Polishing of an aerobically pre-treated domestic sewage by constructed wetlands in Qarawit Bani-Zeid village

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This thesis was prepared under the supervision of Dr. Nidal Mahmoud and has been approved by all members of the examination committee.

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Dr. Nidal Mahmoud (Chairman)..............................
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The findings, interpretations and conclusions expressed in this study don't necessarily express the view of Birzeit University, the views of the individual members of the MSc-Committee or the views of their respective employers.

Abstract

Constructed wetland relies on the removal or degradation of contaminants as water moves through the media, using physical, chemical and biological processes for water treatment. However, the performances of these systems depend on the site characteristics, sources water quality and the process conditions applied. Therefore, this study focused on analyzing the potential of constructed wetland for removal of organic matter, nutrients and pathogens from pre-treated water. Horizontal subsurface flow constructed wetlands (HSSFCWs) are being used worldwide to treat wastewater from a variety of sources.

An extensive literature review was conducted to update the current state of scientific knowledge on the performance of constructed wetlands for domestic wastewater treatment. This study were carried out on horizontal subsurface flow constructed wetlands in Qarawit Bani-Zeid village. Nine perforated pipes were placed in constructed wetland to take samples every two weeks over the study period (7months). Three pipes were placed after 1.5 m from the inlet of constructed wetland, another three pipes were placed in the middle of constructed wetland after 25m from the inlet of the constructed wetland, and 3pipes were placed 1.5m from the outlet of constructed wetland. Effluents were analyzed for biological oxygen demand (BOD), Chemical oxygen demand (COD), total khejldahl nitrogen (TKN), Nitrate (NO_3^--N), total dissolved solids (TDS), total suspended solids (TSS), pH, phosphate (PO_4^{3-}-P), electrical conductivity (EC) and fecal coliform (FC).

COD removal of 47%, BOD removal of 46.3%, TKN removal of 27%, NO_3^--N removal was BDL, PO_4^{3-}-P removal of 25.8%, sulphate removal of 46%, TSS removal of 65%, and (FC) removal of 98.8% were achieved by the constructed wetlands in Qarawit Bani-Zeid village. The dissolved oxygen (DO) of wastewater at each pipe in constructed wetland was close to zero. The TDS and fecal coliform (FC) in the effluent of the constructed wetland were 1052 mg/L 2628CFU/100mL respectively.

The constructed wetland was efficient in terms of COD and BOD removal and achieved the Palestinian standards for using treated effluent for reuse and discharge to wades. But, in terms of TSS and fecal coliform the constructed wetland didn't achieve those standards.

Evapotranspiration in the constructed wetland was measured by two methods, the first one was by a mini pilot of constructed wetland (plastic barrel), and the second one was by calculating the evapotranspiration in the constructed wetland itself by calculating the difference between influent and effluent flows, which was considered as water lost through evapotranspiration. The water lost through evapotranspiration calculated by the two methods was identical of around 20% of the influent flow.

الخلاصة

تعمل الأراضي الرطبة المنشأة على ازالة الملوثات من المياه العادمة وذلك باستخدام العمليات الفيزيائية والكيميائية والعمليات الحيوية. ومع ذلك، يعتمد اداء هذه الانظمة على خصائص الموقع ونوعية المياه والظروف التشغيلية. وتستخدم الأراضي الرطبة المنشأة في مختلف دول العالم لمعالجة المياه العادمة. يتضمن هذا البحث دراسة واسعة النطاق تستعرض المعرفة العلمية المتعلقة بهذه التكنولوجيا.

وقد اجريت هذه الدراسة على الأراضي الرطبة المنشأة في قرية قراوة بني زيد. حيث تم وضع تسعة أنابيب مثقبة في الأراضي الرطبة المنشأة لأخذ العينات منها مرة كل اسبوعين خلال فترة الدراسة. ثلاثة أنابيب وضعت على بعد ١,٥ متر من مدخل الأراضي الرطبة المنشأة، وتم وضع ثلاثة أنابيب اخرى في منتصف الأراضي الرطبة المنشأة على بعد ٢٥م من مدخل الأراضي الرطبة المنشأة، وثلاثة أنابيب اخرى على بعد ١,٥ م من مخرج الأراضي الرطبة المنشأة. وقد تم تحليل عينات المياه المأخوذة من الأنابيب في مدخل ومنتصف ومخرج الأراضي الرطبة المنشأة.

وقد كانت الأراضي الرطبة المنشأة فعالة في ازالة الأكسجين المستهلك كيميائيا وحيويا حيث كانت نسبة ازالة الأكسجين المستهلك كيميائيا ٤٧%، ونسبة ازالة الأكسجين المستهلك حيويا ٤٦,٣%، وكانت نسبة ازالة النيتروجين الكلي ٢٧%، والنترات كانت تحت الحد المسموح به، ونسبة ازالة الفوسفات ٢٥,٨%، والكبريتات كانت نسبة ازالتها ٤٦%، والمواد الصلبة المعلقة ٦٥ %، وقد حققت الأراضي الرطبة المنشأة ٩٨,٨% في ازالة البكتيريا القولونية البرازية، وقد تم قياس الأكسجين المذاب في كل الأنابيب وكان قريب من الصفر.

وقد تم قياس التبخر في الأراضي الرطبة المنشأة بطريقتين، الطريقة الاولى بواسطة برميل بلاستيكي يمثل الأراضي الرطبة المنشأة والثانية عن طريق حساب الفرق بين تدفق المياه الداخلة والخارجة من الأراضي الرطبة المنشأة وكانت المياه المفقودة من خلال التبخر بواسطة الطريقتين متطابقة وتساوي ٢٠%.

Dedication

I Dedicate My Work

To Whom I Belong

To My Parents

To My Husband

To My Brothers

For their help, support and encouragement

Acknowledgments

Most of all, I acknowledge the incessant blessings for God Almighty granted me wisdom and made everything successful.

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I also extend my sincere and grateful thanks to my mother, father, and brothers and husband for their encouragement and support throughout this time.

Scope of Study

The scope of this study includes assessment of the process performance of constructed wetlands (CWs) systems for polishing anaerobically pre-treated sewage under the semi-arid Mediterranean climatic conditions, with emphasis on biotransformation, evapotranspiration and water balance. The experiments were carried out in Birzeit University/ Palestine. Wastewater samples were taken from the pipes that was placed in Constructed wetland in Qrawit Beni-Zeid village, the performance of the constructed wetland was evaluated using water quality parameters: pH, EC, TSS, TDS, TKN, NO_3^--N and PO_4^{3-}-P, Chemical COD, BOD, and Fecal Coliform.

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Abbreviations

BDL	Below Detection Limit
BOD	Biological Oxygen Demand
CFU	Colony Forming Unit
CIA	Capillary Ion Analyzer
COD	Chemical Oxygen Demand
CWS	Constructed Wetland System
DO	Dissolved Oxygen
EC	Electrical Conductivity
FC	Fecal Coliform
HSSFC	Horizontal Subsurface Flow Constructed
mg	Milligram
ml	Milliliter
NO_3^-	Nitrate
PO_4^{3-}	Phosphate
CW	Constructed Wetlands
STD	Standard Deviation
T	Temperature
TDS	Total Dissolved Solids
TKN	Total Khejldal Nitrogen
TSS	Total Suspended Solids
WHO	World Health Organization

Chapter one

Introduction

1.1 Background

At present still about 1 billion people in the world lack access to improved water supply and some 2.6 billion people lack access to proper sanitation (WHO, 2007). This lack of wastewater collection and treatment facilities results in serious quality deterioration of both surface and groundwater resources. The accelerated expansion and development in Palestine have resulted in an increase of water consumption and consequently in generation of large quantities of wastewater from various sources.

It is important for the developing countries to use a proper wastewater treatment system which meets the local requirements in terms of water quality, costs and operational skills are required, maximize the potential for local reuse (non-potable or potable) and have least impact on the environment. Natural wastewater treatment systems like soil aquifer (SAT) and constructed wetlands (CW) are robust barriers, can remove multiple contaminants, minimize the use of chemicals, use relatively less energy and have a small carbon footprint. Natural treatment systems rely on natural processes comprising different physical, chemical and biological removal mechanisms and combinations there for improvement in water quality. These systems have been applied for wastewater treatment and reuse in different parts of the world. These systems are very appropriate for developing countries and countries in transition and at the same time equally applicable in developed countries (Khalili, 2007).

Constructed wetlands are manmade engineered, marsh like area designed to treat wastewater depending on physical, chemical and biological processes of natural ecosystems. Wetlands are those areas that are inundated or saturated by surface or groundwater a frequency and duration sufficient to maintain saturated conditions, can remove multiple contaminants, and minimize the use of chemical. It’s a natural treatment system that relies on natural process comprising different physical, chemical and biological removal mechanisms and combinations. Therefore, these system are very appropriate for developing countries and countries in transition and at the same time equally applicable in developed countries (Khalili, 2007).

Constructed wetlands are wetlands intentionally created from non-wetland sites for wastewater or storm water treatment. These are being used worldwide to treat wastewater, including that from mines, animal and fish farms, highway runoff, industry of all types, and municipal and domestic sewage (Hoddinott, 2006). They can remove multiple aquatic pollutants by making use of natural, biological processes driven by solar energy, requiring minimal maintenance and external energy inputs.

These systems can be either free water surface or subsurface wetlands. Free water systems include a shallow basin where water is exposed to atmosphere and flows horizontally. Subsurface systems consist of a basin with porous media with water level below the surface of the media and the water flows horizontally (Converse, 1999).

A variety of applications for constructed wetland technology for water quality improvement has started to be implemented in developing countries like India, Nepal, Iran, Thailand and Egypt. All constructed wetlands are attached growth biological reactors. Flow regime may be free water surface and sub-surface flow. The removal mechanisms associated with wetlands include sedimentation, coagulation, adsorption, filtration, biological up take and microbial transformation. Constructed wetlands are not recommended for treatment of raw wastewater so that it must be preceded by a pre-treatment step (El-Khateeb *et al*., 2008).

CWs are more complex than conventional treatment processes due to the diffusive flow and the large number of processes involved in wastewater degradation. The various types of treated wastewater are expected to have different size distribution of contaminants which might be influential in the CW performance (Maltby *et al*., 2013). Consequently, removal efficiency is more unpredictable due to the influence of varying hydraulics and a dynamic internal environment (Mburu *et al*., 2013). CWs systems are applied to improve water quality in developing centuries like Nepal, India and Egypt.

1.2 Problem statement

The performance of the constructed wetland in Qarawit Bani-Zeid village/ Palestine as a polishing unit of anaerobically pre-treated sewage under the semi-arid climatic conditions of Palestine, and the sewerage characteristics of Qarawit Bani-Zeid village in terms of organic matter (BOD, COD), nutrient (N, P) and pathogen removal (FC) is hard to predict from the existing literature.

1.3 Main objective

The overall objective of this research was to assess the process performance of constructed wetlands (CWs) systems for polishing of anaerobically pre-treated sewage the arid to semi-arid climatic conditions of Palestine; with emphasis on biotransformation and water balance.

1.4 Specific objectives

The specific objectives are:

1. To assess the overall performance of the CWs in terms of organic matter (COD, BOD), nutrients (NO_3^--N, TKN, PO_4^{3-}) pathogens (FC) and effluent physical quality (TSS, TDS, pH, EC),
2. To assess the oxic status, and transformations, in terms of the parameters mentioned in the sub objective 1, at different random locations along the beds of the wetland,
3. To assess the quantity of the water lost through evapotranspiration in constructed wetland over the study period.

1.5 Research questions

What is the removal efficiency of CW under the different weather conditions (hot and cold periods)?

What is the oxic status along the wetland basin?

What is the quantity of water lost through evapotranspiration in CW?

1.6 Research methodology

The research was carried out on the existing constructed wetland in Bani-Zeid. Additionally, small scale CW made of plastic barrel was installed to measure water lost through evapotranspiration over the study period.

Chapter two

Literature Review

2.1 Background

In the early 1950s, first experiments to use wetland plants to treat wastewater was carried out by Dr. Käthe Seidel, full scale system for wetlands were operated was at the late of 1960s, after that the constructed wetland systems have been spreading around the world, free water surface systems with various types of vegetation- free-floating, floating-leaved, submerged and emergent are used in many countries (Vymazal, 2005).

Excessive nitrogen and phosphorous loading to natural watercourses due to urbanization and intensive farming highlight the need to protect these ecosystems from eutrophication by reducing nutrient inputs. Constructed Wetland research has been ongoing firstly in Europe with urban waste streams. Research investigations spread to other countries and since the mid 80's, constructed wetlands have been examined in greater detail (Forbes *et al*., 2004).

Constructed wetlands are used for purification of industrial wastewater, agricultural wastewater and storm waters. Also, they are applied to strip nutrients of atrophied surface waters before these are discharged into nature reserves (Rousseau *et al.,* 2004). Constructed wetlands have been used to treat acid mine drainage, storm water runoff, municipal wastewater, industrial wastewater and agricultural effluent form livestock operations. Constructed wetlands can remove significant amounts of suspended solids, organic matter, nitrogen, phosphorus, trace elements, heavy metals and microorganisms contained in wastewater (Sa'at, 2006).

The first full-scale constructed wetland for wastewater treatment was built in the Czech Republic in 1989. By the end of 1999, about 100 constructed wetlands were put in operation. Most of these systems are horizontal subsurface flow and are designed for the secondary treatment of domestic or municipal wastewater. The size of constructed wetlands ranges between (18 - 4500) m² and between (4 – 1100) population equivalents. *Phragmites australis* is the most commonly used plant. The treatment efficiency is high in terms of BOD_5 and suspended solids. However, the removal of nutrients is lower for vegetated beds. The early systems, built in 1970s and early 1980s used mostly soil materials which failed to maintain high hydraulic conductivity. 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).

Original hybrid constructed wetland systems were developed by Seidel in Germany. The process is 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. The vertical beds were planted with *P. 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. It consisted of four and two parallel vertical flow beds in the first and second stages, respectively. A similar system was built in 1987 in UK. The first stage consisted of six vertical beds (8m² each) intermittently fed and planted with *P. australis*.

The second stage consisted of three vertical beds ($5m^2$ each) planted with. *P. australis, Schoenoplectus lacustris (bulrush) and Iris pseudacorus*. Hybrid systems have the advantage of producing effluent low in BOD which is fully nitrified and partly denitrified and so that has a much lower total-N outflow concentrations (Vymazal, 2005).

Constructed wetlands for wastewater treatment in the Czech Republic. Vymazal stated that there are over 100 constructed wetlands in the Czech Republic. All of these are horizontal subsurface flow constructed wetlands treating municipal or domestic wastewater. Vymazal admitted that his data is somewhat limited by Czech legislation which requires standards only for suspended solids and biological oxygen demand parameters for sources of pollution from less than 500 PE (Hoddinott, 2006).

There are many factors that can influence the performance of constructed wetlands such as hydraulic properties, temperature, vegetation, and wind, shape of the system, inlet–outlet configuration, width-to-length ratio, depth and baffles. Reduced 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 hydraulic retention time and poor treatment efficiency (Suliman *et al*., 2007).

There are a lot of uses for constructed wetland such as, purification of industrial wastewater, agricultural wastewater and storm water (Rousseau *et al*., 2004). Constructed wetlands have been used to treat acid mine drainage, storm water runoff, municipal wastewater, industrial wastewater and agricultural effluent form livestock operations. Constructed wetlands can remove significant amounts of suspended solids, organic matter, nitrogen, phosphorus, trace elements, heavy metal sand microorganisms contained in wastewater (Sa'at, 2006).

Oxygen diffusion is limited in these systems. Oxygen must be provided to the nitrifying microbes through oxygenation of the wetland with the presence of plants in order to enhance nitrogen removal efficiency. Plants provide oxygen to the rhizosphere via passive or active oxygen transport through their stems from the atmosphere to the roots. Aerated constructed wetlands 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 constructed wetlands in colder climates (Landry *et al*., 2009).

Constructed wetlands are planted with emergent vegetation such as bulrushes, cattails and reeds. A fundamental characteristic of wetlands is that their functions are largely regulated by microorganisms and their metabolism. Microorganisms include bacteria, yeasts, fungi, protozoa, and algae. Microbial activity transforms a great number of organic and inorganic substances into insoluble substances, alters the redox conditions of the substrate and affects the processing capacity of the wetland (Davis, 1989).

Evapotranspiration in a CW is the only means by which wetlands lost water. Evapotranspiration is nearly related to a metrological conditions (Kumar *et al*., 2012), but it also related to the plant growth, ET differs greatly from winter to summer, with maximum ET rate at mid-summer (Kadlec and Wallace, 2009). ET has an effect on treatment performance, mainly because water loss increases hydraulic retention time (Kadlec and Wallace, 2009).

The capital costs of subsurface flow constructed wetlands 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).

2.2 Advantages and disadvantages of Constructed Wetland System

Constructed wetland (CWs),have been designed by engineers for waste water treatment, and CWs is use a natural processes, to purification waste water, involving wetland vegetation, soils, and the associated microbial accumulation to assist in treating waste water. Constructed wetlands are designed to take advantage of many of the same processes that happen in natural wetlands within a more controls environment (Vymazal, 2010).

2.2.1 Advantages of Constructed Wetlands include

Constructed wetlands are designed to take advantage of many of the same processes that occur in natural wetlands within a more controlled environment. Advantages of constructed wetlands include:

* Site location flexibility,

* No alteration of natural wetlands,

* Process stability under varying environmental conditions,

* Constructed wetlands do not produce sludge as the constructed wetland's influent is already pre- treated and contains low concentrations of pollutants. Subsurface flow constructed wetlands have many advantages over ponds. Where in ponds sludge accumulates over time, and the sludge has to be removed after approximately 10 years (Hoffmann and Winker, 2011).

* Horizontal subsurface flow constructed wetlands (HSSFCW) for wastewater treatment can be easily adapted to cold climate. In these systems, risks of hydraulic failure due to freezing are reduced because water flows under the bed surface. Natural or artificial insulation layer can also protect them from freezing (Plamondon *et al.*, 2006).

* Other benefits of treatment using constructed wetlands are decreased potential 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).

The need for use of constructed wetlands in grey water treatment may provide a simple and inexpensive solution for controlling many water pollution problems facing small communities, industries, and agricultural operations (Niyonzima, 2007). Grey water after treatment in a constructed wetland tends to have no colour (Hoffmann and Winker, 2011).

2.2.2 Disadvantages of Constructed Wetlands include

The potential problems with Free Water Surface constructed wetlands include mosquito, start-up problems in establishing the desired aquatic plant species with free water surface and subsurface Flow wetlands (Niyonzima, 2007). Other problem in constructed wetland 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 constructed wetland technology in urban and rural areas where land is scarce and expensive (Stefanakis and Tsihrintzis, 2009).

There are several problems caused by the use of wetlands for wastewater treatment like mosquito, and bad odors, 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).

2.3 Types and functions of Constructed Wetlands

Constructed wetlands can be classified according to the flow direction into vertical and horizontal flow. Also, other two types of constructed wetlands have been carried out. They are the free water surface systems and the subsurface flow systems which also called root zone, rock-reed filters or Vegetated submerged bed systems as presented in Fig. 2.1 (Niyonzima, 2007).

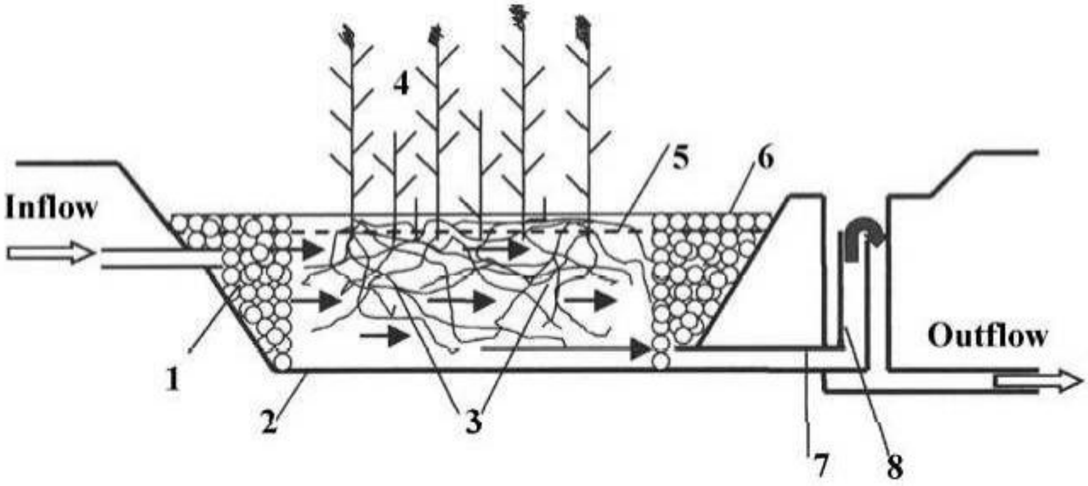

Fig. 2.1. Sub-surface constructed wetland flow. 1, distribution zone filled with large stones; 2, impermeable liner; 3, filtration medium (gravel, crushed rock); 4, vegetation; 5, water level in the bed; 6, collection zone filled with large stones; 7, collection drainage pipe; 8, outlet structure for maintaining of water level in the bed. The arrows indicate only a general flow pattern (Borst, 2011)

Combination of aerobic and anaerobic processes can upgrade constructed wetlands to treat industrial wastewater containing less-degradable organic pollutants (Yamagiwa *et al.*, 2008).

Anaerobic and aerobic activities in a vertical constructed wetland were investigated with and without supplementary aeration which boosted the carbon removal and nitrification. Constructed wetlands may be classified according to the life form of the dominating macrophyte into systems with free-floating, rooted emergent and submerged macrophytes (Vymazal, 2005).

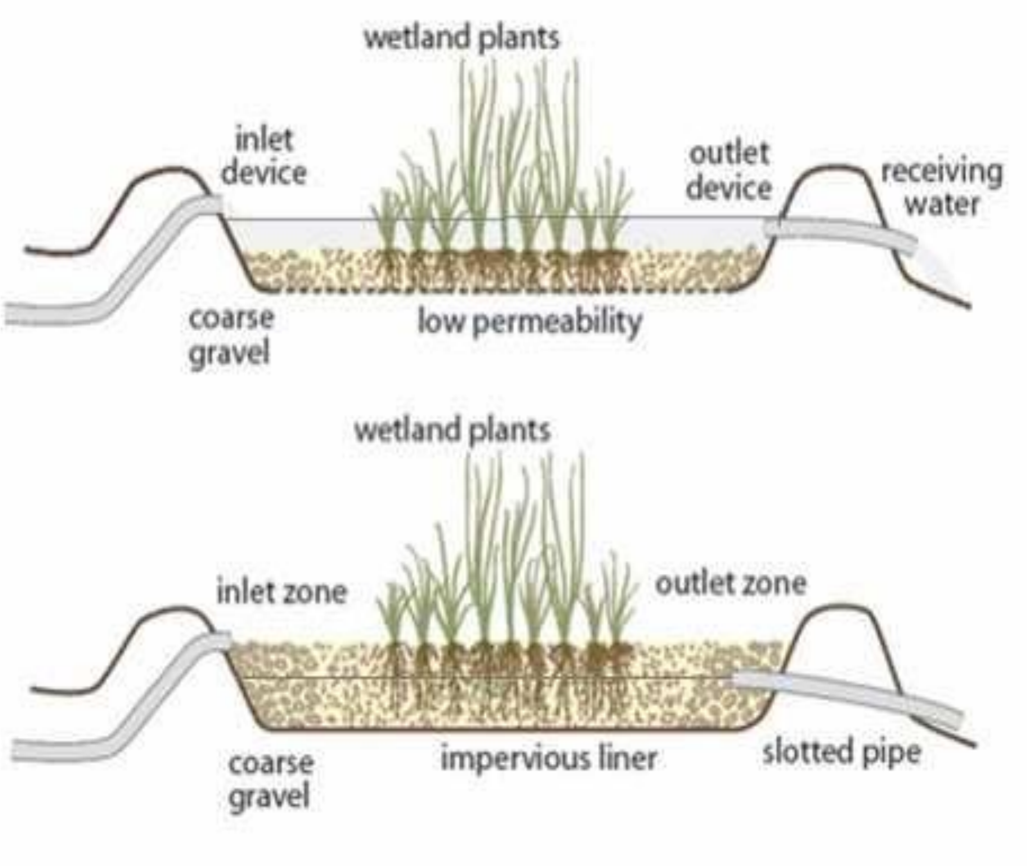

Fig. 2.2. Type of constructed wetland (a) free water surface (b) Subsurface (Sa'at, 2006)

2.4 History and presentation of constructed wetlands

Pollutant removal in constructed wetlands is a function of several physical, chemical and biological processes. The biological microbial processing drives the removal of organic matter and nitrogen. The microbial transformations involved generation of greenhouse gases: carbon dioxide, nitrous oxide, and methane. Greenhouse gases production in constructed wetland systems deserve increasing attention as the area covered by them increases. Constructed wetlands lose their treatment capacity when they are overloaded for an extended time period (Hoffmann and Winker, 2011). Results obtained by several authors regarding constructed wetlands are presented in Table 2.1.

Table 2.1. Comparison between different constructed wetland setups (Abed *et al*., 2016)

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	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 m^3/days	0.078m^3/d	0.078m^3/d		1.04 ml/min	17m^3/	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%	
NH_4^+-N				95%	98%		63.80%
NO_3^-		82%	86%		45%		
TKN				62%			
phosphate	34-53%	89%	93%	72%, (TP: 52%)	TP :43%	38%	
E. coli						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)

CWs are used to remove many pollutant, and it's a function of several physical, chemical and biological processes. Biological microbial are used to remove organic matter and nitrogen, the microbial transformations involved generation of greenhouse gases such as, carbon dioxide, nitrous oxide, and methane. Long time that will lose the constructed wetland treatment capacity (Hoffmann and Winker, 2011).

The rate of methanogenesis are controlled availability by amount of Oxygen and Carbon the factors regulating the oxygen delivery to the wetland matrix are critical in controlling greenhouse gases emissions in constructed wetlands. Plant presence may reduce or increase CH_4 fluxes (Landry *et al*., 2009).

Landry *et al.* (2009) identified 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 constructed wetland. 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 ammonium 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 nitrogen 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 and non-aerated treatments and during the summer period. In addition, the addition of artificial aeration reduced CH_4 fluxes and CO_2-equivalents.

Ong *et al*. (2010) found that the organic matter and NH_4^+-N removal efficiencies was significantly higher than the non-aerated wetland reactor, The supplementary aeration has enhanced the aerobic biodegradation of organic matter and nitrification and its perform better in the removal of aromatic amines.

Luederitz *et al.* (2001) compared the purification performances of constructed horizontal flow wetlands and vertical flow wetlands including a small horizontal flow wetland, a sloped HFW, larger HFW, a stratified vertical flow wetland and an unstratified 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.

The effect of six experimental hydraulic retention times in subsurface flow constructed wetlands was examined by Chazarenc *et al.* (2003). They found that the major factor affects HRT was evapo-transpiration. Also, they examined the influence of flow paths on the efficiency of wastewater treatment in constructed wetlands.

Horizontal flow constructed wetlands need a large surface area to construct, that increased amount of water lost due to evapotranspiration. Vertical flow beds are preferable to horizontal flow beds because they have an unsaturated upper layer in the bed and a short pretentions time than horizontal flow beds (Hoffmann and Winker, 2011).

Niyonzima (2007) designed and operated a Horizontal Sub-surface Flow pilot- scale constructed wetland 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 3.5mx0.8mx0.8mdeep. 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 (*Typhalatifolia spp*) were used as plants species. The effluent flow rate of the plant was0.327m^3/day and there tension time was 15hrs. 72% to 79% of BOD, COD, SS, Grease, and Fecal Coliform removal were achieved, while the nutrients (Nitrogen and Phosphate) removal was the range of 34% to 53%.

Sarafraz (2009) examined the performance of four horizontal subsurface flow wetlands which were constructed at the Research Station of Tehran University, Iran. Gravel and zeoilte were used in this study as substrate. The results in dictated 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 constructed wetlands (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 constructed wetlands are efficient in removing Zn, Pb and Cd from agricultural wastewater. Plants types such as Phragmites Australisand Juncus Inflex as can contribute in treating wastewater, while Zeolite and gravel materials provide a suitable plant growth medium to replace conventional sand and gravel substrates.

Vymazal (2009) evaluated the treatment performance of Constructed wetland 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 m² 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 56.3m³/d. The second wetland consisted of Vortex-type grit chamber, Imhoff tank and four beds (2500 m² total area, 625 m² 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 constructed wetlands were sampled for BOD5, COD, TSS, TP, ammonia-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 Constructed wetland Ondrˇejov showed that removal of phosphorus is steady but low with average raw, inflow and outflow concentrations of 11.6 mg/L, 10.1 mg/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 constructed wetland planted with vetiver grass and receiving landfill leachate. 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 1×10^3FC/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 horizontal subsurface flow reed beds treating dairy parlor effluent and domestic sewage. Removal of suspended solids 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 fecal streptococci by more than 98%. Nitrates, chlorides, sulfates, anionic and non-ionic surface-active agents and heavy metals were detected only in low concentrations.

The effect of six experimental hydraulic retention times in subsurface flow constructed wetlands was examined by Chazarenc *et al.* (2003). They found that the major factor affects HRT was evapo-transpiration. Also, they examined the influence of flow paths on the efficiency of wastewater treatment in constructed wetlands.

Ghrabi *et al.* (2011) monitored the performance of wastewater treatment plant in Tunisia for three months. It is 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, and 7.1% for to take nitrogen and 38.08% for PO_4^{3-}.

One of the best methods for determining and analyzing constructed wetland flow paths is using the evaluation of hydraulic residence time (HRT) distribution by the impulsion tracer method. This method is usually employed for determining non- ideal flow in chemical reactors. The resulting HRT distribution gives information about mixing and dispersion in a given filter. Two ideal reactors are commonly used: the plug flow reactor (PFR) and the continuous flow steady-state reactor (CFSTR).

The saturated flow of a constructed wetland has non-ideal flow behavior. Chazarenc *et al*. (2003) determined the practical HRT for SSFCW with the classical method of a stimulus-response experiment. They aimed to compare hydraulic behavior variations, due to season, with inflow characteristics. The use of classic a models gave a first approach of the dispersion and mixing levels in the reed bed.

The presence of plants improved the flow by creating connection between the surface and rhizosphere. Influence of precipitation or snow melt have a direct influence on treatment performances and general flow paths. Evapotranspiration is more beneficial and seems to improve all performances. They concluded that, at the filter inlet, mixing zones and wide centered effluent injection is recommended to prevent dead volumes from occurring.

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 horizontal subsurface flow constructed wetland so pre-treated 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: on eat the upstream end of the unit length and the other two at1/3and2/3 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.

Results showed that for conductivity and pH there is no significant variations during the stage operated with step-feeding. For DO, seasonal variations occurred with higher values during winter period, when oxygen solubility in water is higher, and lower values during the summer period. It seems that the step-feeding application did not alter dramatically the behavior of the physicochemical parameters (Stefanakis *et al*., 2011).

Zurita *et al*. (2009) investigated four commercial-valuable ornamental species (Zantedeschiaaethiopica, Strelitziareginae, Anturiumandreanum and Agapanthus africanus) in two types of subsurface wetlands (Horizontal and Vertical wetlands) for domestic wastewater treatment. Several water quality parameters were evaluated at the inlet and outlets of a pilot-scale system. The results for pollutant removal were significantly higher in the vertical subsurface- flow constructed wetlands for most pollutants. The average removals were more than 80% for BOD and COD; 50.6% for Org-N; 72.2% for NH_4^+-N, 50% for Total- P and 96.9% for TC. Nitrate (NO_3^-) and Total suspended solids (TSS) were removed in higher percentages in the horizontal subsurface-flow constructed wetlands (NO_3^-, 47.7% and TSS, 82%). Also, the study showed that it is possible to produce commercial flowers in constructed wetlands without reducing the efficiency of the treatment system.

There are several processes are effective to reduce pollutant by plants: phytoextraction, phytostabilization, transpiration, and rhizofiltration. Vegetation provides several storage and reduction mechanisms.

- Phytoextraction plant uptake of toxicants. Metals are taken up by plants, 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 soils 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 transfer 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 carbon dioxide 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 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 organisms (Sa'at, 2006).

Reed grows frequently in the West Bank and it is particularly abundant in and around streams that carry waste water. Wetlands already constructed in the West Bank have all used reed as wetland vegetation for treatment (Khalili, 2007).

2.5 Removal mechanisms of horizontal subsurface flow constructed wetlands

Different processes such as, physical, chemical and biological processes (microbial metabolic activity and plant uptake) take place in a wetland system. The Physical-chemical processes such as sedimentation, adsorption and precipitation (Sa'at, 2006).

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

Pollutant	Removal Process
Organic Material (BOD)	biological degradation, sedimentation, microbial uptake
Organic Contaminants(pesticides)	adsorption, volatilization, photolysis, biotic/abiotic degradation
Suspended solids	sedimentation, filtration
Nitrogen	sedimentation, nitrification/denitrification, microbial uptake, plant uptake, volatilization
Pathogens	natural die-off, sedimentation, filtration, adsorption
Heavy metals	sedimentation, adsorption, plant uptake

2.5.1 Biodegradable Organic Matter Removal

Microbial degradation is considered to play the main role in the removal of biodegradable organic matter. Aerobic degradation of organic material can be enhanced by plant in the constructed wetlands that supply oxygen to constructed wetland. At the same time, anaerobic degradation of organic material takes place in the bottom sediments. Both free water surface and subsurface flows wetland function as attached growth biological reactor or known as 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).

Aerobic heterotrophic bacteria in horizontal flow constructed wetlands are able to degrade soluble organic matter. Also, organic compounds containing nitrogen are degraded under aerobic and anaerobic conditions by ammonifying bacteria. Insufficient supply of oxygen will greatly reduce the performance of aerobic biological oxidation. Nitrifying bacteria also utilize oxygen to cover their physiological needs (Vymazal, 2005).

2.5.2 Suspended Solids Removal

Sedimentation and filtration are considered the most suitable method to remove solids. Suspended solids removal is not a design variable in the normal sense, though solids accumulation must be considered during system design. To remove larger sediment and avoid clogging in the wetland, it’s very important to add sedimentation ponds prior constructed wetlands (Sa'at, 2006).

2.5.3 Nutrients Removal

Considerable amounts of nutrients 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 (Vymazal, 2005).

Reduction of nitrogen and phosphorus compounds requires the long detention times. Nitrification/denitrification are the main removal mechanism for nitrogen. The Nitrosomonas bacteria oxidize ammonia to nitrite aerobically. The nitrite is then oxidized aerobically by Nitrobacter bacteria to produce nitrate. 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 constructed wetlands (Vymazal, 2005).

Nitrification which is performed by strictly aerobic bacteria is mostly restricted to areas adjacent to roots and rhizomes where oxygen leaks to the filtration media. Prevailing anoxic and anaerobic conditions offer suitable conditions for denitrification but the supply of nitrate is limited as the major portion of nitrogen in sewage is in the form of ammonia (Vymazal, 2005).

Vipat *et al.* (2008) evaluated the treatment efficiency of a field scale constructed wetland. It was constructed in an area of 700 m^2 having 0.7 m depth and lined with clay and filled with gravels (0.7 cm to 2.5 cm diameter). The constructed wetland showed a removal of NH4-N up to 78.6 and TKN 59%, organic nitrogen 67.5% where the turbidity removal efficiency ranges was (83.8 to 88.4%).

Phosphorus is stored in new constructed wetland sediments. Phosphorus removal can involve a number of processes such as adsorption, filtration, sedimentation, complexation/precipitation and assimilation/ plant uptake (Sa'at, 2006).

Phosphorus is removed primarily by lig and exchange reactions, where phosphate displaces water or hydroxyls from the surface of Fe and Al hydrous oxides. Gravel used in horizontal subsurface flow constructed wetlands does not contain great quantities of Fe, Al or Ca so that removal of phosphorus is generally low.

Aerobic conditions are more favorable for P sorption and co-precipitation. Removal of nitrogen and phosphorus through plant harvesting removes small fraction of the phosphor content (Vymazal, 2005).

2.5.4 Metals removal

The physiological reasons for heavy metal uptake in constructed wetlands depend on the plant species. In grey water and domestic wastewater heavy metals are not an issue, because their concentration is relatively low. On the otherhand, Industrial effluent could contain significant amounts of heavy metals depending on the industry type (Hoffmann and Winker, 2011).

Metals are removed in treatment wetlands by three major mechanisms (i) Binding to soil, sediments, particulates and soluble organic by cation exhange 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 constructed wetlands were attributed to precipitation-absorption phenomena. Precipitation was enhanced by wetlands 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 Reuse for irrigation

Subsurface flow constructed wetlands treat wastewater to a standard suitable for discharge to surface water or suitable for various reuse applications according to WHO guidelines. The design of the subsurface flow constructed wetlands depends on the desired effluent quality for disposal or reuse.

The most common type of reuse is irrigation, such as drip irrigation or subsurface irrigation, for lawns, green spaces or crop production. In this case, utilization of nutrients contained in wastewater rather than nutrient removal is desirable. Relevant guidelines must be followed to ensure this practice is hygienically safe for the consumers of the crops as well as for workers who can be in contact with treated wastewater. International standards for reuse and an explanation of the important multiple-barrier concept can be found in WHO (2006) (Hoffmann and Winker, 2011).

Chapter three

Material and Methods

3.1 Introduction

The research was carried out in the existing community onsite wastewater treatment plant receiving part of Bani-Zeid village waste water. The following methodology was applied to achieve the research objectives: The methods and experimental procedures used for data collection are explained below. Wetlands have been constructed by the Palestine Hydrology Group (PHG) in three different locations in the West Bank in the year 2004. The wetlands have been designed to receive primary treated. Wastewater from three villages (Iraq Burin, Shadda and Bani-Zeid). The wetlands in Iraq Burin and in Shadda are not working due to a combination of poor maintenance, lack of funds and insufficient flow. The wetland Bani-Zeid village consists of four cells. The liner consists of a thick plastic liner covered with imported sand. The rooting medium is gravel and the plant used in the wetland is the domestic common reed. Finally a cement tank with the capacity of 70 m^3 stores the water before it is used for irrigation. Currently the effluents received are not sufficient and it is causing some problems in the system. The first wetland cell is working well but due to lack of funds and bad maintenance the inflow to the wetland has not been increased. For those reasons no testing to investigate treatment efficiency has been performed so far (Khalili, 2007). Therefore, there is a need for monitoring “restore and maintain the chemical, physical, and biological integrity of the Nation’s waters. The performance of wetland in Bani-Ziad with focus on overall performance, evapotranspiration, water balance course of transformation along the bed.

3.2 Description of Bani-Zeid pilot wastewater treatment plant

General

The Bain-Zeid wastewater treatment plant consist of an integrated anaerobic constructed wetland system. The Bani-Zeid pilot plant was constructed in 2004 by the Palestinian hydrology group (PHG). The pilot plant was rehabilitated in 2010 by PHG supported by the Palestinian Water Authority. The wastewater collection system and the pilot treatment plant of Bani-Zeid village serve the two villages of Beit Reema and Deir Ghassaneh (municipality of western Bani-Zeid) within the boundaries and limits of the municipality. The lengths of the existing sewer pipes are around 4500 meters, where 100 houses could be connected to the system. So far 70 households have been connected to the system. The number of beneficiaries connected to the system is estimated to be 420 persons in addition to one school. The plant was designed to yield wastewater effluents suitable for direct discharge into the wadis, or reuse in agricultural irrigation under the full capacity of the plant. The municipality of Western Bani-Zeid is the official body responsible for the operation and maintenance of the treatment plant, the wastewater department in particular nominated a specialized technician to be responsible for the daily operation and maintenance follow up, which will guarantee the sustainability of the project.

Location of Bani-Zeid WWTP

Bani-Zeid Waste Water Treatment Plant is located in the town of Western Bani-Zeid (Beit Reema and Deir Ghassaneh) 27 km North –West from Ramallah city. Though the villages are among the first to have tap water, all sewage from the municipal area, from 70 houses just, is currently untreated. The agricultural production methods and the crop production are typical of the West Bank and the high productivity of the local farmers is well known. The existing pilot treatment facilities are located at an elevation of around 390m, 600 meters to the nearest house, and three kilometer far away from the nearest water resource.

Pilot treatment Plant and System Description

The pilot plant consists of the following main treatment units:

1-Combined UASB-Septic reactor

The anaerobic reactors system consist a combined UASB reactor followed by two septic tanks followed by two septic tanks operated. They were well plastered to avoid water leakage. A screen is also placed before the septic tank (Photo1).

The volume of the anaerobic reactors system is about 300 cubic meters (3.5*12.25*7.15) m^3, distribution as follow:

a) First basin (3.5*9*7.15) m^3 : UASB reactor.

b) Second basin (4.2*3*3.5) m^3 : septic

c) Third basin (2.2*3*3.5) m^3: septic

Photo 1. Headworks and UASB reactor of Bani-Zeid pilot

2- Wetlands

The wetlands system consists of four basins. The basins are about 1800-square meter with an area of $450m^2$ for each. The basins are lined with plastic sheets, filled with sand and gravel size between 2-10 cm, and planted with reeds (Photos 2-6). One out of four basins is planted with the roots of reeds due to the limited number of connected households at the time of operation; other three basins are to be planted in order to be sufficient for the treatment of the extra flow if more and more houses are connected.

Photo 2. Wetlands construction in 2004 (Photo by PHG 2004)

Photo 3. Reeds planted in the constructed wetland basin of Bani-Zeid pilot WWT

Photo 4. Reeds planted in the constructed wetland basin of Bani-Zeid pilot WWTP

Photo 5. Constructed wetland basin of Bani-Zeid pilot WWTP

Photo 6. Gravel in the constructed wetlands basin of Bani-Zeid pilot WWTP

1- Storage Tank

It is a cement tank with the capacity of 70 m^3 (4*5*3.5) m^3 which collects water going out of the wet land before using it for agriculture.

3.3 Research Setup

1. CW of Bani-Zeid pilot plant

This research was mainly carried out on the operated basin of Bain-Zeid CW (photos 1 and 2). The wetlands system consists of four basins. The basins are about 1800-square meter with an area of 450m^2 for each. The basins are lined with plastic sheets, filled with sand and gravel between 2-10 cm, and planted with reeds. Nine perforated pipes were placed in constructed wetland to take samples every two weeks over the study period (7months). Three pipes were placed after 1.5m from the inlet of constructed wetland, another three pipes were placed in the middle of constructed wetland after 25m from the inlet of the constructed wetland, and 3pipes were placed 1.5m from the outlet of constructed wetland.

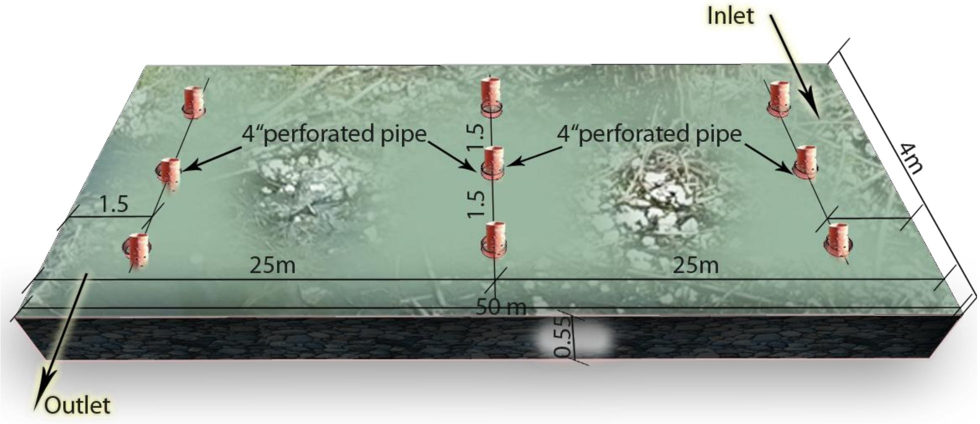

Photo 1. Perforated pipes were planted in constructed wetland

Photo 2. Perforated pipes were planted in constructed wetland

2. Mini pilot CW

1. A mini pilot of the constructed wetland has been used to calculate the quantity water lost through evapotranspiration photo (3-5). To carry out this experiment, a plastic barrel was put near a constructed wetland and fill with 45cm of gravel and 20reed have been selected randomly and planted in a barrel, then barrel was filled of the same wastewater that entering the constructed wetland, after 24hr wastewater was discharged from it to illustrate the quantity of water lost through evapotranspiration from a barrel.

Photo 3. Plastic barrel to calculate the quantity of evapotranspiration, photo date (15/January, 2016)/Qarawit Bani–Zeid village/ Palestine

Photo 4. A mini pilot of the constructed wetland plastic barrel to calculate the quantity of evapotranspiration

Photo 5. Section in the plastic barrel to measure the quantity of water lost through evapotranspiration

3.4 Research Operation

1. Composite samples were collected from all the pipes that are placed in the constructed wetland, nine perforated pipes were placed in constructed wetland to take samples every two weeks over the study period (7months). Three pipes were placed after 1.5m from the inlet of constructed wetland, another three pipes were placed in the middle of constructed wetland after 25m from the inlet of the constructed wetland, and 3pipes were placed 1.5m from the outlet of constructed wetland.

   Water samples were collected between 8 am and 11:00 am. Samples were collected over the period (November/ 2015 to June/ 2016). The collected samples were placed into plastic bottles and stored at 4 ºC. Samples were analyzed as soon as they arrived to the laboratory. Samples were analyzed for BOD, COD, TKN, NO_3^--N, TDS, TSS, pH, EC and fecal coliform,

2. Evapotranspiration in the constructed wetland was measured by two methods, the first one was by a mini pilot of constructed wetland (plastic barrel), and the second one was by calculating the evapotranspiration in the constructed wetland itself by calculating the difference between influent and effluent flows, which was considered as water lost through evapotranspiration. The water lost through evapotranspiration calculated by the two methods was identical of around 20% of the influent flow

Table 3.1. Average evapotranspiration in a pilot scale (barrel)

Date	Et_{avg}
December	15%
January	10%
February	12%
March	20%
April	25%
May	25%
June	30%
Avg	20%

Table 3.2. Average evapotranspiration in constructed wetland

Date	$Q_{in}(m^3/d)$	$Q_{out}(m^3/d)$	ET_{avg}
December	51	44	14%
January	50	46	12%
February	50	44	١٠%
March	47	39	17%
April	46	34	26%
May	59	44	25%
June	60	41	32%
	Avg.		19.70%

3.5 Analytical Methods and Equipment

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

3.6 Measurement of physical parameters (EC, DO and pH)

The electrical conductivity and temperature for influent and effluent water was measured with conductivity meter. During the measurement the probe of the meter was inserted in the pipes which are placed in the constructed wetland (that presented above), and the reading was recorded in the site.

The dissolved oxygen was measured with the specific HACK HQ10 oxygen meter, the reading was recorded in the site. The measurement of pH was carried out by using Metrohm-691 pH meter which was calibrated prior to the measurement. The meter probe was immersed in the pipes that are placed in the constructed wet land (that presented above). The stable final reading was then taken, and recorded in the site.

3.6.1 Chemical parameters

Biological Oxygen Demand, Chemical Oxygen Demand, Ammonia, Nitrate, Phosphate were measured according to Standard methods (APHA, 2005).

3.6.2 Ammonia (NH_4^+-N)

The measurements of ammonia were carried out by using Nesslerization 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. Also, calibration curves were prepared for other parameters such as COD and PO_4^{3-}.

3.6.3 Nitrate (NO_3^-- N)

Measurements of Nitrate were carried out by using Capillary Ion Analyzer (CIA) method. The method used to measure the concentration of other parameters are listed in Table 3.1

Table 3.3. Methods used and water quality parameters measured for the wetland 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)
PO_4^{3-}	Ascorbic acid method	Automated ascorbic acid reduction
TDS	Total dissolved solid dried at 105˚C (Gravimetric method)	Filtration Apparatus
Conductivity	Laboratory method pH-meter 3320, Jenway	Conductivity meter, 4320, Jenway
DO	Membrane electrode method	DO meter/ Fluroprobe (FL-3-H)Luminefcent oxygen analyzer
pH	Electrometric method	pH-meter 3320, Jenway
Fecal coliform	9222-B, 9221-E	
COD, BOD_5		Hach COD reactor DO meter – Oxi 197

3.6.4 Biological parameters

Fecal coliform was analyzed according to 9221-E methods (APHA, 2005).

Chapter four

Results and Discussion

4.1 General

The interpretation of the CWs results are presented in the following sections. The presented average data value are calculated over a 7-month period from (November/ 2015 to June/ 2016), and the standard deviation are presented between parenthesis. The main physical, chemical and biological results for these samples are presented in the following sections.

4.2 Wastewater treatment

4.2.1 Physical parameters

For pH values, no significant variations occurred along the wetland zone. The mean pH value increased slightly between influent and effluent, observed along the zones during all periods. The average pH values in the influent was 6.4 in the cold period and 6.1 in the hot period, at the mid zone in the constructed wetland was 6.6 in the cold period and 6.5 in the hot period and, the effluent was 6.5 in the cold period and 6.3 mg/L in the hot period.

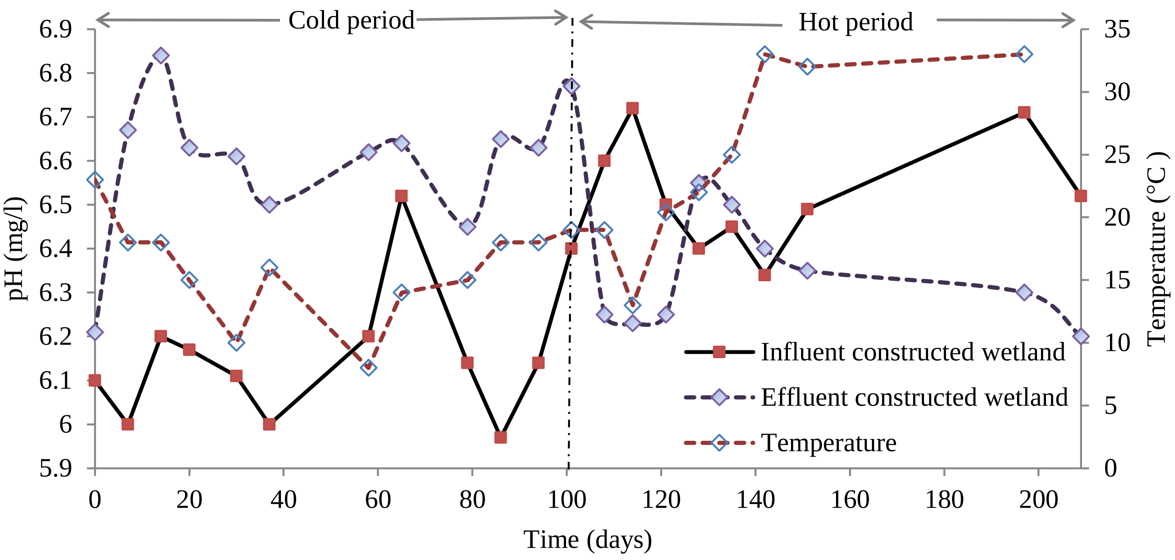

Fig. 4.1. Influent and effluent pH concentration and temperature variation in constructed wetland treating anaerobically waste water in Qarawit Bani-Zeid Village, Ramallah/ Palestine

4.2.1.1 Dissolved Oxygen

Average influent of DO was 0.37 mg/L in the cold period, and 0.34 mg/L in the hot period, and average effluent of DO was 0.43mg/L in the cold period and 0.37 mg/L in the hot period. Dissolved oxygen concentration was low during the hot period, thus indicate oxygen consumption by pollutants.

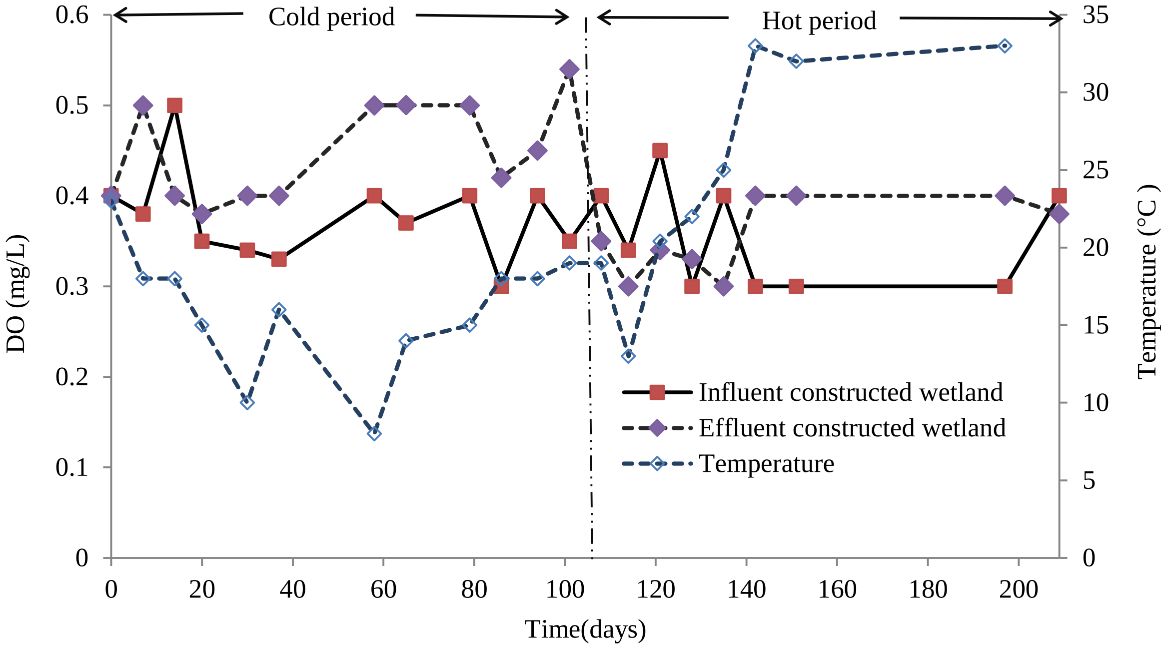

Fig. 4.2. Influent and effluent DO concentrations and temperature variation in a constructed wetland treating anaerobically pretreated wastewater in Qarawit Bani-Zeid village, Ramallah/ Palestine

4.3 Chemical Parameters

Chemical parameters for the wetland are presented in Table 4.1.

Table 4.1. Average influent, effluent concentrations and removal percent of wastewater at cold period and hot period during the project period (3/Dec/2015-29/June/2016)

Param.	Source of water	Cold period		Hot period		Over all	
		Avg.	Range	Avg.	Range	Avg.	Range
BOD	Influent	28 (3.5)	20-35	30 (13)	22-50	25.8 (3.7)	20-50
	Effluent	16.5 (1.29)	13-20	17 (2.6)	14-22	16.7 (16.9)	13-22
	Removal	48.45 (9.80		44.6 (8.9)		46.3 (8.2)	
COD	Influent	65.75 (5.7)	44-79	66.66 (6.8)	59-80	66.14 (5.6)	44-80
	Effluent	44 (16.06)	13-20	41 (8.5)	15-22	43 (1.4)	13-22
	Removal	42.2 (20.5)		53.5 (5.04)		47.04 (16.04)	
TKN	Influent	169.8 (15)	144-202	177.7 (9.7)	163-188	173 (16)	144-202
	Effluent	157.01 (4.8)	110-174.3	153.4 (7.3)	145-162	154 (14)	110-174.3
	Removal	20.09 (9.5)		36.7 (6.17)		27 (16)	
NO_3^--N	Influent	BDL	-	BDL	-	BDL	-
	Effluent	BDL	-	BDL	-	BDL	-
	Removal	BDL	-	BDL	-	BDL	-
PO_4^{3-}-P	Influent	22.11 (4.4)	15-38	25 (1.7)	22.5-28	24(3.7)	14.6-38.1
	Effluent	20 (4.2)	15-27	23 (2)	25-27	21.4(3.5)	14.5-27
	Removal	21 (5.8)		32 (3.35)		25.8(7.3)	
SO_4^{2-}	Influent	119 (6.3)	88-150	167 (18.9)	140-187	139.5 (22)	88-187
	Effluent	85.95 (6.3)	70.98-91.24	90.15 (3.4)	70.14-96	89 (7)	70.14-96
	Removal	35.4 (12.3)		59 (6.03)		46 (15)	
pH	Influent	6.4 (0.16)	6.14 -6.72	6.55 (0.056)	6.1-6.2	6.3 (0.23)	6.1 - 6.72
	Effluent	6.1 (0.012)	6.21-6.84	6.3 (0.08)	6.2-6.55	6.5 (0.19)	6.2-6.84
	Removal	11.22 (4.6)		22.1 (6.2)		15.8 (7.5)	
TDS	Influent	781(97)	640-966	1204 (278)	788-1555	959 (199)	640-1555
	Effluent	833 (84)	735-940	1344 (375)	722-1985	1052 (172)	722-1985
	Removal	19.7 (0.93)		-323 (314)		11 (11)	
TSS	Influent	154 (75)	95.2-264	146 (9.8)	120-150	150(51)	95.2-264
	Effluent	50 (6)	44-63	74 (4.4)	71-79	62.6(19)	44-79
	Removal	68 (11)		56 (2.5)		65(9.9)	
EC	Influent	1660.8 (280)	1228-1965	2381.7 (181)	1770-2525	1970 (3820	1228-2525
	Effluent	1550 (187)	1288-1905	2263 (252.7)	1670-2522	1856 (305)	1288-1905
	Removal	18.7 (11.8)		28.9 (2.7)		23 (10)	
FC	Influent	7.8 *10E+05	5.4E+03 - 9E+06	4.8 *10E+06	3E+06 - 8.5E06	2.1*10E+06	5.4E+03 - 9E+06
	Effluent	3056.3	0-1360	1772	1023-29875	2628	0-29875
	Removal	99.8	-	98.7	-	98.8 (1.5)	-

*The influent and effluent of the constructed wetlands were analyzed for TKN, NO_3^-, PO_4^{3-}, COD, DO and pH from 3/Dec/2015 to 29/June/2016.

*Standard deviation values are presented between brackets.

* All units are in mg/L, except FC in CFU/100mL.

*Average of 25 samples during the period from 3/Dec/2015 to 29/June/2016.

4.3.1 Biochemical Oxygen Demand (BOD)

As presented in Table 4.1, the average influent BOD value was 28 mg/L in the cold period and 30 mg/L in the hot period. At the mid zone of the constructed wetland, average BOD value in the cold period was 24.5 mg/L and 21.7 mg/L in the hot period. Average effluent BOD value in the cold period was 16.5 mg/Land 17 mg/L in the hot period. The obtained average BOD removal efficiency in this experiment of 46.3%, is lower than that reported by Zurita *et al*. (2009) who found a 78.2% BOD removal for a HSSFCW planted with one species (*Zantedeschia aethiopica*) treating domestic wastewater and a higher removal of 81.5% for the same system planted with three different species. BOD removal efficiency for a HSSFCW fed with grey water was in the range of (72-79) % as found by Niyonizima (2007). BOD removal efficiency of 85.4% was achieved in HSSFCW filled with gravel (Ghrabi *et al*., 2011). In addition, BOD removal rate of 65.7% was reported by Vipat *et al*. (2008).

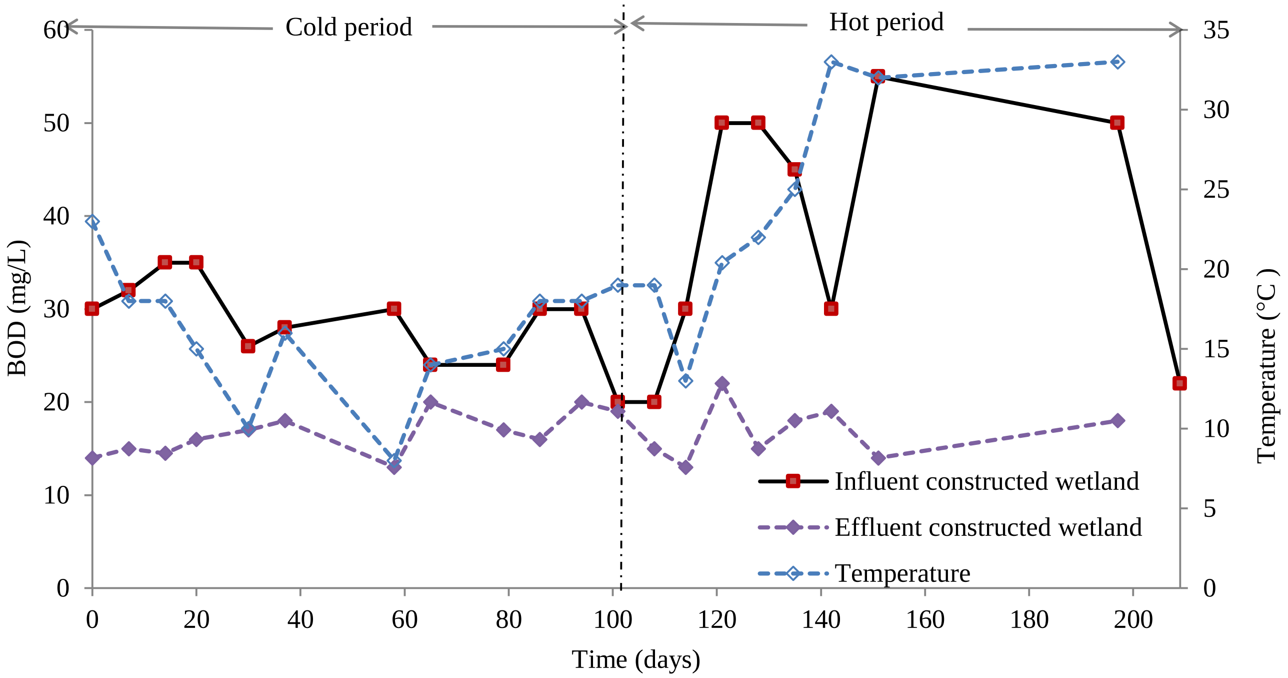

Fig. 4.3. Influent and effluent BOD concentrations and temperature variation in a constructed wetland treating anaerobically pretreated wastewater in Qarawat Bani-Zeid village, Ramallah/ Palestine

Depending on the above results, the rate constant (KBOD) for influent wastewaters was calculated (Table 4.2). Average calculated KBOD equaled to0.386m/d in the cold period, 0.351 m/d in the hot period, and 0.374 m/d in the overall period. The KBOD values reported in literature. Vymazal (2005) reported an average KBOD value of 0.118 m/d for 66 village systems after 2 year of CW operation. The KBOD value is a key design variable.

Table 4.2. Calculated rate constant (KBOD) for the investigated wastewaters

Investigated wastewater	Cold period	Hot period	Over all
KBOD (m/d)	0.3386	0.351	0.374

These values were calculated depending on measured concentration influent and effluent BOD using the following equation:

$KBOD = Qd (\ln C_{in} — \ln C_{out})/Ah$

Where:

Ah: surface area of constructed wetland

C_{in} is influent BOD concentration

C_{out} is effluent BOD concentration.

4.3.2 Chemical Oxygen Demand (COD)

The achieved COD removal efficiency was 47%. The COD removal rates reported in the literature for horizontal flow wetlands such as 42.7% (Ghrabi *et al*., 2011), 71.8% (Avsar *et al*., 2007) and 72-79% for a wetland treating grey water (Niyonizima, 2007), 93.6% for a wetland treating dairy and agricultural wastewater (Pucci *et al*., 1998), 77.8% for a wetland treating domestic wastewater (Vipat *et al*., 2008), 76% (Zurita *et al*., 2009) and 90-94% removal rate in up flow constructed wetlands (Ong *et al*., 2010). At the aeration points COD concentration dropped drastically, where the aerobic conditions facilitated the growth of aerobic microbes and boosted the degradation of organic matters (Ong *et al*., 2010). The average influent COD value in the cold and hot periods respectively 65.7 mg/L, 66.6 mg/L. The average effluent COD value was 59 mg/L in the cold period and 65 mg/L in the hot period. BOD and COD associated with suspended solids in wastewater are removed by sedimentation while that in colloidal and soluble form are removed through metabolic activities of microorganisms and physical and chemical interactions with the root zone/substrate (Vipat *et al*., 2008).

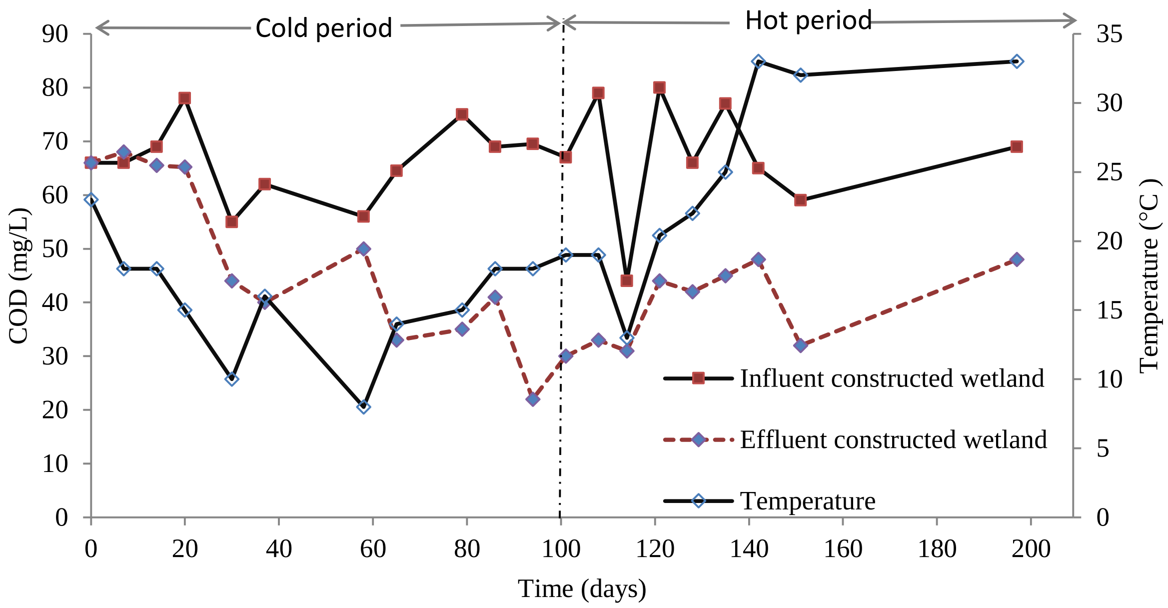

Fig. 4.4. Influent and effluent COD concentrations and temperature variation in the constructed wetland treating anaerobically pretreated wastewater in Qarawat Bani-Zeid village, Ramallah/ Palestine

4.4 Removal of Nitrogen

4.4.1 Total kjeldahl Nitrogen (TKN)

High concentrations in TKN were detected in the influent throughout the experimental period; the average influent concentration was 169.8, 177.7 mg/L at the cold period and hot period respectively. Average effluent concentration was 157 and 153 mg/L at cold and hot period respectively. The removal efficiencies was 27%. Nitrogen removal was not only due to ammonia removal but also due to organic nitrogen removal. Plandom *et al*. (2006) concluded that TKN removal was very high in HSSFCW when a low organic load is used. A removal rate of 8.9%wasrecorded by Vipet *et al*. (2008).

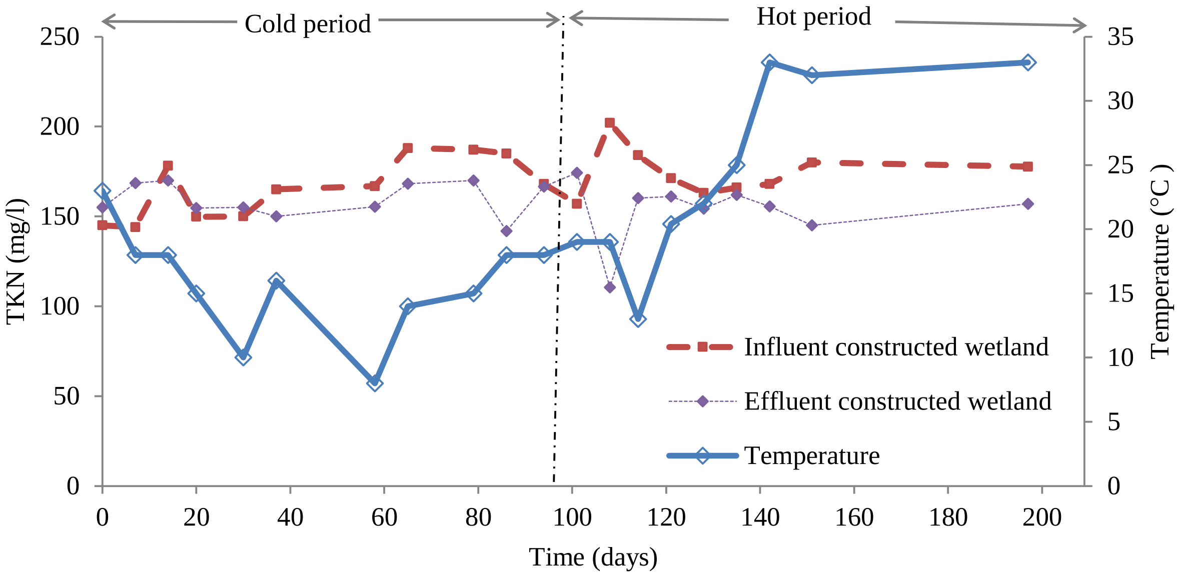

Fig. 4.5. Influent and effluent TKN concentrations and temperature variation in a constructed wetland treating anaerobically pretreated waste water in Qarawat Bani-Zeid village, Ramallah/ Palestine

Table 4.3. Average influent and effluent concentrations (with standard deviation) in mg/L of NO_3^--N and PO_4^{3-}-P over the project period (3/December/2015-29/June/2016)

Parameter	Influent	effluent
NO_3^--N	BDL	BDL
PO_4^{3-}-P	(2.4)	(1.1)

*All units are in mg/L

4.4.2 Nitrate Nitrogen (NO_3^--N)

NO_3^--N results are presented in Table 4.3, Influent NO_3^--N concentration was below detected limit and it still below Detected limit at mid zone and to the effluent nitrate concentration.

4.5 Phosphate (PO_4^{3-}-P)

Average influent phosphorus concentrations were 22.11, 25.3 mg/L in the cold and hot period respectively. At mid zone in the constructed wetland average phosphorus concentration were 21, 24.3 mg/L in the cold and hot period respectively. Average effluents phosphorus concentrations were 20.25, 23 mg/L in the cold and hot period respectively. A PO_4^{3-}-P removal was 26% during project period, Vymazal (2009) reported that the phosphorous removal was stable and it's low in horizontal subsurface flow constructed wetlands. The results obtained in this study for phosphorous removal was 26%, lower than value that is obtained by Mantovi *et al*. (2003) who recorded a 60% removal, there is some previous study illustrate efficiency removal of PO_4^{3-}-P, as (Chung *et al*., 2008) was recorded removal of it 72%, and 89% removal reported by (Sarafraz, 2009).

Several factors contribute to phosphorous removal, including vegetation, fauna, microorganisms, and substrate, The main removal mechanism of phosphorous is adsorption to the substrate (Yang *et al.*, 2001), most wetland studies have shown that the soil compartment is the major long-term phosphorous storage pool (Chung *et al*., 2008), adsorption and saturation of phosphorus at long term, so removal of phosphorous was decreased (Vymazal 2011).

The most important removal mechanisms of phosphorous are precipitation and physicochemical sorption process, and it doesn't influence for temperature variation (Pucci *et al*., 2000; Yang *et al*., 2001).

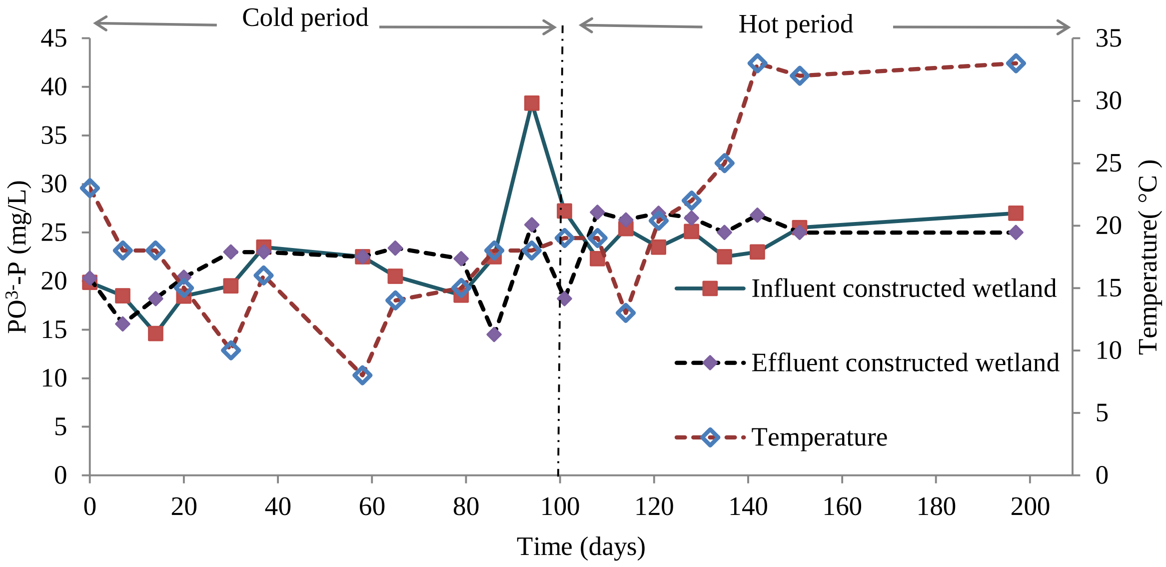

Fig. 4.6. Influent and effluent PO_4^{3-} concentrations and temperature variation in a constructed wetland treating anaerobically pretreated waste water in Qarawit Bani-Zeid village, Ramallah/ Palestine

4.6 Removal of Sulphate (SO_4^{2-})

Average influent concentrations of sulphate (SO_4^{2-}) were 119, 166.5 mg/L in the cold and hot period respectively, average effluent of (SO_4^{2-}) concentrations were 86, 90.15 mg/L, in the cold and hot period, respectively. At the aerobic conditions removal of (SO_4^{2-}) is low in constructed wetland (Abed *et al*., 2016).

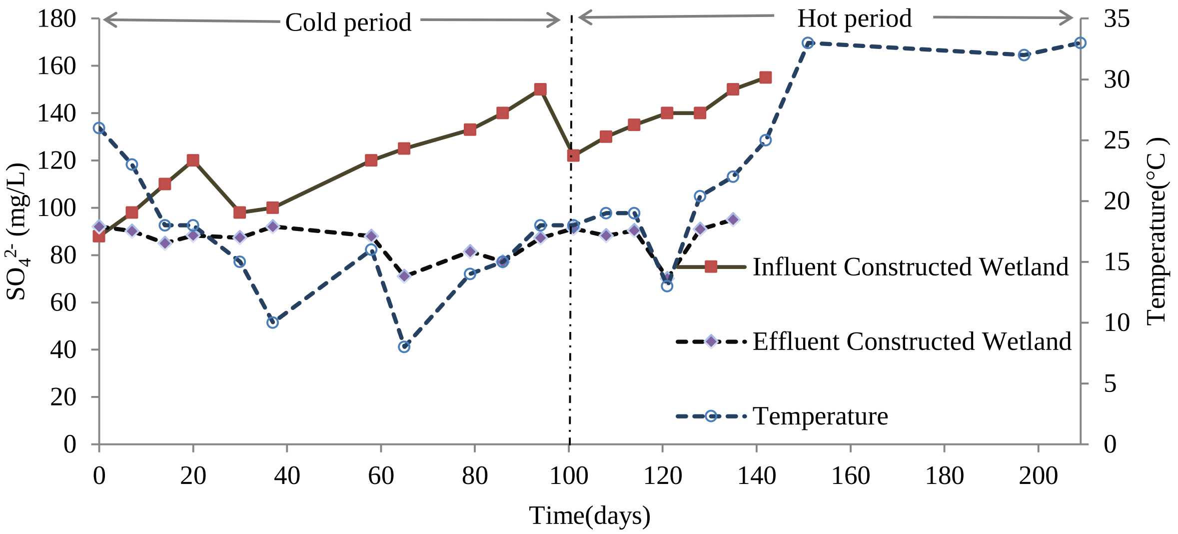

Fig. 4.7. Influent and effluent SO_4^{2-}concentrations and temperature variation in a constructed wetland treating anaerobically pretreated wastewater in Qarawat Bani-Zeid village, Ramallah/ Palestine

4.7 Total Suspended Solids (TSS)

The removal efficiency of total suspended solid in CWs was 69%. Zurita *et al.* (2009) was reported, HSSFCW that is planted with one species and fed with domestic wastewater, achieved high removal TSS, the most important ways to remove total suspended solid is the physical processes such as sedimentation and filtration followed by aerobic or anaerobic microbial degradation in the substrate. TSS that is removed by wetlands due to the filtering action of the bed media. Filtration occurs by impaction of particles onto the sedimentation and filtration followed by aerobic or anaerobic microbial degradation in the substrate. TSS that is removed by wetlands due to the filtering action of the bed media. Filtration occurs by impaction of particles onto the roots and stems of the *phragmites* or onto the gravel particles in the constructed wetland systems (Zurita *et al.*, 2009) the roots and stems of the *phragmites* or onto the gravel particles in the constructed wetland systems (Zurita *et al.*, 2009).

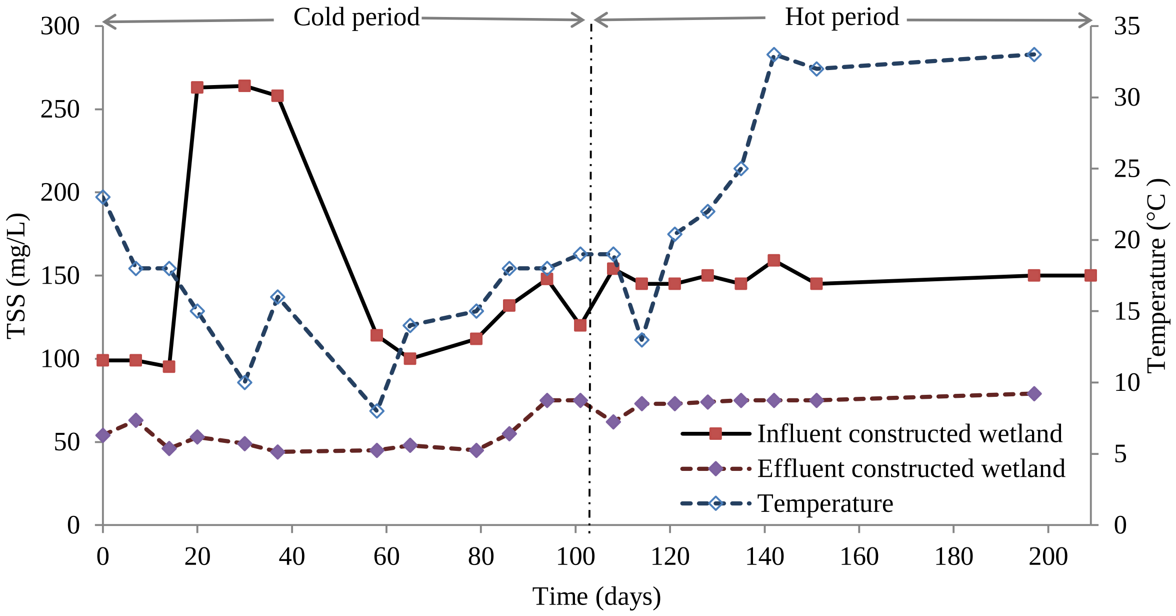

Fig. 4.8. Influent and effluent total suspended solid concentrations and temperature variation in a constructed wetland treating anaerobically pretreated waste water in Qarawat Bani-Zeid village, Ramallah/ Palestine

4.8 Total Dissolved Solids (TDS)

As its clear from the result, during the project period, influent TDS concentrations and EC were increased due to the evapotranspiration. Total dissolved solids (TDS) were increased due to mineralization process. The plants degrade and produce TDS at the same time.

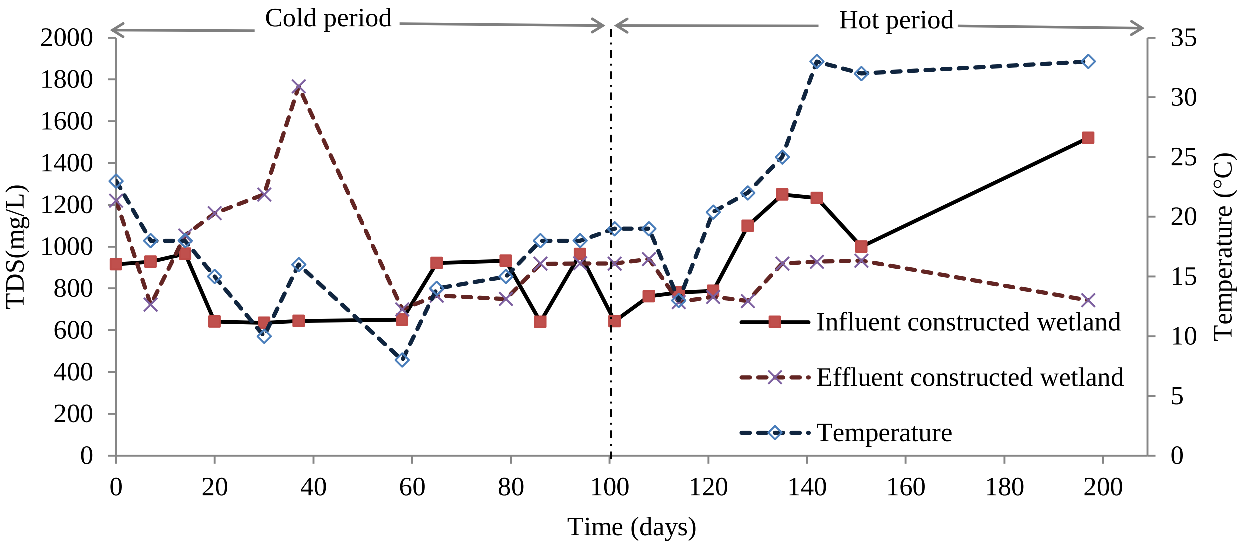

Fig. 4.9. Influent and effluent total dissolve solid concentrations and temperature variation in a constructed wetland treating anaerobically pretreated wastewater in Qarawit Bani-Zeid Village, Ramallah/ Palestine

4.9 Biological Parameter

Influent and effluent fecal coliform concentrations are presented in Table 4.4.These results are indicate to other studies that is recorded by other researchers, e.g., 99.7% by Pucci *et al*. (2000), 99% by Mantovi *et al*. (2003), 72-79% by Niyonizima (2007), and 98.7% by Vipat *et al*. (2008). Also Avsar *et al*. (2007) reported 92.9% removal.

Table 4.4. Average fecal coliform concentrations for the influent and effluent in (cfu/100ml) of the constructed wetland during the period (3/December/2015-29/ June/2016)

Influent	CFU/100ml	8.00E+06
Effluent	CFU/100ml	72000
Removal	%	98.8(1.5)

4.10 Discussion

The findings of this research clearly indicate the high potential of CWs for enhancing the quality of anaerobically pre- treated effluents in the semi-arid Palestine. The CW was inefficient in terms of total nitrogen removal due to high effluent concentration of TKN although nitrate (NO_3^-) concentration below detected level, so it did not a chive the Palestinian requirements for using treated effluent for recharge the aquifers (Table 4.5). Treatment in the CW has shown tolerance to different influent concentration of pollutants. This is in line with the findings of several authors (Mantovi *et al*., 2003; Mayo and Bigambo, 2005; Landry *et al*., 2009).

Higher removal efficiencies for COD that obtain in the result, similar result were found for BOD. In TKN removal, constructed wetlands did not give the best result. The TSS did not achieve the Palestinian standards. The calculated specific removal rate of phosphate, nitrogen, and BOD of the reed planted CWS fed with Qarawat Bani-Zeid village were (25.68, 261, 63.450 Kg/ha/year), respectively. The specific removal rate for small-scale, microcosms constructed wetland were (e.g. 1.471, 15.329, 5.980 Kg/ha/year) (Abed *et al*., 2016).

Based on water mass balance, it was found that approximately 20% of the influent water was lots as result of evapotranspiration. Glenn *et al*. (2013) reported over an annual cycle that 54% of inflows had supported evapotranspiration, and 10% in winter in an anthropogenic coastal desert wetland. This indicates that the actual effluent quality is even better than measured. Accordingly, the installation of CW in semi- arid region like Palestine will surely help in protection of the scarce water resources, especially the precious groundwater.

The application of CWs as a natural treatment will indeed reduce the technical requirement of sophisticated mechanical treatment methods. CWs in Palestine would increase the amount of green space in the arid landscape, which contribute to habitats and ecosystems for many animals and birds, the disappearances of many indigenous birds are a national concern.

Table 4.5. Wastewater characteristic for constructed wetlands effluents and specifications for treated water for reuse

Parameter	Constructed wetland effluents (This study)			Wastewater characteristics for reuse (PSI, 2003)			
	Cold period	Hot period	Over all	Class A	Class B	Class C	Class D
BOD	16.5	17	16.7	20	20	40	60
COD	44	41	43	50	50	100	150
NO_3^--N	-	-	-	20	20	30	40
TKN	157	153.4	154	30	30	45	60
TSS	50	74	62	30	30	50	90
FC	30563	1772	2628	200	1000	1000	1000

Chapter five

Conclusions and recommendations

5.1 Conclusions

The following conclusions can be drawn for the performance of CW polishing anaerobically pre-treated sewage:

1- The oxygenation capacity of the system is not adequate to rise DO as it was close to zero, and as such nitrification did not take place since nitrates were always BDL and TKN removal was negligible.

2- The system was efficient for organic matter (BOD, COD) removed as.

3- The system was efficient for sulphate removed since 35.4% were removed during cold period and 59% during hot period.

4- The system was efficient in removed TSS as it achieved a removal efficiency of 65%.

5- The water lost through evapotranspiration calculated by the two used methods was identical of around 20% of the influent flow.

6- The system was efficient for fecal coliform removed as removed of 98.8% was achieved.

5.2 Recommendations

Further research is recommended to investigate the benefits of aerating the anaerobic effluent before the CW.

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Annexes A

Table A 1. Calculated rate constant (KBOD) for the water influents

Date	#of days	BOD_{in} (mg/L)	BOD_{out} (mg/L)	KBOD (m/d)
03/12/15	0	30	14	0.402409947
10/12/15	7	32	15	0.560081271
17/12/15	14	35	14.5	0.558327947
23/12/15	20	26	16	0.307617752
02/01/16	30	28	17	0.316160803
09/01/16	37	30	18	0.377602301
30/01/16	58	24	13	0.388462994
06/02/16	65	24	20	0.134772095
20/02/16	79	30	17	0.359874686
27/02/16	86	30	16	0.464667521
06/03/16	94	20	20	0
13/03/16	101	20	19	0.034469094
20/03/16	108	30	15	0.512374396
26/03/16	114	50	13	0.987854009
Average KBOD (Cold Period)				0.3386048201
02/04/16	121	45	22	0.528986331
09/04/16	128	30	15	0.439178054
16/04/16	135	55	18	0.70770676
23/04/16	142	22	19	0.077406634
02/05/16	151	22	14	0.334107403
17/06/16	197	24	20	0.134772095
29/06/16	209	25	16	0.23563959
Average KBOD (Hot Period)				0.351113838
Average KBOD (Over All)				0.374932722

Annex B: Calculations

These values were calculated depending on measured concentration influent and effluent BOD using the following equation:

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

Where:

Ah: surface area of constructed wetland

C_{in} is influent BOD concentration

C_{out} is effluent BOD concentration.