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Effect of Wastewater Quality on the Performance of a CW-SAT Hybrid System in an Arid Region

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This Thesis was Submitted in Partial Fulfillment of the Requirements for the Master Degree in Water and Environmental Science from the Faculty of Graduate Studies at Birzeit University, Palestine

Birzeit University

January, 2015

Effect of Wastewater Quality on the Performance of a CW-SAT Hybrid System in an Arid Region

تأثير نوعية مياه الصرف الصحي على أداء النظام الهجين للأراضي الرطبه المنشأه مع نظام معالجة الطبقة الجوفية للمياه بواسطه التربة في أرض جافة

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Thesis was prepared under the supervision of Dr. Nidal Mahmoud and has been approved by members of the Examination Committee.

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Date of Defense: January, 2015

The findings, interpretations and conclusions expressed in this study do not necessary express the views of Birziet University, the views of individual members of MSc- committee or the views of their respective employers.

Dedication

To my family, who offered me unconditional love and support, to

whom I Belong, to my parents …

To my wife ….

To my brothers….

To those who are looking forward to enrich their knowledge…

For their help, support and encouragement…..

Acknowledgments

I wish to express my sincere appreciation to my supervisor Dr. Nidal Mahmoud for his guidance, help and encouragement throughout research work and writing up. My appreciations are due to Birzeit University, especially the Institute of Environmental and Water Studies including all staff members who have developed my skills during my study for the Master degree.

My gratitude also goes to all of my friends who directly or indirectly help me during my studies and to each member in IEWS staff.

I would like to forward my heartfelt love and thanks to my wife Malak Abu Al-Huda. I also extend my sincere and grateful thanks to my mother (Najah), my father (Adnan) and brothers (Ahmad, Mohamed, Khalil and Ibrahim) for their encouragement and support throughout this time.

This study was carried out as a part of the project ‘ Natural Systems for Wastewater Treatment and reuse: Technology Adaptation and Implementation in Developing Countries (NATSYS) of which UNESCO-IHE/The Netherlands, Univalle Cali/ Colobmia, Birzeit University/Palestine and King Abdullah University of Science and Technology (KAUST)/ Saudi Arabia are partners. This project is financially supported by the Dutch Government (DGIS) for financial support through UNESCO-IHE Partnership Research Fund (UPaRF), which is highly appreciated. We highly appreciate the continuous support of the team leader of the joint, Dr. Saroj Sharma, UNESCO-IHE Institute for Water Education, the Netherlands.

Biographical Sketch

Mahran A. A. Shahada was born on July 4, 1985 in Nablus, Palestine. In 2002 he graduated from Al-Islamiyah secondary school (Al- Dahiya, Nablus-Palestine). In 2007 he graduated from An-Najah National University (Nablus-Palestine) with the degree of Bachelor of Physics. In 2014 he has been engaged in research under the supervision of Dr. Nidal Mahmoud in BZU (Birziet, Ramallah-Palestine).

Abbreviations

COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen Demand
CWs	Constructed Wetlands
DO	Dissolved Oxygen
HRT	Hydraulic Retention Time
HSSFCWs	Horizontal Subsurface Flow Constructed Wetlands
VF	Vertical Flow
TN	Total Nitrogen
TSS	Total Suspended Solids
SS	Suspended Solids
TVS	Total Volatile Solids
NTS	Natural Treatment System
FC	Fecal Coliform
ASR	Aquifer Storage and Recovery
RBF	Riverbank Filtration
BZU	Birzeit University
SAT	Soil Aquifer Treatment
HLR	Hydraulic Loading Rate

Abstract

The present study aims to investigate the impacts of the quality of preliminarily-treated, sanitation and wastewater on the hybrid treatment system that consists of CW and SAT as a filtering system from various disease, pollutants in order to satisfy the Palestinian standards related to wastewater treatment.

In addition, this study looks into the potentials of pollutants concentration reduction, and effects of wastewater quality on the performance a CW-SAT hybrid system. This technology able to improve wastewater treatment and feeding aquifers since they are not costly and can be applied easily.

The hybrid treatment system (CW-SAT), that consists of two successive systems to treat wastewater by using CWs with SAT system as a filtering system to purify wastewater from pollutants, disease and suspended solid materials, involves several physical and biochemical processes, and mainly based on operating conditions, the site, and the sources of polluted water. The technologies of wetlands and the vertical filtering system by soil are used in many countries to treat polluted water.

Three identical systems of (CW-SAT) have been constructed with similar operating conditions at the same time and locations. Samples were taken from three different sources:(I) secondary effluent from a contact process activated sludge serving of (BZU) treatment plant (around 10,000 person); (II) tertiary treated effluent of Al-Bireh municipal wastewater treatment plant (around 50,000 person) and (III) influent wastewater of Al- Bireh (Raw-after grit). The CW system was supplied with ventilation source and gravels with 42% pores. In every CW, about 12 – 18 reed plants were planted. Samples were collected from this system and supplied to the aquifer treatment system 0.85 – 1.18 mm sand posts.

The samples were collected and analyzed from both the influent and effluent of the CW, and the vertical filtering system by using sand with certain specifications under constant climatic and operating conditions at the same time and location.

After 40 days of the operation which is called the ripening and maturation, the hybrid system was observed and followed up by testing and analyzing all the pollutants for a period of approximately 200 days. The study was divided into two stages: the operation stage and steady state stage.

The importance of this study, lies in the finding that the hybrid system has the capability of treating various types of wastewater pre-treatment. By this application, it was found out that there was a significant decrease in the concentrations of the following pollutants: BOD_5, COD, NO_3-N, NH_4-N, TSS, and FC bacteria. The final outcomes of the decrease in the pollutants concentrations that were obtained from the hybrid system for wastewater treatment of raw, treated wastewater of Al-Bireh Plant and the BZU were as follows: COD (89.9, 76.9, 79.9%); BOD_5 (89.7, 71.9, 91.3%); NH_4-N (94.4, 92.4, 95,4%); NO_3-N (92, 99.3, 95,3%); TSS(90, 99,6, 91.5%); and FC (99, 99.6, 98.6%), respectively.

The study reached remarkable findings in treating wastewater from different sources by using the hybrid system that satisfy the requirements of the Palestinian standards for the concentrations of each of the COD, BOD_5, NH_4, NO_3, TSS and FC.

Therefore, a CW-SAT hybrid system has achieved much better results than using CW or SAT system.

الخلاصة

لقد كان الهدف من وراء هذه الدراسة هو البحث في تأثير نوعية مياه الصرف الصحي والمياه العادمة المعالجة بشكل أولي على أداء النظام الهجين المكون من الأراضي المنشأه الرطبة ونظام معالجة الطبقة الجوفية للمياه بواسطة أعمدة التربة كنظام فلترة من مسببات الأمراض والملوثات المختلفة والمغذيات حتى تحقق بذلك متطلبات المواصفات الفلسطينية فيما يتعلق بمعالجة المياه العادمة.

تبحث هذه الدراسة في إمكانية تخفيض تراكيز الملوثات ودراسة تأثير المياه العادمة على أداء النظام الهجين المكون من نظامي معالجة. هذه التقنية قادرة على ان تطبق في محطات المعالجة حيث تحسن من جودة المياه المعالجة ولتغذية أحواض الطبقة الجوفية كونها غير مكلفة ويمكن تطبيقها بسهولة دون أي صعوبه.

إن النظام الهجين المكون من نظاميين متتاليين لمعالجة المياه العادمة بإستخدام منشأه للأراضي الرطبة وأعمده التربه كنظام تنقية من الملوثات ومسببات الأمراض والمواد الصلبة العالقة يتضمن العديد من العمليات الفيزيائية، الكيميائية والحيوية ويعتمد بشكل أساسي على الظروف التشغيلية والموقع ومصادر المياه الملوثة. تستخدم تقنيات الأراضي الرطبة ونظام التنقية العمودي بواسطة التربة في مختلف الدول لمعالجة المياه الملوثة، حيث يضم هذا البحث دراسة واسعة وشاملة عن هذه الطريقة.

تم بناء وتشييد ثلاثة أنظمة متماثلة بنفس الظروف التشغيلية ونفس المكان والزمان، أخذت العينات من ثلاثة مصادر مختلفة وهي: المياه العادمة الداخلة لمحطة البيرة، المياه المعالجة الخارجة من محطة البيرة والمياه المعالجة من محطة المعالجة في جامعة بيرزيت. تم تزويد نطام منشأة الأراضي الرطبة بمصدر تهوية وحصمة مسامتها 42% وزرعت في كل منشأه حوالي 12-18 نبته من القصب وتم جمع العينات من هذا النظام وتزويدها لنظام معالجة الطبقة الجوفية للمياه عن طريق أعمدة الرمل الذي كان حجمه 0.85-1.18 ملم.
جمعت وحللت العينات من مدخل ومخرج نظام منشأة الأراضي الرطبه وكذلك من نظام الفلترة العمودي بإستخدام الرمل بمواصفات معينة تحت ظروف مناخية وتشغيلية ثابتة بنفس المكان والزمان بعد 40 يوماً من التشغيل وسميت هذه الفترة بمرحلة التحضير والنضوج. وقد تمت متابعة ومراقبة النظام الهجين وفحص العينات وتحليلها لكل الملوثات مده 200 يوما تقريبا، حيث تم تقسيم مراحل الدراسة على مرحلتين وهما مرحلة التشغيل ومرحلة الثبات.

تظهر أهمية هذه الدراسة في التوصل أن النظام الهجين يمتلك القدرة في معالجة محتلف أنواع المياه العادمة بشكل أولي، وبواسطة هذا التطبيق تبين أن هنالك إنخفاضا واضحا في تراكيز الملوثات التالية:

الأكسجين المستهلك حيويا وكيميائيا والنيترات والأمونيا والنيتروجين والمواد الصلبة العالقة والبكتيريا القولونية البرازية.وقد سجلت النتائج النهائية لانخفاض تراكيز الملوثات التي تم الحصول عليها من النظام الهجين للمياه العادمة الخام من محطة البيرة والمياه المعالجه منها ومياه بيرزيت المعالجة على الترتيب: (89.9 ، 76.9، 79.9%) للأكسجين المستهلك كيميائيا، و(89.7، 71.9، 91.3 %) للأكسجين المستهلك حيويا، و (94.4، 92.4، 95.4%) للأمونيا، و(92، 99.3، 95.3%) للنيترات، و (90، 99.6، 91.5%) للمواد الصلبة العالقة، و (99، 99.6، 98.6%) للبكتيريا القولونية العالقة.

لقد تم التوصل إلى نتائج مميزة في معالجة المياه العادمة من مصادر مختلفة عن طريق النظام الهجين والتي تحقق متطلبات المواصفات الفلسطينية بتراكيز كل من الأكسجين المذاب حيويا وكيميائيا والأمونيا والنيترات والمواد العالقة الصلبة، لكن لم ينجح هذا النظام في تحقيق هذه المتطلبات في تخفيض تركيز البكتيريا القولونية البرازية للمياه العادمة الداخلة لمحطة البيرة فقط ليلبي متطلبات المواصفات الفلسطينية بهذا الشأن.

لقد أظهرت النتائج أن استخدام النظام الهجين كنظام لمعالجة المياه العادمة كفاءة عالية في تخفيض تراكيز الملوثات ومسببات الأمراض أفضل بكثير من استخدام نظام منشأة الأراضي الرطبة أو نظام اعمدة التربة لوحدها كنظام معالجة بشكل واضح.

The Scope of this Research Includes:

CW-SAT, where the CW was placed inside the campus of BZU and SAT was placed indoor IEWS lab. During the research period, data was collected from the experimental (CW-SAT) for treating three wastewater types for (I) secondary effluent from a contact process activated sludge serving of BZU treatment plant, (II) influent wastewater of Al- Bireh (Raw-after grit) and (III) tertiary treated effluent of Al-Bireh municipal wastewater treatment plant.

The experiments were carried out in BZU/Palestine. Wastewater samples were taken from the inlet and outlet of the three CW-SAT systems. The plants was used in this study were common reed (Phragmites Austrails) in CW and sand as a filter in soil columns of SAT setup. The performance of CW-SAT was evaluated using water quality parameters: pH, DO, TSS, TVS, NH_4-N, NO_3-N, COD, BOD, Evapo-transpiration (Water balance through CW) and FC.

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Chapter One

Introduction

1.1 Background

Water supply and availability of water in term of quantity is not only the problem faced by people around the world, but also there is a very necessary issue which called quality. Nowadays, about 1.2 billion people are at risk of sources water supply and clean water. Otherwise, 2.6 billion people lack enough sanitation in the world. The very rapid generation of agricultural and industrial waste has produced a huge pressure on natural water resource resulting in serious quality deterioration of water supply which is divided to surface and groundwater resources. It has been estimated that, by 2025, 1800 million people will be living in their countries with absolute water scarcity, and two thirds of the world population could be under water stress conditions (WHO, 2007).

It's necessary for the developing countries to choose a proper treatment technology method which meets with the requirements of water quality, impact on the environmental, cost and the potential for local reuse, operational skills and natural treatment system, i.e. constructed treatment wetlands (Hoffmann and Platzer, 2010).

CWs depend on physical, chemical and biological process of natural ecosystem. It can remove many aquatic pollutants by nature, and solar energy is considered as an important term to bioprocess operation which requires minimal maintenance. This system is either free water surface which includes a shallow basin where water is exposed to atmosphere and flows horizontally or subsurface wetland consists of a basin with porous media with water level below the surface of the media and the water flows horizontally (Converse, 1999).

CWs are built to create from non-wetland sites for wastewater treatment, these are being used around the world to treat wastewater, such that animal waste and fish farms, industry of all types, municipal and domestic sewage (Hoddinott, 2006).

CWs are man-made analogs of natural wetlands that utilize the biological, chemical and physical process that occur normally in wastewater treatment. CWs are divided into surface flow and subsurface flow which avoid odor problems and mosquito proliferation. CWs can also be used at a household and at a large scale the recovery of nutrients to minimize the eutrophication potential of the receiving water bodies (Davis, 1989).

CWs systems were applied to improve water quality in developing countries like Nepal, India and Egypt and all CWs attached to growth of biological reaction and microorganism, so the CWs are recommended to be preceded by a pre-treatment step for treatment of raw wastewater (El-Khateeb *et al.*, 2008).

There are multiple Natural wastewater treatment systems that have been applied and reused wastewater around the world like (CW) and (SAT), those can remove many types of contaminants, minimize the use of chemical material, use less energy and constitute robust barriers. NTS depend on natural processes comprising different biological, chemical and physical removal pollutants and combinations which have an important role in water quality (Khalili, 2007).

The recharge augmenting of surface water occurs through underground formations and it can be either direct or indirect. In direct recharge, water transmitted via injection wells into an aquifer. Indirect recharge is represented in spreading water on land through the vadose zone down to the aquifer. There are multiple methods for spreading water including creating artificial recharge changes and by over irrigation which needs using construction technical methods (Asano and Cotruvo, 2004; Stuyfzand and Dooment, 2004).

Most of to-date researches have shown the removal of organic matter and trace organic pollutants during CWs and soil passage, but less knows about the mechanism of NTS with regard to pre-treatment. Therefore, there is a need for more deep understanding of removal of bulk organic matter and organic micro-pollutants during NTS in order to ensure safe water reuse.

NTS project aims to investigate the potential for CW treatment as a pretreatment for (SAT). The major constraints of SAT are also space use and nutrient removal, so the project aims to optimize space efficiency and nutrient removal in CWs before water is discharged to SAT treatment. In this project, artificial aeration is one novel method that has been used to increase nitrification rates in CWs. The research also aimed to track several pollutant removal performances to investigate whether different water sources may have an impact on the removal efficiency in the wetland.

1.2 Problem Statement

CW-SAT Treatment are needed to be further adapted to increase their performance under local conditions (climate, wastewater quality and quantity) in terms of pre-treatment to obtain the desired removal efficiencies. Under the climatic conditions in Palestine, this research project aims to investigate the treatment capability of main vegetation-based natural systems for wastewater treatment for the removal of different contaminants such as organics, pathogens and nutrients under different water quality (Al Bireh wastewater, Al Bireh tertiary treated wastewater, and BZU treated wastewater).

In this research, the performance of CW-SAT treatment systems represented the behavior of the removal of multiple contaminants and pathogen to obtain more insight into their capabilities so that these can be successfully implemented in developing countries. A clear focus of the performance of CW-SAT for removal of different contaminants from various types of wastewaters (effluents) still need to be elucidated.

This MSc research studies the variables were the influent type and aeration are conducted on HSSFCWs which were fed with different source water (Al Bireh wastewater, Al Bireh tertiary treated wastewater, and BZU treated wastewater) with the same plant type (reed). The three wetlands were operated under the same conditions, same HRT and same loading rate, and the effluent water of wetlands put again in three SAT system.

1.3 Research Objectives

The main goal of this research is to investigate the effect of source water quality on the performance of (CW-SAT) with respect to the removal of solids, pathogens and nutrients. Different types of wastewater effluents were examined during the study including (I) secondary effluent from a contact process activated sludge serving of BZU treatment plant; (II) tertiary treated effluent of Al-Bireh municipal wastewater treatment plant) and (III) influent wastewater of Al- Bireh (Raw-After Grit).

The specific objectives are: To investigate the potential of CW- SAT for treating various types of wastewater under the arid to semi arid climatic conditions of Palestine and to elucidate the pollutants concentration, contaminants conversion and removal mechanisms.

1.4 Research Questions and Hypotheses

The research questions were:

Does the CW-SAT treatment system achieve high removal efficiency, if these work together as a hybrid system?

Does the (CW- SAT) effluent meet the Palestinian standards for recharge?

The research hypothesis is: The (CW-SAT) will be able to treat efficiently the secondary treated wastewater and tertiary treated to fit ground water recharge requirements.

The (CW-SAT) will be able to degrease pollutants concentration in wastewater.

1.5 Research Methodology

Experimental Set-up.

Three units of CW was operated in parallel outdoor with three units of SAT was operated indoor and each unit of CW-SAT was fed with one of the different source water. The dimensions of the CW and soil columns are as described by Mahmoud and Sharma (2012) and Abed *et al*. (2012).

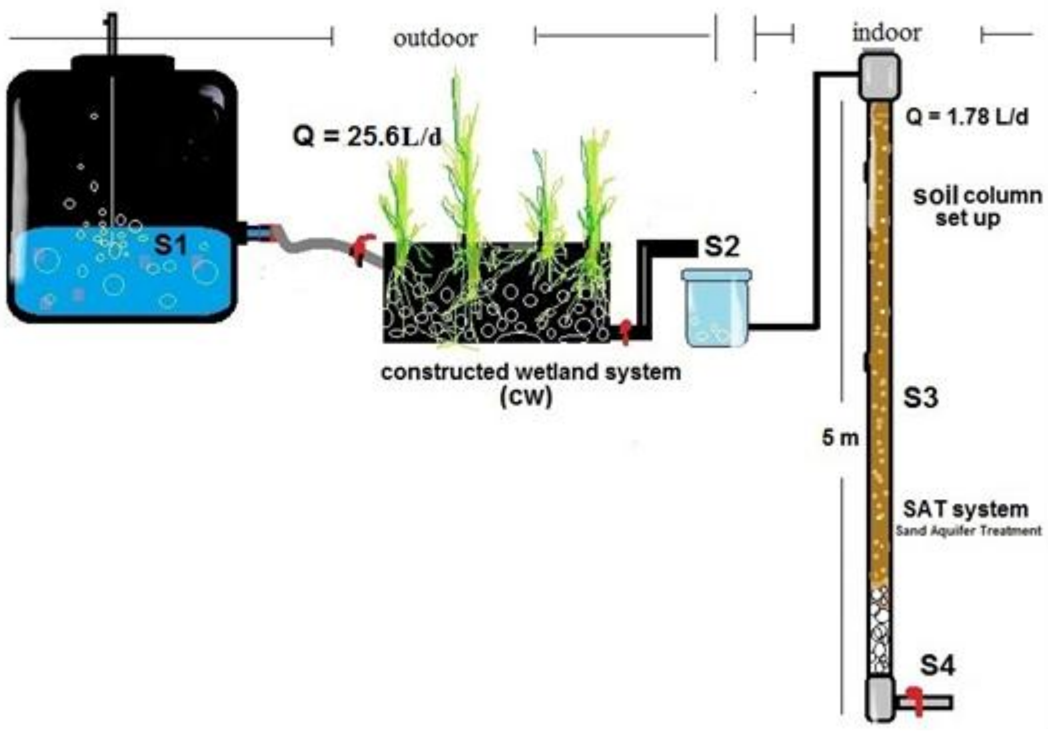

Figure 1.1: CW-SAT set-up

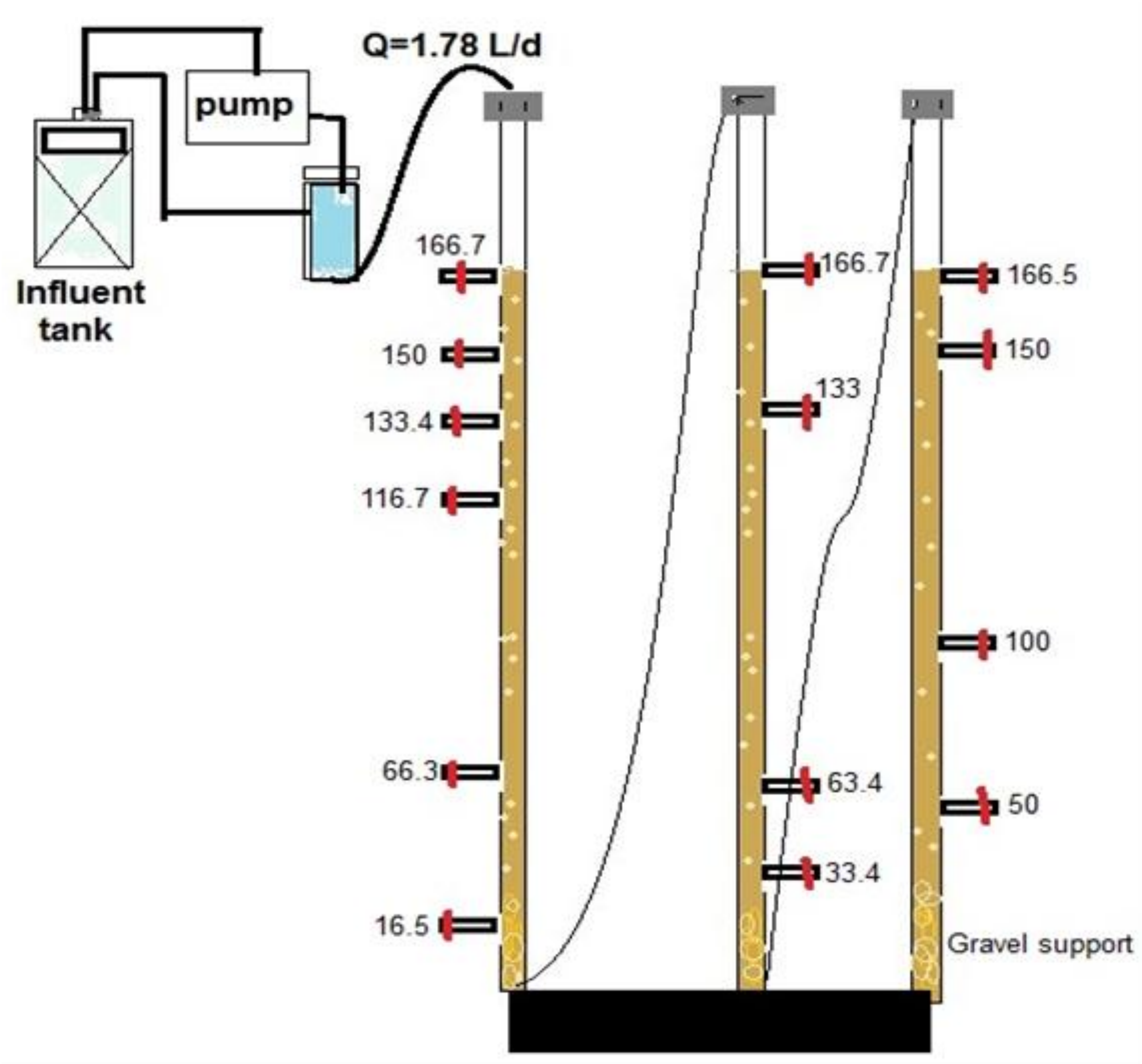

Figure 1.2: Schematic diagram for the SAT set-up (*numbers are distance in cm measured from bottom of columns; all numbers in cm expect Q in L/d*)

Pilot Plant Operation

During the experiment period, the CW-SAT hybrid system was operated and maintained including running the irrigation, maintaining the system, monitoring plant growth and plant’s unit's performance. Air temperature, relative humidity and wastewater temperature was monitored. During the ripening period, the influent and effluent of the CW-SAT was analyzed twice weekly for COD, NH_4, and FC. After one to three months, steady state was reached.

During steady state, three sets of influent, effluent of CW and SAT and also a middle point in the SAT columns was analyzed for COD, BOD, TSS, TVS, pH, DO, T, NH_4, NO_3, and FC over a round 10 days. The flow rates was measured in order to make water mass balances.

1.6 Thesis Structure

This thesis is divided into five chapters as follows:

- Chapter one is an introduction providing a general background about the Thesis subject, statement of the problem, objectives, research question and hypotheses.
- Chapter two provides comprehensive literature review on the state of the art of CW-SAT.
- Chapter three describes the materials and methods used.
- Chapter four includes a discussion for the main results.
- Chapter five contains conclusions and recommendations.

Chapter Two

Literature Review

2.1 Background

CW research has been firstly in Europe with urban waste streams in case study of HSSF, and because nutrient N, P loading to natural watercourses due to urbanization and intensive farming highlight the need to protect these ecosystems from eutrophication by reducing nutrient inputs (Forbes *et al*., 2004).

In 1953, using wetland macrophytes for wastewater treatment was carried out by K¨athe Seidel in Germany. The HSSFCWs were initiated by Seidel in the early 1960s and improved by Reinhold Kickuth under the name: Root Zone Method in the late 1960s till the early 1970s. In the late 1980s, the first HSSFCWs were built in many European countries. By the end of 1986, the major change in the design was the use of very coarse filtration material to ensure HSSF (Vymazal, 2005).

About 100 CWs were put in operation. Most of these systems are HSSF and are designed for the secondary treatment of domestic or municipal wastewater; these were built in the Czech Republic in 1989 with ranges between (18 - 4500) m^2 and between (4- 1100) population equivalents (Vymazal, 2005).

CWs are used for purification of industrial, agricultural wastewater and storm waters. Also, they are applied to strip nutrients of eutrophied surface waters before these are discharged into nature reserves (Rousseau *et al.*, 2004).

CWs have been used to treat acid mine drainage, storm water runoff, municipal wastewater, industrial wastewater and agricultural effluent form livestock operations. CW can remove significant amounts of suspended solids, organic matter, N, P, trace elements and heavy metals and microorganisms contained in wastewater (Sa'at, 2006).

This resulted in surface flow and lower treatment efficiency. In the late 1980s, the coarse materials with high hydraulic conductivity were introduced and were found to meet the other requirements. The experience from operational systems has shown that the 8-16 mm gravel size fraction provides sufficient hydraulic conductivity while supporting a healthy macrophyte growth and good treatment efficiency (Vymazal, 2002).

USEPA in 1993, published the first full technology assessment, Hans Brix authored a 1994 article that presented a large worldwide database of results that showed impressive wastewater treatment by HSSFCWs. Vymazal stated that there are over 100 constructed wetlands in the Czech Republic used HSSFCWs treating municipal or domestic wastewater which requires standards only for TSS and BOD parameters for sources of pollution from less than 500 PE (Hoddinott, 2006).

CWs were developed by Seidel in Germany which are known as the Seidel system. The Seidel design consisted of two stages of several parallel vertical flow beds followed by two or three horizontal flow beds in series. Australis and the horizontal beds were planted with a number of other emergent macrophytes. By 1980s, several hybrid systems of Seidel’s type were built in France with a system at Saint Bohaire, which was put in operation in 1982.

This system consisted of four and two parallel vertical flow beds in the first and second stages respectively. Hybrid systems have the advantage of producing inlet low level in BOD parameter which is fully and partly nitrified so that it has much lower level of total-N outflow concentrations (Vymazal, 2005).

In 1991, the first HSSFCWs for treatment of domestic wastewater was built which used a septic tank followed by an aerobic vertical down-flow biofilter succeeded by a HSSFCWs. This aerobic biofilter is very necessary to remove and degrease the level of BOD and achieve nitrification in a climate where the plants are dormant during the change of climate season. Nitrogen removal in the range of 40 to 60% is achieved. Removal of indicator bacteria is high and < 1000 thermo-tolerant coliforms/100 *ml* is normally achieved (Niyonzima, 2007).

A fundamental characteristic of CWs is that their functions are largely regulated by microorganisms and their metabolism. Microorganisms include yeasts, bacteria, fungi, protozoa, and algae. Microbial activity transforms a great number of organic and inorganic substances into insoluble substances, alters the redox conditions of the subsurface and affects the processing of the wetland (Davis, 1989). The capital costs of subsurface flow CWs depend on the costs of the bed media in addition to the cost of land. Financial decisions on treatment processes should be made on net present value or whole-of-life costs, which includes the annual costs for operation and maintenance (Hoffmann and Winker, 2011).

2.1.1 Advantages and Disadvantages of Constructed Wetland System

Natural CWs are within a more controlled environment. Advantages of CW include: Constructed wetlands do not produce sludge as the CWs influent is already pre-treated and contains low concentrations of pollutants, Site location flexibility, no alteration of natural wetlands and Process stability under varying environmental conditions (Hoffmann and Winker, 2011). (HSSFCW) for wastewater treatment can be easily adapted to cold climate (Plamondon *et al.*, 2006).

CWs are decreased potentially for spills by eliminating the need for offsite transportation, sharp reduction in use of transportation fuel and decreased energy consumption by using natural processes (Basham, 2003).

Grey water after treatment in a constructed wetland tends to have no color (Hoffmann and Winker, 2011). This system use of CWs in grey water treatment may provide a simple and inexpensive solution to control many water pollution problems facing small scales, agricultural, industries, operations (Niyonzima, 2007).

There are some problems facing constructed wetlands such as mosquito, start-up problems in establishing the desired aquatic plant species with free water surface and subsurface flow wetlands especially with Free Water Surface (Niyonzima, 2007). CWs is the high surface area demand (in the order of 2- 10 m^2 per person for domestic wastewater, depending on the type of CW used, the climatic conditions, pre-treatment, etc.). This restricts the use of CW technology in urban and rural areas where land is scarce and expensive (Stefanakis and Tsihrintzis, 2009).

2.1.2 Types and Functions of Constructed Wetlands

Two types of CW (vertical and horizontal flow Constructed wetlands) have been carried out. They are the free water surface systems and the HSSF systems which also called root zone, rock-reed filters or Vegetated submerged bed systems as presented in Fig. 2.1 (Niyonzima, 2007).

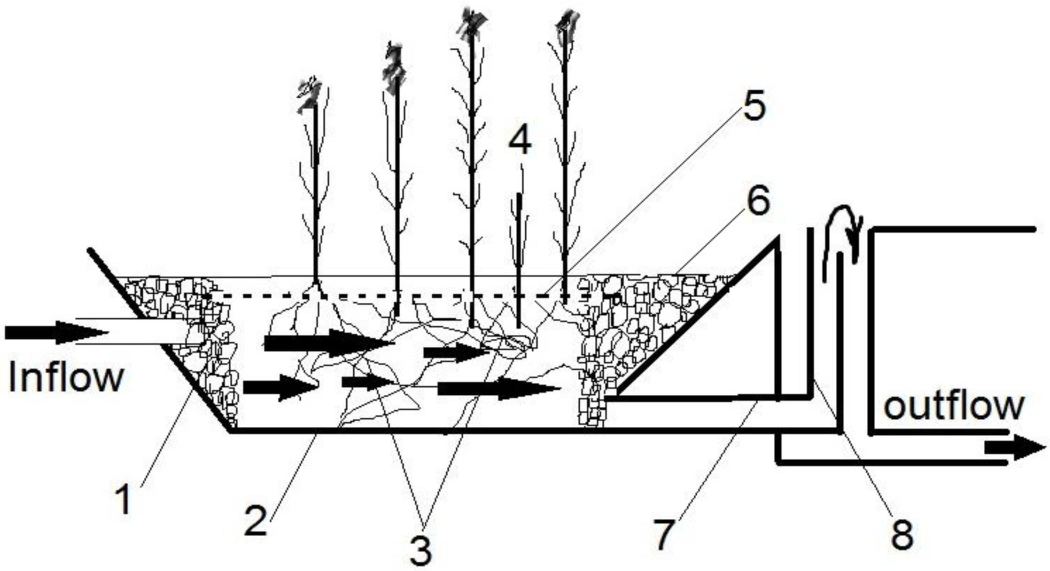

Figure 2.1: CW with HSSF (1. Distribution zone filled with large stones; 2. Impermeable liner; 3. Filtration medium (gravel, crushed rock); 4. Vegetation; 5. Water level in the bed; 6. Collection zone filled with large stones; 7. Collection drainage pipe; 8. Outlet structure for maintaining of water level in the bed. The arrows indicate only a general flow pattern Borst (2011))

Aerobic and anaerobic processes can upgrade CW to treat industrial wastewater containing less-degradable organic pollutants (Yamagiwa *et al*., 2008). These two process activities in a vertical CWs were investigated with and without supplementary aeration which boosted the carbon removal and nitrification (Vymazal, 2005).

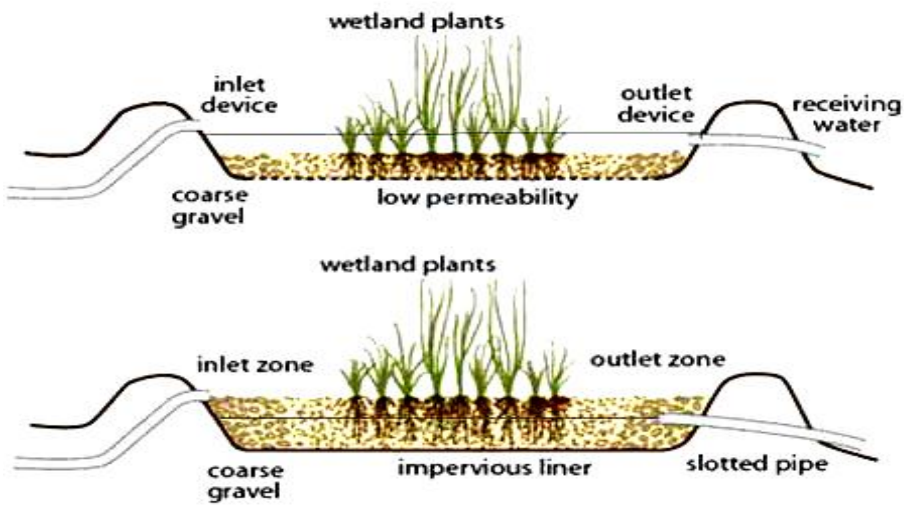

Figure 2.2: CWs types: (a) free water surface and (b) subsurface flow (Sa'at, 2006)

2.2 History and Presentation of Constructed Wetlands

CWs were used for pollutant removal and it's a function of several physical, chemical and biological processes. The biological microbial processing drives the removal of organic matter and nitrogen. CWs lose their treatment capacity when they are overloaded for an extended time period (Hoffmann and Winker, 2011). Results obtained by several authors regarding CWs are presented in Table 2.1.

Table 2.1 Comparison between different constructed wetland setups

Comparison between different constructed wetlands							
Constructed wetland type	HSSFCW	HSSFCW	HSSFCW	HSSFCW	Up-flow constructed wetland	HSSFCW	HSSFCW
Dimensions	3.5, 0.8, 0.8 deep	1.3, 0.5 and 0.4m	1.3, 0.5 and 0.4m	0.45, 0.54, 0.15m	70x18 cm	(10,20, 0.8) for HSSFCW	length: 70cm , 40 cm depth
Aeration					aerated		
Media	coarse sand	Gravel	zeolite	sandy loamy soil with compost	gravel	Gravel	volcanic tofa
Wastewater type	grey water	Agricultural wastewater	Agricultural wastewater	municipal wastewater	industrial waste water	Domestic wastewater	Domestic wastewater
Flow rate	0.48 m3/days	0.078m³/d	0.078m³/d		1.04 ml/min	17m³/	26 l/day
Hydraulic retention time	15 days HRT	1.2 d	1.2 d	5days	3	3days	5 days
DOC				72%			
BOD	72-79%					85.40%	
COD	72-79%				94%	42.70%	71.80%
SS	72-79%						92.90%
Fecal	72-79%						
Grease	72-79%						
Nitrogen	34-53%				69%	TN: 7.1%	
NH4-N				95%	98%		63.80%
NO3		82%	86%		45%		
TKN				62%			
phosphate	34-53%	89%	93%	72%, (TP: 52%)	TP :43%	38%	
E.coli (logFU/100ml)						0.35	
Reference	Niyonzima (2007)	Sarafraz (2009)	Sarafraz (2009)	Chung et al.(2008)	Ong *et al.*, 2010	Ghrabi et al., 2011	Avsar et al.,2007

The Factors regulating the oxygen delivery to the wetland matrix are critical in controlling green house gases emissions in CWs. Also, nitrous oxide production is a function of oxygen and carbon, as it is a by-product of nitrification and denitrification, a chemo-autotrophic aerobic and an anaerobic heterotrophic microbial process, respectively. Plant presence may reduce or increase CH_4 fluxes (Landry *et al.*, 2009).

By Identifying the effects of three species of macrophytes (Phragmites australis, Typha angustifolia, Phalaris arundinacea) and artificial aeration on the variation of greenhouse gases production (Nitrous oxide) over three different seasons using experimental CW, they found that total nitrogen removal was higher in summer and in planted and aerated units with the highest mean removal in units planted with Typha angustifolia. Export of NH_4 was higher in winter and in unplanted and non-aerated units. Planted and aerated units had the highest export of oxidized nitrogen. Also, results showed that denitrification was the main N_2 sink in most treatments accounting for 47–62% of TN removal, while sediment storage was dominant in unplanted non-aerated units and units planted with P. arundinacea. Plant uptake accounted for less than 20% of the removal. They concluded that greenhouse gases fluxes were higher in unplanted, non-aerated treatments and during the summer. In addition, the addition of artificial aeration reduced CH_4 fluxes and CO_2- equivalents (Landry *et al.*, 2009).

Niyonzima (2007) designed and operated a HSSF pilot scale CW on the Kwame Nkrumah University of Science and Technology (KNUST) Kumasi, Ghana. The study was carried out in a sedimentation tank of 3.65 x 0.65 x 0.4 m deep and a Horizontal Sub-surface constructed wetland of 3.5 x 0.8 x 0.8 m deep. The grey water flow rate of (0.48) m^3/d was flowed through vegetated wetland and sandy pilot plant. The filter media consisted of 0.6 to 2 mm of coarse sand, 368.78 cm^3/d of hydraulic conductivity and cattails (*Typha latifolia spp)* were used as plants species. The effluent flow rate of the plant was 0.327 m3/ day and the retention time was 15hrs. 72% to 79% of BOD, COD, TSS, Grease, and FC removal were achieved while the nutrients (Nitrogen and Phosphate) removal was the range of 34% to 53%.

Sarafraz (2009) examined the performance of four HSSFCWs which were constructed at the Research Station of Tehran University, Iran. Gravel and *zeoilte* were used in this study as substrate. The results indicated that the system had acceptable pollutant removal efficiency. The examined system achieved the NO_3-N removal of (79%) in Planted wetland with zeolite substrate (ZP), (86%) in zeolite CWs (Z), (82%) in planted wetland with gravel bed (GP) and finally (87.94%) in gravel bed (P) wetlands. Results for P removal were 93, 89, 81 and 76% were respectively achieved for ZP, GP, Z and G. Moreover, results showed that CWs are efficient in removing Zn, Pb and Cd from agricultural wastewater. Plants types such as Phragmites Australis and *Juncus Inflexus* can contribute in treating wastewater, while *Zeolite* and gravel materials provide a suitable plant growth medium to replace conventional sand and gravel substrates.

Ong *et al.* (2010) found that the organic matter and NH_4-N removal efficiencies in the aerated wetland reactors were better than the non-aerated wetland reactors. The supplementary aeration has enhanced the aerobic biodegradation of organic matter and nitrification.

Vymazal (2009) evaluated the treatment performance of CW Ondrˇejov in Czech Republic and constructed wetland in Spalene Porici near Pilsen in western Bohemia; these systems were operated over a period of 15-year**.** The first wetland consisted of a horizontal grit chamber, Imhoff tank and a single 806 m^2 bed filled with gravel (3–15 mm) and planted with common reed. It is designed for 362 PE, and the average measured flow over the monitored period was 56.3m^3/d. The second wetland consisted of Vortex-type grit chamber, Imhoff tank and four beds (2500m^2 total area, 625m^2 each) filled with gravel (2–4 mm) and planted with P. australis and reed canary grass (Phalaris arundinacea) planted in bands perpendicular to water flow. Both CWs were sampled for BOD_5, COD, TSS, TP, NH_4-N, and TN; CW Ondrˇejov was also sampled for nitrate-N and TKN**.** Also, aboveground biomass was sampled during the peak standing crop. Results for CWs Ondrˇejov showed that removal of phosphorus is steady but low with average raw, inflow and outflow concentrations of 11.6 mg/l, 10.1mg/l and 7.0 mg/l, respectively. Also, average BOD_5 raw, inflow and outflow concentrations were as follows, 192 mg/l, 157 mg/l and 18 mg/l, respectively. For the other wetland, the annual average inflow BOD_5 concentrations were mostly <30 mg/l. The average inflow BOD_5 concentrations were 24.5 mg/l and 122 mg/l in the first and second periods respectively. The corresponding outflow concentrations were 4.2 mg/l and 10.3 mg/l.

Plant uptake could account for less than10% of nitrogen removal and denitrification seemed to be the dominant process removing nitrogen within a wetland. Lin *et al*. (2001) compared waste material from coal refuse, fly ash soil and gravel as a growth substrate for a CW planted. Results showed that cinder substrate treatment showed the best performance in removing COD, NO_3-N and TSS. While the coal refuse treatment showed best performance in removing NH_4-N and TP. However, fly ash and soil showed a low hydraulic conductivity and poor pollutant removal performance. Also, they concluded that the factor controlling denitrification is the C: N ratio. So that, to achieve a much better removal efficiency of nitrate, the ratio of C: N - 5:1 is a must. NO_3-N removal efficiency increased with additional sawdust concentration.

Kimwaga *et al.* (2003) introduced an alternative approach of improving further the waste stabilization ponds effluent by coupling them to Dynamic Roughing Filters and Horizontal Subsurface Flow Constructed Wetlands. They found that a coupled Dynamic Roughing filters and HSSFCW gave the fecal coliform concentrations of 790 FC/100ml suggesting that effluents guidelines of less than 1000 FC/100ml would be met for restricted irrigation without endangering the health of both farmers and the end users of the irrigated crops.

Mantovi *et al.* (2003) evaluated the performance of two HSSFCWs reed beds treating dairy parlor effluent and domestic sewage. Removal of TSS and organic load constantly remained at levels above 90% while those of the nutrients N and P, were about 50% and 60% respectively. The total number of coliform bacteria and Escherichia Coli was reduced by more than 99% and FC streptococci by more than 98%. Nitrates, chlorides, sulfates, anionic and non-ionic surface-active agents and heavy metals were detected only in low concentrations.

Luederitz *et al.* (2001) compared the purification performances of HSSFCWs and vertical flow wetlands VFWs including a small horizontal flow wetland, a sloped HFW, larger HFW, a stratified vertical flow wetland and an un-stratified VFW. Results showed that both the horizontal flow and vertical flow systems can remove more than 90% of organic load and of total N and P, if there is a pretreatment step, and if the specific treatment area is great enough (50 m^2/m^3 per d). HFWs have an advantage in long-term removal of P because it is bound to organic substances to a high degree.

Ghrabi *et al.* (2011) monitored the performance of wastewater treatment plant in Tunisia for about three months. It consisted of one imhoff tank, HSSFCW, subsurface vertical flow CW and horizontal flow CW. The removal efficiencies from the SSFCW equal to 85.4% for Biological oxygen Demand, 42.7 % for chemical oxygen demand, 7.1% for total nitrogen and 38.08 % for PO_4-P.

Stefanakis *et al.* (2011) examined the effect of wastewater step feeding (the gradational inflow of the wastewater into the wetland, the wastewater inflow at more than one input points along the wetland length) on the performance of pilot scale HSSFCWs operated for 3 years planted with common reed. During the first two years of operation, one inflow point was used at the upstream end of the unit. During the third year of operation, wastewater step-feeding was adopted. Wastewater was introduced to the unit through three inlet points: one at the upstream end of the unit length and the other two at 1/3 and 2/3 of the unit length. Two wastewater step-feeding schemes were examined during the second working period: 33%, 33%, 33% and 60%, 25%, 15%. Three HRTs (6, 8 and 14 days) were applied. Results showed that the removal of organic matter (BOD_5 and COD), TKN, ammonia and phosphorus (Total Phosphorus and ortho-phosphate) was improved under the step-feeding Scheme 60:25:15, while the other scheme affected negatively the wetland performance.

2.3 Comparison of Subsurface Flow Constructed Wetlands with Vertical Flow Constructed Wetlands

Horizontal flow of CW in larger surface area made increase the water loss due to evapo-transpiration. Vertical flow beds are preferable to horizontal flow beds because they have an unsaturated upper layer in the bed and a shorter retention time than horizontal flow beds (Hoffmann and Winker, 2011).

2.3.1 Advantages of Vertical Flow Constructed Wetlands

These systems were used for treating municipal, domestic, industrial, dairy and oil refinery wastewater. In the case of municipal wastewater mean removals reach 95% for BOD_5 and TSS, 90% for TKN and more than 50% for phosphorous (Stefanakis and Tsihrintzis, 2009). Vertical flow CWs can achieve higher oxygen transfer rate as wastewater percolates through the wetland by gravity and this enhances aeration and the microbial activity.

2.3.2 Disadvantages of Vertical Flow Constructed Wetlands

Ten pilot scale vertical flow of CW units which were constructed and operated for one year. Each unit has its settings (substrate thickness, porous media, ventilation tubes and vegetation). The unit with the thickest substrate material and the existence of fine material resulted in significant removal efficiency for all pollutants (organic matter, nitrogen and phosphorous) (Stefanakis and Tsihrintzis, 2009).

HRT for CW range from 10-20 m/year for secondary treatment and 50-100 m/year for tertiary treatment. Different loading rates are applied depending on the type of CW. In general, CWs have proven to be very efficient in removing organic matter (>90%), solids (>90%) and pathogens (3-4 log units). But nitrogen (40-60%) and phosphate removal (20-40%) reach medium levels (Stefanakis and Tsihrintzis, 2009).

2.4 Comparison of Subsurface Flow Constructed Wetlands with Ponds

More than 10000 person equivalents in areas where land is available cheaply, ponds have lower capital costs than CWs, ponds are easier to design, construct, do not need a substrate and have lower capital costs for large-scale plants. CW have significantly lower operation and maintenance costs compared to high-rate aerobic processes for energy use and operator time (Hoffmann and Winker, 2011).

2.5 Horizontal Subsurface Flow Constructed Wetlands

2.5.1 Design Parameters

There are many design of CWs which may be based on several models: the first-order k - C model, Monod-type equations, and complex dynamic and compartmental model. Rules of thumb are the fastest but it's the roughest design methods. They are based on observations from a wide range of systems, climatic conditions and wastewater types. Rules of thumb show a large variation and uncertainty. Regression equations are a useful tool in applying input–output I/O data. However, important factors such as climate, bed material, bed design, etc. are neglected, leading to a wide variety of regression equations and thus a large uncertainty in the design. Most of the regression equations rely on wastewater concentrations. Where only a limited number of regression equations rely on both influent concentration and HLR as inputs to predict the effluent concentration (Rousseau *et al.,* 2004).

First-order models are that equations are based on the assumptions of plug flow and steady state conditions. Small scale wastewater treatment plants under which most treatment CWs can be ranged are subject to large influent variations whereas the larger ones are subject to hydrological influences thus causing in both cases non steady state conditions. Short-circuiting and dead zones are common phenomena in CWs causing non-ideal plug-flow conditions. Another impossibility of the first-order model is the fact that the removal rates continue to increase with increasing loading rates (Rousseau *et al.,* 2004).

a) Pretreatment

The major removal process of TSS in CWs are filtration and sedimentation. Pretreatment is essential because high level of concentrations of TSS may speed up the clogging process in the beds resulting in lower treatment efficiency. The average removal of suspended solids SS in the Czech constructed wetlands amounts to 84.3% with the average effluent concentration of 10.2 mg/l (Vymazal, 2002). TSS most solids measured which settle to the bottom and are degraded by anaerobic bacteria; because that HSSFCWs are primarily designed for secondary or tertiary treatment of wastewater proceeded by a septic tank as a pre-treatment step (Hoddinott, 2006). The accumulation of trapped solids is a major threat for good performance of HSSF systems as the solids may clog the bed. Therefore, the effective pretreatment is necessary for HF systems (Vymazal, 2005).

b) Surface Area and Bed Configuration

The following equation which was used for sizing of HSSF systems for domestic sewage treatment (Vymazal, 2005):

$$KBOD = Q_d\ (ln\ C_{in} - C_{out}) / Ah$$

Where:

*K*BOD: the rate constant (m/day),
*A*h: the surface area of the bed (m^2),
Q_d: the average flow (m^3/day),
C_{in}: the influent BOD5 (mg/l),
C_{out}: the effluent BOD5 (mg/l).

*K*BOD is usually lower than 0.19 m/day. Constant Rate is increased with hydraulic loading rate and BOD_5 mass loading rate. The average of *K*BOD value for 66 village systems after 2 years of operation was 0.118 ± 0.022 m/day (Vymazal, 2005).

Cross sectional area for the bed can be calculated using Darcy's Law: (Converse, 1999)

$$Ac = Q/Ks \times S$$

Where:

Ac = cross sectional area of bed (m^2)
Q= design flow (m^3/d)
Ks = hydraulic conductivity (259 $m^3/d/m^2$ for gravel)
S = hydraulic gradient (1% - 2% bottom slope)

CWs have been mainly based on rule of thumb approaches using specific surface area requirements or simple first order decay models. It has been reported that first order models are inadequate for the design of treatment wetlands (Langergraber, 2008).

c) Aspect Ratio

The length to width ratio, it is calculated from Darcy's Law. This ratio has been considered to be of critical importance in maintaining adequate flow through the wetland (Hoddinott, 2006).

$$Ac = Qs / (Kf(d H / d S)$$

Where:

Ac: cross sectional area of the bed (m^2)
Qs: average flow (m^3/s)
K_f: hydraulic conductivity of the media (m/s)
Dh/Ds: slope (m/m)

Czech CWs are designed with a narrow bed and designed with an aspect ratio < 2 to achieve a wider inflow rather than a long. Clogging is minimized by using larger gravel at the inlet. On the otherwise, experiments in Spain indicate that aspect ratio is not a critical element in bed flow mechanics as previously thought. This conclusion for the warm weather of Spain may not necessarily apply to colder climates because warm climate CWs sometimes have a high rate of water loss through evapotranspiration which can change flow characteristics (Hoddinott, 2006).

d) Depth and Bottom Slope

The (0.6 - 0.8)m depth of Czech beds was derived from the maximum depth of the Macropites root of the frequently used common reed; slopes are less than 0.01 with the use of finer gravel. A water depth of (0.27) m yields the best removal efficiencies in a bed (0.6 - 0.8) m deep. The improved efficiency of shallower water depth was related to increased and pumped oxygen flux from the plants and reeds resulting in much higher rates of nitrification and denitrification. The downward pull of surface water by plant roots assured adequate mixing of water in deeper beds. Taking in consideration that almost all of the aerobic processes occur within about 35mm of the plant roots. A minimal bottom slope is necessary if substrate with suitable flow characteristics is used (Hoddinott, 2006).

e) Filtration Media

Suliman (2007).They found that dividing the constructed wetland into several sections when filling the filter medium into the constructed wetland basin will improve the treatment efficiency. The filling strategies were based on dividing the constructed wetland into several sections prior to filling the filter medium into the constructed wetland. HSSFCWs are generally considered as anoxic. So that, it is assumed that the outflow concentration of DO is usually very low (<2 mg/l). However, some systems provided relatively high concentration of DO (>5 mg l^{-1}) (Vymazal and Kröpfelová, 2008).

f) Sealing the bed

USA and many countries require sealing with plastic liners between thickness about (0.8 - 2.0) *mm*. These liners must be protected on both sides by geotextile or soil to prevent root penetration and damage by sharp edges. Clay liners were used in early Czech and North American CWs (Hoddinott, 2006). The fine-grained soils always show better nitrogen N removal through adsorption than the coarse-grained soil. This can be explained by the higher cation exchange capacity of the fine grained soils (Vymazal, 2005).

g) Vegetation

The plants is very important part of CWs, which used in CWs should be tolerant to high organic and nutrient (N, P) loadings and have rich belowground organs (roots and rhizomes) in order to provide substrate for attached bacteria and oxygenation exchange of areas adjacent to roots and rhizomes (Sa'at, 2006).

Plant in HSSF around the world is *Phragmites australis* (common reed). Other species frequently used are *Phalaris arundinacea* (reed canarygrass), *Glyceria maxima* (sweet managrass), *Typha* spp.(cattails) and *Scirpus* spp. (bulrush) (Sa'at, 2006).

CWs used plants are usually metal tolerant, fast growing, and of high biomass, such as Phragmites australis and Typha latifolia. Many wetland plants could colonize both uncontaminated and heavily metal polluted areas. Some wetland plants have the ability to take up > 0.5% dry weight of a given element and bio-concentrate the element in its tissues to 1000-fold the initial element supply concentration. Other wetland plants can tolerate high concentrations of several metals in their tissues, which do not show negative effects on plant growth (Yang and Ye, 2009).

Reed beds have high efficiency in reducing the total amount of sludge; the much higher quality of the final product and the very long sludge retention times (7 – 10 years), there has been built an increasing number of sludge treatment plants. The use of sludge drying reed beds has been a real success for years (Platzer, 2000).

Many processes in term of physics, biochemical are effective in pollutant reduction: phytoextraction, phytostabilization, transpiration, and rhizofiltration. Vegetation provides several storage and reduction mechanisms.

- Phytoextraction: depends on plant uptake of toxicants. Metals are taken up by plants by this method, and may be stored in the roots and rhizomes. The plant need to be harvested frequently and processed to reclaim the metals.
- Phytostabilization: refers to the use of plants as a physical means of holding sand and soil and treated matrices in place. It relates to sediment trapping and erosion prevention in those systems.
- Wetland plants possess the ability to transfer significant quantities of gases to and from their root zone and the atmosphere. Stems and leaves of wetland plants contain airways that transport oxygen to the roots and vent water vapor, methane, and CO_2 to the atmosphere. The dominant gas outflow is water vapor, creating a transpiration flux upward through the plant.
- Rhizofiltration: refers to a set of processes includes physical, biological and chemical that occur in the root zone, resulting in the transformation and immobilization of some contaminants. Plants help create the vertical redox gradients that foster degrading microorganisms (Sa'at, 2006). Nitrogen removed by oxygen flux from the plant, Oxygen flux fell off rapidly after 35 mm from the root, so plants with rhizosomes wider apart than that will not be as efficient in nitrogen removal.

Allen showed that all plants enhanced treatment capacity of HSSFCWs compared to unplanted (Allen *et al.*, 2002).

- Microbial growth and improve the transfer of oxygen into the root zone which is part of the filter bed is the important process. The positive effect for the operation of HSSFCWs in winter (Hoffmann and Winker, 2011). The treatment wetlands already constructed in the West Bank have all used reed as wetland vegetation (Khalili, 2007).

h) Treatment Efficiency

CWs are more complex than any conventional treatment processes due to the diffusive flow of water and the large number of processes involved in wastewater degradation. In other hand, removal efficiency is less easily predictable with the influence of these varying hydraulics and with the influence of internal environment (Hoddinott, 2006).

Many factors such as temperature, vegetation, wind, shape of the system, inlet–outlet configuration, width-to-length ratio, depth and baffles effect on the performance of CWs. Treatment efficiency can occur when wetlands are constructed without considering the influence of the filter medium heterogeneity on the hydraulic parameters and the hydraulic performance of the system. The heterogeneity in the hydraulic parameters of the filter bed can lead to non-uniform flow patterns and dispersion that will cause variations in the HRT and poor treatment efficiency (Suliman *et al.*, 2007).

DO concentration at the effluent of horizontal subsurface flow does not provide good information about the processes occurring in the filtration beds focused on nitrification and sulfate-reduction as processes occurring under strictly aerobic and anaerobic conditions, respectively. The obtained data showed that in systems with very low outflow concentrations of DO, nitrification was frequently very limited but in some systems a substantial reduction of NH_4 occurred (Vymazal and Kröpfelová, 2008).

The HSSF of CWs less effective for nitrogen removal unless a longer hydraulic retention time and enough oxygenation are provided (Zurita *et al*., 2009), where aerated CWs have higher nitrogen removal rates than non-aerated wetlands. Nitrification is a temperature dependent process and it depends on season and become inhibited below 10 °C, reducing the efficiency of CW in colder climates (Landry *et al*., 2009).

The process controlled in nitrogen removal in CWs include volatilization, ammonification, nitrification, denitrification, plant uptake, and matrix adsorption. Ammonification and nitrification, denitrification are the major nitrogen removal mechanisms. Low rate of nitrification are achieved in HSSF wetlands due to anoxic, anaerobic conditions in the wetlands (Vymazal, 2002).

Lower winter temperatures, low oxygen availability are a common limiting factor in HSSFCW during the growing season. Oxygen solubility is higher in colder water, but gas exchange in HSSFCWs may be reduced by the additional insulation layer found that more than 95% of TSS was removed during the experiment regardless of season, presence of plant or aeration. There was no apparent difference in TSS removal between planted and unplanted wetlands as expected from a pollutant whose removal is mainly due to physical processes (Plamondon *et al.*, 2006).

Removals of NH_4, NO_3, and soluble reactive phosphorus were related to three factors (presence of vegetation, medium types, and time period for the test). Also, they found that the main removal mechanism for ammonia was nitrification while nitrate was removed mainly by denitrification and plant uptake in vegetated systems. The main removal mechanism for soluble reactive phosphorus was chemical adsorption in the unsaturated soil bed systems. Also, the results showed that the subsurface flow gravel bed CW system with vegetation was the optimal one for the removal of total inorganic nitrogen (Yang, 2001).

Removal mechanisms of Horizontal subsurface flow constructed wetlands

Physical, chemical and biological processes such as plant uptake, microbial metabolic activity and many microorganism process. Physical-chemical processes such as sedimentation, adsorption and precipitation (Sa'at, 2006).

Transpiration that the process which plants up-take the wastewater, this process will somewhat reduce the overall volume of wastewater. Lower portions of the CW cells do not receive enough oxygen to maintain aerobic conditions and become anaerobic. This zone will transform the nitrates (produced by the nitrification process), into compounds that are easily removed. Denitrification breaks those components down into nitrogen and nitrous oxide gas.

These gases are then released into the atmosphere through a process called volatilization. Depending on the level of phosphorus removal desired, the CW may be designed to optimize its removal. Removal can occur by the adsorption of phosphorus to the gravel media, precipitation of insoluble phosphates with ferric iron, calcium (Ca), and aluminum (Al) found in media, or small amounts will be absorbed by the CW vegetation. Fecal coliform reductions in the CW cell systems depend on the hydraulic residence time. FC reduction in wastewater is attributed to natural die-off of the pathogens while passing through the media (OHIOEPA, 2007).

Table 2.2: Overview of pollutant removal mechanisms (Sa'at, 2006)

Pollutant	**Removal Process**
Organic Contaminants	Adsorption, Volatilization, Photolysis, Biotic/Abiotic degradation
Organic Material	Biological degradation, Sedimentation, Microbial uptake
Suspended solids	Sedimentation, Filtration
Pathogens	Natural die-off, Sedimentation, Filtration, Adsorption
Heavy metals	Sedimentation, Adsorption, Plant uptake
Nitrogen	Sedimentation, Nitrification/Denitrification, Microbial uptake, Plant uptake, Volatilization
Phosphorus	Sedimentation, Filtration, Adsorption, Plant & microbial uptake

Anaerobic or anoxic degradation of organic material takes place in the bottom sediments and free water surface and subsurface flow wetland function as attached growth biological reactor which called biofilms. Biofilms are formed as microorganisms attach themselves to the plant and to the substrate. Wastewater is exposed to this biofilm when it passes through the wetland (Sa'at, 2006).

When high organic loading and oxygen is limiting, In the first step of anaerobic degradation, the primary end products of fermentation are fatty acids, such as acetic, butyric and lactic acids, alcohols and the gases Carbon dioxide CO_2 and H_2, bacteria and methane-forming bacteria then utilize the end-products of fermentation depend on the complex community of fermentative bacteria to supply substrate for their metabolic activities (Vymazal, 2005).

Suspended Solids, Nutrients and Metal Removal

A sedimentation pond is added prior to the wetland system to remove larger sediment and avoid clogging in the wetland and because solids are removed through sedimentation and filtration (Sa'at, 2006).

Nutrients N, P can be bound in the biomass. The uptake capacity of emergent macrophytes is roughly in the range 50 to 150 Kg P ha-1 year-1 and 1000 to 2500 Kg N ha-1/yr. Reduction of N and P compounds requires the long detention times. Nitrification or denitrification are the main removal process for nitrogen. The Nitrosomonas bacteria oxidize NH_4 to NO_2 aerobically. The NO_2 is then oxidized aerobically by Nitrobacter bacteria to produce NO_3. Nitrate is reduced to gaseous forms under anaerobic conditions (denitrification). Volatilization, adsorption and plant uptake play much less important role in nitrogen removal in horizontal subsurface flow CWs (Vymazal, 2005).

Heavy metal uptake in CWs depends on the plant species and plant structure. In grey water and domestic wastewater heavy metals are not a big problem, because their concentration is relatively low. Metals are removed by three major process in treatment CWs (i) Binding to soil, sediments, particulates and soluble organic by cation exchange and chelation (ii) Precipitation as insoluble salts, principally sulfides and oxyhydroxides and (iii) Uptake by plants, including algae and by bacteria. The predominant removal mechanisms in the CWs were attributed to precipitation absorption phenomena.

Precipitation was enhanced by CW metabolism, which increased the pH of inflowing acidic waters to near neutrality. Trace metals have a high affinity for adsorption and complication with organic material and are accumulated in wetlands ecosystem. Plant uptake and microbial transformations may contribute to metal removal (Sa'at, 2006).

2.6 Soil Aquifer Treatment SAT

2.6.1 Background

CW-SAT can remove many types of pathogen and degrease pollutants concentration by natural treatment systems method, which is depend on natural processes comprising different biological, chemical and physical removal mechanisms and combinations, these systems can be applied in developing countries (Khalili, 2007).

NTS are increasing popular and enhance water resources through a multiple of techniques such as RBF and SAT. The percentage of drinking water by RBF in Switzerland 80%, Slovak republic 50%, France 50%, Hungary 45%, Germany 16% (Berlin 60%) and Netherlands 5% (Amy and Drewes, 2007). In no-European countries like Brazil, India and South Korea are also used (RBF) by some water works (Schmidt *et al*., 2007). Similarly, ASR and SAT are being effective in many parts of Europe and Middle East (Fox, 2001; Idelovitch *et al*., 2002).

Groundwater is augmented by RBF, ASR, and SAT is similar except their source of influent water. RBF is a natural mechanism that has been used for more than a hundred years under this name (Schmidt, 2003).

2.6.2 Natural Treatment System NTS

Organic matter present in treated wastewater and surface water are of major concern if groundwater recharge through NTS and subsequent reuse is concerned, but by applied the pre-treatment the bulk organics and organic micro pollutants removed and there for a term of water quality. Previous researches have shown that is a substantial removal of contaminate such as pathogenic microorganism, organic matter, heavy metal and trace elements, and organic micro pollutants during soil passage (Schmidt, 2003).

The removal of organic matter and trace organic pollutants during a CW and soil passage. But less is know about the mechanism of NTS with regard to pre-treatment. The type of source water quality surface water, primary, secondary or tertiary, and the process condition such as retention time, flow rate, hydraulic loading rate and oxic and anoxic conditions.

The current research was conducted within the frameworks of the NATSYS project at the IEWS Institute in BZU, Palestine. The NATSYS project investigates sustainable urban water management, including a focus on the role of NTS options. NATSYS project aims to investigate the potential for CW treatment as a pretreatment for SAT. The major constraints of SAT are also space use and nutrient removal, so the project aims to optimize space efficiency and nutrient removal in CWs before water is discharged to SAT treatment.

In this project, artificial aeration is one novel method that has been used to increase nitrification rates in CWs. The research also aimed to track several pollutant removal performances to investigate whether different water sources may have an impact on the removal efficiency in the wetland.

2.6.3 SAT Design system

The very rapid urban growth of the last few decades has produced huge pressure on natural water resource which resulted with their depletion and pollution. With this grows there will be increased demand for portable water as well as an increased production of wastewater.

Many communities throughout the world are approaching or have already reached the limits of their available water supply. In due course, water is becoming a scarce commodity in these areas. The escalating scarcity of water over the world along with rapid population increase in urban areas for concern and the need for appropriate water management practices. In contrast to the increasing demand for fresh water and shortage of the available fresh water, surface water is rapidly deteriorating throughout the world. The discharge of wastewater with little or no treatment, agricultural runoff, waste from industrials and commercial centers are the most notable reasons for surface water pollution. To deal with the polluted water through advanced treatment is expensive in poor countries. Therefore, to get rid the challenge of water scarcity and pollution, it is very attractive to look for other options of treating and reusing both surface water and treating wastewater through processes, For example NTS (Schmidt *et al*., 2007).

SAT is robust barrier, can remove pollution and contaminates, minimize the use of chemicals, use relatively less energy and have a small carbon footprint. SAT rely on natural processes comprising different physical, chemical and biological for improvement in water quality. These system have been applied for waste water treatment and reuse in different parts in the world. The suitability and performance of such NTS, however, depend on source water quality, process condition applied, hydro geological condition and water quality goals to be achieved by treatment. It is expected that with further improvement of these system, a comprehensive system for wastewater treatment can be developed which can be applied for treatment of different types of wastewater (Schmidt *et al*., 2007).

Chapter Three

Material and methods

3.1 Introduction

During the research period, data was collected from the experimental (CW-SAT). Then the collected data was analyzed. The methods and experimental procedures used for data collection are explained hereafter.

3.2 Preliminary Laboratory Tests

Hydraulic conductivity and analysis of different gravel was carried out in order to determine the suitability of the filter medium to be used in CW. The gravel sieved between (12.5-19) mm. The identification of plants species in the wetland were done by technicians from the BZU where they confirmed that common reeds (*Phragmites*), was available. They have capacity to grow quickly and carry enough oxygen through their roots. About (9-14) reed plants were planted into each CW at the beginning of the experiment but some of them dried up and died in the two weeks of operation. The death of reed in the initial stage did not affect the rapid increase of young plants during the experimental period. The CW was designed for influent flow rate of 25.6 L/day. The wetlands were constructed in 25/March/2013. Also, they were put in operation on the same day with influent water from BZU treatment plant effluent. This influent was used at the beginning of the experiment in order to provide an accessible and near influent source to irrigate the plants. After one month, one of the wetlands (system 3) was continued to be irrigated with this type of treated wastewater but the other two systems were fed with Al-Bireh i) influent wastewater (raw) and ii) tertiary treated wastewater.

Then, the systems were kept in operations with these influents for one month from the date of operation and then the samples collected from influent and effluent were analyzed weekly for a limited set of parameters (COD, BOD_5, NH_4, NO_3, T, DO and pH).

Photo 1: HSSFCW in operation, photo date (27/March, 2013)/ BZU/ Palestine

Photo 2: HSSFCW in operation, photo date (23/April, 2013)/ BZU/ Palestine

SAT columns were operated continuously under oxic condition from 25/3/2013 to 1/10/2013. In order to conduct detailed analysis, water sample along the soil column, for the three types of source water, were collected over the period from 15/April/2013 to 30/July/2013 for ripening period, and over a period during 1/July/2013- 1/September/2013 for steady state operation period.

Steady state period was conducted in order to assess the impact of rather long term operation on the soil columns performance. The main physical, chemical and biological results for these samples are presented in the following sections.

During this period, three thorough campaigns of monitoring took place namely for CW-SAT set-up, (Ripening period) during from 10/April/2013 – 30/July/2013, and steady state period during 1/July/2013-1/September/2013, and the last stage number 3 during about one month to calculate the removal which was based on mass load (water balance)

3.3 Experimental Setup

3.3.1 Constructed wetland setup (CW)

This setup was made of stainless steel (60cm length, 45 width and 45 depth). Wastewater depth was 30-35 cm and gravel depth was 40-42 cm. The system was constructed to suit the operation under three water types. There were three such setups to run the tests with different influent water quality at the same time. A valve to control the HLR under gravity was installed at the inlet point. These effluents water were stored in refrigerator in the lab. The CWs were fed with wastewater daily using plastic containers which were cleaned everyday.

Three HSSFCWs were located inside the campus of BZU, Palestine. Three tanks system were used to store the effluent. The influent was distributed at the inlet of each system by gravity. At the outflow of each unit, there was a level control to keep the water level at 35-40 cm from the base. Also, a graduated beaker was used to collect and measure the quantity of treated effluent being discharged daily. The three systems were filled with gravel (12.5-19.5 mm, porosity 0.42). The water table was kept 5 cm below the substrate surface. The effluents were artificially aerated by an air pump.

3.3.2 Soil Aquifer Treatment setup

SAT experimental setup was placed outdoors the campus of BZU. The soil columns was made of uPVC pipe with internal diameter of 42.6 mm, with 3 columns of each 1.67m (where the total height of each system is 5 m) working height joined in series with a connection plastic tube. The bottom of each column was filled with fine gravel of around 10 cm thick, then filled to top with silica sand of size 0.85 – 1.18 mm.

The soil columns were placed indoor inside the laboratories of the Institute of Environmental and water Studies (IEWS) of BZU. The setup was provided with a backwashing system in order to clean the filter media with clean tap water whenever the effluent flow rate would be reduced as a result of clogging if any. Each soil column set as provided with an influent tank sufficient to contain the daily needed amount of wastewater. The wastewater was pumped continuously by peristaltic pump from the influent tank to an intermediate small feed bottle of around 1.2 liter from where the soil column was fed and the surplus was returned via a return flow pipe to the influent tank. The main function of the intermediate feed bottle was to maintain a constant water head of the columns. A schematic diagram of the filter is illustrated in Figure 3.2.

3.3.2.1 Soil columns start –up, operation and monitoring

The three different types of wastewater effluent were collected from the source once or twice weekly, and stored at 4℃. The daily needed a mount of wastewater for feeding the soil columns was taken out of the refrigerator and left indoor to heat up to room temperature. Afterwards, pre-filtration of the source water was done with 140 micrometer, sieve to avoid settling of large size materials before application to the soil columns.

The pre-filtration wastewater was analyzed, each time the wastewater batches were brought from three sources, for TSS, COD, NH_4, DO and pH.

3.4 Design parameters

3.4.1 Flow pattern

The three CWs systems were designed as (HSSF) systems, and in addition of the three SAT were designed as (VF).

3.4.2 Types of wastewater

Three types of treated wastewater were used to feed the (CW-SAT) system. These types are:

1. Al-Bireh tertiary treated effluent (around 50,000 population equivalent).
2. Al-Bireh influent waste water.
3. BZU secondary treated effluent (around 10,000 population equivalent).

3.4.3 Hydraulic retention time

HRT was monitored daily and kept around 1.9 days.

3.4.4 Aspect ratio

Which means the ratio between (length: width) must be less than 2 in order to distribute wastewater to as wide a profile as possible in order to avoid local clogging of the inlet zone.

Calculation of aspect ratio (CW system):

Volume = 0.6*0.45*0. 45*0.4 = **0.0486** m³

HRT = **1.9** days

Flow = V/HRT= **25.6** L/d

To account for evaporation Q= **25.6** L/d will be supplied to the system

Aspect ratio = length/ width = 0.6/0.45 = 1.33 <2 **ok.**

Calculation of (SAT system):

Diam	Diam	Height	Volume	Area	HRT	Flow	Vol.
mm	m	m	L	m^2	d	L/d	m/h
42.6	0.0426	5	7.1	0.00142459	4	1.8	1.25

A hydraulic loading rate of 1.26 m/d was maintained, corresponding to an empty bed contact time of 4 days. The flow rate was monitored daily by measuring cylinder and stop watch and adjusted as a necessary using a gate valve which was installed at the outlet of the column.

3. 4.5 Validation and quality control

Standard calibration curves for most of the analyzed parameters were prepared using the appropriate concentration that cover the range of samples concentration. Also, blank samples were used with suitable solvent to reduce matrix effects on the analyzed parameters.

3.5 Measurement of water quality parameters

The wetlands were constructed in 25/March/2013. Also, they were put in operation on the same day with influent water from BZU treatment plant effluent. This influent was used at the beginning of the experiment in order to provide an accessible and near influent source to irrigate the plants. After one month, one of the wetlands (system 3) was continued to be irrigated with this type of treated wastewater but the other two system were fed with Al-Bireh i) influent wastewater (raw) and ii) tertiary treated wastewater. Then, the systems were kept in operations with these influents for one month from the date of operation and then samples from influent and effluent were analyzed weekly for a limited set of parameters, The samples were collected weekly at the inlet and outlet of each wetland and columns. Physical, chemical and biological water quality parameters were measured as described in the Standard Methods for the examination of Water and Wastewater (APHA, 2005).

Samples were filtered by 0.45μm membrane for dissolved organic carbon which was measured by the wet chemistry method on an OI Analytical Aurora 1030 TOC analyzer. For all the measured parameters composite samples which is composed of three samples were taken at the inlet and outlet of each system. Water samples were taken for NH_4, NO_3, and COD after six week of operation. samples were prefiltered (Whatman 934-AH) for TSS measurements and filtered by 0.45μm membrane for DOC. COD was measured by the closed reflux colorimetric method (method#5220 D) and TSS was measured using the TSS dried at 103°C –105°C (method#2540 D). Temperature, pH and redox potential were measured using an YSI multi-probe (YSI model 556) in the piezometers.

3.5.1 Laboratory analysis

Several parameters was carried out at the BZU Testing Laboratories, BZU, Palestine NO_3 was analyzed using Capillary Ion Analyzer (CIA) method. The methods used to analyze the other parameters are shown in Table 3.1. During the experiment, new calibration curves were drawn each month or in the case at which new reagents were prepared.

3.5.2 Process conditions

a) Oxic conditions

Oxic conditions were maintained by aeration of influent water. During aeration DO concentration was maintained around 4 mg/l.

b) Hydraulic loading rate

(CW-SAT) requires a low HLR and a long HRT to achieve efficient pollutant removal taking in consideration the fact of a lack of criteria to define what is meant by high or low HLR.

$$\mathbf{HLR = Q / A}$$

Where:

HLR: hydraulic loading rate (m/d)
Q: flow (m^3/d)
A: Surface area of the constructed wetland (m^2)

HLR for the HSSFCWs fed with Q = 25.6 L/d and has a cross sectional area of (0.45 x 0.6) m^2 equals:

$$HLR = 0.0256 / (0.45x0.6) = 0.1 m/d$$

HLR for the VSSFSAT (soil column) fed with Q=1.78 L/d and A= 0.00142459 m^2 equals:

HLR = 0.00178 / 0.001424 = 1.26 m/d

3.6 Analytical Method and Equipment

The methods, reagents and equipments used to measure different parameter during the study are presented below.

3.6.1 Measurement of physical parameters (T, DO and pH)

Temperature of all effluent and influent water was measured with conductivity meter. During measurement the probe of the meter was inserted in the sample, the sample was stirred to ensure uniform mixing and when stable reading obtained, the reading was recorded. DO was measured with the specific HACK HQ10 oxygen meter. The DO was measured in the lab immediately after taking the samples to limit the time at which the sample will be with contact with air as much as possible. Measurement of pH was carried out by using Metrohm-691. pH meter which was calibrated prior to the measurement. Samples were collected in glass bottles from the influent and effluent.

3.6.2 Chemical parameters

NH_4, NO_3, BOD and COD were carried out by using Nesslarization method. In order to prepare calibration curve (NH_4-N versus Absorbance), a series of standards were made by diluting a prepared standard solutions to 50ml. The method used to measure the concentration of other parameters are listed in Table 3.1.

3.6.3 Biological parameters

FC were analyzed according to 9221-E methods (APHA, 2005).

3.7 Sampling

Samples were analyzed for both influent and effluent of the (CW-SAT) set-up during the project period. On 15/April/2013 they were analyzed for COD, NH_4, T, pH and DO. From 15/April/2013 to 1/September/2013, wastewater samples were analyzed weekly for the same parameters mentioned in addition to BOD_5, COD, TSS, TVS, NH_4, DO, NO_3, pH and FC.

3.7.1 Sample collection

Samples were analyzed for both the inlet and outlet of the (CW-SAT) system units were collected in sterile plastic bottles and stored at 4 °C. Each sample is composed of three samples collected between 9:00 am-12:30 pm during from 10/April/2013 – 30/July/2013, and kept in the refrigerator until collecting all of the three samples. The sample size was 200 ml which took about 25-30 minutes to be collected. It was collected in glass bottles and then mixed to form a composite sample. The composite samples were analyzed for the all the parameters presented in Table 3.1.

3.7.2 Water sampling methods

The parameters used for the determination of the efficiency of the system were TSS, COD, BOD_5, NO_3-N, NH_4-N, pH, FC, TSS, TVS, DO and Temperature. The characteristic parameters were measured according to Standard Methods of Analysis (APHA, 2005).

Table 3.1 Methods used and water quality parameters measured for the CW-SAT samples.

Element	Analytical method	Instrument used for analysis
NO_3	Capillary Ion Analyzer (CIA)	UV 300/ UV-Visible spectrophotometer/ UNICAM (λ=220 nm)
NH_4	Nesslerization method (direct and following distillation)	UV 300/ UV-Visible spectrophotometer/ UNICAM (λ=225 nm)
TDS	Total dissolved solid dried at 105 °C (Gravimetric method)	Filtration Apparatus
DO	Membrane electrode method	DO meter/ Fluroprobe (FL-3-H)Luminefcent oxygen analyzer
FC	9222-B 9221-E	
Organic material COD BOD_5		Hach COD reactor DO meter – Oxi 197

Chapter Four

Results and Discussion

4.1 General

CW-SAT setup were operated continuously under an oxic condition from 25/3/2013 to 1/10/2013. In order to conduct detailed analysis, water sample along the soil column, for the three types of source water, were collected between the period from 15/April/2013 - 30/July/2013 for ripening, and over a period during 1/July/2013- 1/September/2013 for stable period. The main physical, chemical and biological results for these samples were collected from CW-SAT which are presented in the following sections:

4.2 Wastewater treatment

4.2.1 Physical parameters

There were no significant variations in pH values occurred during the CW-SAT in repining and operation period. In this case pH values showed a trend to be kept on a slightly basic range, these interactions may have resulted in release of salts from the substrate to the water, explaining the slight increase of conductivity, observed along from CW-SAT units during all periods. The average pH values in the influent CW-SAT which called S_1 for BZU, tertiary treated effluent of Al-Bireh municipal wastewater treatment plant (Raw) and influent wastewater of Al-Bireh (out) respectively are (7.70, 7.71 and 7.76), and the average pH values in the effluent CW-SAT which called S_4 are (7.9, 7.60 and 7.7), Similar results were achieved by Zurita *et al*. (2009).

Table 4.1: Average pH value in each CW-SAT system

Source of wastewater	S_1	S_2	S_3	S_4
Effluent from BZU	7.701	7.629	7.873	7.847
Effluent from Al-Bireh municipal wastewater (out)	7.758	7.497	7.575	7.702
Influent from Al-Bireh municipal wastewater (raw)	7.7143	7.893	7.884	7.581

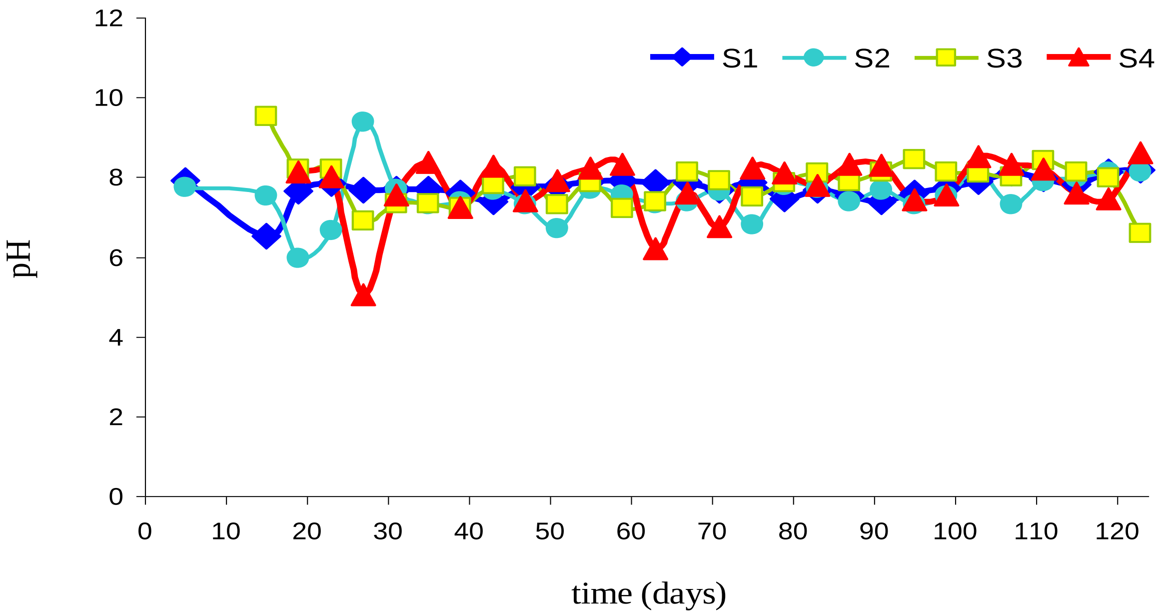

Figure 4.1: pH value in CW-SAT treating secondary treated wastewater in Birzeit University treatment plant, Ramallah/Palestine

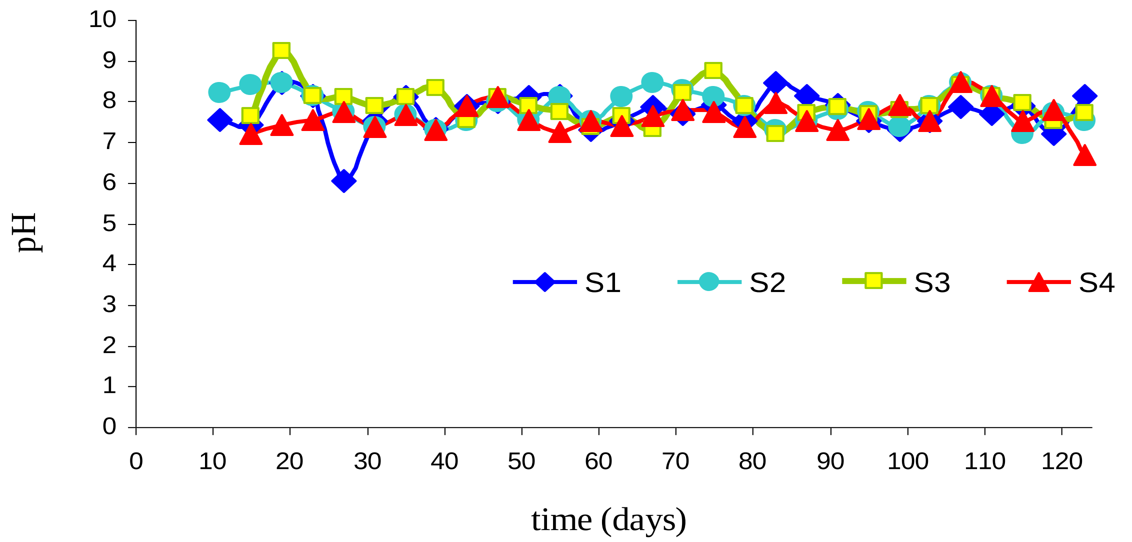

Figure 4.2: pH value in CW-SAT of influent wastewater of Al- Bireh (Raw-after grit)

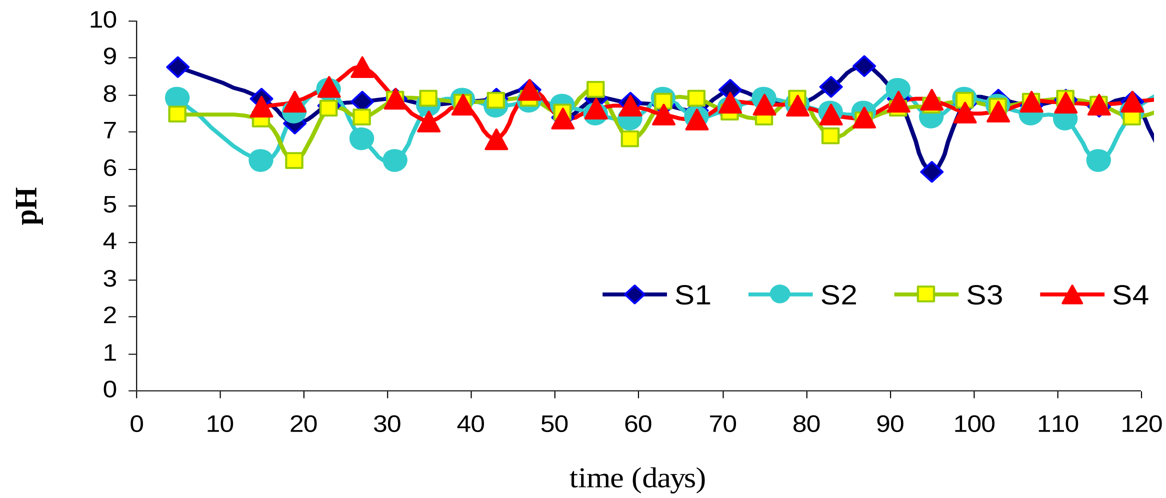

Figure 4.3: pH value concentrations in CW-SAT treating tertiary treated effluent of Al-Bireh municipal wastewater treatment plan (out)

Dissolved oxygen

CW-SAT set-up includes two parts for treatment wastewater, CW connected with sand filter columns respectively. CW with shallow depth was created to increase the oxygen level in the substrate. DO concentrations were slightly decreased in the CW, indicating oxygen consumption by pollutants (Fig.4.4). Artificial aeration which was used in NTS improved the removal efficiency in the wetland as Landry *et al.* (2009) concluded. The role of plants goes beyond the sole addition of oxygen as a concentration O_2, probably by enabling a more diversified and active micro fauna development near the root zone (Plandom *et al*., 2006). Also, Ong *et al*. (2010) concluded that aerated reactors resulted in a better performance in the biodegradation of organic matter and nitrification. The samples which were collected from S_1, S_2 from (CW), S_3 and S_4 from (SAT).

The DO profiles of all systems under repining period in the fist 30 days from starting operation interval, and steady state period in HLR 1.25 m/d, three columns in series each 1.67 m long with internal diameter 42.6mm, media size 0.85 – 1.20 mm with oxic condition. More than 100 samples were collected from CW-SAT set up for each system, and S_1 and S_4 were called influent and effluent wastewater on series.

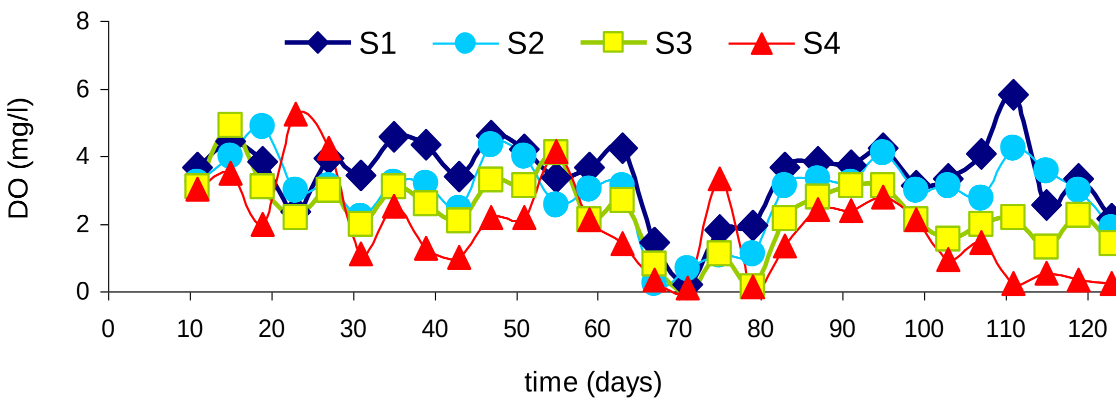

Figure 4.4: DO concentration values in a CW-SAT treating secondary treated wastewater in Birzeit University treatment plant, Ramallah/Palestine

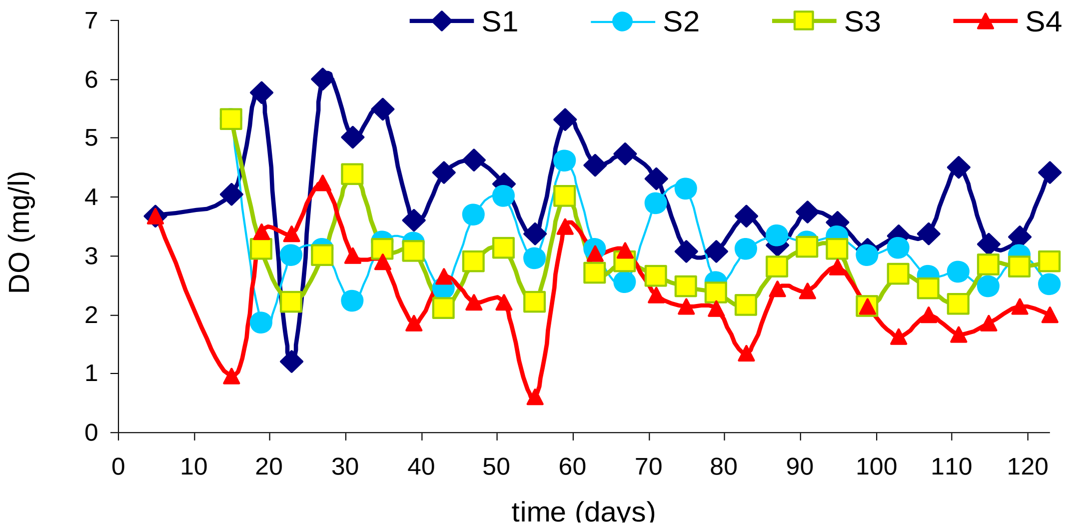

Figure 4.5: DO concentration values in a CW-SAT of influent wastewater of Al-Bireh (Raw-after grit)

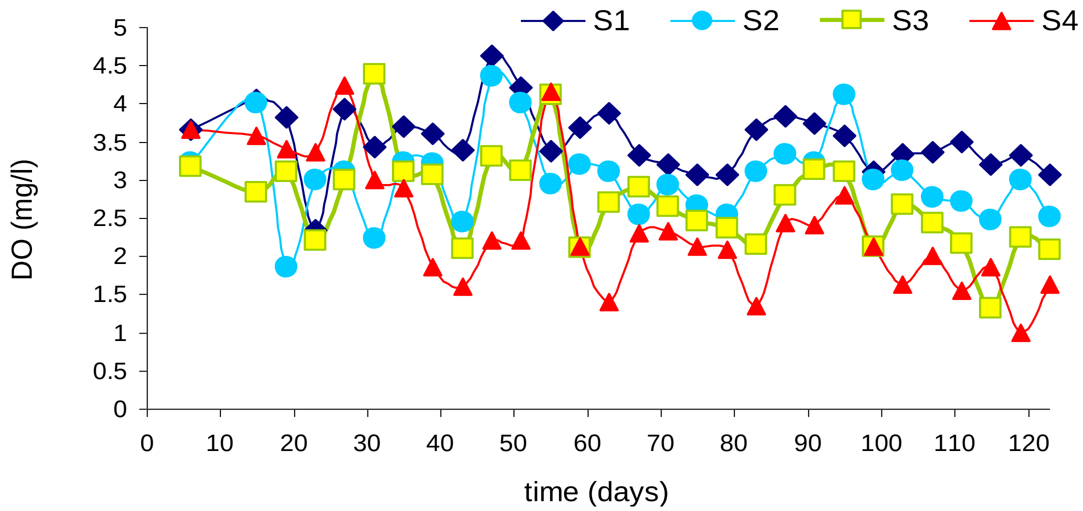

Figure 4.6: DO concentration values in a CW-SAT treating tertiary treated effluent of Al-Bireh municipal wastewater treatment plan (out)

The Table 4.2 below, shows the average DO values where the data were collected from each unit of CW-SAT from four position (Fig 4.1), using three types of wastewater source.

Table 4.2: Average DO value in each CW-SAT system in mg/l

Source of wastewater	S1	S2	S3	S4
Effluent from BZU	3.434	3.401	2.677	1.863
Effluent from Al-Bireh municipal wastewater (out)	3.492	3.127	2.717	2.422
Influent from Al-Bireh municipal wastewater (raw)	4.022	3.310	3.174	2.566

4.2.2 Chemical parameters

Chemical parameters for the CW-SAT during the ripening and steady state periods are presented in Table 4.3. The influent and effluent of the CW-SAT were analyzed from 1/July/2013- 1/September/2013 for NH_4, NO_3, TSS, TVS, COD, DO, FC and pH after 30 days of repining period. Data were collected from four positions which are called S_1, S_2, S_3 and S_4 as shown in the Fig 4.7 bellow:

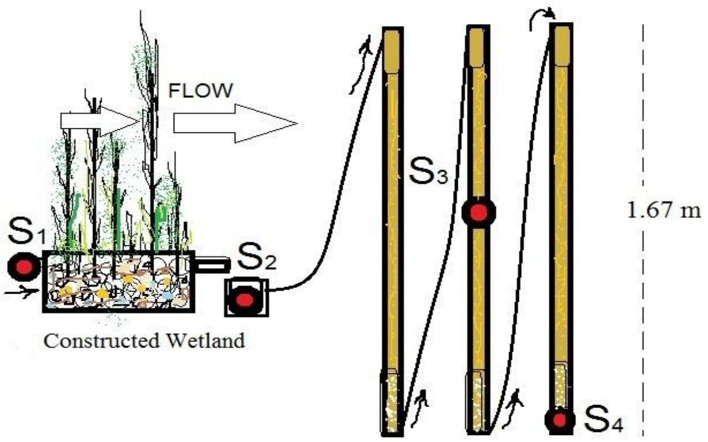

Figure 4.7: Locations where samples were collected from CW-SAT system

Table 4.3: Average influent, effluent concentrations and removal for three wastewater influents during the project period (15/April/ 2013 - 10/September/2013) for both ripening and steady state periods

Parameter	# of Samples	Source Water	Concentration		
			Birzeit	Al-Bireh / raw	Al-Bireh / out
BOD_5 (mg/l)	32	Influent	33.86	417	21.18
		Effluent	2.94	42.66	5.94
		Removal (%)	91.3	89.7	71.9
COD (mg/l)	32	Influent	61.445	957.5	49.5
		Effluent	12.5	96.2	11.4
		Removal (%)	79.6	89.9	76.9
NH_4 - N (mg/l)	80	Influent	10.66	21.55	5.104
		Effluent	0.485	1.625	0.2835
		Removal (%)	95.4	92.4	94.4
NO_3-N (mg/l)	28	Influent	15.6	37.65	14.11
		Effluent	0.72	3	0.095
		Removal (%)	95.3	92	99.3
pH	120	Influent	7.70	7.71	7.75
		Effluent	7.84	7.58	7.70
		Removal (%)	1.8	1.6	0.64
TSS (mg/l)	28	Influent	32.22	133	8.922
		Effluent	2.73	13.17	0.028
		Removal (%)	91.5	90	99.6

Parameter	# of Samples	Source Water	Concentration		
			Birzeit	Al-Bireh / raw	Al-Bireh / out
TVS (mg/l)	28	Influent	9.5	35.54	3.12
		Effluent	0.214	1.118	0.1
		Removal (%)	97.7	96.8	96.7
Fecal coliform (cfu/100ml)	28	Influent	1537.42	5321536.85	2601.85
		Effluent	20.85	46612.29	3.285
		Removal (%)	98.6	99	99.6

Biochemical Oxygen Demand (BOD)

This parameter which is called BOD depend on the oxygen status at the deposition point, and undergoes aerobic or anaerobic decomposition in the NTS. (Vipat *et al.*, 2008). A steady state period for BOD removal started after interval of time which about 9 days from operation period. As shown in Fig. 4.8, this figure presented the behavior of BOD for a secondary treated wastewater in BZU treatment plant, Ramallah/Palestine, which the data was collected from CW-SAT through S_1, S_2, S_3 and S_4 during 22 /July to 10 / September of 2013.

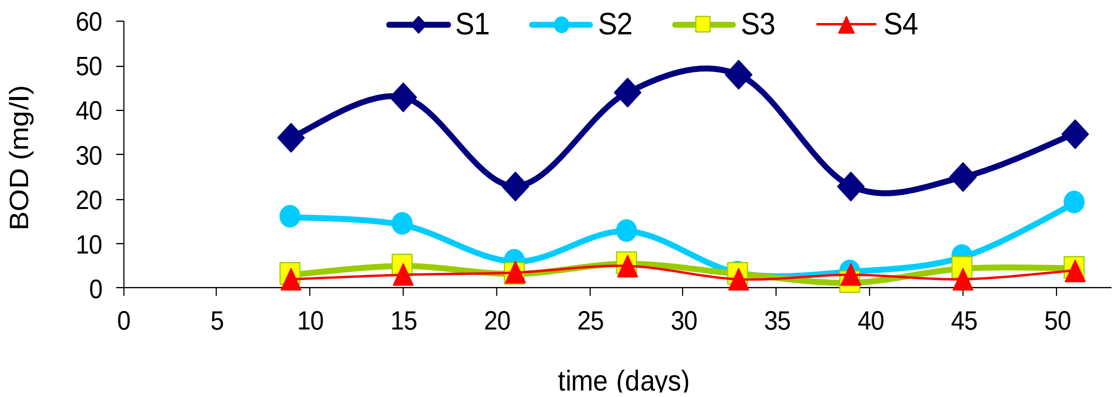

Figure 4.8: Influent and effluent BOD concentration in CW-SAT treating secondary treated wastewater in Birzeit University treatment plant, Ramallah/Palestine

Influent and effluent BOD concentration values in a CW-SAT of influent wastewater of Al- Bireh (raw-after grit) represented in Fig 4.9. The stable state started after 15 days from operation period as shown below. BOD concentrations were varying between 622 -20 mg/l and the average influent and effluent are (417, 42.6) in unit of mg/l, during at the same time of operation interval time.

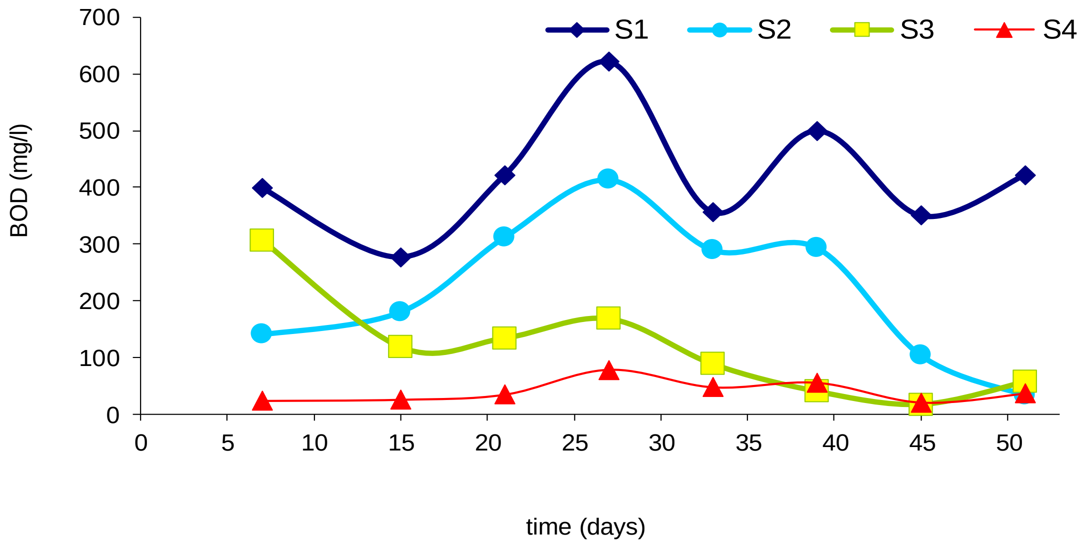

Figure 4.9 Influent and effluent BOD concentration values in a CW-SAT of influent wastewater of Al- Bireh (Raw-after grit)

For the system fed with Al-Bireh secondary treated wastewater and after a period of 28 days, average BOD value in the influent was 21.18 mg/l and in effluent was 5.94 mg/l over the period during 22 /July to 10 / September. The results presented in Fig. 4.10 reveal that the BOD concentration was marginally improved.

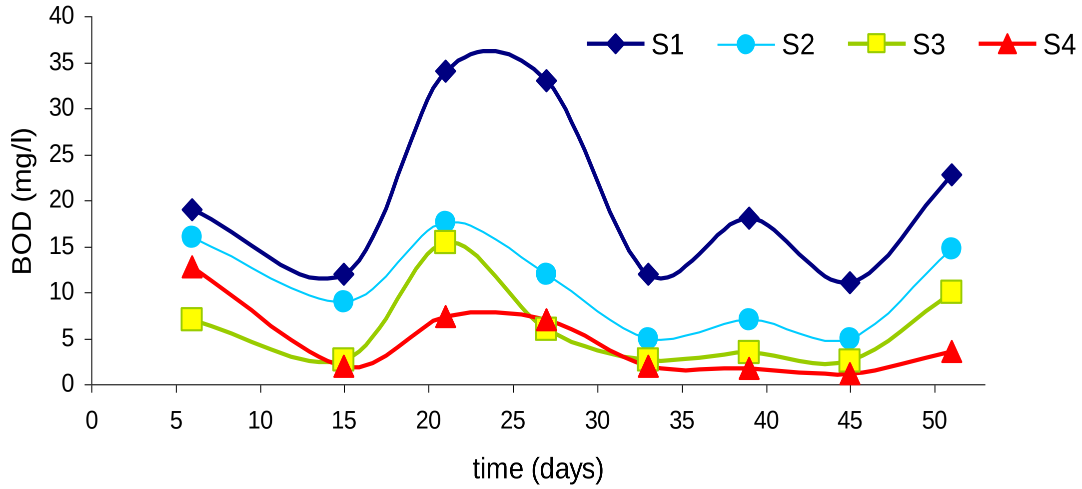

Figure 4.10: Influent and effluent BOD concentration values in a CW-SAT treating tertiary treated effluent of Al-Bireh municipal wastewater treatment plan (out)

The BOD removal efficiency was obtained from CW-SAT experiment were 91.3, 89.7 and 71.9% for Birzeit, Al-Bireh inlet and outlet waters, respectively, are higher than that reported by Zurita *et al.* (2009) who found a 78.2% BOD removal for a HSSFCW planted with one species (Zantedeschia aethiopica). Removal efficiency from CW-SAT better than use CW treatment only, because SAT units depends also on VSSF of wastewater. These results and data were referred to the effective distribution of roots in CWs and sand filter columns which can be achieved when three species are used in addition to the increased opportunity of creating a great diversity of microbial communities. BOD removal efficiency for wastewater was in the range of (72-84.8) % as found by Niyonizima (2007) and Ghrabi *et al*. (2011).

The Fig 4.11 as shown below, represented the behavior of effluent BOD from three source of wastewater, where the data were collected from S_4 of SAT column, these data were collected at the same operation period. Table 4.4 represented the average effluent BOD concentration value for three wastewater source.

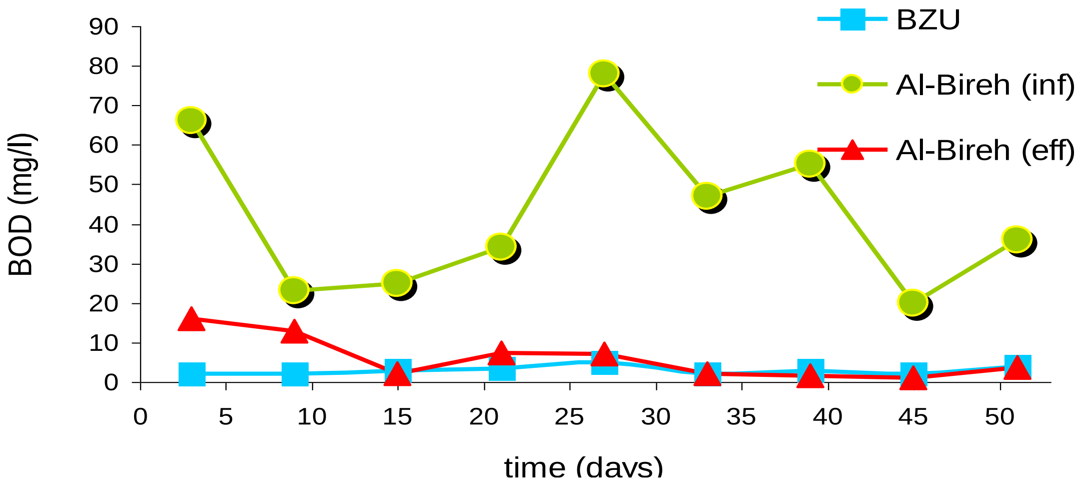

Figure 4.11: Effluent BOD concentration values in a CW-SAT for three water source in the same operation period time

Table 4.4: Average effluent BOD concentration value in unit of (mg/l) for three source of water during of (22 /July to 12/September of 2013)

Source of wastewater	Average effluent of BOD Concentration
Effluent from BZU	2.94
Effluent from Al-Bireh municipal wastewater (out)	5.94
Influent from Al-Bireh municipal wastewater (raw)	42.66

Chemical Oxygen Demand (COD)

High removal rates of COD were achieved in stable period after about 60 days of operation period that COD removal efficiencies were 79.6% for Birzeit, 89.9% for influent from Al-Bireh municipal wastewater (raw) and 76.9% for effluent from Al-Bireh municipal wastewater (out).

Part of COD removal efficiency was achieved by CW system and the other part of SAT. In CWs, the removal of COD of HSSFCWs as found 72-79% for a wetland treating grey water (Niyonizima, 2007), 42.7% (Ghrabi *et al.*, 2011) and 71.8% (Avsar *et al.*, 2007), COD concentration dropped drastically at the aeration points where the aerobic conditions facilitated the growth of aerobic microbes and boosted the degradation of organic matters (Ong *et al.*, 2010).

The results presented in Fig 4.12 show that the CW-SAT have a stable removal of COD after about 32 days of interval period. Before this, the interval time was called repining period which the behavior of removal COD was irregular. The graph bellow represented COD reached maximum growth after about 25 days of operation period.

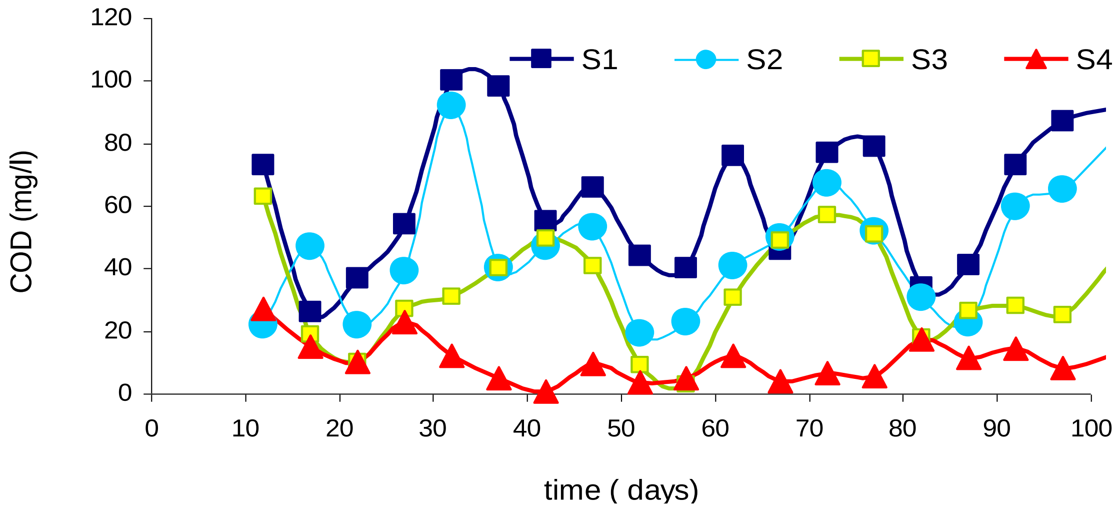

Figure 4.12: COD concentration value in a CW-SAT treated wastewater in Birzeit University treatment plant, Ramallah/Palestine

The concentration of COD in CW-SAT of influent wastewater of Al-Bireh (raw wastewater – after grit) represented in Fig 4.13 bellow, during the repining and steady state period. After 22 days of operation time, the steady state was clear as shown. The maximum COD concentration was 1467 mg/l of S_1 degrease to 67 mg/l of S_4 by CW-SAT system, where the removal efficiency was 89.9% and the concentration of COD represented in table 4.5.

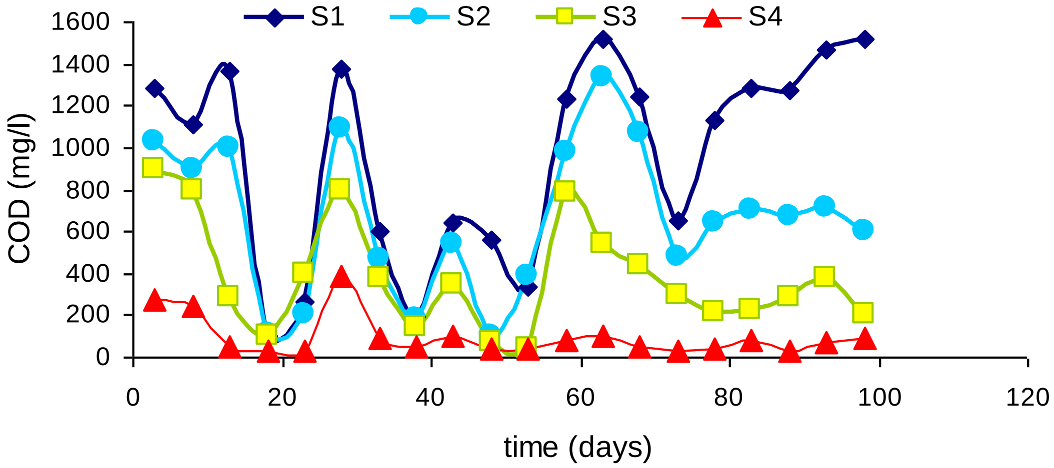

Figure 4.13: COD concentration values in a CW-SAT of influent wastewater of Al- Bireh (raw-after grit)

Table 4.5: COD concentration values in *(mg/l)* and standard deviation for influent wastewater of Al-Bireh (after grit)

No. of days	S_1	S_2	S_3	S_4
3	1280	1032	896	273
8	1106	900	797	242
13	1370	1003	284	56
18	103	112	99	33
23	264	203	400	34
28	1373	1090	794	390
33	600	465	374	88
38	195	188	142	54
43	645	543	342	100
48	560	105	76	39
53	334	386	43	44
58	1232	980	786	86
63	1518	1340	545	105
68	1243	1070	435	48
73	656	475	293	29
78	1130	639	218	40
83	1280	700	226	78
88	1276	671	283	29
93	1467	712	380	67
98	1518	601	199	89
Average (STD)	958 (481)	661 (358.4)	381 (257.4)	96 (95)

The COD concentration values in a CW-SAT treating tertiary treated effluent of Al-Bireh municipal wastewater treatment plan (out treated wastewater) represented in Fig 4.14. The steady state began after 37 days during the operation of project, and the average COD concentration value of S_1, S_2 were (49.51, 11.63) in mg/l respectively. The removal efficiency was 67.9 %.

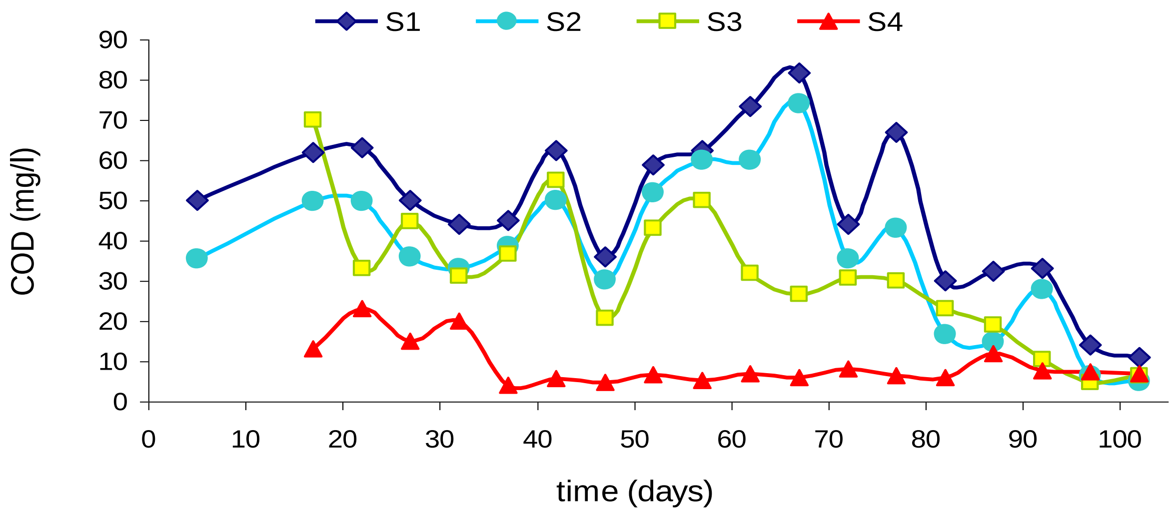

Figure 4.14: COD concentration values in a CW-SAT treating tertiary treated effluent of Al-Bireh municipal wastewater treatment plan (out)

BOD and COD associated with the situation of solids in wastewater is diluted and removed by sedimentation while that in colloidal and soluble form is removed as a metabolic activity of microorganism's process, physical and chemical interactions (Vipat *et al.*, 2008).

Table 4.6: The estimated removal capacity in kg/ha/year in the CW systems

Water source	Parameter	
	COD	BOD_5
Effluent from BZU	9154	3349
Effluent from Al-Bireh municipal wastewater (out)	55633	26037
Influent from Al-Bireh municipal wastewater (raw)	4366	1548

Table 4.7: The estimated removal capacity in kg/ha/year in the SAT systems

Water source	Parameter	
	COD	BOD_5
Effluent from BZU	3140	1410
Effluent from Al-Bireh municipal wastewater (out)	34000	13933
Influent from Al-Bireh municipal wastewater (raw)	3943	928

The removal rate presented in Tables 4.6 and 4.7 was calculated using the following equation:

$$\text{Removal Rate} = Q\,(C_{in} - C_{out})/A$$

In Constructed Wetland CW, the removal rate was calculated based on mass balance using the following equation:

$$\text{Removal Rate} = Q_{in}*C_{in} - Q_{out}*C_{out}/\ Q_{in}*C_{in}$$

Also, we can used the equation below, which was calculated based mass load:

$$\text{Removal Rate} = 1 - 0.07\ C_{out} / C_{in}$$

Where:

Q: flow rate in L/d.

C_{in} and C_{out}: influent and effluent concentrations in mg/l.

A: surface area of the Constructed Wetland or Soil Aquifer Treatment in m^2.

Table 4.8: The removal rates in CW-SAT system calculated based on mass balance and standard deviation

Source of wastewater / Parameter		**Effluent from BZU**			**Influent from Al- Bireh wastewater (raw)**			**Effluent from Al-Bireh wastewater (OUT)**
	CW	SAT	CW- SAT	CW	SAT	CW- SAT	CW	SAT	CW- SAT
BOD_5	0.79(7.6)	0.7(2.8)	0.78(5.8)	0.6(111)	0.8(65)	0.92(67)	0.65(7)	0.4(4.20	0.8(7)
COD	0.47(21)	0.7(15)	0.8(16.4)	0.51(419.7)	0.8(226)	0.92(288)	0.46(18.6)	0.6(13.6)	0.83(14.2)
NH_4-N	0.73(4.2)	0.8(3)	0.96(2.6)	0.7(9.7)	0.8(4)	0.94(8.2)	0.89(1)	0.6(0.8)	0.96(0.7)
NO_3-N	0.5(4.6)	0.9(3.50	0.96(1.3)	0.6(11.9)	0.8(6.9)	0.94(8.5)	0.82(3.7)	0.9(1.5)	0.99(2.3)
TSS	0.68(11.3)	0.8(5)	0.94(9.5)	0.4(24.2)	0.8(12)	0.92 (21.9)	0.69(2.3)	0.9(1.5)	0.99(0.7)
TVS	0.7(1)	0.9(0.5)	0.98(0.75)	0.7(7.8)	0.9(2.2)	0.97(6.3)	0.6(0.25)	0.9(0.2)	0.97(0.2)
FC	0.7(1x10^3)	0.9(357)	0.99(672)	0.8(2,2x10^6)	0.9(1x10^6)	0.99(1,2x10^6)	0.93(1,9x10^3)	0.9(271)	0.99(1,6x10^3)

Table 4.8, represented the removal rate and standard deviation based on mass load for CW, SAT and CW-SAT together. And as shown, we get a high efficiency removal rate by CW-SAT system.

Removal of nitrogen

a) Ammonium

High nitrogen removal efficiency and ability of nitrogen uptake was found by plants as (Lin *et al.,* 2001). As can be seen from Figures (4.15, 4.16 and 4.17). Found that significant nitrogen transformation was observed through denitrification and nitrification in addition to plants which has a contribution in nitrogen removal as Mayo and Bigambo (2005) reported**.**

However, in the first treatment natural system which is called CWs, N_2 removal through (reeds) uptake requires harvesting from the CWs. The main nitrogen N_2 removal process in low nitrogen loads is plant uptake, yet in high loads, different biological, physical and chemical processes. The influent nitrogen for three types of wastewater in S_1 were (32.9, 49.5 and 21.7) and the effluent in S_4 were (3.3, 7.6 and 1.7) in unit of mg/l for BZU, Al- Bireh wastewater (raw) and Al–Bireh treated water (out)respectively.

The average pH values in the effluent CW-SAT which is called S_1 for BZU, tertiary treated effluent of Al-Bireh municipal wastewater treatment plant (raw) and influent wastewater of Al-Bireh (out) respectively are (7.766, 7.756 and 7.807) in units of mg/l, and the average pH values in the influent CW-SAT which is called S_4 are (7.959, 7.671 and 7.73) in units of mg/l as shown in table 4.1. Showing that ammonium was abundant in the plants as NH_4, which is the favorable form of nitrogen uptake by the plants.

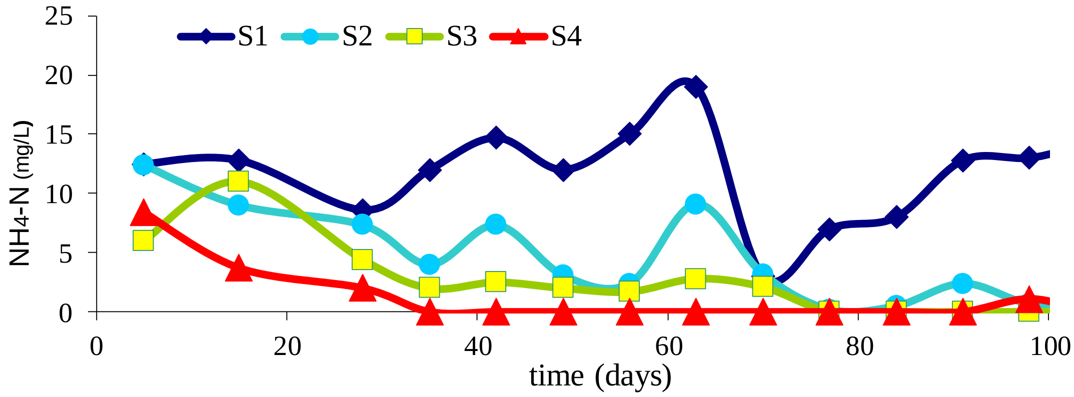

Figure 4.15: NH_4-N concentration in CW-SAT treating secondary treated wastewater in Birzeit University treatment plant, Ramallah/Palestine

NH_4 increasing within the soil column due to ammonification of organic Nitrogen. But NH_4-N concentration was decreased after about 2 to 3 meters depth. Ammonia was measured according to Nesselerization method which has an error about 1-2 mg/l. It was clear to explain the NH_4-N concentration during this period. There was a variation of influent and effluent concentration due to CW-SAT system for each type of wastewater in the operation period.

The average NH_4-N influent concentrations were (10.6, 21.5 and 5.10 mg/l) and the average effluent concentration (0.48, 1.62 and 0.28 mg/l) for BZU, Al- Bireh wastewater (Raw) and Al–Bireh treated water (out) respectively. There was a clear picture variation of difference three types of wastewater and difference in the removal efficiencies detected between the three types of water influents and effluents. It is clear that NH_4-N was almost removed from all types of investigated waters due to CW-SAT. Also, the results reveal that NH_4-Neffluent reached stable low level of concentration after 21, 22 and 15 days for Birzeit, Al-Bireh (Raw wastewater after grit), and Al-Bireh (effluent wastewater), respectively.

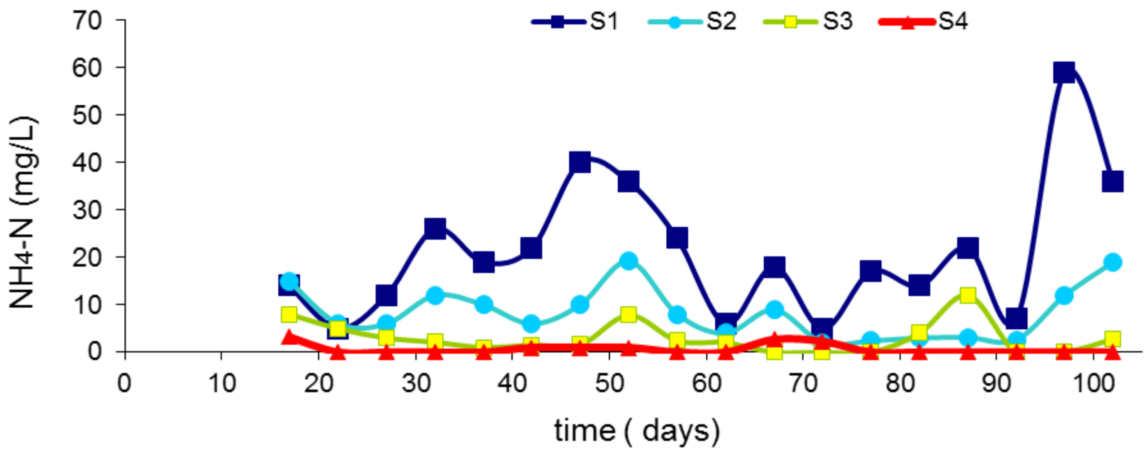

Figure 4.16: NH_4-N concentration values in a CW-SAT of influent wastewater of Al- Bireh (Raw-after grit)

The average NH_4-N removal efficiencies were (95.4, 92.4 and 94.4 mg/l) for BZU, Al- Bireh wastewater (Raw) and Al–Bireh treated water (out) respectively, although the NH_4-N removals were low concentration during the first month of monitoring period. In addition, (Zurita *et al*., 2009) reported that a relatively low nitrate removal efficiency in wetlands and referred that to the good nitrification, the nitrate removed by denitrification process was immediately substituted by nitrate produced by nitrification (Yang *et al.*, 2001) had observed a relatively good amount of removal of NH_3-N up to about 50% on average in a CW. Also, by the end of his experiment results showed that removal efficiency was increased up to 80%. Also, SAT help to remove NH_4-N by biological, physical and chemical process. However, CW-SAT decrease the level of concentration of NH_4-N, which represented in figures (4.15, 4.16 and 4. 17) and as shown in Table 4.8.

Table 4.9: Influent and Effluent Concentration and Removal efficiencies of NH_4 –N for Different Wastewater Sources Treated in CW-SAT

	No. of samples	BZU	Al –Bireh (in)	Al –Bireh (out)
Influent (mg/l)	80	10.66	21.55	5.104
Effluent (mg/l)	80	0.485	1.625	0.2835
Removal (%)		95.4	92.4	94.4

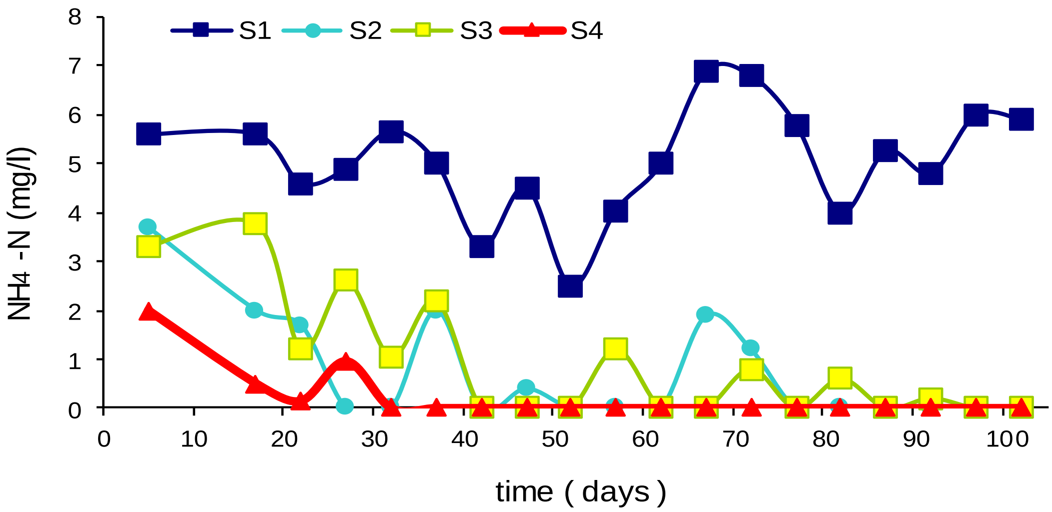

Figure 4.17: NH_4-Nconcentration values in a CW-SAT treating tertiary treated effluent of Al-Bireh municipal wastewater treatment plan (out)

It is clear that NH_4-N removal efficiency in the three systems operated with different waters consistently achieved near-complete NH_4-N removal by CW-SAT system respectively. TN removal efficiency that observed in this study is the result of these main processes such as: N_2O production via nitrification and incomplete denitrification, plant uptake by reeds, sediment storage. Also, they concluded that, artificial aeration in tanks strongly influenced and increased N_2 removal up to 12 %(Landry *et al.*, 2009). Also suggested that N_2 removal takes place through several processes biological, physical and chemical via plant uptake (reeds) in CWs, ionic exchange in CW-SAT, NH_4 volatilization in CW-SAT, nitrification and denitrification. However, NH_4-N is removed through adsorption on the substrate but once the available attachment sites were saturated the process will be revised and more endurable process such as nitrification and plant uptake become more important (Zurita *et al.*, 2009).

b) Nitrate

The average influent NO_3-N concentrations in the three types of investigated waters were very close of (15.6, 37.65 and 14.11 mg/l) for BZU, Al- Bireh wastewater (Raw) and Al – Bireh treated water (out) respectively. As shown that the removal efficiencies of NO_3-N were achieved in all waters, indicating a decrease of nitrate concentration level in the effluent. The effluent NO_3-N concentration in the three type of different water source were (0.72, 3 and 0.095 mg/l) for BZU, Al- Bireh wastewater (Raw) and Al–Bireh treated water (out) respectively.

The removal efficiency of NO_3-N concentration was varying between three type of wastewater were (95.3, 92 and 99.3 in mg/l) for BZU, Al-Bireh wastewater (Raw) and Al –Bireh treated water (out) respectively. Stable period was observed after (17, 15 and 16 days) during the operation period project for BZU, Al- Bireh wastewater (Raw) and Al–Bireh treated water (out) respectively. As represented in figures (4.18, 4.19 and 4.20).

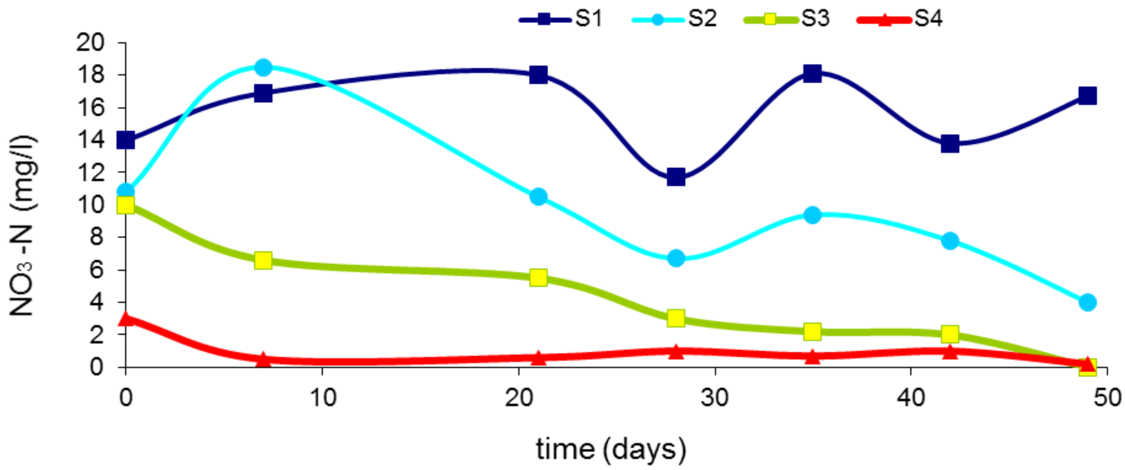

Figure 4.18: NO_3-N concentration in CW-SAT treating secondary treated wastewater in Birzeit University treatment plant, Ramallah/Palestine

Nitrate was removed efficiently from all investigated wastewater as the nitrate was detected in low levels; same result was reported by Mantovi *et al.* (2003). Steady state was after 17- 20 days during the operation period for different types of wastewater source.

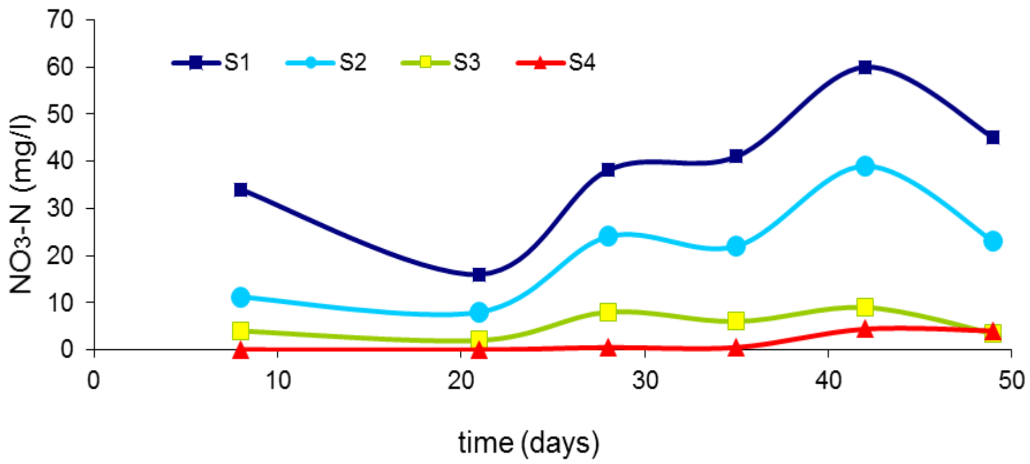

Figure 4.19: NO_3-N concentration values in a CW-SAT of influent wastewater of Al- Bireh (raw-after grit)

The level of NO_3-N concentration decrease during the operation time as we observed through the experiment because of plant uptake and denitrification (Yang *et al.*,2001), and biological, physical and chemical process which operated in SAT as a filtration and bioprocess which is depend also on vertical flow. Since the operation period included summer months (higher temperatures).

Mayo and Bigambo (2005) reported that the removal efficiency of nitrogen in HSSF system are denitrification (29.9%), plant uptake (10.2%) and net sedimentation (8.2%). The average removal efficiency of NO_3-N for the three different wastewater from CW in addition to SAT were (95.3%) for BZU, (92 %) for Al-Bireh Influent wastewater and (99.3%) for Al-Bireh effluent wastewater.

We can compare the result of removal efficiency of NO_3-N which we had from this NTS project (CW-SAT) and the result of *Mayo* and *Bigambo* (2005). The average removal efficiency of NO_3-N was very high due the CW-SAT respectively, comparing with used CW only. Where a removal rates from CW only 40%, 62% and 49.3% were recorded by (Pucci *et al.,* 1998), (Vipat *et al.,* 2008) and (Zurita *et al.,* 2009).

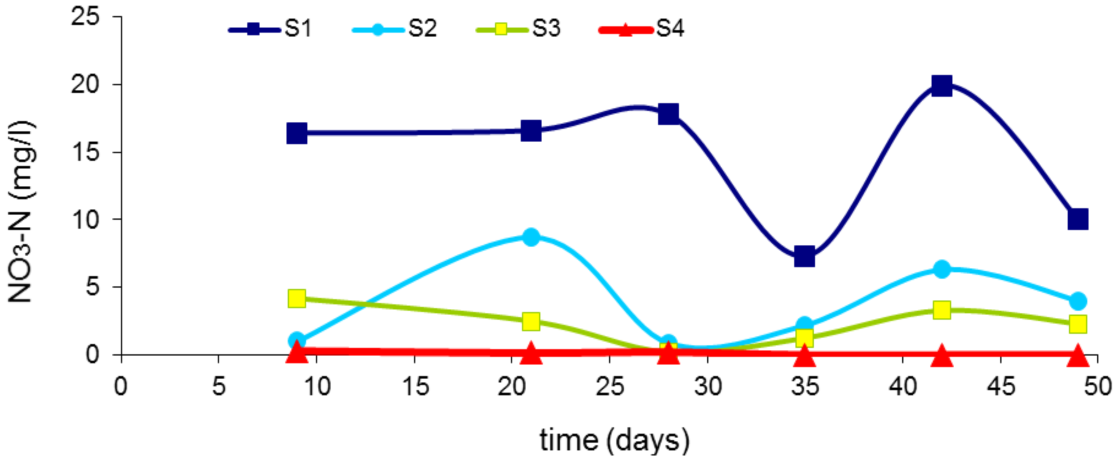

Figure 4.20: NO_3-N concentration values in a CW-SAT treated effluent of Al-Bireh municipal wastewater treatment plan (out)

Total Suspended Solids (TSS)

The average influent TSS for a different wastewater which were studied were 32.3, 133 and 8.9 mg/l for BZU, Al-Bireh wastewater (raw) and Al–Bireh treated water (out), respectively. The average effluent TSS concentration was (2.7, 13.7 and 0.028 in mg/l) for three different types respectively. In this study, which used two NTS respectively (CW-SAT), the removal efficiency higher than used CW only. For example, (Zurita *et al.*, 2009) reported that the TSS removals for HSSF as CW planted with one species and fed with domestic wastewater was in the range of (80-84) % with 57 and 11mg/l influents and effluent TSS concentrations. It is clear that TSS were not reduced effectively in the CW. Table 4.10 represented influent and effluent TSS concentration for the three different type of wastewater and as shown in figures (4.21, 4.22 and 4.23).

The TSS concentration decrease during the operation and monitoring period. The graphs below, represented the decreasing of TSS during S_1, S_2, S_3 and S_4 from CW-SAT project for the three types of wastewater. There was a varying between the different wastewater sources.

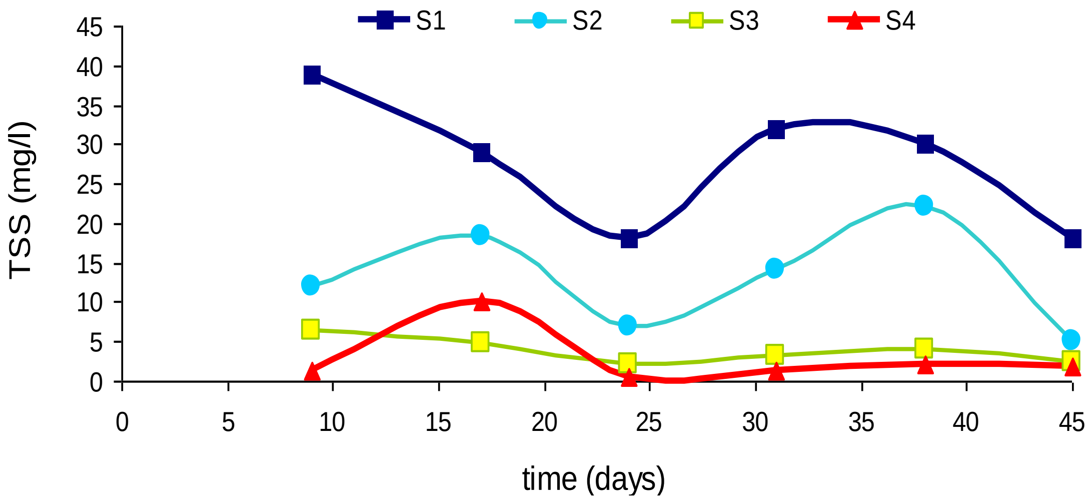

Figure 4.21: TSS concentration in CW-SAT treating secondary treated wastewater in Birzeit University treatment plant, Ramallah/Palestine

CWs units and SAT system (CW-SAT) as a hybrid system, were being monitored and operation maintenance was performed during the interval period of this study. Because that, there was a clear trend of treatment as represented bellow. TSS has been removed slowly due the CW-SAT for each wastewater source where the removal efficiency of TSS concentration during the operation and maintenance period were 91.5% for BZU, 90% for Al-Bireh (raw–after grit) and 99.6% for Al-Bireh (out–treated wastewater).

Table 4.10: Influent and Effluent Concentration and Removal efficiencies of TSS for Different Wastewater Sources Treated in CW-SAT

	No. of samples	BZU	Al-Bireh- Raw	Al-Bireh- out
Influent (mg/l)	28	32.22	133	8.922
Effluent (mg/l)	28	2.73	13.17	0.028
Removal (%)		91.5	90	99.6

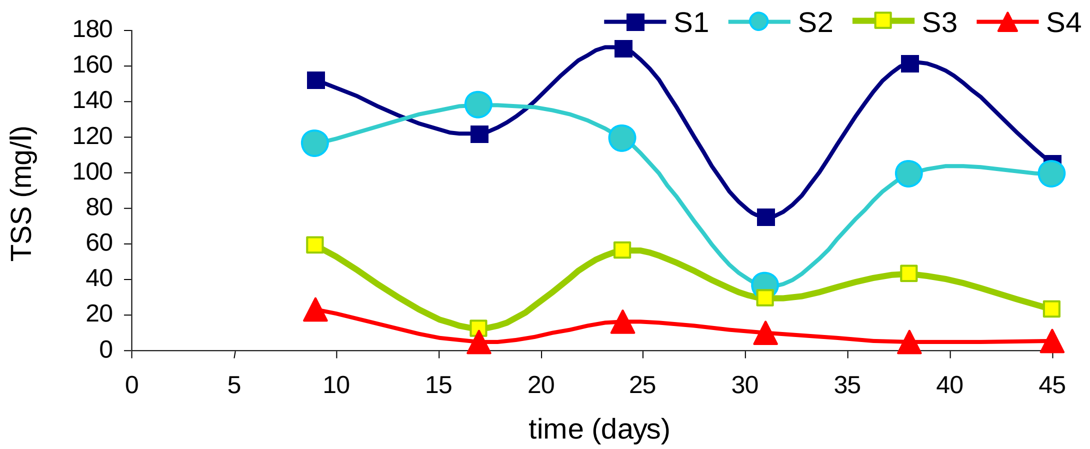

Figure 4.22: TSS concentration values in a CW-SAT of influent wastewater of Al- Bireh (Raw-after grit)

This result will have an adverse effect that observed on the opportunity of the influent reuse as it will cause a problem if used in agriculture that use drip irrigation technology but we prevent this problem by mentoring and made a maintenance of CW-SAT periodically every day. So that, it is clear that physical removal step of TSS is needed to assure the required low TSS concentrations of CW, but it more clearly in SAT system for each type of different wastewater which used in this study during the operation time.

As can be seen from Figures 21, 22 and 23, TSS was reduced effectively and the removal rate is lower in comparison to other pollution parameters. Variation between influent and effluent concentrations of TSS is rather low and unchanged during most of the experiment. With regard to the lower TSS removal efficiencies reported, they were probably as a result of the (1.2-1.9) cm diameter substrate which is induced the rapid seepage of the wastewater through the wetland reducing the retention of TSS as suggested by (Zurita *et al.*, 2009).

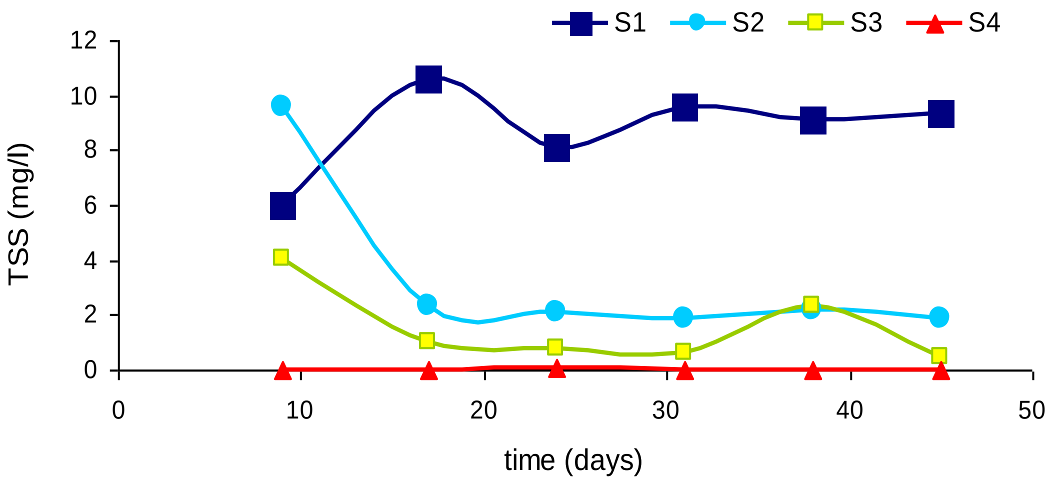

Figure 4.23: TSS concentration values in a CW-SAT treating tertiary treated effluent of Al-Bireh municipal wastewater treatment plan (out)

We can compare the result of removal efficiency of NO_3-N which we had from this natural treatment project (CW-SAT) and the result of *Mayo* and *Bigambo* (2005). The average removal efficiency of NO_3-N was very high due the CW-SAT respectively, comparing with used CW only. Where a removal rates from CW only 40%, 62% and 49.3% were recorded by (Pucci *et al.*,1998), (Vipat *et al.*,2008) and (Zurita *et al.*,2009). Monitoring and operation maintenance of CW units and SAT system (CW-SAT).

SAT system in addition with CW system was used to increase the ratio of removal efficiency of TSS and that occurs clearly in figures 21, 22and 23 as shown. However, HSSF of wastewater through CW-SAT units help for TSS remove and decrease during the two NTS respectively. TSS are mainly removed by physical processes such as sedimentation and filtration in CW followed by aerobic or anaerobic microbial degradation in the substrate. TSS is removed by CW due to the filtering action of the bed media. Filtration occurs by impaction of particles onto the roots and stems of the phragmites (reeds) or onto the gravel particles in the CW systems (Zurita *et al.*, 2009).

Total Volatile Solids (TVS)

The average influent TVS for a different types of wastewater which studied were 9.5, 32.5 and 3.12 mg/l for BZU, Al-Bireh wastewater (raw) and Al–Bireh treated water (out) respectively, and the average effluent TVS concentration were (0.2, 1.12 and 0.11 in mg/l) for three different types respectively.

The removal efficiency is higher than used CW only. TVS removals for HSSF as CW planted with one species and fed with wastewater was in the range of 96.7 - 97.7%. It is clear that (TVS) were not reduced effectively in the CW clearly and specially in first interval of operation period. Table 4.11 represented influent and effluent TVS concentration for the three different type of wastewater and as shown in figures (4.24, 4.25 and 4.26).

Table 4.11: Influent and Effluent Concentration and Removal efficiencies of TVS for Different Wastewater Sources Treated in CW-SAT

	No. of samples	BZU	Al- Bireh (raw)	Al- Bireh (out)
Influent (mg/l)	28	9.5	35.54	3.12
Effluent (mg/l)	28	0.214	1.118	0.1
Removal (%)		97.7	96.8	96.7

TVS concentration decrease during the operation of CW-SAT and monitoring period time. the figures (4.24, 4.25 and 4.26), represented the decreasing of TVS during the influent and effluent wastewater collected from CW-SAT project. TVS was a varying between the different wastewater sources.

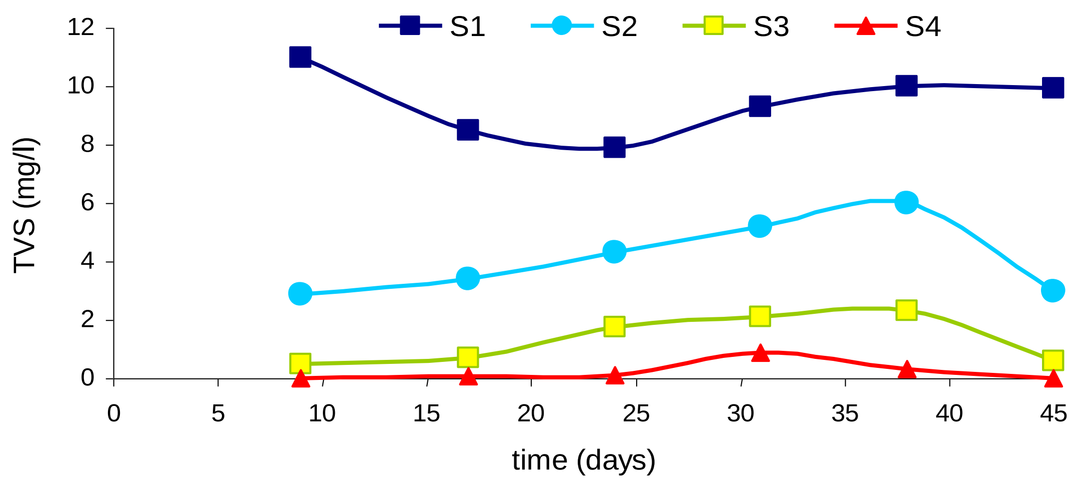

Figure 4.24: TVS concentration in CW-SAT treating secondary treated wastewater in Birzeit University treatment plant, Ramallah/Palestine

This result in this study will have an adverse effect that observed on the opportunity of the influent reuse wastewater because there was a problem in agriculture that use drip irrigation technology in CW at the beginning operation period, but we prevent this problem by mentoring of CW-SAT periodically and check the flow rate of wastewater for CW-SAT set– up every day. So that, it was clear that physical removal step of TVS is needed to assure the required low TVS concentrations of CW, but it more clearly in SAT set-up for each type of different wastewater which used during the operation period.

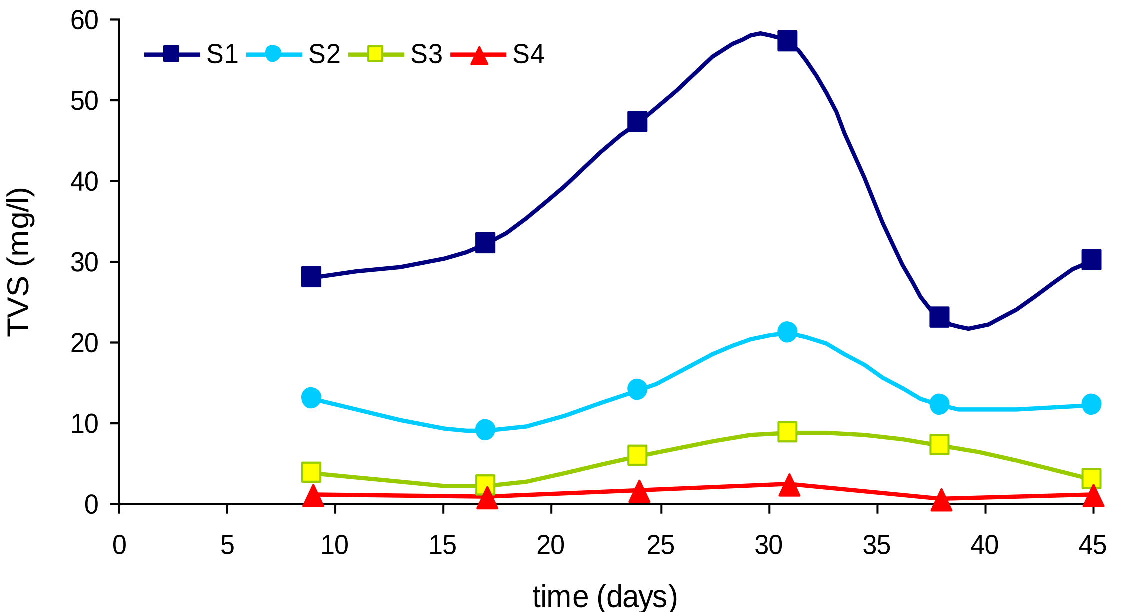

Figure 4.25: TVS concentration values in a CW-SAT of influent wastewater of Al- Bireh / Influent wastewater (Raw-after grit)

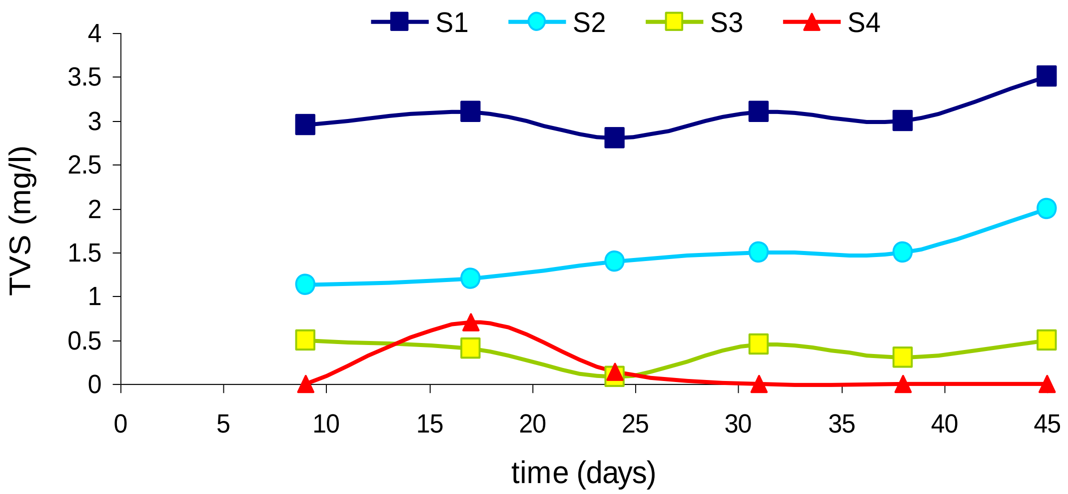

Figure 4.26: TVS concentrations value in a CW-SAT treating tertiary treated effluent of Al-Bireh municipal wastewater treatment plan (out)

4.2.3 Biological parameter

FC is a very important parameter for water quality, where FC consider as an indicator, if there was a disease born transfer through wastewater came from someone sick. It can be noticed that this stable removal didn't apply perfectly to the system fed with tertiary treated wastewater. Also, The role of temperature and technique of treatment system effected on growth or decay FC. The total number of FC was reduced by more than 99% as (Mantovi *et al.*, 2003) recorded. Also, a 99.7% removal was recorded (Pucci *et al.*, 1998).

Kimwaga *et al.* (2003) introduced an alternative approach of improving further the waste stabilization ponds effluent by coupling them to Dynamic Roughing Filters and HSSFCWs. They found that a coupled Dynamic Roughing filters and HSSFCW gave the FC concentrations of 790 FC/100ml suggesting that effluents guidelines of less than 1000 FC/100ml would be met for restricted irrigation without endangering the health of both farmers and the end users of the irrigated crops.

Table 4.12: Influent and Effluent Concentration and Removal efficiencies of FC for Different Wastewater Sources Treated in CW-SAT

	No. of samples	BZU	Al-Bireh /Raw	Al-Bireh /out
Influent (cfu/100ml)	28	1537.42	5321536.85	2601.85
Effluent (cfu/100ml)	28	20.85	46612.29	3.285
Removal		98.6%	99%	99.6%

FC reductions in the CW-SAT cell systems depend on the HRT. FC reduction in wastewater is attributed to natural die-off of the pathogens while passing through the media (State of Ohio Environmental Protection Agency (OHIOEPA), 2007).

In CW-SAT system, the average influent and effluent concentration of FC for the three different types of water were represented in Table 4.11. Also, as we see the removal efficiency FC concentration for BZU, Al-Bireh influent and effluent were (98.6%, 99% and 99.6%) respectively.

There was a clear variation of decreased FC for different sources of wastewater as represented in Figures 4.27, 4.28 and 4.29 as shown also in Table 4.9. In this study, we reached a good result for FC removal efficiency by CW-SAT.

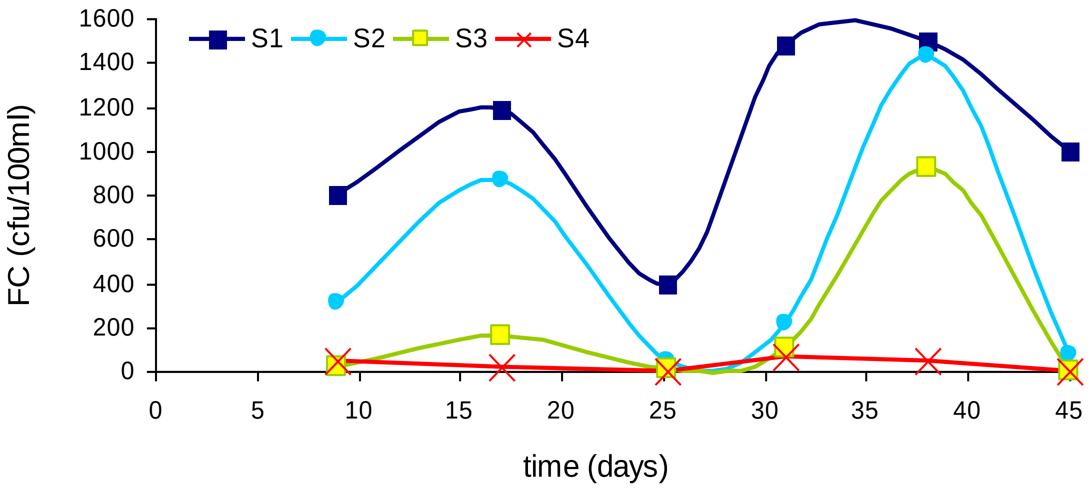

Figure 4.27: FC concentration in a CW-SAT treated wastewater in BZU treatment plant, Ramallah/Palestine

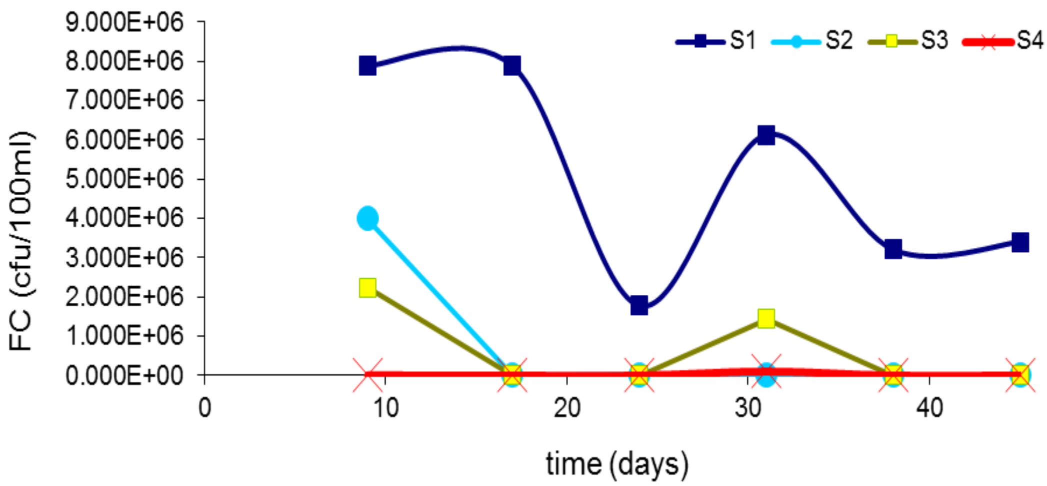

Figure 4.28: FC concentration values in a CW-SAT of influent wastewater of Al-Bireh / Influent wastewater (Raw-after grit)

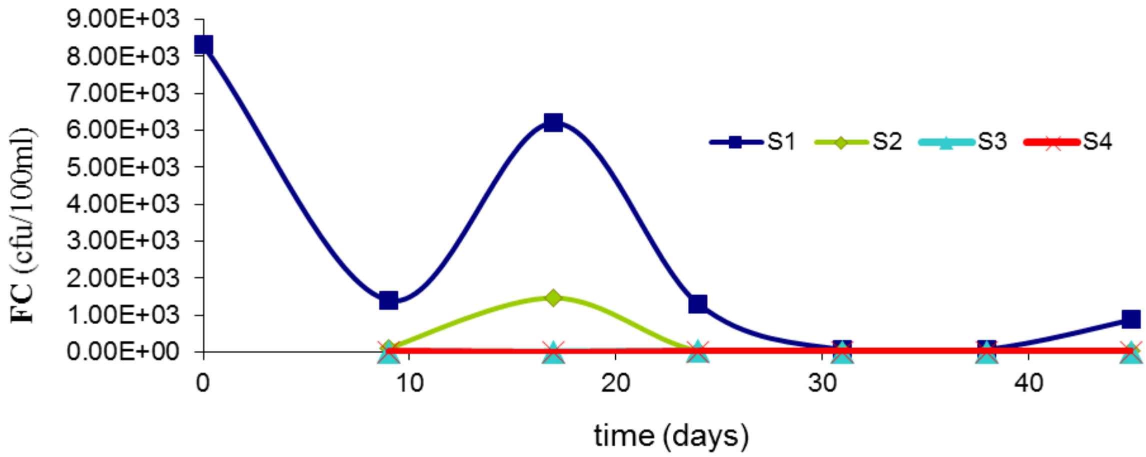

Figure 4.29: FC concentration values in a CW-SAT treating tertiary treated effluent of Al-Bireh municipal wastewater treatment plan (out)

4.3 Evapo-transpiration

Removal mechanisms in Horizontal subsurface flow constructed wetlands

Physical process, chemical and biological processes includes microbial metabolic activity and plant uptake take place in a wetland system. Physical-chemical processes were found in CWs such as sedimentation, adsorption, precipitation and Evapo-transpiration (Sa'at, 2006).

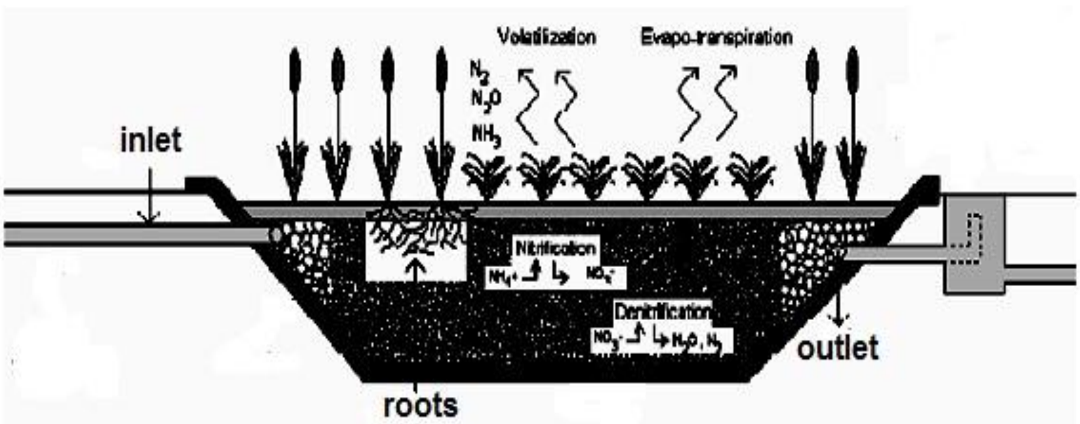

Figure 4.30: Processes that occur in CW (Sa'at, 2006).

Figure 4.31 as shown below, represented evapo-transpiration of CW for each type of wastewater after operation period from 12/10/2013 to 30/10 of 2013.

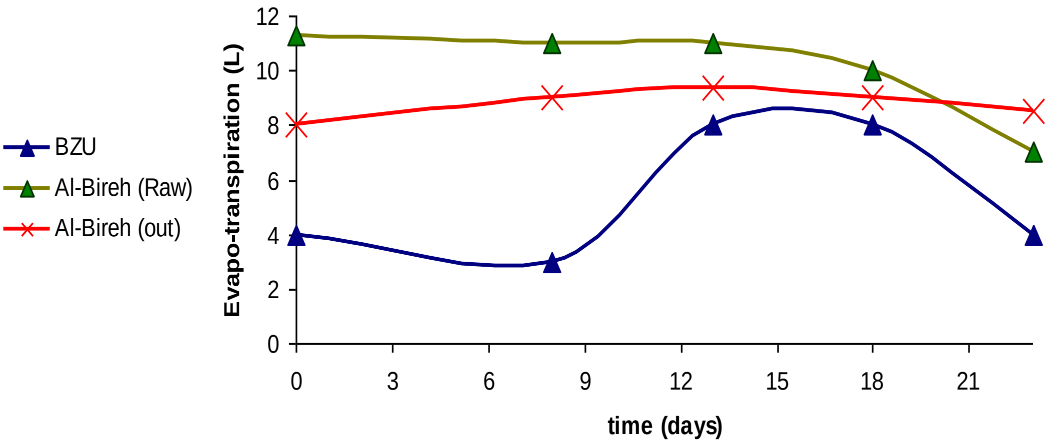

Figure 4.31: Evapo-transpiration of CW

As the wastewater flows through the CW cell, plants up-take the wastewater in a process which is called transpiration. This process will somewhat reduce the overall volume of wastewater.

Lower portions of the CWs cells do not receive enough oxygen to maintain aerobic conditions and become anaerobic. This zone will transform the nitrates (produced by the nitrification process), into compounds that are easily removed. Denitrification breaks those components down into nitrogen and nitrous oxide gas. These gases are then released into the atmosphere through a process called volatilization (Hoddionott, 2006).

Table 4.13: Evapo-transpiration of CW for each type of wastewater after operation period

Wastewater source	remaining	in	out	evaporated	% out	% evaporated
Al- Bireh (raw)	12	26	14.5	11.5	56	44
	13	25	14	11	56	44
	13	25	15	10	60	40
	13	25	18	7	72	28
Average		25			61	39
Al-Bireh (out)	12	26	22	4	85	15
	13	25	22	3	88	12
	8	30	22	8	73	27
	14	24	20	4	83	17
Average		26			82	18
BZU	12	26	20	6	77	23
	12.5	25.5	16.5	9	65	35
	9	29	20	9	69	31
	12	26	17	9	65	35
Average		27			69	31
Overall average					**71**	**29**
STD					**11**	**11**

*all numbers in liter per day

Table 4.13 represented evapo-transpiration of CW, which was calculated by the ratio between inlet and outlet wastewater in a constant operation conditions such as climate, time, flow rate and site. The flow rate Q was constant which equals 25.6 L/d (in and out) of CW for each system. So that, the removal rate was calculated based on mass balance. HLR for the HSSFCWs has a cross sectional area of (0.45 x 0.6) m^2 equals:

$$HLR = 0.0256 / (0.45x0.6) = 0.1 \text{ m/d}$$

Discussion

Three HSSFCWs were constructed outdoor was connected with three VSSFSATs were constructed indoor in the campus of BZU, Palestine. CW was planted with reed and filled with gravel, and SAT was filled with silica sand. In midsummer (July), reed biomass reached maximum growth rate, because the temperature was very high. The CW-SAT system relies on the removal and degradation of contaminants as water moves by horizontal and vertical flow through gravel and soil aquifer to recovery well. The system use physical, chemical and biological process in the CW-SAT.

Little oxygen is lost to the rhizosphere. However, many studies have shown that the oxygen release from the roots of different plants is far less than the amount needed for aerobic degradation of the oxygen consuming substances delivered with wastewater. As a result, organic compounds are degraded aerobically as well as anaerobically by bacteria attached to plant roots and rhizomes and media surface.

In this study, the HRT was 1.9 days for CW and 4 days for SAT which was sufficient enough for plants to filter and nutrients uptake in the wastewater. The system was artificially aerated in order to enhance nitrogen removal efficiency (landry et al. 2009). The difference in the results of this study may not agree with other author's findings due to the difference in experimental setup, substrate, and plant species.

- The CW-SAT was efficient in terms of total nitrogen removal and achieved the Palestinian requirements. Nitrogen removal efficiency is high and ability of nitrogen uptake by plants and soil in CW-SAT by many physical, biological and chemical process and there is no varying rang DO between the three different types of wastewater. The CW-SAT showed a good result for the NH_4-N and NO_3-N removal efficiency.

- Operation period of CW-SAT was started in mid-April/2013 to July/2013 for ripening period, and over a period during July/2013-September/2013 for steady state period. CWs were operated in the summer season. Landry *et al.* (2009) found that winter and fall removals were generally lower than the summer removal. The treatment in the CWs has shown tolerance to different influent concentration (Pucci *et al.*, 1998). Surrounding temperature didn't effect on the SAT system, because SAT was inside the lab. Generally, there is no variation temperature between S_3 and S_4.

- The result in this study show that, pH was low varying for the different types of wastewater which were studied. SAT gave a good result for TSS removal which is better than using CW alone, but generally CW-SAT was able to remove and reduce TSS concentration.

- Also, CW-SAT has a good reduction efficiency level for BOD, COD and NH_4-N concentration in mg/l. Effluent concentrations of BOD, COD and NH_4 also have positive results in CW-SAT system together.

- A different NH_4-N concentration influent and effluent which found in this study for a different wastewater source during operation period decreased significantly, we get a high NH_4-N removal rate efficiency from CW-SAT. The effluent concentration of NH_4-N decreased and part of it was removed and almost stable.

- Also, the removal efficiencies for NO_3-N and NH_4-N in the CW-SAT were generally positive result, they were the most effective in the CW-SAT when they were compared with BOD and COD. The average removal efficiencies in NH_4-N from CW-SAT units were 95.4%, 92.4% and 94%, and NO_3-N were 95.3%, 92 %and 99.3%. TSS were 91.5%, 90% and 99.6%. FC were 98.6%, 99% and 99.6% for BZU, wastewater of Al-Bireh (Raw-after grit) and effluent of Al-Bireh wastewater treatment plant, respectively.

- In CW nitrogen retention is thought to occur mainly as a result of ammonification where dissolved nitrogen in wetland was converted to

NH_4, this process which is called nitrification (Landry *et al.*, 2009). Several process interaction into soil columns where the wastewater filtration. In this research, SAT system has a positive result of removal NH_4 and NO_3, and reduce BOD, COD and TSS with high efficiency, as shown in Table 4.3.

- In this study, if we use CW-SAT as a hybrid system to treat BZU effluent wastewater, we will get a good result. CW-SAT system can be used as a disposal option and pathogen removal. The results reveal that CW-SAT effluents achieved Palestinian requirements, all parameter (BOD_5, COD, NH_4-N, NO_3-N, TSS, FC and TN) achieved most of Class A of Palestinian requirements expect COD achieve Class B requirements, as represented in Table 4.14.

Table 4.14: Wastewater characteristic for CW-SAT effluents and specifications for treated water for reuse. *(References: Palestinian specification No. 34-2012 and Palestinian Specification 742-2003)*

Parameter	**CW-SAT effluent**			**Wastewater characteristics for reuse**			
	BZU	Al-Bireh (raw)	Al-Bireh (out)	Class A	Class B	Class C	Class D
BOD_5	2.9	42.6	5.9	20	20	40	60
COD	79.6	89.9	76.9	50	50	100	150
NH_4-N	0.43	1.6	0.2	5	5	10	15
NO_3-N	0.7	3	0.09	20	20	30	40
TSS	2.7	13.17	0.02	30	30	50	90
FC	20	46612	3.2	200	1000	1000	1000
TN	3.3	7.6	1.7	30	30	45	60

- Al–Bireh (Raw wastewater) treatment plant's effluent by using CW-SAT is not well treat where CW-SAT system can be used as a removal option for that wastewater. NH_4-N, NO_3-N and TSS parameter achieved and BOD_5, COD achieved Class C requirements, and Class D for FC. In this case, this type of wastewater is very dangerous, toxic which FC concentration is very higher than other wastewater sources.

- All parameter achieved Class A to meet Palestinian requirements, by using CW-SAT hybrid system for Al-Bireh (treated water-out) expect COD parameter achieved Class B. the results as shown, represented a good removal rate efficiency.

- CW-SAT systems were operated with BZU wastewaters and Al-Bireh (out) showed a higher removal rates for COD than that obtained for Al-Bireh (raw wastewater). Similar results were found for BOD removal efficiency. For NH_4-N and NO_3-N, the CW achieved high removal rates for all wastewater.

- The average removal rates for NH_4-N were (95.4, 92.4 and 94.4%) and for NO_3-N were (95.3, 92 and 99.3 in mg/l) for BZU, wastewater of Al- Bireh (raw) and effluent of Al-Bireh wastewater treatment plant (out), respectively.

- The CW achieved poor results regarding FC removal.
- Also, CW only without SAT system achieved poor results regarding FC removal, where we get a good result of FC removal efficiency during CW-SAT together. In addition, influent wastewater of Al- Bireh (Raw-after grit) has a higher evapo-transpiration than other type of wastewater which was studied as a water balance, as represented in Figure 4.31 and Table 4.12. The flow rate Q was constant which equals 25.6 L/d (in and out) of CW for each system. So that, the removal rate was calculated based on mass balance.

Chapter five

Conclusions and recommendations

5.1 Conclusions

- The pollutant removal rates in a hybrid CW-SAT were positive for all the pollutants, except FC, The removal efficiencies in all CW-SAT were generally on the high end of the ranges reported in CW-SAT for Al-Bireh (out) and BZU.
- The results reveal that CW-SAT effluents achieve most of Class A requirements expect FC requirements for reuse in irrigations or to recharge the aquifer.
- The systems were operated with Al-Bireh (out) and BZU wastewaters showed a higher removal rates for nitrogen and COD than that obtained for Al-Bireh (raw wastewater). Similar results were found for BOD removal efficiency.

The results of the water analyses performed on the influent and the effluents of the CW-SAT systems are:

- In this research, reveal that CW-SAT effluents achieve most of Class A requirements expect COD achieve of most class B. The removal rates for COD were 79.6 %, 89.9% and 76.8% on average wastewater for BZU, Al-Bireh wastewater (Raw) and Al–Bireh treated water (out), respectively. However, percentage reduction for COD was generally lower than some removal percentages reported in the literature.

- The average BOD removal efficiencies were high in all CW-SAT. The removal efficiencies observed in the CW-SAT waters fall within the range of results found in the literature. The BOD removals are slightly lower than the average value of 85% BOD removal for different countries reported by other authors. But in this study, by CW-SAT system achieve a good result of BOD removal efficiency were 91.3%, 89.7% and 81% for BZU waters, Al- Bireh wastewater (Raw) and Al – Bireh treated water (out), respectively.
- NH_4-N reduction was observed at high levels for all the CW-SAT units. The maximum NH_4-N reduction was observed as 95.4 % in the system fed in BZU water. The second one is 94.4% for Al – Bireh treated water (out), and the lower NH_4-N removal efficiency is 92.4 % for Al- Bireh wastewater (raw).
- Nitrification and denitrification remained high in CW with shallow depth, and therefore NH_4-N and nitrate NO_3-N is effectively removed in the wastewater. The role of plants (reeds) could promote the removal efficiency of ammonia and nitrate in CW.
- Also, CW-SAT system achieved a high NH_4-N and NO_3-N removal efficiency than used CW only, because many physical, chemical and biological process were effected into sand filtration columns which was used in this research.

- Ammonium was not sensitive to nitrification because the NH_4-N concentration was lower than the NO_3-N concentration in the inflow as shown in this study, where nitrogen removal efficiency is high and ability of nitrogen uptake by CW-SAT together. The development of anoxic zones in the HSSFCW along their performance was probably due to the high porosity of the gravel which caused the retention of a bigger amount of water inside their porous; it was not possible for the gravel to get completely dry as the performance advanced. Also, the gravel and sand into columns of SAT caused a retention time for many chemical process that observed and effected on the NO_3-N removal.
- In this study, obtained for COD removal was not high compare with other parameter. In CW, TSS is removed mainly by physical processes in CW-SAT systems such as sedimentation and filtration followed by aerobic or anaerobic microbial degradation inside the substrate in CW. These processes are achieved when the wastewater passes through the system at a low velocity with controlled flow rate equal 25.6L/d for CW and 1.78 L/d of SAT columns because of the presence of vegetation and the substrate in CW, and with SAT system complementary together, achieve a high removal.
- SAT was more effective at reducing total FC through the SAT units than the HFCWs by CWs. Such results agree with those reported by (Vacca *et al.,* 2005) who found a higher reduction of total FC in VF. The main difference between the two types of NTS was the higher O_2 concentration

in the VF, as well as a slightly higher temperature (Vymazal, 2005). So that, using CW-SAT system as a NTS is better than using CW only for more effective.

5.2 Recommendations

- Artificial aeration treatment in CW-SAT system is very new, economic and energy analysis are lacking and should be investigated.
- CW-SAT as a hybrid system together are more effective for removal pollutants than using CW only, where the CW-SAT decreases the contaminants concentration.
- Using CW-SAT technique in wastewater treatment plants achieve high removal efficiency for NH_4-N and NO_3-N in sensitive groundwater recharge areas is recommended to protect groundwater quality.
- Farther research is required on the effect of wastewater quality on the performance of CW-SAT hybrid system in an arid region under a controlled environment and the evaluation of the performance during longer period of time.

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Annex A

Table 1 Inflent, effluent for different wastewater source for water balance and evapotransprision. (From 12/10-27/10 of 2013)

Date	*Parameter*	*RAW*	*BZU*	*OUT*
12/10/2013	*T1*	*26*	*26*	*26*
	T2	*27*	*27*	*27*
	Tave	*26.5*	*26.5*	*26.5*
	Vin	*38.0*	*38.0*	*38.0*
	Vout	*14.5*	*20*	*22*
	Vres	*12.2*	*12*	*12*
	Vevap	*11.3*	*8*	*4*
19/10/2013	*T1*	*27*	*27*	*27*
	T2	*27*	*26*	*28*
	Tave	*27*	*26.5*	*27.5*
	Vin	*38.0*	*38.0*	*38.0*
	Vout	*14*	*16.5*	*22*
	Vres	*13*	*12.5*	*13*
	Vevap	*11*	*9*	*3*
24/10/2013	*T1*	*25*	*25*	*26*
	T2	*27*	*26*	*26*
	Tave	*26*	*25.5*	*26*
	Vin	*38.0*	*38.0*	*38.0*
	Vout	*15*	*20*	*22*
	Vres	*13*	*9*	*8*
	Vevap	*10*	*9*	*8*
27/10/2013	*T1*	*24*	*25*	*24*
	T2	*25*	*25*	*26*
	Tave	*24.5*	*25*	*25*
	Vin	*38.0*	*38.0*	*38.0*
	Vout	*18*	*17*	*20*
	Vres	*13*	*12*	*14*
	Vevap	*7*	*9*	*4*

Table 2 COD concentration values for influent wastewater of Al- Bireh (Raw-after grit) from.

No. of date	*S1*	*S2*	*S3*	*S4*
3	*1280*	*1032*	*896*	*273*
8	*1106*	*900*	*797*	*242*
13	*1370*	*1003*	*284*	*56*
18	*103*	*112*	*99*	*33*
23	*264*	*203*	*400*	*34*
28	*1373*	*1090*	*794*	*390*
33	*600*	*465*	*374*	*88*
38	*195*	*188*	*142*	*54*
43	*645*	*543*	*342*	*100*
48	*560*	*105*	*76*	*39*
53	*334*	*386*	*43*	*44*
58	*1232*	*980*	*786*	*86*
63	*1518*	*1340*	*545*	*105*
68	*1243*	*1070*	*435*	*48*
73	*656*	*475*	*293*	*29*
78	*1130*	*639*	*218*	*40*
83	*1280*	*700*	*226*	*78*
88	*1276*	*671*	*283*	*29*
93	*1467*	*712*	*380*	*67*
98	*1518*	*601*	*199*	*89*
Average :	*957.5*	*660.75*	*380.6*	*96.2*

Table 3 Average influent, effluent concentrations and removal for three wastewater influents during the project period (15/April/ 2013 - 10/September/2013) for both ripening and steady state periods**.**

Parameter	*# of Samples*	*Source Water*	*Concentration (mg/l)*		
			Birzeit	*Al-Bireh / Inlet*	*Al-Bireh / outlet*
BOD (mg/l)	*32*	*Influent*	*33.86*	*417*	*21.1*
		Effluent	*2.94*	*42.66*	*5.94*
		Removal (%)	*91.3*	*89.7*	*71.9*
COD (mg/l)	*32*	*Influent*	*61.445*	*957.5*	*49.5*
		Effluent	*12.5*	*96.2*	*11.4*
		Removal (%)	*79.6*	*89.9*	*76.9*
NH_4 - N (mg/l)	*80*	*Influent*	*10.66*	*21.55*	*5.104*
		Effluent	*0.485*	*1.625*	*0.2835*
		Removal (%)	*95.4*	*92.4*	*94.4*
NO_3-N (mg/l)	*28*	*Influent*	*15.6*	*37.65*	*14.11*
		Effluent	*0.72*	*3*	*0.095*
		Removal (%)	*95.3*	*92*	*99.3*
pH	*120*	*Influent*	*7.70*	*7.71*	*7.75*
		Effluent	*7.84*	*7.58*	*7.70*
		Removal (%)	*1.8*	*1.6*	*0.64*
TSS (mg/l)	*28*	*Influent*	*32.22*	*133*	*8.922*
		Effluent	*2.73*	*13.17*	*0.028*
		Removal (%)	*91.5*	*90*	*99.6*
TVS (mg/l)	*28*	*Influent*	*9.5*	*35.54*	*3.12*
		Effluent	*0.214*	*1.118*	*0.1*
		Removal (%)	*97.7*	*96.8*	*96.7*
Fecal coliform (cfu/100ml)	*28*	*Influent*	*1537.42*	*5321536.85*	*2601.85*
		Effluent	*20.85*	*46612.29*	*3.285*
		Removal (%)	*98.6*	*99*	*99.6*

Annex B

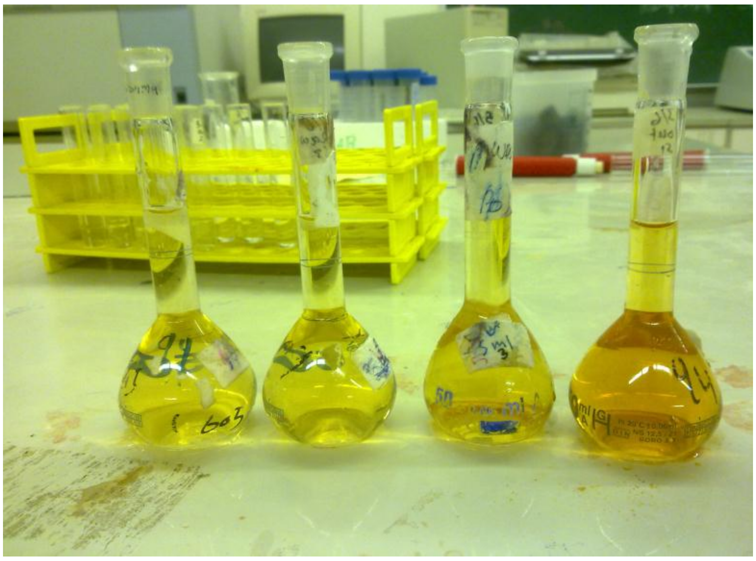

Photo 1: a part of ammonia experiment in the lab of Institute of Environmental and Water Studies inside the campus of Birzeit University BZU. (In 10 June, 2013)

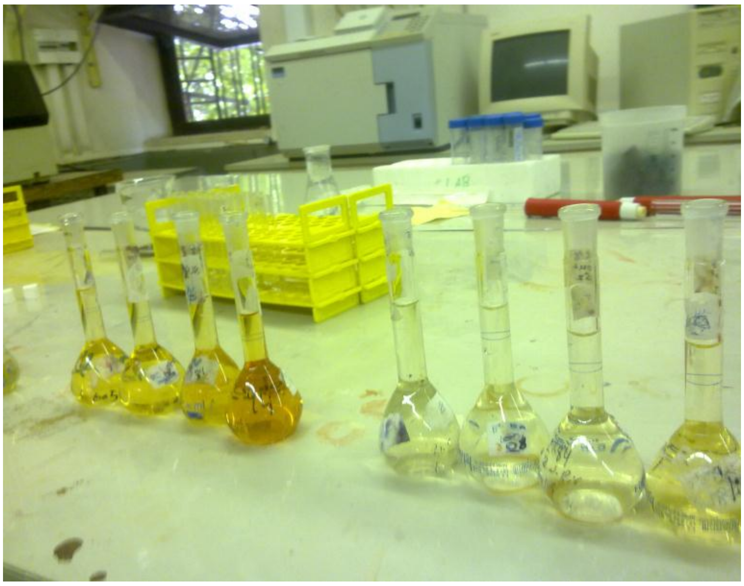

Photo 2: NH4 and COD experiment in the lab of IEWS inside the campus of BZU.(in 10 June ,2013)

Photo 3: CW experiment outdoor the campus of Birzeit University BZU. (In 7 July, 2013)

Photo 4: CW experiment outdoor the campus of Birzeit University BZU during the operation period .(in 15 May ,2013)

Photo 5: a side of Al-Bireh wastewater treatment station, during collecting samples of influent and effluent wastewater/ Al-Bireh /Palestine. (15 July, 2013)

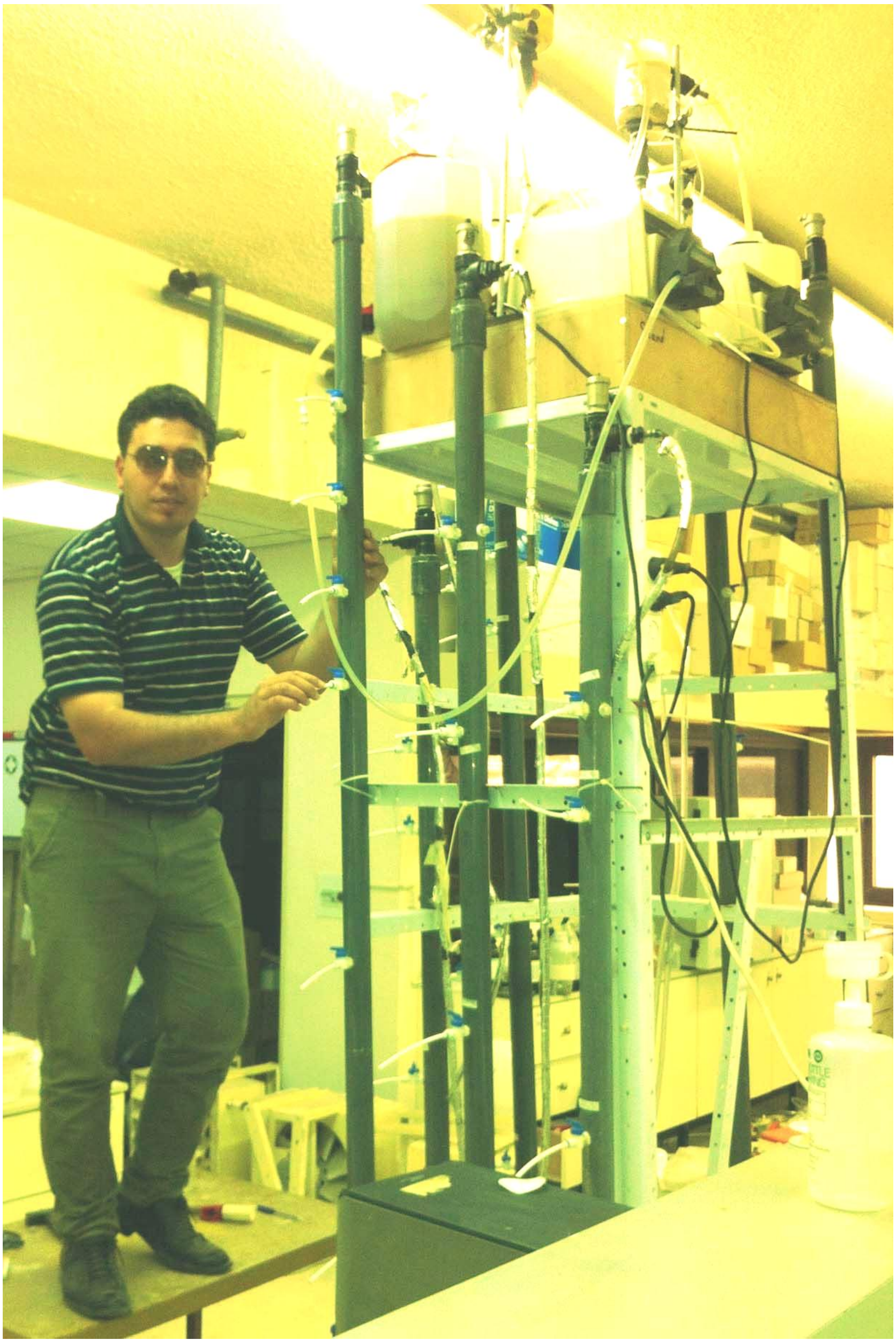

Photo 6: a side of SAT at IWES lab during repining and steady state period / BZU/ Palestine. (15 July, 2013)