from WSP can be successfully exploited for irrigated agriculture, to save the amount of new water and accomplish monetary advantages regarding supplements like nitrogen, phosphorus and potassium. Moreover, they can be used in centralized or semi-centralized sewerage systems, serving cities or towns; they can also be used as onsite systems serving a single entity (e.g., community center, etc.) (Figure 1).

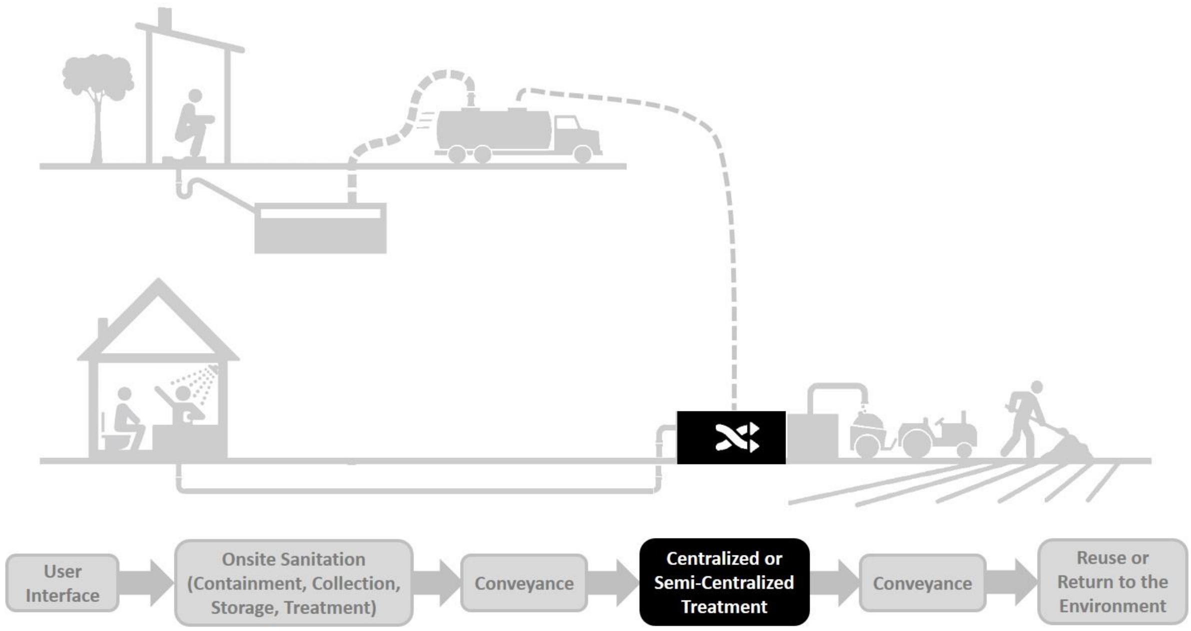


Figure 1: Waste stabilization ponds are a centralized or semi-centralized treatment technology in the overall sanitation service chain.

There are many types of WSPs are anaerobic ponds, facultative ponds, maturation ponds, aerated ponds, and high-rate algal ponds (HRAPs). These lakes contrast as far as their capacity in the general wastewater treatment framework, the fundamental capacity of anaerobic, facultative and aerated air through lakes is the evacuation of carbon-containing natural matter, while the principal capacity of maturation ponds is the removal of pathogens. HRAPs were created to improve the productivity of organic matter expulsion while at the same time considering the recovery of broke down supplements that become joined into the algal biomass (Verbyla et al, 2017). These distinctive lake types are recognized from one another by their profundity, pressure driven and organic loading rates, and by whether they utilize motorized hardware for blending or air circulation. When all is said in done, 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); maturation ponds are shallowest (≤1.5 m), and are utilized rearward in arrangement. Aerated ponds through lakes might be utilized anyplace in a progression of lakes, and HRAPs are frequently utilized in without help from anyone else or among anaerobic and development lakes (Von Sperling, 2007).

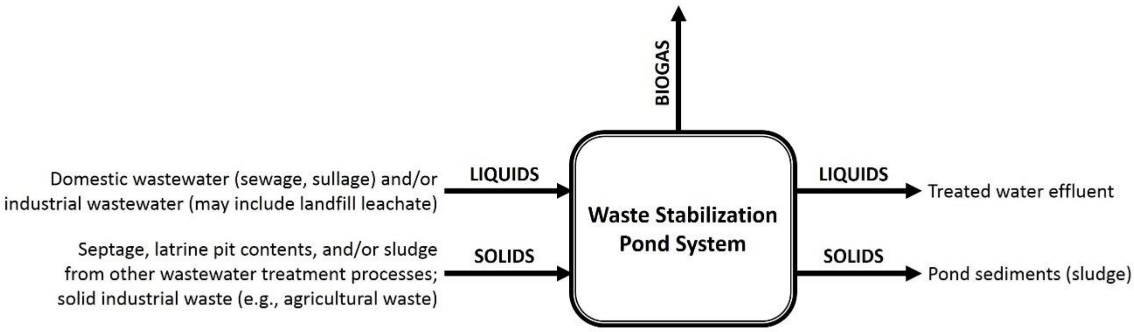


Figure 2: Typical inputs and outputs from waste stabilization pond systems.

WSPs can be utilized to treat an assortment of water and waste streams, hence the data sources may incorporate wastewater, septage, toilet pit substance, or potentially sludge from other wastewater treatment measures.

Some WSP frameworks additionally get landfill leachate. WSPs may get untreated wastewater that has experienced primer treatment (for example screening and grit removal), or they may get auxiliary emanating from some other treatment measure, like anaerobic reactors, activated sludge, or trickling filters. Regular focuses for pathogens in wastewater, septage, restroom pit substance, and additionally slime is given in Part Three of GWPP (Mihelcic, 2018).

The outputs from WSP frameworks incorporate the treated effluent (fluid), sludge/sediments (solids), and biogas. The treated fluid emanating from WSPs is regularly persistently released; be that as it may, administrators of certain system (particularly in colder environments) may stop discharging for months at a time, allowing the lakes to top off and releasing once the temperature gets hotter (this additional maintenance time compensates for the slower pace of treatment during colder months). Sludge collects after some time at the lower part of WSPs, and should be eliminated at regular intervals (anaerobic lakes), consistently (essential facultative lakes), or like clockwork (optional facultative or development lakes). Sludge eliminated from WSPs is defiled with pathogens and should be securely figured out how (to prevent exposure) or treated (to lessen the convergence of microbes) (Mihelcic, 2018).

Up to these days there is no fixed strategy to design ponds and wetlands for phosphorus evacuation, considering phosphorus expulsion is quite possibly the most troublesome things to be accomplished in stabilization ponds systems (WSPs) and wetland (Powell et al., 2008). This could be due to the lack of clear methods for completely removing phosphorous from a stabilization pond or wetland system (Gratziou & Chalatsi, 2017). Pycha, & Lopez (2015) show that this removal Process depends on the phosphorus form in the sewage. In wastewater, the Phosphorus (P) completely appears in the form of phosphates; including organic phosphates, inorganic phosphates, polyphosphates and orthophosphate (Gratziou & Chalatsi, 2017).

2.6 Duckweed-waste stabilization ponds

Duckweed can be used in wastewater treatment ponds, where the use of duckweed in low-cost, easy-to-operate wastewater treatment systems has been studied in the literature (Korner and Vermaat, 1998). The rapid growth rates of duckweed achieve high levels of nutrient removal. In addition, the low fiber and high protein content make it a valuable feed (Korner et al., 1998).

According to Cheng et al., (2002): Duckweed is a small, free floating aquatic plant belonging to Lemnaceae family. Duckweed has characteristics that its high productivity and high protein content in temperate climates. They are green and have a small size (1-3 mm). Also, they have short but intensive roots (1-3cm) (Altay et al., 1996). Hasar et al., (2000) illustrate that duckweed fronds grow in colonies that, in particular growing conditions, form a dense and uniform surface mat.

Some characteristics make duckweed-based wastewater treatment (DWWT) very attractive. It is used to recover nutrients along with wastewater treatment. The reason for this is the rapid multiplication of duckweeds and high protein content of its biomass (Caicedo et al., 2000). The study of Korner et al., (1998) illustrates duckweed wastewater treatment systems have been studied for a wide range of wastewater types. Most studies have shown that nutrient removal efficiency and removal rates are between 50-95% for systems in which duckweed appears (Zimmo et al., 2000). A study showed that duckweed grew 10-20% higher when duckweed was grown on a medium containing NH_4^+, compared to the growth at NO_3^-.

2.7 Constructed wetlands

One of modern wastewater treatment is engineered constructed wetlands that have been designed and constructed to utilize the natural processes but do so within a more controlled environment (Vymazal, 2011). The CWs are applied for different types of wastewater treatment, agricultural drainage, stormwater runoff, domestic, industrial and municipal waste streams (Dou, 2017).

Constructed wetlands may classified by the different design parameters, the two most important criteria are based on hydrology (open water-surface flow and subsurface flow), and flow path (horizontal and vertical) (Vymazal, 2008). Focal points and obstructions of constructed wetland framework are expected to abuse a critical number of the same estimates that occur in normal wetlands inside a more controlled environment. Focal points of fabricated wetlands include:

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

Well-designed and operated vertical flow constructed wetlands have an efficient pre-treatment job of municipal wastewater with treated effluents that meets national standards for the removal of toxic substances and pathogens. Also, Subsurface flow constructed wetlands with underground flow have several important advantages over a natural wetland. (Hoffmann and Winker, 2011).

From what has been published by Plamondon et al., (2006), the efficiency of sub-surface horizontal flow wetlands is not affected by the decrease in ambient temperature. The reason for this is the thickening of the layer that prevents cooling or freezing of the water flow path. Thus, the water feed is kept below the medium thickness media layer.

There are practical advantages to constructed wetlands for wastewater treatment, because the operational and capital expenditures for transporting wastewater by pipes and the low energy consumed in this system, and minimal uncontrolled effluent discharge into surrounding environment. (Basham, 2003).

The requirement for utilization of built wetlands in dark water treatment may give a straightforward and modest answer for controlling many water contamination issues confronting little networks, industries, and horticultural activities (Niyonzima, 2007). The expected issues with Free Water Surface built wetlands incorporate mosquito, fire up issues in building up the ideal sea-going plant species with free water surface and subsurface Flow wetlands.

2.8 Types and functions of Constructed Wetlands

Constructed wetlands can be grouped by the stream course into vertical and horizontal stream. Likewise, other two kinds of constructed wetlands have been completed. They are the free water surface frameworks and the subsurface stream frameworks which additionally called root zone, rock-reed channels or Vegetated lowered bed frameworks as introduced in Fig. 4 (Niyonzima, 2007).

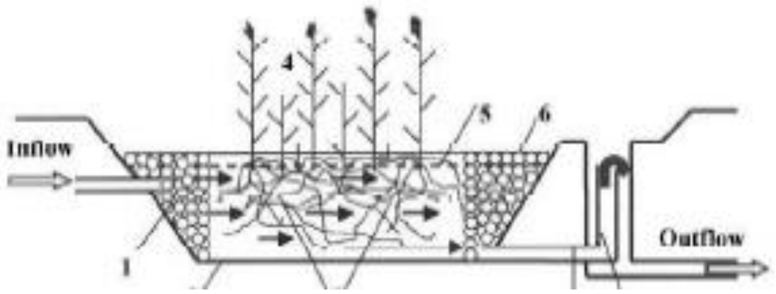


Figure 3: Constructed wetland with horizontal sub-surface flow

Blend of aerobic and anaerobic cycles can overhaul constructed wetlands to treat modern wastewater containing less degradable organic poisons (Yamagiwa et al., 2008). Anaerobic and aerobic exercises in a vertical constructed wetland were researched with and without beneficial air circulation which supported the carbon expulsion and nitrification. Developed wetlands might be ordered by the existence type of the ruling macrophyte into frameworks with free-gliding, established rising and lowered macrophytes (Vymazal, 2005).

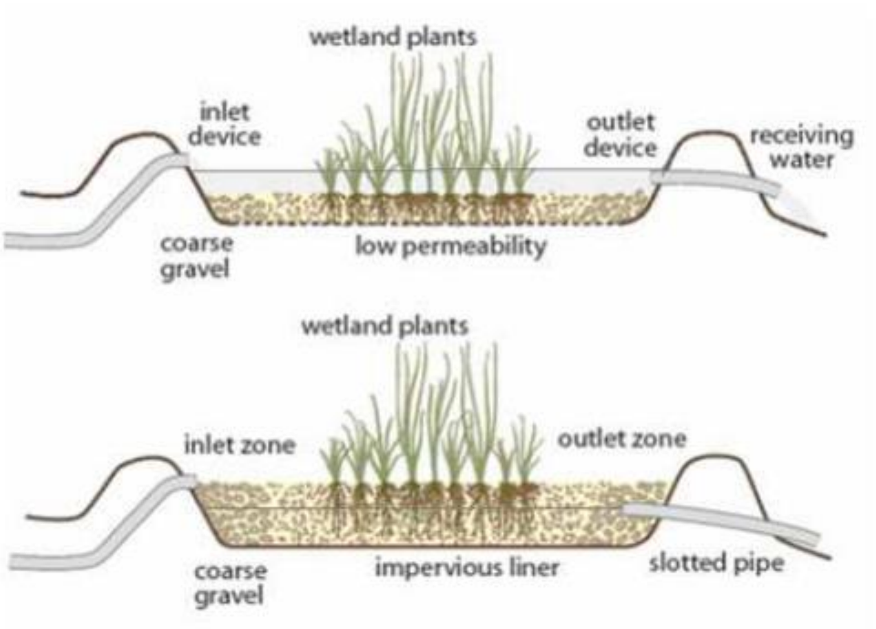


Figure 4: CWs types: (1) free water surface (2) Subsurface flow (Sa'at, 2006).

2.9 Historical and presentation of applications of constructed wetlands

The 1960s in Germany saw the first application of constructed wetlands. Pollutants are removed in constructed wetlands in a number of ways, including: physical, chemical and biological. The process of transporting oxygen through the roots promotes the microbial degradation process, as nutrients are absorbed by plants and microorganisms in the medium. Hoffmann and Winker, (2011) reported that the production of oxygen and the consumption of carbon dioxide is through photosynthesis and assimilation of biomass in natural wetlands and carbon-neutral ecosystems. Reducing greenhouse gases by chemical weapons companies has boosted the spread of chemical weapons premiums in Europe, the USA and Asia.

Luederitz et al. (2001) illustrated the cleaning exhibitions of constructed vertical flow wetlands (VFW) and horizontal flow (HFW) wetlands including a little even stream wetland, a slanted HFW, bigger HFW, a defined vertical flow wetland and un-stratified VFW. It was revealed by research published by Luederitz et al. (2001) found that more than 90% of the organic pollution loads and acceptable levels in nutrient removal processes (N and P) were removed by both HFW and VFWs.

After pretreatment stage nitrogen and phosphorous were controlled. In HFWs the efficacy in nutrient removal was lower due to the phosphorous adsorption on natural organic particles and materials. Six wetlands constructed from sandy soil filters were studied under variable flow patterns and hydraulic retention time (HRT). HRT and the flow pattern in CW have been found to play a major role in the effectiveness of removal of organic elements and nutrients (Chazarenc et al., 2003). Ghorabi et al. (2011) investigated the effectiveness of wastewater treatment plants in Tunisia for a quarter of a year. The wastewater treatment plants included Imhoff reservoir, HSSFCW, subsurface vertical current CW, and level flow CW. The variants curing ratio for SSFCW reached 85.4% for BOD, 42.7% for COD, with a lower expulsion rate for nitrogen (7.1%) and 38.08% for phosphorous discharge.

Shazarink et al. (2003) contemplated the impact of HRT in SSFCW utilizing diverse stream designs. They found that the progression of water in the subsurface spillover caused an increment in oxygen in the made media through the lower speeds and the higher stream.

Developed CWs have built up a sound miniature biologist inside the water surface and root zone. Notwithstanding arranged water utilizes, happening is more advantageous and seems to improve soil design and treatment viability.

Zurita et al., (2009) inspected four wetland treatment frameworks including two subsurface wetlands (flat and vertical stream wetlands) for homegrown wastewater treatment. The examination gathering (Zurita et al., 2009) presumed that vertical subsurface stream CWs were more effective contrasted with HFCs for the greater part of contaminations. The ordinary evacuation rate was accounted for as 80% for BOD and COD, 50.6% for TKN, 72.2% for NH4. Nitrate and complete suspended solids (TSS) were decreased at higher rates in the HSS stream CWs (NO3 = 47.7% and TSS = 82%). A new audit distributed by Nivala et al., (2020) investigated progresses in plan, establishment, activity and support of enormous scope circulated air through developed wetlands.

2.10 Correlation of VF with SF constructed wetlands

Bigger surface territory of even stream developed wetlands made addition the water adversity due to evapotranspiration. Vertical stream beds are attractive over flat stream bottoms since they have an unsaturated top layer in the bed and a more restricted upkeep time than even stream beds (Hoffmann and Winker, 2011).

2.10.1 Positive conditions of vfCWs

Vertical flow constructed wetlands (vfCWs) can achieve great oxygenation limit through aloof invasion and void spaces in the media, accordingly improves the ecological interaction conditions for wastewater treatment. Arrangement of oxygen is critical for the microbial exercises in high-impact natural and nitrification. Oxygen consuming conditions upgrade heterotrophic action for contamination oxidation. These natural conditions in CWs are practical for homegrown and civil wastewater treatment. Stefanakis and Tsihrintzis (2009) covered

VFCWs treating civil sewage with high BOD5 (95%) evacuation and 90% for nitrogen and with just about half adequacy altogether phosphorous expulsion.

2.10.2 Detriments of vfCWs

Low degrees of phosphorous evacuation rates in characteristic constructed wetlands (Stefanakis and Tsihrintzis, 2009) were accounted for because of deficient water driven maintenance times (diminished contact time among biomass and substrate). The normal energy utilization detailed for developed wetlands range from 10 to 20 kWh/PE*year, arriving at auxiliary treatment. For tertiary treatment, 50-100 kWh/PE*year are burned-through. Thinking about the arranged treatment targets, energy could change contingent upon the treatment innovation picked. Generally speaking, created wetlands have shown to be incredibly successful in controlling the COD substance (>90%), suspended solids (>90%) and microbes (3-4 log units). Nonetheless, with less limit in supplement evacuations (TKN 40-60% and absolute phosphate 20-40%) as detailed by Stefanakis and Tsihrintzis (2009).

2.11 Examination of subsurface stream-built wetlands with lakes

Lakes are difficult to consolidate in metropolitan areas in light of their immense water surface, mosquitoes and aroma. On the other hand, lakes are easier to design and grow moreover; they needn't mess with a material and have lower standard costs for tremendous extension plants. Built wetlands have basically lower action and upkeep costs appeared differently in relation to cutting edge and expanded advancement impacts related with energy utilization and coordination's.

2.12 Wastewater Reuse and Reclamation

Many nations around the planet are confronting the expanding pressing factor of new water supply and that new water assets are getting lacking to fulfill water interest. As urban water shortage is developing and water purging innovation is propelling, wastewaters are being recovered in expanding volumes and being reused for additional reasons around the planet (Levine and Asano, 2004).

The phenomenon of water scarcity has prompted communities to reuse water (also known as water recycling or water reclamation), which is based on recovering water from a variety of sources and then treating and reusing it. Thus, it can be used in many fields such as: potable water supply, agriculture and irrigation, groundwater replenishment, industrial processes, and environmental restoration. Water reuse can provide alternatives to existing water supply and use to enhance water security, sustainability and resilience (Demortain, 2020).

Sewage water has increased in recent decades due to the increase in population, and the United Nations (FAO) defines the term sanitation as "the water consumed or used in the community or factory amounts to about 99 percent of most wastewater, and only 1 percent is waste. Thus, the shortage of potable water can be overcome by using water treatment and purification. Sewage water is an unconventional source of water after it is treated to make it suitable for reuse. In addition, wastewater treatment and disposal preserve the environment and improves the quality of the environment (Vigneswaran and Sundaravadivel, 2004).

The use of wastewater in agriculture to irrigate crops has become remarkably popular (Ayres et al., 1996), more sophisticated technologies can be used to conserve water, the quality of treated water can exceed that of normal drinking water (Zhang, 2012). Also, wastewater can be used on a large scale because all the pollutants that can be detected can be removed from wastewater, despite the original pollution levels, all types of wastewater can be reused if it undergoes appropriate reclamation treatments (Levy et al., 2010).

The reuse of wastewater is related to the establishment of a wastewater treatment plant, the inclusion of water assets for executives, the critical and monetary examination and public recognition. Given the need to add wastewater treatment to the previous treatment and supply new lines for transporting treated water to be reused, and consequently the costly capital expenditures are an important issue for wastewater reuse (Asano et al., 2007).

2.13 Guidelines for Wastewater Reuse in the Gaza Strip, Palestine

In the Gaza Strip, the problems of groundwater became a concern, and therefore it was necessary to find alternatives to alleviate the pressure on water sources. Subsequently, endorsement of the employments of non-consumable wastewater got perhaps the main needs. All the more as of late, this necessary the advancement of public rules. The climate and the safeguarding of general wellbeing are of the essential concerns.

Hence, in Afifi's study (2006), he suggested that there should be an administration in order to control the reuse of water in accordance with national reclamation rules to ensure public health and protect the environment. He also confirmed in his study (Afifi, 2006) that the reuse of treated wastewater in the Gaza Strip has requirements, including source separation, advanced treatment, and capacity enhancement. Salt water infiltration from coastal areas into the groundwater can be reduced through the use of treated water to recharge the guava reservoir.

- The water reuse regulations entail following principles:
    1. Economic and financial principles
    2. Institutional and the executives' standards: The capacity of the competent subject matter experts and all authority bodies at all levels ought to be clearly described and the domains of obligation officially settled. The construction and course of action of the wastewater reuse the chiefs ought to be arranged to empower the commitment by the skilled experts at different levels with help of private region consideration. Similarly, limit working for all establishments for treated wastewater reuse should be considered and center individual bodies, for instance, association, NGP and close by chambers should be improved.

3. Water is authentically not an ordinary business thing yet a meager normal resource which ought to be gotten, defended and treated correspondingly and ought to be given as a key need by giving safe water to all purchasers. One of the critical portions for wastewater reuse is wastewater demand charge and the inspirations ought to be given to propel the all over reuse. In addition, solicitation and supply the heads for treated wastewater must considered.
4. Natural Principles Exercises related to the reuse of wastewater ought to be masterminded and executed with due regard for all their biological implications, including the security of spring from pollution and over misuse. Furthermore, the short-and long stretch effects of the reuse of wastewater ought to be noticed so the improvements can be upheld and negative impacts restricted.

2.14 Mediterranean Regional wastewater reuse

In numerous countries of the Mediterranean locale, characterized by continuous dry spell periods, agrarian production regularly happens submerged inadequacy or conditions that cause the exhaustion of the current water resources (Libutti et al., 2018).

Libutti et al., (2018) illustrated that was clarified through a study conducted in Italy that assessed the effects of irrigation with treated agricultural wastewater on soil properties, crop productivity and the specific characteristics of crop products, including their microbiological integrity, as three types of water were used to irrigate crops: ground water, secondary treated wastewater and tertiary treated wastewater to irrigate the tomatoes and broccoli. The study showed that crops irrigated with treated wastewater did not significantly affect the marketability nor the specificity of tomato and broccoli crops except for the content of Na^+ and NO_3^- (below the limit levels specified by the European Vegetable Guidelines).

2.14.1 Wastewater Reuse in Palestine

Wastewater reuse in water system gives extra water supply to horticulture and saves freshwater assets for human utilization. Through these advantages, wastewater reuse can fundamentally lighten the water shortage in Palestine and fit to the intricacy of the international setting. Nonetheless, the administration of reusing treated wastewater in Palestine is understudied. The paper connects this information hole by illustrating the administration factors that impact the reuse of treated wastewater for water system in Palestine (Al-Khatib et al., 2017).

Al-Khatib et al., (2017) showed that the interviews and document reviews that were conducted using the Governance Assessment Tool, identified three governance-related factors:

1. Poor coherence between actors, which is reflected in unclear overlapping responsibilities.
2. The weakness of the extent and coherence of legal instruments, which indicates the absence of laws, overlapping and conflicting provisions.
3. Lack of resources, such as adequate infrastructure.

So, the limitation of wastewater reuse in Palestine are:

There are as yet numerous difficulties and issues that should be defeated to reuse wastewater (treated water). The future reuse tasks will be endorsed in the fields of different activities and better administration and control of reuse activities dependent fair and square of need and interest for water. or water reuse requires a better evaluation of the economic and financial viability. Methodological aspects also need to be improved. The need to educate and guide farmers in order to promote these practices, which aims to achieve higher agricultural production without negative impacts on nature, has also become. In Palestine, the use of treated wastewater is more difficult, and the reason is due to the scarcity of available information regarding the quality and quantity of wastewater, and also the absence of a clear re-use system and policy (Afifi, 2006).

CHAPTER 3: Materials and Methods

3.1 Materials

The project intends to study the treatment of a poultry slaughterhouse wastewater using both CWs and WSPs pilot-scale in Birzeit campus. Firstly, the two adjustable peristaltic feed pumps (100-1000 l/day) which are connected to the inlet pipe of both systems. Then operate two pumps on 200 l/day and monitoring of systems. In addition, there is an equalization tanks with a capacity 6.0 m^3, which feeds each dWSPs and vfCWs at BZU campus. Since the poultry wastewater contains high organic pollution loads, domestic sewage from the equalization tank of BZU STP will balance the main feed for the vfCWs and DWSPs pilot systems.

Sampling and characterization of industrial wastewater poultry slaughterhouse reflecting a natural municipal wastewater, include pH, temperature, dissolved oxygen, chemical oxygen demand (COD), total suspended solids (TSS), ammonium-N (NH_4-N), nitrate-N (NO_3-N), total phosphorus (TP) are measured in the inlet and outlet of both DWSPs and vfCWs as well as vegetation samples (stems and leaves) from the constructed wealds. Biological parameters include fecal coliforms (FC), *Faecal streptococci* (FS). All samples are 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 (vfCWs) and duckweed-based waste stabilization ponds (dWSPs), installed on the campus of Birzeit University, Palestine.

2. Aims and Group Samples

Slaughterhouse holders, municipalities, water and environmental foundation

3. Research Tools/ equipment:

Secondary treatment, Basins constructed wetland and waste stabilization ponds

4. **Research method of analysis**

System monitoring and process control, sampling and lab analysis at Birzeit University Testing Laboratory Center.

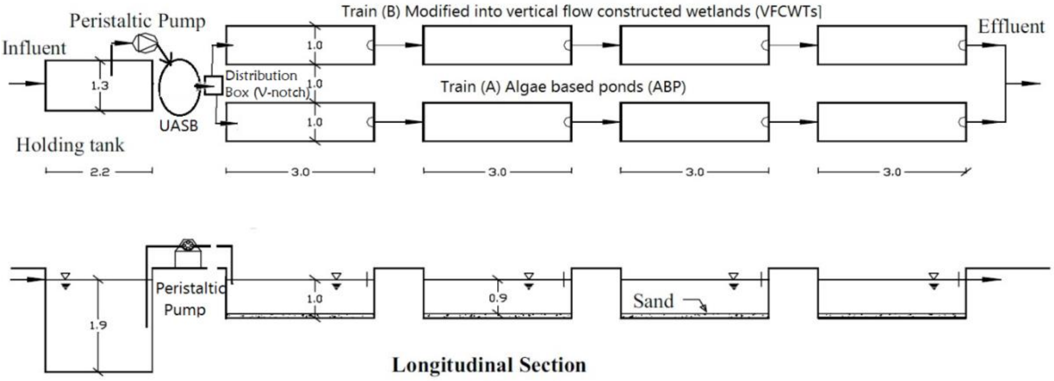


Figure 5: Duckweed-based waste stabilization ponds (Train A) and Vertical flow constructed wetlands (Train B).

3.3 Water Sampling and Analysis

The poultry wastewater from a slaughterhouse in Birzeit town was collected and transported by a truck to BZU campus. Wastewater was placed in the equalization tank (5 m^3), using peristaltic pumps, UASB reactors were fed, and wastewater was pretreated anaerobically using two UASB reactors (Najajra, 2020).

Figure 6: Pilot system of vfCWs and dWSPs at Birzeit University campus

Water samples were taken from the inlet and outlet of both waste stabilization ponds and constructed wetland cells. The CWs system, four built cells in series, was operated in a vertical flow mode. Each the of the CWs and WSPs ponds, constructed in series, has an area of 3 m^2 with a volume of 3 m^3 (in total 12 m^2 and about 12 m^3). Common reed (Phragmites australis) was planted in all CWs cells in gravel, where roots assume a vital part in filtering the approaching anaerobically pretreated wastewater. All of the Phragmites australis species (P. australis) planted in the wetlands were cut, where they were built on a large scale in Missilia and were used in the research of the master student Hiba Al Faqeeh (Faqeeh, 2021).

Figure 7: Sampling procedure of the outlet of CWs and WSPs (1,2,3 and 4) ponds under study

During study period (November2020- February 2021), grab samples (after the start-up stage) were collected from the inlet and outlet of constructed wetland beds (CW1, CW2 and CW4) and waste stabilization ponds (WSP1, WSP2 and WSP4) and analyzed for TSS, COD, TKN, NO_3^-, pH and PO_4^{-3} 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 Hydraulic Retention Time (HRT)

- During November and December 2020, the wastewater flow was 0.200 m^3/day.

Hydraulic Retention Time = $volume/flow$

HRT = 3m^3 *4/0.2 m^3/day = 60 day

January and February 2021, the wastewater flow was increased to 0.27 m^3/day

HRT= $volume/flow$

HRT= 12 m^3/0.27 m^3/day; equals 45 day

3.5 Hydraulic Loading Rate (HLR)

- During November and December 2020, the wastewater flow was 0.200 m^3/day.

Hydraulic Loading Rate = $Flow/Area$

HLR = 0.2 m^3/day/12 m^2 = 0.017 m^3/m^2/ day = 17 l/m^2/day

January and February 2021, the wastewater flow was increased to 0.27 m^3/day

HLR= $Flow/Area$

HLR= 0.27 m^3/day /12 m^2; equals 0.0225 m^3/m^2/day = 22.5 l/m^2/day

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

The both WSPs, CWs pilot systems were 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.

3.7 Scope, Challenges and Limitations

According to our knowledge and reliance on previous studies, this study is the first of its kind that compares two industrial water treatment systems, the waste stabilization ponds system and wetland ponds, especially the water of slaughterhouses (poultry slaughterhouses) under variable hydraulic and organic surface loading rated. Previous 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).

Chapter4: Results and Discussion

This part sums up the discoveries and commitments made during this examination study, and gives a short discussion about them. The two systems consist four vfCWs and four dWSPs beds in series, over the study period (November to February 2020).

4.1 Effluent physical parameters of systems

4.1.1 pH value

In the case of pH, no huge varieties happened during the vfCWs and dWSPs activity period. In general, pH values demonstrated a pattern to be kept on a marginally essential reach. The average pH value in the influent was 7.01, and in the effluent of vfCWs and dWSPs were 7.67 and 7.39 respectively for the length of period (Nov 2020- Feb 2021).

4.1.2 Temperature

The water temperature was influenced by the surrounding temperature of the neighborhood climate conditions, which shifted somewhere in the range of 2 and 20°C during the study period.

4.1.3 Dissolved oxygen

In this study, the shallow ponds were obtained to increase DO but the noticed that DO is low in ponds when is measured by dissolved oxygen meter. In WSPs, the DO measured was 2.6–3.5 mg/l during winter. DO concentrations in duckweed ponds decreased rapidly with the distance from the water surface, it was less than 1 mg/l.

4.2 Constructed Wetlands and Waste stabilization ponds Performance

4.2.1 COD removal efficiency

The overall assessment for CWs and WSPs to reduce organic loading rate, the anaerobic treatment that precedes these regimens reduces organic load. The figures below show the removal efficiency for vfCWs and dWSPs for different organic loading rate.

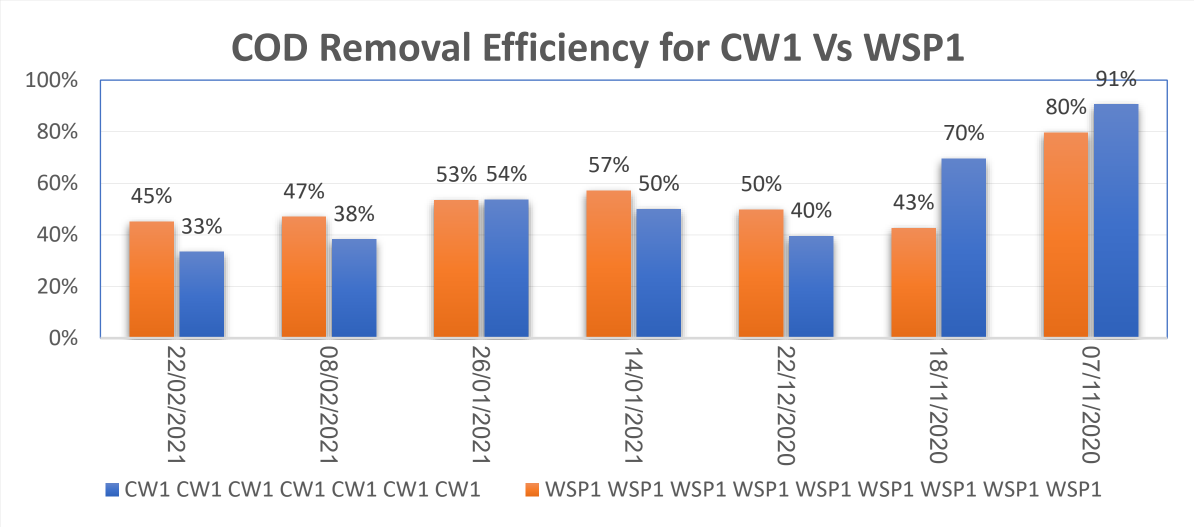


Figure 8: COD Removal efficiency for CW1 and WSP1 vs Time

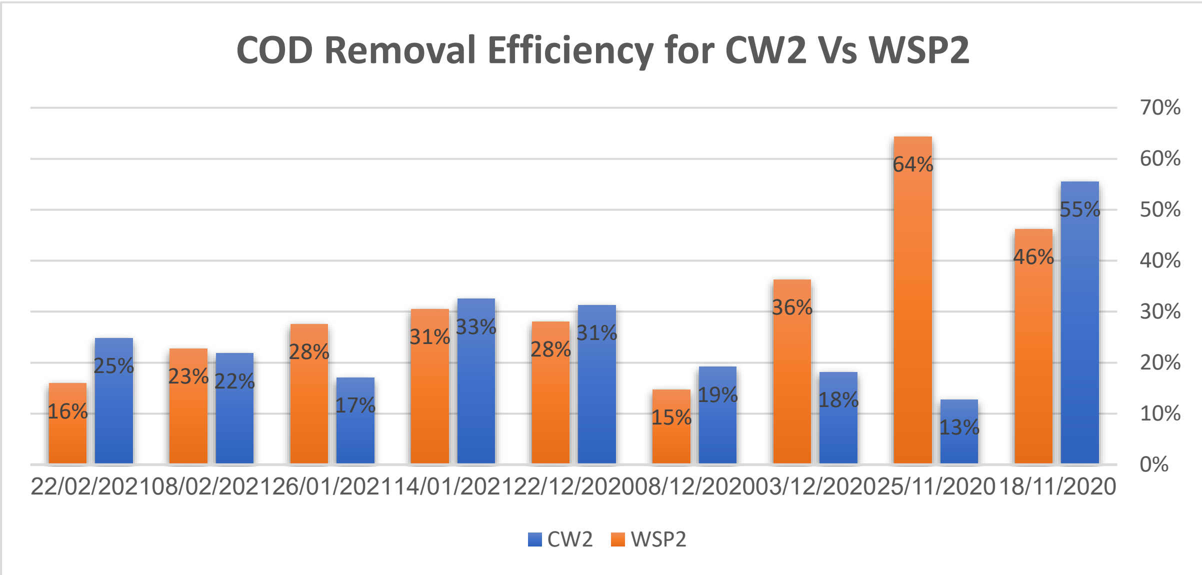


Figure 9: COD Removal efficiency for CW2 and WSP2 vs Time

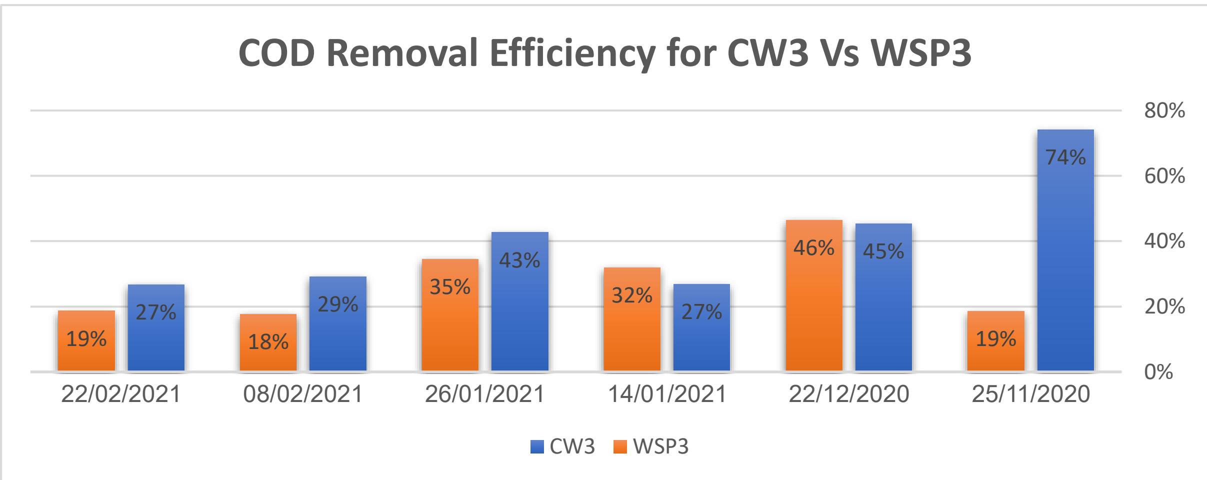


Figure 2: COD Removal efficiency for CW3 and WSP3 vs Time

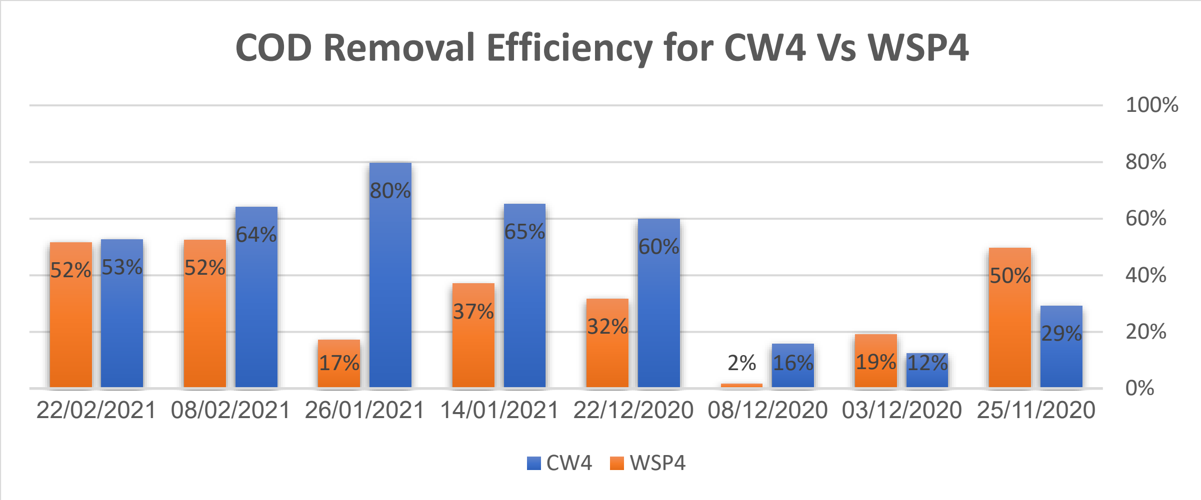


Figure 3: COD Removal efficiency for CW4 and WSP4 vs Time

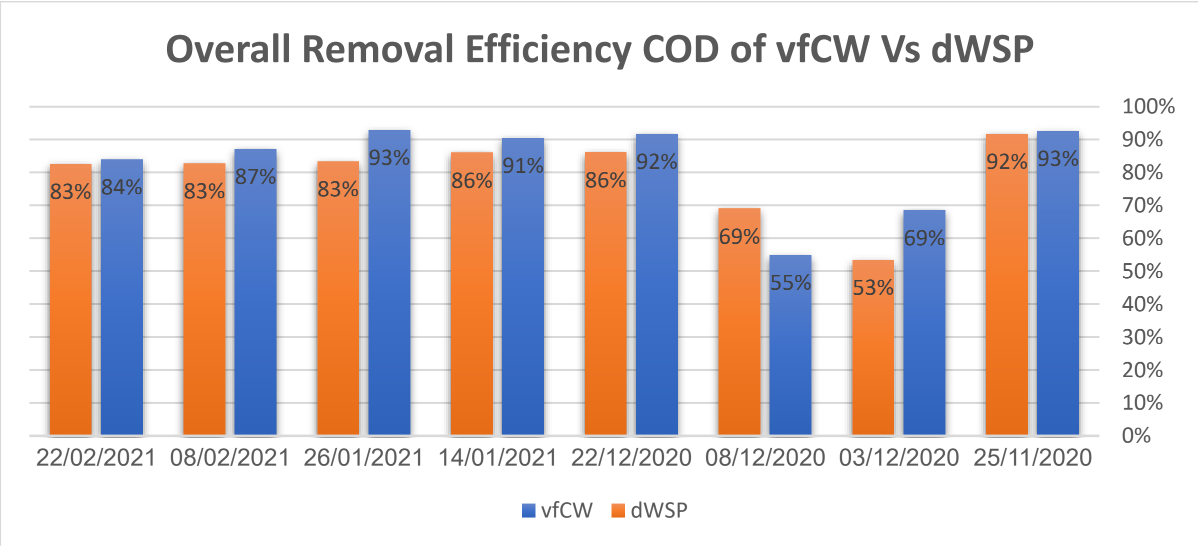


Figure 4: Overall Removal efficiency COD for vfCW and dWSP vs Time

The overall removal efficiency COD is differing from vfCW to dWSP, A summary for the results is as follows:

- As shown in figure 8 the removal efficiency is different from CW1 to WSP1, in startup phase (November and December) the organic loading rate was 170 gCOD/(m^2.day) for pond No.1 with 0.2 m^3/day and the average removal efficiency in the same period was 70%, 51% for CW1 and WSP1 respectively. After that, the flow was increased to 0.27 m^3/day (January and February) the organic loading rate

200 gCOD/(m^2.day) because that the average removal efficiency became 40%, 51% for CW1 and WSP1 respectively.

- As shown in figure 9 the removal efficiency is different from CW2 to WSP2, in startup phase (November and December) the organic loading rate was 96.9 gCOD/(m^2.day) for pond No.1 with 0.2 m^3/day and the average removal efficiency in the same period was 30%, 40% for CW1 and WSP1 respectively. After that, the flow was increased to 0.27 m^3/day (January and February) the organic loading rate 112.5 gCOD/(m^2.day) because that the average removal efficiency became 24%, 24% for CW2 and WSP2 respectively.
- As shown in figure 10 the removal efficiency is different from CW3 to WSP3, in startup phase (November and December) the organic loading rate was 59 gCOD/(m^2.day) for pond No.1 with 0.2 m^3/day and the average removal efficiency in the same period was 60%, 33% for CW1 and WSP1 respectively. After that, the flow was increased to 0.27 m^3/day (January and February) the organic loading rate 85.2 gCOD/(m^2.day) because that the average removal efficiency became 31%, 26% for CW3 and WSP3 respectively.
- As shown in figure 11 the removal efficiency is different from CW4 to WSP4, in startup phase (November and December) the organic loading rate was 50.7 gCOD/(m^2.day) for pond No.1 with 0.2 m^3/day and the average removal efficiency in the same period was 29%, 26% for CW1 and WSP1 respectively. After that, the flow was increased to 0.27 m^3/day (January and February) the organic loading rate 66.5 gCOD/(m^2.day) because that the average removal efficiency became 65%, 40% for CW4 and WSP4 respectively.

The overall removal efficiency COD is differing from vfCW to dWSP:

- <u>The vfCW system:</u>
    - At average loading rates for COD (58-187 g/ (m^2.d), the removal efficiency for COD in the four CWs ponds (beds) are depicted in above Figures. A summary for the results is as follows:
    - COD removal efficiency range for CW system (55-93%), Average value (83 %).
    - 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.
- <u>The dWSP system:</u>
    - At average loading rates for COD (58-187 g/ (m^2.d), the removal efficiency for COD in the four WSP ponds (beds) are depicted in above Figures. A summary for the results is as follows:
    - COD removal efficiency range for CW system (53-92%), Average value (79 %).
    - 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

As discussed in literature, the settlement and filtration of suspended solids are two mechanisms for the major organic matter removal in CWs, plant take-up and natural decay measures by microorganisms under aerobic as well as anaerobic conditions. (Stottmeister et al., 2003; Akratos and Tsihrintzis, 2007; Kadlec and Wallace,2009; Stefanakis et al., 2014; Vergeles et al., 2015).

Despite the application of high load of organic matter (46.7 g COD/m2. d) and without use of aeration tool, vfCWs showed high a significant removal efficiency in terms of COD (83%). Compared to dWSPs (79%), see Annex 2.

4.2.2 Total Nitrogen

4.2.2.1 Total Kjeldahl Nitrogen

The vfCWs and dWSPs systems showed different removal efficiencies for total Kjeldahl nitrogen (TKN). The below figures illustrate the data on TKN in the inlet and outlet of CWs vs WSPs including the removal percentages in both systems with time. In this study, CWs and WSPs were worked and observed at average loading rates for TKN (6.1-21.5g / (m^2.d). More detailed outcomes on the removal percentages and mass removal rates (g TKN/m^2. d) for the overall system can be found in Annex 3.

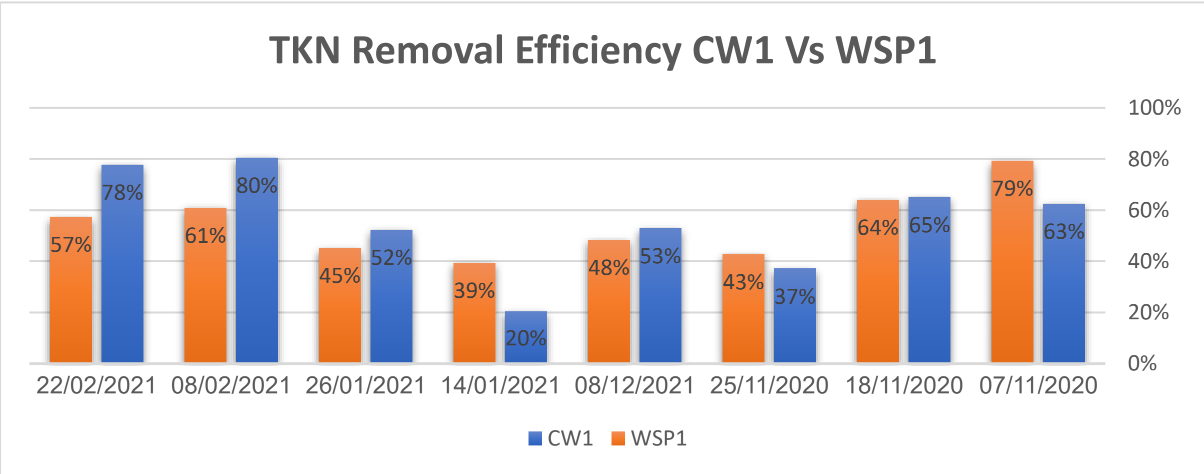


Figure 5: TKN Removal efficiency for CW1 and WSP1 vs Time

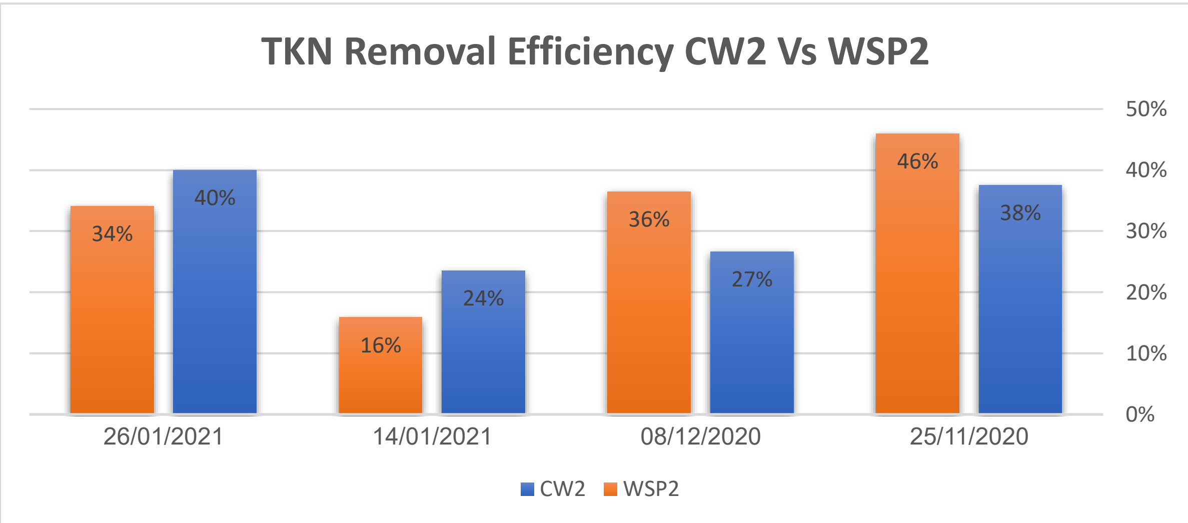


Figure 6: TKN Removal efficiency for CW2 and WSP2 vs Time

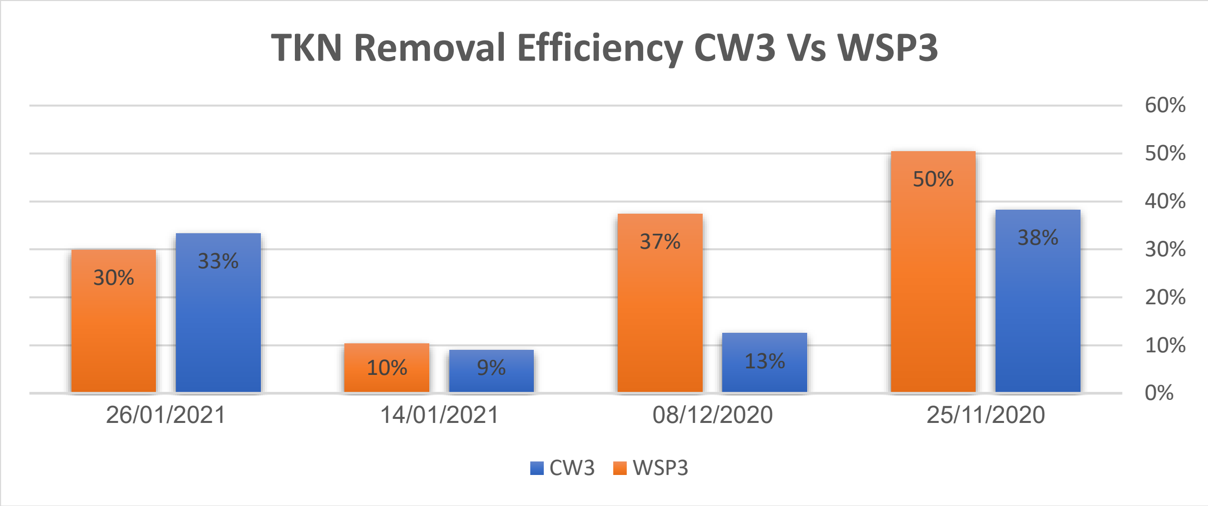


Figure 7: TKN Removal efficiency for CW3 and WSP3 vs Time

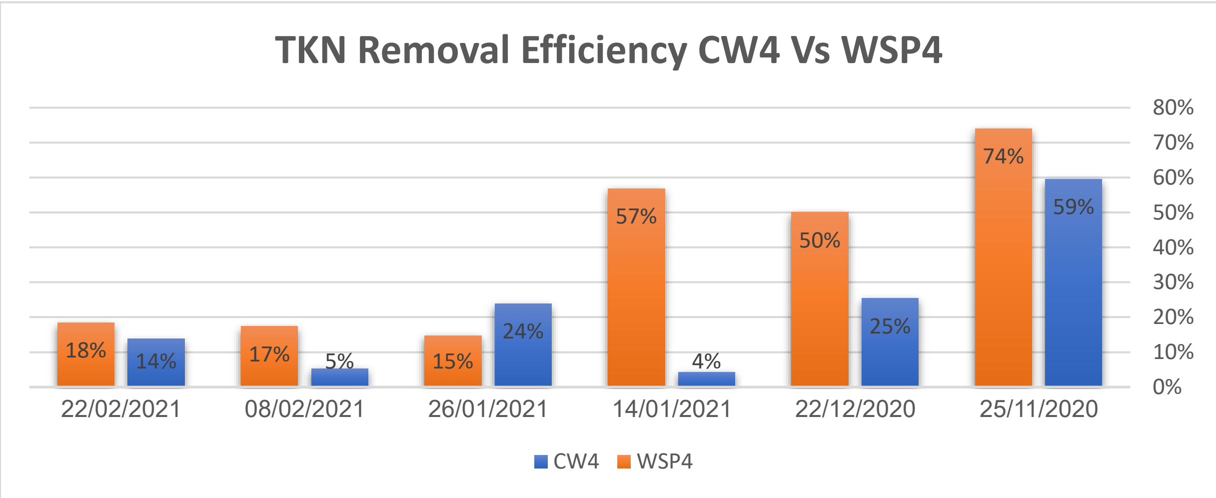


Figure 8: TKN Removal efficiency for CW4 and WSP4 vs Time

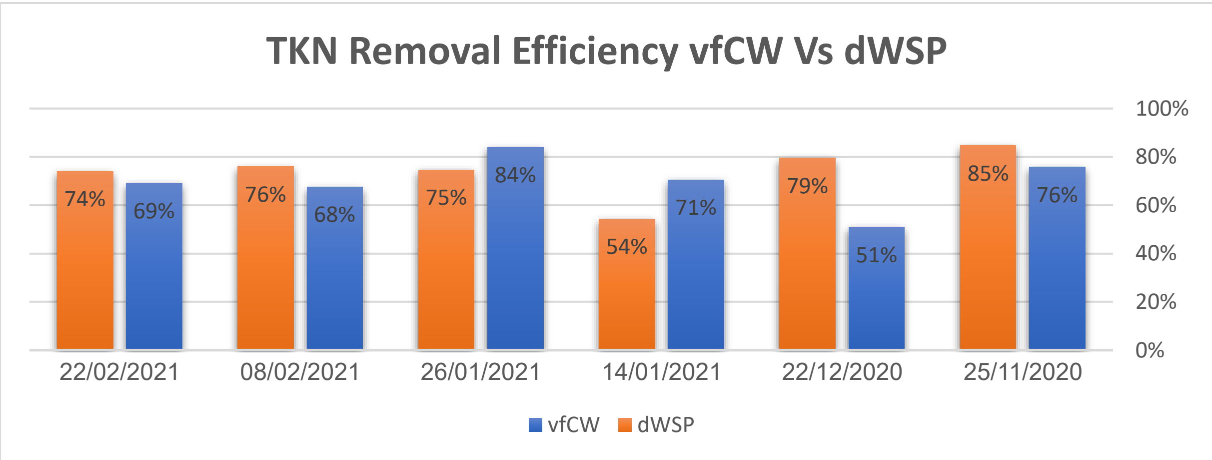


Figure 9: Overall Removal efficiency TKN for vfCW and dWSP vs Time

TKN removal efficiency for the CWs was different at over period of study, as shown in above figures the overall removal efficiency in November was 76% then dropped to 51% then increased again to reach 84% although HLR has increased in January from 0.2 m^3 to 0.27 m^3, but in February, it was observed that the overall removal efficiency decreased to 68%. In other hand, the WSPs started from 85% for removal efficiency TKN and was decreasing to 79%, 54%. After that, the percentage began increasing again to 75%.

4.2.2.2 Nitrate (NO_3^-)

The table 4.1 show the result of NO_3^- test for both system CWs and WSPs

Table 0-1: the NO3- result effluent and influent for CWs and WSPs

Date	CWs		WSPs	
	Influent (mg/l)	Effluent (mg/l)	Influent (mg/l)	Effluent (mg/l)
25/11/2020	0.14	0.9	0.14	0.09
22/12/2020	0.05	1.2	0.05	0.61
14/01/2021	0.01	9.6	0.01	0.26
26/01/2021	0.01	2.6	0.01	1.7
08/02/2021	0	0.3	0	0.62
22/02/2021	0	0.4	0	0.34

As presented in table 4.1 NO_3^- was differenced from CWs to WSPs. In general, the WSPs has less value NO_3^- from CWs. It was observed that when increased flow to 0.27 m^3 the NO_3^- has increased 9.6 mg/l then it began declined in CWs. Conversely in WSPs the increasing flow was not affected as no significant change in the NO_3^- value was observed.

So, the total nitrogen is TKN with neglectable NO_3^- and NO_2^-. The average nitrogen loading rate in first stage (flow = 0.2 m^3) is 5.42 (g/m^2.day) for CWs and WSPs, and in the second stage (flow = 0.27 m^3) NLR is 5.33 (g/m^2.day).

4.2.3 Orthophosphate (PO4--P)

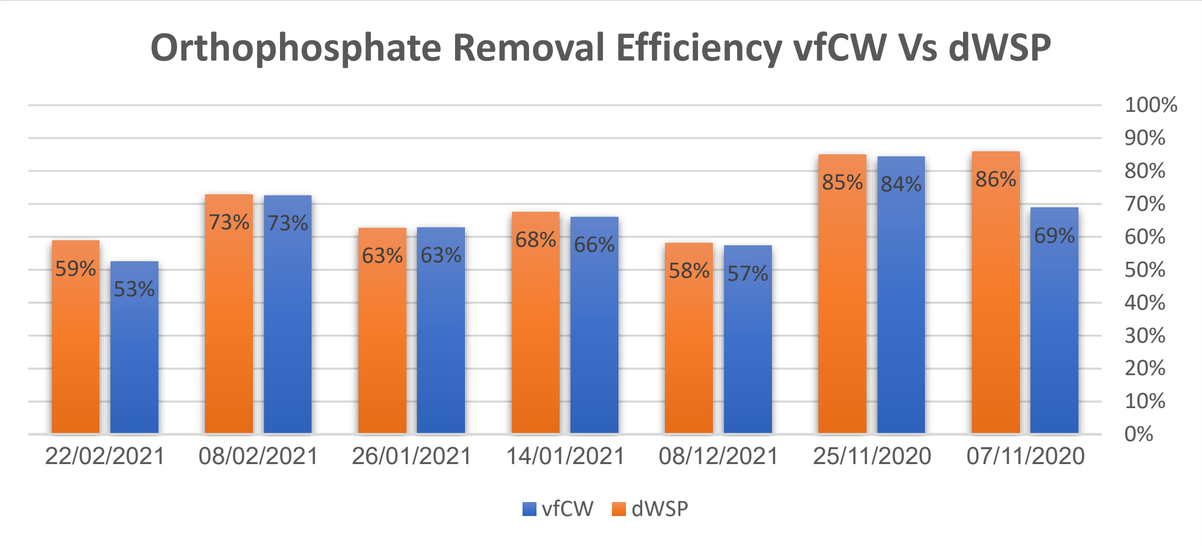


Figure 18: Overall Removal efficiency orthophosphate for vfCW and dWSP vs Time

In this study, the phosphorous test was approved, and not all samples were examined because the device that performs the examination was broken and the laboratory was unable to repair it due to the Corona pandemic.

The figure 18 represents the overall removal efficiency orthophosphate for vfCW and dWSP vs Time, as shown the removal efficiency ranged between (53-84%) and (58-86%) for vfCW and dWSP respectively. Other results illustrated in annex 3.

4.2.4 Total suspended solids (TSS)

During the study period (November 2020 - February 2021), the removal performance of total suspended solids (TSS) in CW1, CW4 compared to WSP4, WSP1 were illustrated in Figures

19 and 20.

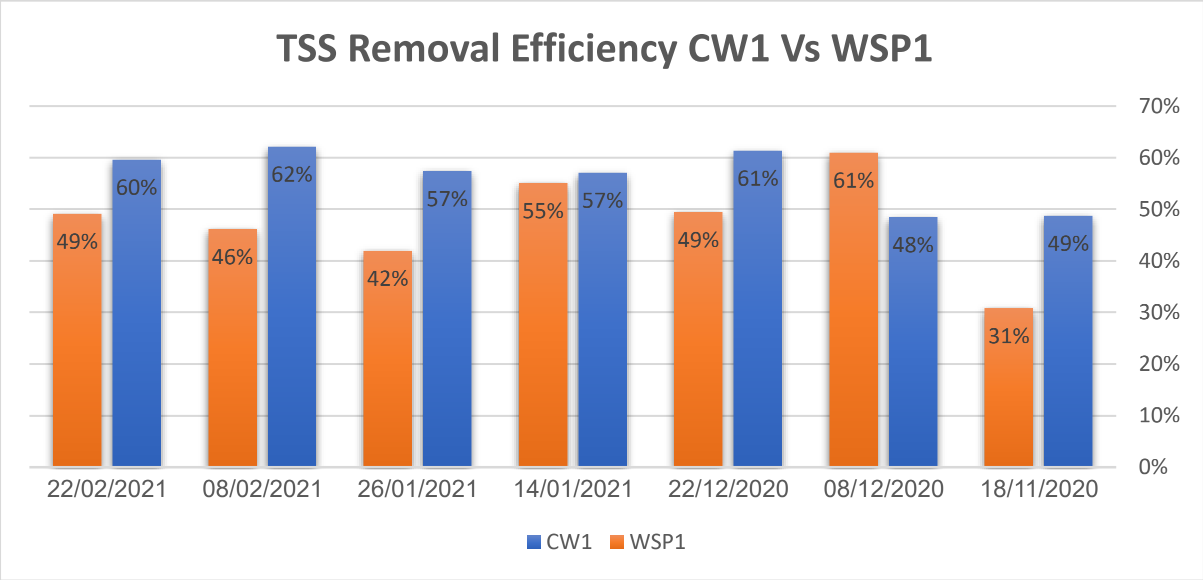


Figure 19: TSS Removal efficiency for CW1 and WSP1 vs Time

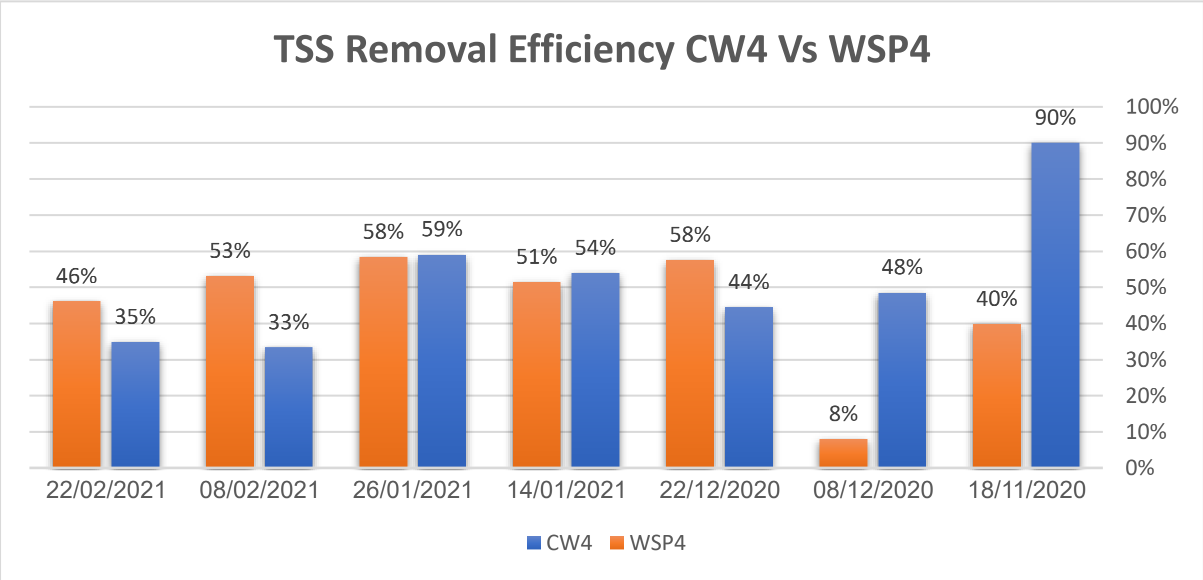


Figure 10: TSS Removal efficiency for CW4 and WSP4 vs Time

As shown in figure 19 TSS removal efficiency in CW pond#1 ranges between (48%-62%) and no difference happened when changed flow but regarding WSP pond#1 TSS removal efficiency ranges between (31%-61%). Hence it has lower efficiency than the CW1 system.

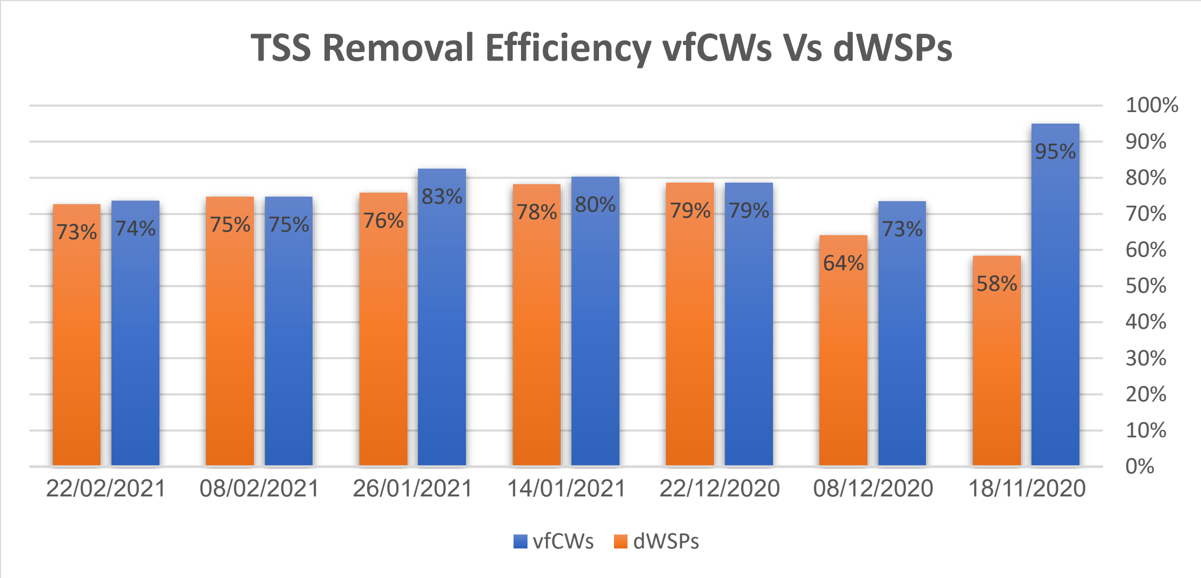


Figure 11: Overall TSS Removal efficiency for vfCW and dWSP vs Time

The data in Figure (21) entails the following facts:

I. TSS removal efficiency range in constructed wetland (overall) is (73-95%), Average value (80%) with HLR = 23 gTSS/(m^2.day)

II. TSS removal efficiency range in constructed wetland (overall) is (58-79%), Average value (72%) with HLR = 23 gTSS/(m^2.day)

The vfCWs system with 80% TSS removal efficiency showed better efficacy in treating slaughterhouse wastewater than the dWSPs system which TSS removal efficiency 72% in overall study period.

Chapter 5: Conclusion and Recommendations

5.1 Conclusion

From the above discussion the following points can be concluded:

- Significantly higher COD removal efficiency was achieved in vfCWs (83%) than dWSPs (79%). This suggests that vertical flow constructed wetlands are more efficient at higher organic loading than duckweed based-waste stabilization ponds.
- Nitrogen removal rates in vfCWs and dWSPs mostly as the same and no gap between them. Where the rate of TKN removal in the vfCWs system was 70% and 74% in the dWSPs system in average.
- Similar phosphorus removal rates in the vfCWs and in the dWSPs were observed at low and high organic loading periods. Phosphorus removal was higher in dWSPs than vfCWs during the low and high organic loaded periods, due to uptake by duckweed in the former system.
- The temperature fluctuated during the study period, ranged between 4 and 23 degrees Celsius, which have had potential impacts on the treatment processes in both systems.
- With regard to TSS, the first system showed high treatment efficacy, as the vfCWs treatment rate was 80% compared to the dWSPs second system 72%.
- During the research, operational costs for nature-based treatment systems were mainly for the feed pumps, system monitoring and lab analysis. The annual operational expenditures should be lower than other mechanical-biological treatment systems.

5.2 Recommendations

Drawing on the results obtained from the studies outlined in the master's thesis, these following topics deserve attention and require further investigation:

- The effectiveness of vfCWs and dWSPs in reducing organic pollution loads from industrial effluents requires confirmation under the variable organic loading rates during the summer season. Results from annual operation provide better design parameters.
- We recommend installing the vfCWs system preceded by a UASB reactor, especially in poultry slaughterhouse, source of agri-food industrial effluents. The vfCWs showed higher removal efficiency compared to dWSPs.
- Further studies are needed on both systems with focus on process optimization through partial effluent recirculation, plug-flow modus, synthetic media amendment, and solar-energy usage for a self-sufficient energy nature-based technology.
- Total coliform is an important factor that should be monitored adjusted and stabilized. This research overlooked this factor. It is highly recommended to consider it in any future research and if ecotechnology treatment systems are to be applied at full-scale.

References

Afifi, S. (2006). Wastewater reuse status in the Gaza Strip, Palestine. Int J Environ Pollut, 28(1-2), 76-86.

Akpor O.B., Muchie M., (2011). Environmental and public health implications of wastewater quality, Afr. j. biotechnol, 10 (13), 2379-2387.

Akratos, C.S., Tsihrintzis, V.A., (2007). Effect of temperature, HRT, vegetation and substrate material on removal efficiency of pilot-scale horizontal subsurface flow constructed wetlands. Ecol. Eng. 29, 173e191.

Al-Khatib, N., Shoqeir, J.A., Özerol, G., & Majaj, L. (2017). Governing the reuse of treated wastewater in irrigation: the case study of Jericho, Palestine. IJGEnvI, 16(1-3), 135-148.

Altay, A., H. Bayhan, L. Akca, (1996). Nutrient removal efficiency of the natural treatment system utilizing duckweed. I st Uludag Environmental Engineering Symposium, Bursa.

Asselin, M., Drogui, P., Benmoussa, H., Blais, J.-F., (2008). Effectiveness of electrocoagulation process in removing organic compounds from slaughterhouse wastewater using mono polar and bipolar electrolytic cells. Chemosphere 72 (11), 1727-1733.

Basham D., (2003). Applicability of constructed wetlands for army installations. Available on: http://www.wbdg.org.

Bull, M.A., Sterritt, R.M., Lester, J.N., (1982). The treatment of wastewaters from the meat industry: A review. J. Environ. Sci. Tech. Let., 3, 117-126.

Bustillo-Lecompte C.F., Mehrvar M., (2015). Slaughterhouse wastewater characteristics, treatment, and management in the meat processing industry: a review on trends and advances. Journal of Environmental Management; 161:287–302.

Bustillo-Lecompte, C.F., Mehrvar, M., Quinones-Bolanos, E., (2013). Combined anaerobic-aerobic and UV/H2O2 processes for the treatment of synthetic slaughterhouse wastewater. J. Environ. Sci. Health A, 48 (9), 1122-1135.

Caicedo, J.R., N.P. Van Der Steen, O. Arce, H.J. Gizjen, (2000). Effect of total ammonia nitrogen concentration and pH on growth rates of duckweed (Spirodela polyrrhiza). Water Res., 34, 3829-3835.

Chazarenc, F., Merlin G., Gonthier Y., (2003). Hydrodynamics of horizontal subsurface flow constructed wetlands. Ecological Engineering. (21), 165–173.

Cheng, J., B.A. Bergmann, J.J. Classen, J.W. Howard, Y.T. Yamamoto, (2002). Nutrient removal from swine lagoon liquid by Lemna minor 8627. Am. Soc. Agri. Eng., 45, 1003-1010.

Crites, R.W., Joe Middlebrooks, J., Reed, S.C., (2006). Natural Wastewater Treatment Systems. CRC Press, Taylor & Francis Group, FL 33487–2742.

Debik, E., Coskun, T., (2009). Use of the Static Granular Bed Reactor (SGBR) with anaerobic sludge to treat poultry slaughterhouse wastewater and kinetic modeling. Bioresour. Technol. 100 (11), 2777-2782.

Demortain, D. (2020). The Science of Bureaucracy: Risk Decision-Making and the USEPA. MIT Press. DOI: https://doi.org/10.7551/mitpress/12248.001.0001.

Dou, T., Troesch, S., Petitjean, A., Gábor, P.T., Esser, D. (2017). Wastewater and rainwater management in urban areas: A role for constructed wetlands. Procedia Environ. Sci., 37, 535–541.

Faqeeh, H., (2021). Effectiveness of Constructed Wetlands for Post-treatment of Mixed Wastewaters from Poultry Slaughterhouse and Olive Mill. M.Sc. Thesis, Birzeit University, Palestine.

Ghrabi, A., Bousselmi, L., Masi, F., Regelsberger, M. (2011). Constructed wetland as a low cost and sustainable solution for wastewater treatment adapted to rural settlements: Chorfech wastewater treatment pilot plant. Water Sci. Technol. 63 (12), 3006-3012.

Gratziou, M., Chalatsi, M. (2017). Efficiency of stabilization pond systems in Northern Greece on phosphorus removal. Water Utility Journal. 16. 105–116.

Grégorio, C., Eric L., (2019). Advantages and disadvantages of techniques used for wastewater treatment. Environmental Chemistry Letters, Springer Verlag, 17 (1), pp.145-155.

Hammouda, O., Gaber, A., Abdel-Hameed, M.S., (1995). Assessment of the effectiveness of treatment of wastewater-contaminated aquatic systems with *Lemna gibba*. J. Enz. Micro. Technol., 17, 317-323.

Hasar, H., U. Ipek, E. Obek, Y. Saatci, (2000). Su mercimeginin (Lemna minor L.) ileri aritimda kullanimi. SKKD, 10, 9-13.

Kadlec, R. H., Wallace, S., (2009). Treatment Wetlands. Boca Raton, FL: CRC Press.

Kadlec, R., Wallace, S., (2009). Treatment Wetlands, second ed. CRC Press, Boca Raton.

Korner, S., G.B., Lyatuu, J.E., Vermaat., (1998). The influence of Lemna gibba L. on the degredation of organic material in duckweed covered domestic wastewater. Water Res., 32, 3092-3098.

Korner, S., J.E., Vermaat., (1998). The relative importance of Lemna gibba L. bacteria and algae for the nitrogen and phosphorus removal in duckweed covered domestic wastewater. Water Res., 32, 3651-3661.

Levine, A.D., Asano, T., (2004). Recovering sustainable water from wastewater. Environ. Sci. Technol. 38 (11), 201A–208A.

Levy, G. J., Fine, P., Bar-tal, A. (2010). Treated Wastewater in Agriculture. In Treated Wastewater in Agriculture. https://doi.org/10.1002/9781444328561.

Li, Y., Zhu, G., Ng, W.J., Tan, S.K., (2014). A review on removing pharmaceutical contaminants from wastewater by constructed wetlands: design, performance and mechanism. Sci. Total Environ. 468–469, 908–932.

Libutti, A., Gatta, G., Gagliardi, A., Vergine, P., Pollice, A., Beneduce, L., ... & Tarantino, E. (2018). Agro-industrial wastewater reuse for irrigation of a vegetable crop succession under Mediterranean conditions. Agric. Water Manag., 196, 1-14.

Luederitz, V., Eckert, E., Lange-Weber, M., Lange, A., Gersberg, R. M. (2001). Nutrient removal efficiency and resource economics of vertical flow and horizontal flow constructed wetlands. Ecological Engineering, 18(2), 157-171. doi:10.1016/s0925-8574(01)00075-1

Masse, D.I., Masse, L., (2000). Characterization of wastewater from hog slaughterhouses in Eastern Canada and evaluation of their in-plant wastewater treatment systems. Can. Agric. Eng. 42 (3), 139-146.

Masse, D.I., Masse, L., (2000). Characterization of wastewater from hog slaughterhouses in Eastern Canada and evaluation of their in-plant wastewater treatment systems. Can. Agric. Eng. 42 (3), 139-146.

Mekonnen, M.M., Hoekstra, A.Y., (2012). A global assessment of the water footprint of farm animal products. Ecosystems 15 (3), 401-415.

Mihelcic, J., (2018). Sludge Management: Biosolids and Fecal Sludge, J. B Rose.

Moazzam, A., Khan, S., Shahid S., Altaf Khan, M., (2009). Growth, yield and nutrient content of sunflower (helianthus annuus l.) Using treated wastewater from waste stabilization ponds, Pak. J. Bot., 41(3): 1391-1399.

Najajra, A. (2020). Efficacy of UASB System for the Pretreatment of Mixed Industrial Wastewaters from Poultry Slaughterhouse and Olive Mill. M.Sc. Thesis, Birzeit University, Palestine.

Niyonzima, P., (2007). MSc thesis entitled: Grey water treatment using constructed wetland at Knust in Kumasi. Nkrumah University of Science and Technology, Ghana.

Oron, G., Porath, D., Wildschut, L.R., (1986). Wastewater treatment and renovation by different duckweed species. J. Environ. Eng., 112 (2), 247-263.

Oron, G., Wildschut, L.R., Porath, D., (1984). Wastewater recycling by duckweed for protein production and effluent renovation. J. Water Sci. Technol., 17, 803-817.

Powell, N., Shilton, A., Pratt, S., Usufchisti, A., (2008). Factors influencing luxury uptake of phosphorus by microalgae in waste stabilization ponds. Environmental Science Technology. 42(16), 5958–5962.

Puigagut, J., Villaseñor, J., Salas, J. J., Bécares, E., García, J., (2007). Subsurface-flow constructed wetlands in Spain for the sanitation of small communities: A comparative study. Ecol. Eng., 30(4), 312–319. doi: 10.101. J. ecoleng.2007.04.005.

Pycha, Ch., Lopez, E., (2015). Municipal Wastewater Lagoon Phosphorus Removal. Department of Environmental Protection, State of Main, U.S.A. http://www.lagoonsonline.com/phosphorous.htm [Accessed 1st November 2014]

Roman, B., Brennan, R.A., (2019). A beneficial by-product of ecological wastewater treatment: An evaluation of wastewater-grown duckweed as a protein supplement for sustainable agriculture. Ecol. Eng. X, 100004. doi: 10.1016/j.ecoena.2019.100004.

Sa'at S., (2006). MSc thesis entitled: Subsurface flow and free water surface flow constructed wetland with magnetic field for leachate treatment site. Faculty of Civil Engineering Universiti Teknologi Malaysia.

Saddoud, A., & Sayadi, S. (2007). Application of acidogenic fixed-bed reactor prior to anaerobic membrane bioreactor for sustainable slaughterhouse wastewater treatment. J. Hazard. Mater., 149(3), 700-706.

Saeed, T., Sun, G., (2012). A review on nitrogen and organics removal mechanisms in subsurface flow constructed wetlands: dependency on environmental parameters, operating conditions and supporting media. J. Environ. Manage. 112, 429–448.

Sangodoyin, A.Y., Agbawhe, O.M., (1992). Environmental study on surface and groundwater pollutants from abattoir effluents. J. Bioresour. Technol., 41, 193-200.

Stefanakis, A.I. (2018). Constructed Wetlands for Industrial Wastewater Treatment. John Wiley and Sons Ltd. NJ, USA.

Stefanakis, A.I., Akratos, C.S., Tsihrintzis, V.A. (2014). Chapter 5 - Treatment Processes in VFCWs, pp. 57-84. In: Vertical Flow Constructed Wetlands-Eco-engineering Systems for Wastewater and Sludge Treatment. 1 st Edition. Amsterdam: Elsevier, The Netherlands.

Stottmeister, U., Wiebner, A., Kuschk, P., Kappelmeyer, U., Kästner, M., Bederski, O., Müller, R., Moormann, H., (2003). Effects of plants and microorganisms inconstructed wetlands for wastewater treatment. Biotechnol. Adv. 22, 93–117.

Tritt, W.P., Schuchardt, F., (1992). Materials flow and possibilities of treating liquid and solid wastes from slaughterhouses in Germany. A review. J. Bioresour. Technol., 41, 235-245.

US EPA, (2004). Effluent limitations guidelines and new source performance standards for the meat and poultry products point source category. U. S. Environ. Prot. Agency (US EPA) Federal Register, 69 (173).

Verbyla, M., von Sperling, M., and Maiga, Y., (2017). Waste Stabilization Ponds. In: J.B. Rose and B. Jiménez-Cisneros, (eds) Global Water Pathogen Project.

Vergeles, Y., Vystavna, Y., Ishchenko, A., Rybalka, I., Marchand, L., Stolberg, F., (2015). Assessment of treatment efficiency of constructed wetlands in East Ukraine. Ecol. Eng. 83, 159–168.

Vigneswaran, S, Sundaravadivel, M. (2004). Recycle and Reuse Domestic Wastewater In Wastewater Recycle, Reuse and Reclamation. Encyclopedia of life Support Systems (EOLSS), Developed under the Auspices of the UNESCO, Eolss Publisher, Oxford, UK, (http//www.eolss.net).

Von Sperling, M., (2007). Waste Stabilisation Ponds, Biological Wastewater Treatment Series, IWA Publishing. London, UK. V (3).

Vymazal J., (2005). Horizontal sub-surface flow and hybrid constructed wetlands systems for wastewater treatment. Ecol. Eng 25, 478–490.

Vymazal, J., (2008). Constructed wetlands, surface flow. InEncyclopedia of Ecology, Jørgensen, S. E., Fath, B., Eds.; Elsevier BV: Amsterdam: Vol. 1.

Vymazal, J., (2011). Constructed Wetlands for Wastewater Treatment: Five Decades of Experience. Environ. Sci. Technol., 45, 61–69.

Vymazal, J., (2011). Plants used in constructed wetlands with horizontal subsurface flow: a review. Hydrobiologia 674, 133–156.

World Bank Group, (2007). Environmental, Health and Safety (EHS) Guidelines for Meat Processing. General EHS Guidelines: Environmental Wastewater and Ambient Water Quality (accessed 10.03.15.).

Wu, S., Kuschk, P., Brix, H., Vymazal, J., Dong, R., (2014). Development of constructed wetlands in performance intensifications for wastewater treatment: a nitrogen and organic matter targeted review. Water Res. 57C, 40–55.

Yamagiwa, K., and Ong, S., (2008). Up flow Constructed Wetland for On-site Industrial Wastewater Treatment. Graduate School of Science and Technology, Niigata University, Japan.

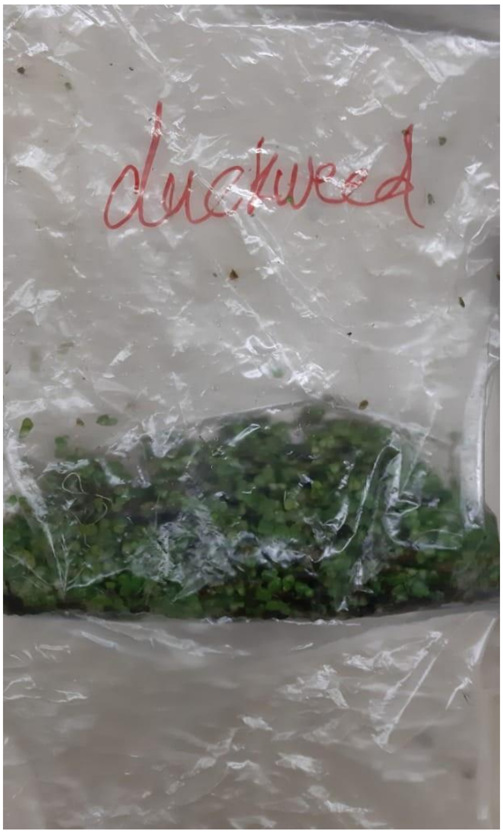
Zhang, Y. (2012). Design of a Constructed Wetland for Wastewater Treatment and Reuse in Mount Pleasant, Utah. All Graduate Plan B and other Reports. 2(16), 1-85.

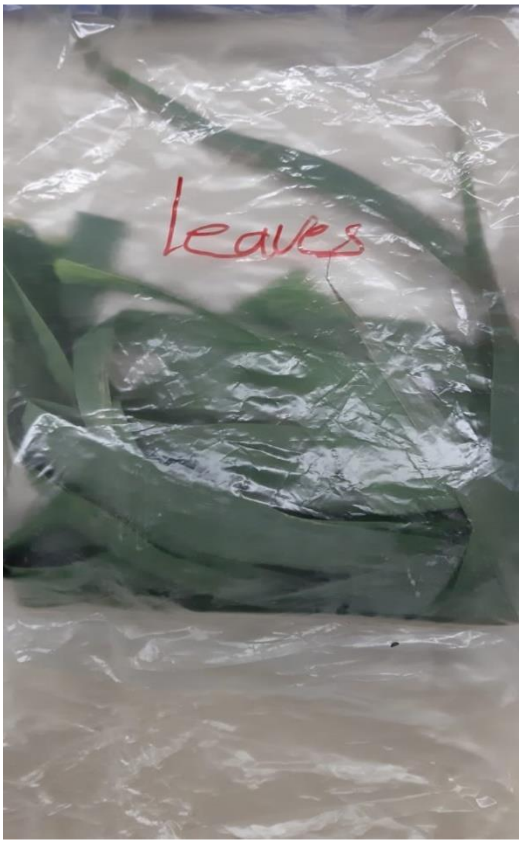
Zimmo, O., M., van der Steen, N.P., Gijzen, H.J., (2004). Nitrogen mass balance across pilot-scale algae and duckweed-based wastewater stabilisation ponds. Water Res. 38 (4):913-20

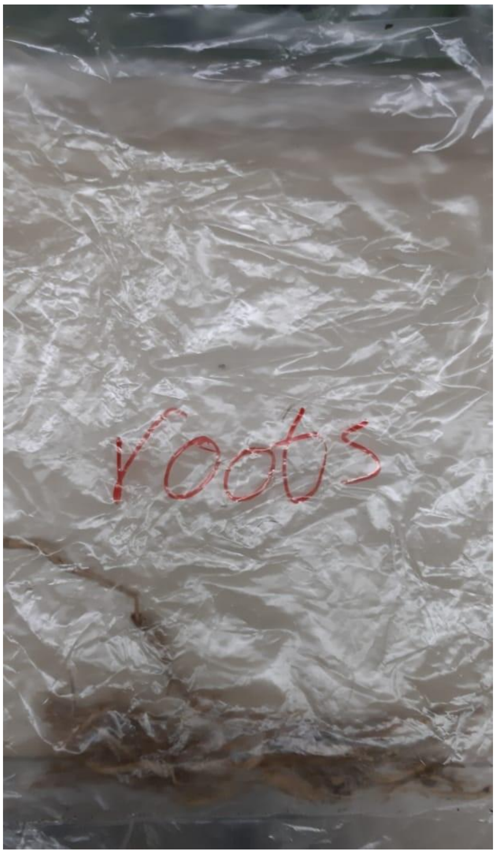
Zimmo, O.R., Al-Sa'ed R., Gijzen, H., (2000). Comparison between algae-based and duckweed-based wastewater treatment: differences in environmental conditions and nitrogen transformations. Water Sci. Tech., 42(10), 215-222.

Zimmo, O.R., Al-Sa'ed R.M., van der Steen, N.P., Gijzen, H.J., (2002). Process performance assessment of algae-based and duckweed-based wastewater treatment systems. Water Sci. Tech., 45(1), 91-101.

Annex 1: Photos from the Lab and study area

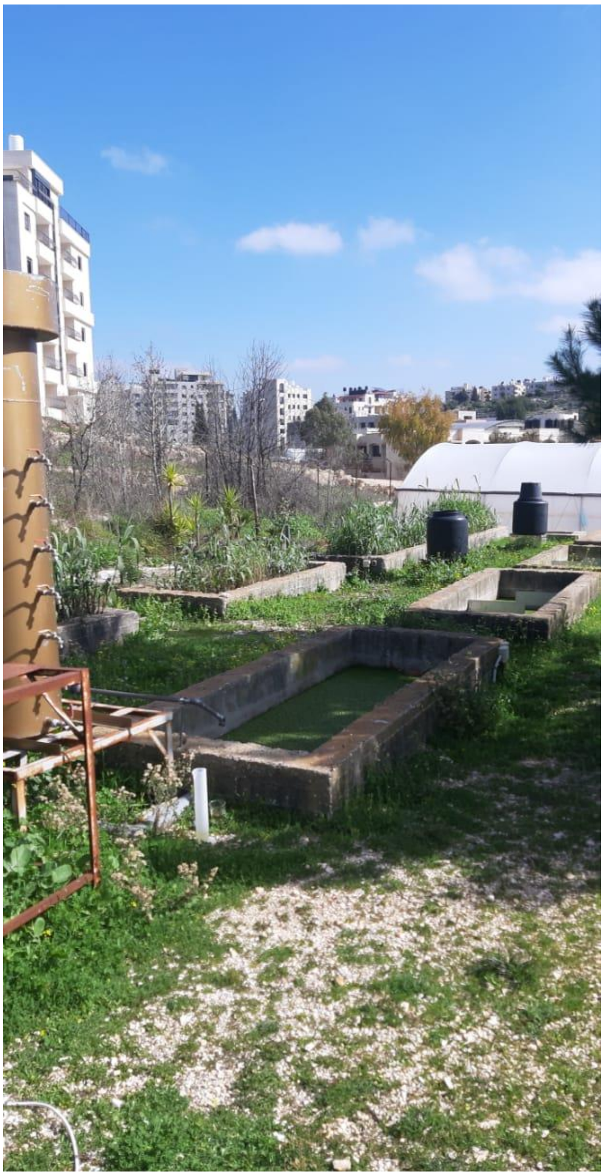







duckweed
leaves
legs
roots

Overview of the pilot UASB-constructed wetlands system




CW
1 → 2 → 3 → 4
26/1/2021

Water samples collected from various beds of the constructed wetlands and waste stabilization ponds

Duckweed pond

water inlet and outlet of constructed wetlands

The temperatures were determined overall period

Month	Date	Temp (C°)	Average
November	15/11/2020	21	21.3
	18/11/2020	20	
	22/11/2020	23	
December	01/12/2020	18	14.5
	03/12/2020	19	
	08/12/2020	17	
	14/12/2020	12	
	16/12/2020	11	
	17/12/2020	12	
	19/12/2020	12	
	22/12/2020	16	
	24/12/2020	18	
	25/12/2020	13	
	27/12/2020	13	
	28/12/2020	10	
	30/12/2020	18	
January	01/01/2021	14	12.1
	04/01/2021	15	
	05/01/2021	16	
	11/01/2021	17	
	14/01/2021	12	
	16/01/2021	12	
	18/01/2021	9	
	20/01/2021	7	
	21/01/2021	11	
	22/01/2021	12	
	25/01/2021	13	
	26/01/2021	11	
	27/01/2021	13	
	29/01/2021	8	
February	01/02/2021	14	11.7
	06/02/2021	19	
	10/02/2021	13	
	13/02/2021	14	
	17/02/2021	4	
	18/02/2021	4	
	25/02/2021	14	

Annex 2: Sampling and COD lab analysis for the inlet and outlet of constructed wetlands[*1)] and waste stabilization ponds[*2)]

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

Constructed wetlands	Date	COD inlet	Loading Rate	COD outlet	COD removal	Flow (m^3/d)	Surface Area	Removal Rate	Removal Efficiency
Bed Number		(mg/l)	g COD/(m^2.d)	(mg/l)	(g/m^3)	(m^3/d)	(m^2)	g COD/(m^2.d)	
CW1	07/11/2020	2200	146.7	206.7	1993.3	0.2	3	132.9	91%
CW1	18/11/2020	3350	223.3	1020	2330	0.2	3	155.3	70%
CW1	22/12/2020	2117	141.1	1280	837	0.2	3	55.8	40%
CW1	14/01/2021	2320	208.8	1160	1160	0.27	3	104.4	50%
CW1	26/01/2021	2113	190.2	980	1133	0.27	3	102.0	54%
CW1	08/02/2021	2280	205.2	1408	872	0.27	3	78.5	38%
CW1	22/02/2021	2183	196.5	1453	730	0.27	3	65.7	33%
Average [NOV-FEB]		2366.1	187.4	1072.5	1293.6	0.2	3.0	99.2	54%

CW2	18/11/2020	1020	68.0	454	566	0.2	3	37.7	55%
CW2	25/11/2020	1020	68.0	890	130	0.2	3	8.7	13%
CW2	03/12/2020	2020	134.7	1653	367	0.2	3	24.5	18%
CW2	08/12/2020	1930	128.7	1560	370	0.2	3	24.7	19%
CW2	22/12/2020	1280	85.3	880	400	0.2	3	26.7	31%
CW2	14/01/2021	1160	104.4	783	377	0.27	3	33.9	33%
CW2	26/01/2021	980	88.2	813	167	0.27	3	15.0	17%
CW2	08/02/2021	1408	126.7	1101	307	0.27	3	27.6	22%
CW2	22/02/2021	1453	130.8	1093	360	0.27	3	32.4	25%
Average [June-September]		890.5	103.9	1025.2	338.2	0.2	3.0	25.7	26%

CW3	25/11/2020	890	59.3	230	660	0.2	3	44.0	74%
CW3	22/12/2020	880	58.7	481	399	0.2	3	26.6	45%
CW3	14/01/2021	783	70.5	573	210	0.27	3	18.9	27%
CW3	26/01/2021	813	73.2	466	347	0.27	3	31.2	43%
CW3	08/02/2021	1101	99.1	780	321	0.27	3	28.9	29%
CW3	22/02/2021	1093	98.4	801	292	0.27	3	26.3	27%
Average [June-September]		926.7	76.5	555.2	371.5	0.2	3.0	29.3	41%

CW4	25/11/2020	230	15.3	163	67	0.2	3	4.5	29%	93%
CW4	03/12/2020	1201	80.1	1053	148	0.2	3	9.9	12%	69%
CW4	08/12/2020	1130	75.3	953	177	0.2	3	11.8	16%	55%
CW4	22/12/2020	481	32.1	193	288	0.2	3	19.2	60%	92%
CW4	14/01/2021	573	51.6	200	373	0.27	3	33.6	65%	91%
CW4	26/01/2021	801	72.1	163	638	0.27	3	57.4	80%	93%
CW4	08/02/2021	780	70.2	280	500	0.27	3	45.0	64%	87%
CW4	22/02/2021	801	72.1	380	421	0.27	3	37.9	53%	84%
Average [June-September]		749.6	58.6	423.1	326.5	0.2	3.0	27.4	47%	83%

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

Determination of COD removal rates (g COD/m².d) for dWSPs

Waste Stabilization Ponds	Date	COD inlet	Loading Rate	COD outlet	COD removal	Flow (m³/d)	Surface Area	Removal Rate	Removal Efficiency
Bed Number		(mg/l)	g COD/(m².d)	(mg/l)	(g/m³)	(m³/d)	(m²)	g COD/(m².d)	
WSP1	07/11/2020	2200	146.7	447	1753	0.2	3	116.9	80%
WSP1	18/11/2020	3350	223.3	1920	1430	0.2	3	95.3	43%
WSP1	25/11/2020	3500	233.3	1250	2250	0.2	3	150.0	64%
WSP1	03/12/2020	2020	134.7	1653	367	0.2	3	24.5	18%
WSP1	22/12/2020	2117	141.1	1063	1054	0.2	3	70.3	50%
WSP1	14/01/2021	2320	208.8	993	1327	0.27	3	119.4	57%
WSP1	26/01/2021	2113	190.2	983	1130	0.27	3	101.7	53%
WSP1	08/02/2021	2280	205.2	1208	1072	0.27	3	96.5	47%
WSP1	22/02/2021	2183	196.5	1198	985	0.27	3	88.7	45%
Average [NOV-FEB]		2453.7	186.6	1190.6	1263.1	0.2	3.0	95.9	51%

WSP2	18/11/2020	1920	128.0	1033	887	0.2	3	59.1	46%
WSP2	25/11/2020	1250	83.3	446	804	0.2	3	53.6	64%
WSP2	03/12/2020	1653	110.2	1053	600	0.2	3	40.0	36%
WSP2	08/12/2020	1653	110.2	1410	243	0.2	3	16.2	15%
WSP2	22/12/2020	1063	70.9	765	298	0.2	3	19.9	28%
WSP2	14/01/2021	993	89.4	690	303	0.27	3	27.3	31%
WSP2	26/01/2021	983	88.5	712	271	0.27	3	24.4	28%
WSP2	08/02/2021	1208	108.7	933	275	0.27	3	24.8	23%
WSP2	22/02/2021	1198	107.8	1007	191	0.27	3	17.2	16%

Average [NOV-FEB]		890.5	96.1	877.0	373.1	0.2	3.0	27.9	0.3

WSP3	25/11/2020	446	29.7	363	83	0.2	3	5.5	19%
WSP3	22/12/2020	765	51.0	410	355	0.2	3	23.7	46%
WSP3	14/01/2021	690	62.1	470	220	0.27	3	19.8	32%
WSP3	26/01/2021	712	64.1	466	246	0.27	3	22.1	35%
WSP3	08/02/2021	933	84.0	768	165	0.27	3	14.9	18%
WSP3	22/02/2021	1007	90.6	819	188	0.27	3	16.9	19%
Average [NOV-FEB]		758.8	63.6	549.3	209.5	0.2	3.0	17.2	28%

WSP4	25/11/2020	363	24.2	183	180	0.2	3	12.0	50%	92%
WSP4	03/12/2020	1930	128.7	1560	370	0.2	3	24.7	19%	53%
WSP4	08/12/2020	1103	73.5	1085	18	0.2	3	1.2	2%	69%
WSP4	22/12/2020	410	27.3	280	130	0.2	3	8.7	32%	86%
WSP4	14/01/2021	470	42.3	296	174	0.27	3	15.7	37%	86%
WSP4	26/01/2021	466	41.9	386	80	0.27	3	7.2	17%	83%
WSP4	08/02/2021	768	69.1	365	403	0.27	3	36.3	52%	83%
WSP4	22/02/2021	819	73.7	396	423	0.27	3	38.1	52%	83%
Average [NOV-FEB]		791.1	60.1	568.9	222.3	0.2	3.0	18.0	33%	79%

[2)] The waste stabilization ponds pilot consists of four (4) cells arranged in series (WSP1, WSP2, WSP3, and WSP4)

Annex 3: Sampling and TKN lab analysis for the inlet and outlet of constructed wetlands*) and waste stabilization ponds*2)

Constructed wetlands	Date	TKN inlet	NO_3^- inlet	Loading Rate	NO_3^- outlet	TKN outlet	TKN removal	Flow	Surface Area	Removal Rate	Removal Efficiency
Basin Number		(mg/l)	(mg/l)	g TKN/(m^2.d)	(mg/l)	(mg/l)	(g/m^3)	(m^3/d)	(m^2)	g TKN/(m^2.d)	
CW1	07/11/2020	299	0.14	19.9	0.35	112	187	0.2	3	12.5	63%
CW1	18/11/2020	326	0.07	21.7	0.15	114	212	0.2	3	14.1	65%
CW1	25/11/2020	326	0.05	21.7	0.10	205	121	0.2	3	8.1	37%
CW1	08/12/2021	351	0.05	23.4	0.02	165	186	0.2	3	12.4	53%
CW1	14/01/2021	128	0.01	11.5	0.07	102	26	0.27	3	2.3	20%
CW1	26/01/2021	241	0.01	21.7	0.06	115	126	0.27	3	11.3	52%
CW1	08/02/2021	287	0	25.8	0.08	56	231	0.27	3	20.8	80%
CW1	22/02/2021	293	0	26.4	0.04	65	228	0.27	3	20.5	78%
Average [NOV-FEB]		281.4	0.0	21.5		116.8	164.6	0.2	3.0	12.8	55%

CW2	18/11/2020	114	0.15	7.6	0.63	41	73	0.2	3	4.9	64%
CW2	25/11/2020	205	0.1	13.7	0.12	128	77	0.2	3	5.1	38%
CW2	08/12/2020	165	0.02	11.0	0.1	121	44	0.2	3	2.9	27%
CW2	14/01/2021	102	6.2	9.2	6.2	78	24	0.27	3	2.2	24%
CW2	26/01/2021	115	1.7	10.4	1.7	69	46	0.27	3	4.1	40%
Average [June-September]		140.2	1.6	10.4		87.4	52.8	0.2	3.0	3.8	0.4

CW3	25/11/2020	128	0.12	8.5	0.23	79	49	0.2	3	3.3	38%

CW3	08/12/2020	72	0.1	4.8	0.31	63	9	0.2	3	0.6	13%
CW3	14/01/2021	78	6.2	5.2	7.90	71	7	0.27	3	0.5	9%
CW3	26/01/2021	69	1.7	4.6	3.60	46	23	0.27	3	1.5	33%
Average [June-September]		86.8	2.0	5.8	3.0	64.8	22.0	0.2	3.0	1.5	23%

CW4	25/11/2020	79	0.07	5.3	0.9	32	47	0.2	3	3.1	59%	76%
CW4	08/12/2020	79	0.82	5.3	1.4	58	21	0.2	3	1.4	27%	77%
CW4	22/12/2020	63	0.72	4.2	1.2	47	16	0.2	3	1.1	25%	51%
CW4	14/01/2021	71	7.9	4.7	9.6	68	3	0.27	3	0.2	4%	71%
CW4	26/01/2021	46	3.6	3.1	2.6	35	11	0.27	3	0.7	24%	84%
CW4	08/02/2021	95	0.2	7.9	0.3	90	5	0.27	3	0.4	5%	68%
CW4	22/02/2021	87	0.15	7.3	0.4	75	12	0.27	3	1.0	14%	69%
Average [June-September]		74.3	1.9	5.4	2.3	57.9	16.4	0.2	3.0	1.1	23%	71%

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

Waste Stabilization Ponds	Date	TKN inlet	NO_3^- inlet	Loading Rate	NO_3^- outlet	TKN outlet	TKN removal	Flow (m^3/d)	Surface Area	Removal Rate	Removal Efficiency
Bed Number		(mg/l)	(mg/l)	g COD/(m^2.d)	(mg/l)	(mg/l)	(g/m^3)	(m^3/d)	(m^2)	g TKN/(m^2.d)	
WSP1	07/11/2020	299	0.12	19.9	0.12	62	237	0.2	3	15.8	79%
WSP1	18/11/2020	326	0.03	21.7	0.03	117	209	0.2	3	13.9	64%
WSP1	25/11/2020	326	0.01	21.7	0.01	187	139	0.2	3	9.3	43%
WSP1	22/12/2020	351	0.03	23.4	0.03	181	170	0.2	3	11.3	48%
WSP1	14/01/2021	208	0.07	18.7	0.07	126	82	0.27	3	7.4	39%

WSP1	26/01/2021	241	0.05	21.7	0.05	132	109	0.27	3	9.8	45%
WSP1	08/02/2021	287	0	25.8	0.0	112	175	0.27	3	15.8	61%
WSP1	22/02/2021	293	0	26.4	0.0	125	168	0.27	3	15.1	57%
Average [NOV-FEB]		291.4	0.0	22.4	0.0	130.3	161.1	0.2	3.0	12.3	55%
WSP2	25/11/2020	187	0.01	12.5	0.06	101	86	0.2	3	5.7	46%
WSP2	22/12/2020	181	0.03	12.1	0.50	115	66	0.2	3	4.4	36%
WSP2	14/01/2021	126	0.07	11.3	0.08	106	20	0.27	3	1.8	16%
WSP2	26/01/2021	132	0.05	11.9	1.50	87	45	0.27	3	4.1	34%
WSP2	08/02/2021	112	0	10.1	0.01	83	29	0.27	3	2.6	26%
WSP2	22/02/2021	125	0	11.3	0.01	91	34	0.27	3	3.1	27%
Average [NOV-FEB]		143.8	0.03	11.51	0.36	97.2	46.7	0.2	3.0	3.6	31%
WSP3	25/11/2020	101	0.06	6.7	0.08	50	51	0.2	3	3.4	50%
WSP3	22/12/2020	115	0.5	7.7	0.53	72	43	0.2	3	2.9	37%
WSP3	14/01/2021	106	0.08	9.5	0.1	95	11	0.27	3	1.0	10%
WSP3	26/01/2021	87	1.5	7.8	1.63	61	26	0.27	3	2.3	30%
WSP3	08/02/2021	83	0.01	7.5	0.1	69	14	0.27	3	1.3	17%
WSP3	22/02/2021	91	0.01	8.2	0.12	76	15	0.27	3	1.4	16%
Average [NOV-FEB]		97.2	0.4	7.9	0.4	70.5	26.7	0.2	3.0	2.0	27%

WSP4	25/11/2020	50	0.08	3.3	0.09	13	37	0.2	3	2.5	74%	85%
WSP4	22/12/2020	72	0.53	4.8	0.61	36	36	0.2	3	2.4	50%	79%
WSP4	14/01/2021	95	0.1	8.6	0.26	41	54	0.27	3	4.9	57%	54%
WSP4	26/01/2021	61	1.63	5.5	1.7	52	9	0.27	3	0.8	15%	75%
WSP4	08/02/2021	69	0.1	6.2	0.62	57	12	0.27	3	1.1	17%	76%
WSP4	22/02/2021	76	0.12	6.8	0.34	62	14	0.27	3	1.3	18%	74%
Average [NOV-FEB]		70.5	0.4	5.9	0.6	43.5	27.0	0.2	3.0	2.1	39%	74%

*2) *The waste stabilization ponds pilot consists of four (4) cells arranged in series (WSP1, WSP2, WSP3, and WSP4)*

Constructed wetlands	Date	$PO4^{-3}$ inlet	Loading Rate	$PO4^{-3}$ outlet	$PO4^{-3}$ removal	Flow	Surface Area	Removal Rate	Removal Efficiency
Basin Number		**(mg/l)**	**g $PO_4/(m^2.d)$**	**(mg/l)**	**(g/m^3)**	**(m^3/d)**	**(m^2)**	**g PO4-/(m^2.d)**	
CW	07/11/2020	16.21	0.3	5.05	11.16	0.2	12	0.2	69%
CW	25/11/2020	26.9	0.4	4.19	22.71	0.2	12	0.4	84%
CW	08/12/2021	11.1	0.2	4.74	6.36	0.2	12	0.1	57%
CW	14/01/2021	15.3	0.3	5.2	10.1	0.27	12	0.2	66%
CW	26/01/2021	13.5	0.3	5.01	8.49	0.27	12	0.2	63%
CW	08/02/2021	17.2	0.4	4.71	12.49	0.27	12	0.3	73%
CW	22/02/2021	10.2	0.2	4.84	5.36	0.27	12	0.1	53%
Average [NOV-FEB]		15.8	0.3	4.8	11.0	0.2	12.0	0.2	66%

Waste stabilization ponds	Date	$PO4^{-3}$ inlet	Loading Rate	$PO4^{-3}$ outlet	$PO4^{-3}$ removal	Flow	Surface Area	Removal Rate	Removal Efficiency
Basin Number		**(mg/l)**	**g PO_4/(m^2.d)**	**(mg/l)**	**(g/m^3)**	**(m^3/d)**	**(m^2)**	**g PO4-/(m^2.d)**	
WSP	07/11/2020	16.21	0.3	2.28	13.93	0.2	12	0.2	86%
WSP	25/11/2020	26.9	0.4	4.02	22.88	0.2	12	0.4	85%
WSP	08/12/2021	11.1	0.2	4.65	6.45	0.2	12	0.1	58%
WSP	14/01/2021	15.3	0.3	4.97	10.33	0.27	12	0.2	68%
WSP	26/01/2021	13.5	0.3	5.03	8.47	0.27	12	0.2	63%
WSP	08/02/2021	17.2	0.4	4.66	12.54	0.27	12	0.3	73%
WSP	22/02/2021	10.2	0.2	4.2	6	0.27	12	0.1	59%
Average [NOV-FEB]		15.8	0.3	4.3	11.5	0.2	12.0	0.2	68%