An-Najah National University

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Performance Assessment of Hybrid Constructed Wetlands for Wastewater Treatment in The West Bank

By

Raed Alary

Supervisors

Dr. Abdel Fattah R. Hasan

Dr. Abdallah Alimari

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This thesis was defended successfully on 15 / 5 / 2019 and approved by:

Defense committee Members	**Signature**
– **Dr. Abdel-Fattah Hasan/Supervisor**	**…..…………….**
– **Dr. Abdallah Alimari / co-Supervisor**	**…………………**
– **Dr. Zaher Barghouthi /External Examiner**	**…………………**
– **Dr. Heba Al-Fares /Internal Examiner**	**…………………**

Dedication

"To my Family"

To every teacher taught me and contributed in building my skills over my educational life.

Acknowledgement

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الإقرار

أنا الموقع أدناه، مقدم الرسالة التي تحمل العنوان:

Performance Assessment of Hybrid Constructed Wetlands for Wastewater Treatment in The West Bank

أقرّ بأنّ ما اشتملت عليه هذه الرّسالة إنما هي نتاج جهدي الخاصّ، باستثناء ما تمت الإشارة إليه حيثما ورد، وأن هذه الرسالة كاملة، أو أي جزء منها لم يقدم من قبل لنيل أي درجة علمية أو بحث علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's name:	**اسم الطالب:**
Signature:	**التوقيع:**
Date:	**التاريخ:**

List of Abbreviations and Symbols

ARIJ	Applied Research Institute – Jerusalem
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CWs	Constructed Wetland Plants
DO	Dissolved Oxygen
EC	Electrical Conductivity
E. coli	Escherichia coli
EPA	Environmental Protection Agency
FWS	Free Water Surface
HF	Horizontal Flow Wetland
KA	Pollutant Degradation Rate Constant based on area
MCM	Million Cubic Meters
MRR	Mass Removal Rate of Pollutant
MoA	Ministry of Agriculture
NARC	National Agricultural Research Center
PHG	Palestinian Hydrology Group
PWA	Palestinian Water Authority
PSI	Palestinian Standards Institute
(PSI 34-12)	Palestinian Obligatory Technical Specifications for Reuse Treated Wastewater in Agriculture
SSF	Subsurface Flow
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
TP	Total Phosphorus
TN	Total Nitrogen
WWTP	Wastewater Treatment Plant
WHO	World Health Organization
VF	Vertical Flow Wetland
UN	United Nations

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Abstract

The Constructed wetlands (CWs) are considered inexpensive and common used technology for treating wastewater worldwide. This research focuses on evaluating the performance efficiency of four selected constructed wetlands in Sarra, Hajjah, Misillya, and BietHasan villages. The wastewater samples had been collected from the studied plants between 10:00 am and 13:00 pm overtime (October/ 2018 to February/2019). The samples had been taken three times over the period. The collected samples had been analyzed for EC, pH, BOD_5, COD, T. Phosphorus, T. Nitrogen, TDS, TSS, E. coli, T. coliform. Dissolved Oxygen and temperature of the wastewater had been recorded in the site at the same time of the samples collection. The overall removal efficiency in terms of the organic pollutants removal (BOD_5, COD, TSS) was higher performance in Sarra treatment plant then Misillya treatment plant, and Hajjah treatment plant, respectively. However, BeitHasan treatment plant achieved lower performance. Although Sarra and Hajjah wetland plants in terms of removing the organic pollutants (BOD_5, COD, TSS) showed overall good performance and achieved above 90%; the effluent characteristics of (BOD_5, COD, TSS) from both of them failed to meet good quality grade (met with Grade C-D) compared with the Palestinian obligatory technical specifications (PSI 34-2012). The reduction

of the organic pollutants (BOD_5, COD, TSS) from effluent of BietHassan plant failed to meet with the (PSI 34-2012). Furthermore, the effluent characteristics of Misillya plant failed to meet with the (PSI 34-2012) in terms of the BOD_5, but COD, TSS met with Grade D (low quality) of (PSI 34-2012).

In terms of the treatment stages of Sarra and Hajjah plants; VF CW beds achieved higher performance compared to the other treatment stages, while in Misillya plant recirculation stage achieved higher performance. The poor performance efficiency of Misillya CW beds may be due to uncompleted maturity of the beds which mean it's still not reached the steady-state. The analysis of data showed promotion in the performance efficiency of Sarra, Hajjah, BietHasan wetland plants is necessary could be achieved by maintenance of the reed beds to avoid clogging and management of the dominant plant (reed common) by harvesting and replanting of plants, as well as the removal of the undesirable vegetation.

Chapter One

Introduction

1.1 Background

Water is considered the core of the sustainable development, it's closely linked to the development and the well- being of all societies in the world. At the same time, this development also places environmental challenges of managing the water resources for different purposes. The Water scarcity and the growing world's population which parallel with the increasing not only in the demand of the fresh water but also in the wastewater discharge, the increase in the world population and the weakness to access to the safe water resource in the world are alarming, at the present more than 2 billion of the world’s population lack access to the healthy drinking water and more than the double of that number lack access to the safe sanitation which couple with the increased global demand for water at annual rate of about 1% as function of the population growth and other factors (UN report, 2018). Thus that situation has generated increased worldwide concerns taking into account the need to manage the water resources for agriculture and other uses (UN report, 2018).

The uncontrolled discharge of the wastewater to the environment is considered one of the most serious threats to the sustainability of the environment. Therefore, the treatment and the safe discharge of the wastewater is essential to preserve the environment (Jhansi *et al*.,2013). The high cost of the conventional water treatment facilities whether in construction and management, the high energy, the labor costs worldwide and the need for expertise are the main reasons for the environmentalists to look for alternatives and unconventional methods for water pollution control (Mohamed and Ali, 2014).

According to the World Bank, “The greatest challenge in the water and sanitation sector over the next two decades will be the implementation of a low cost sewage treatment which will at the same time permit selective reuse of the treated effluents for agricultural and industrial purposes” (Jhansi *et al*., 2013). Considering the current expansion of the set up conventional wastewater treatment plants in Palestine which impose high cost for construction and operation with the rabid increased population growth, arise a necessary demand for alternative simple and a low-cost technology of wastewater treatment with ensuring the environmental soundness, this proposed technology will be a construction of “artificial wetlands,” which use the physical, chemical, and biological processes in natural treatment functions, these particular built wetlands are also referred to as the constructed wetlands.

In Palestine the experience of using low-cost natural treatments such as the full-scale hybrid CW for the wastewater treatment is still recent, most of the constructed wetland reported performance data are results obtained from either home-scale or pilot-scale constructed wetland systems (CWs) connected to an existing treatment plants, as well as there are also some failed experiences applied on the small- scale plants mainly due to the bad design or the inaccurate realizations. Thus, there is lack in the performance data in terms of the centralized or the full- scale hybrid CW plants.

1.2 The Purpose and Objectives of the Research

The aim of the research study was to assess the hybrid constructed wetlands efficiency in treating the domestic wastewater in the Palestinian rural communities, where there is enough space to locate this type of treatment plant in the rural communities. The research sought to measure the ability of the target CWs in reducing the pollutants via wastewater treatment stages to meet with the Palestinian obligatory technical Specifications for reusing the treated wastewater (PSI 34-2012). This research provided insight on a long-term performance of selected CWs systems by focusing on three sites of small communities; Sarra, Hajjah, BeitHasan villages which have hybrid constructed wetlands operated in 2012. In addition to Misillya village which has a French vertical CW operated system since three months ago of conducting the research.

1.2.1 The Specific Objectives of the Study

- Assessment of the overall removal efficiency of the selected CWs in terms of BOD_5, COD, TN, TP, TDS, TSS.
- An assessment of the efficiency at different treatment stages for the selected CW plants.

1.3 The Research Hypothesis

The hypothesis for this study is that the currently studied CWs in the selected rural Palestinian communities work with high efficiency which meets with the Palestinian obligatory technical Specifications (PSI 34-2012) for reusing the treated wastewater in agriculture.

1.4 The Research Question

Is the performance of the full-scale constructed wetland systems provide treated wastewater which is complying with the Palestinian obligatory technical Specifications for reusing treated wastewater in agriculture?

1.5 Research Structure

The first chapter is the introduction of this thesis, and discuss the water situation and the wastewater treatment in the world, and the need for this study in Palestine, as well as, the research hypothesis and the main objectives. Followed in second chapter with a literature review present the current water supply and the wastewater situation in Palestine, as well as, the reclaimed wastewater reuse and the constructed wetlands in Palestine and discussing the international guidelines and standards for reusing the treated wastewater. The last section of this chapter deal with the constructed wetland systems for wastewater treatment. The third Chapter explain the followed methodology in conducting the research and characterizing the studied sites. The four chapter present the results and the data analysis including an interpretation of the results. The Chapter five deal with the conclusions and the recommendations of the research.

Chapter Two

Literature Review

2.1 General Situation

2.1.1 The Current Water Supply Situation in Palestine

Palestine is considered one of the scarcest water availability in the world. This is due to both natural and man-made causes. The water shortage is expected to become a greater problem as a result of the population growth, high standards of living, the growing challenges of the climate change, and the political situations which imposed threats on both the water resources management and the Sustainable development (ARIJ, 2015). The West Bank and Gaza strip have a significant growing shortfalls in the available water supply for the domestic use with growing population at an average annual rate of 2.8 percent coupled with the weakness of accessing to the safe water resource especially in Gaza strip (World Bank, 2018). The World Health Organization (WHO) sets100 liters per capita per day as the benchmark minimum for the domestic consumption to achieve full health and hygiene benefits (World Bank, 2018). The total amount of the water consumption in the West Bank and Gaza Strip is only 62 and 89 liters per capita per day (World Bank, 2018). Therefore, the domestic water consumption in the West Bank is considered as one of the lowest water consumption rates in the world (PWA, 2016). According to the PWA, the available water for different purposes in the West Bank in 2015 was estimated of about 188 MCM/year;

37% for domestic water consumption and 37% consumed in agriculture. On the other hand, the available water in Gaza strip in 2015 was estimated of 177.5 MCM/year; 53% for domestic water consumption and 47% for agriculture (PWA, 2018). The population growth rate in the West Bank and Gaza Strip is 2.6% and 3.5% respectively (PCBS, 2013). Thus, the population is expected to be double by 2050 resulting in sharp water shortages, and this required measures to cover the gap between the water supply and the water demand (Mizyed, 2018).

2.1.2 The Current Wastewater Situation in Palestine

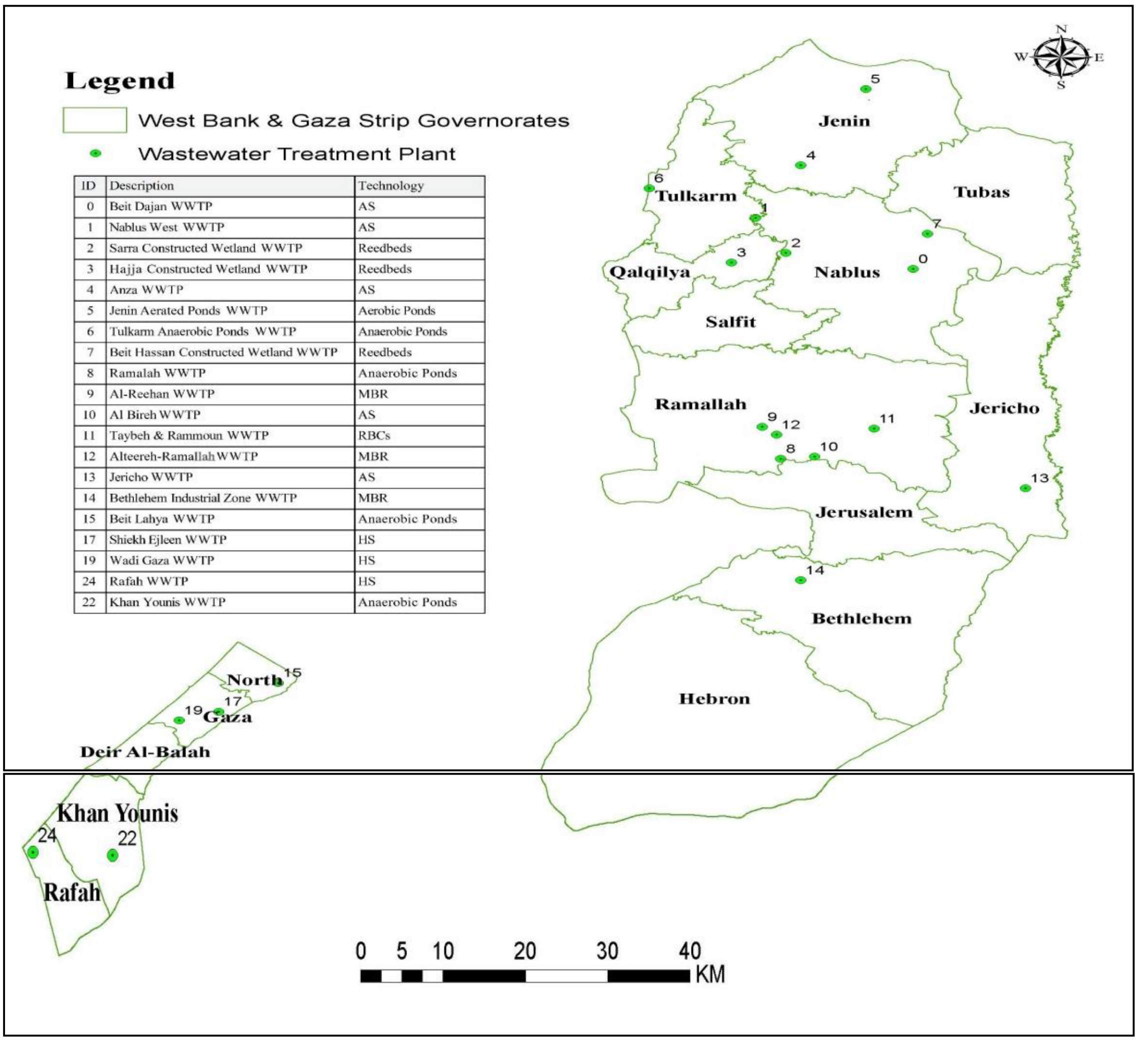
The environmental sound management for the wastewater requires appropriate methods of collection, treating the wastewater, disposal or reuse of the treated wastewater. The current management practices for the wastewater sector in Palestine imposes a real environmental and health threats to the Palestinians which are mostly limited to the collection of the wastewater by sewage networks and the cesspits. According to the PWA the wastewater in many West Bank cities is still discharged into valleys and natural waterways (PWA, 2016). Two-thirds of the West Bank residents still use constructed cesspits which are emptied by vacuum tankers then usually dumped in an open areas, valleys, sewage networks, or dumpsites, which increase the risks of the environment and the groundwater contamination (World Bank, 2018). The total volume of the wastewater generated in the West Bank and Gaza Strip are estimated of 62 MCM and 44 MCM respectively (PWA, 2016). World Bank, 2018 reported that about 9.5 MCM of the collected wastewater in the West Bank is only treated whereas 25 MCM of the wastewater is discharged into the environment every year from 350 locations, about 21.4 MCM of this quantity is discharged beyond the West Bank boundaries where the Israeli occupation charges the Palestinian Authority on the pretext for a necessary treatment; Israel billed the PA of US$ 31 million in 2017 (World Bank, 2018).

2.1.3 The Reclaimed Wastewater Reuse in Palestine

Reusing the treated wastewater is referred as a promising option to alleviate the water scarcity in Palestine, as well as to face the environmental threats which result from discharging the pollutants of wastewater to the environment (McNeill *et al*., 2008). In the West Bank only two thirds of the generated wastewater which is collected in the sewage networks is discharged into a wastewater treatment plant, the annual wastewater collected by the sewage networks is estimated of around 15 MCM/year; in which around 10.3 MCM/year is treated totally or treated partially through six centralized wastewater treatment plants in addition to 16 collective wastewater treatment plants (ARIJ, 2015; PWA, 2012). ARIJ, 2015 reported that in the West Bank the volume of the reused treated Wastewater in the West Bank for agriculture or industrial purposes remains close to zero (ARIJ, 2015). In Gaza strip the amount of the reused treated wastewater is around 1 MCM/year, 13 MCM/year is treated and is discharged into the aquifer for recovery, and 46 MCM/year of the wastewater still untreated or is treated partially and discharged into the valleys, being infiltrated in the ground then to the sea (World Bank, 2018). The treated wastewater is considered as an valuable non-conventional water resource which constitute additional source of the fresh water for agricultural uses, reusing the treated wastewater in agriculture provides a significant potential for health, environment and economic benefits; therefore it reduces the amount of the fresh water demand which is used for irrigation, as well as the amount of the contaminated wastewater which is discharged in the environment (Al-Khatib *et al*., 2017). Taking into account the water scarcity in Palestine reusing treated wastewater especially in agriculture is the most promised alternatives for water demand management. However, the achievements which is made in terms of wastewater reuse is very limited when compared to the efforts and the investments (Abu Madi *et al*., 2009). Although many efforts have been made in terms of constructing WWTPs, there is still a lot of work to be done. PWA and some non-governmental organizations (NGOs) and academic institutions have established centralized and collective wastewater treatment systems in several urban and rural area as shown in figure (2.1) which lack sewage collecting networks and depend on cesspits to dispose the wastewater for improvement and support the water supply and the sanitation in Palestine (MoA, 2016). Wastewater in many West Bank cities is still discharged into valleys and natural waterways. Currently, many activities have been implemented for constructing and expanding the wastewater networks, as well as constructing and operating WWTPs such as Nablus-West wastewater treatment plant, Jericho, Anaz, Attil, and Tubas-Tayaseer (PWA, 2016).

2.1.4 The Constructed Wetland Plants in Palestine

The Constructed wetland plants (CWs) for wastewater are used in the Palestinian rural areas due to the simple operation, technology and the availability of the land. The existing treatment plants are in the small, medium and large scale size categories. Zeita, Sarra, Hajjah, and BeitHasan, Mesillya WWTPs are examples of the existed constructed wetlands planted with fragment estuaries plants in the rural areas of the West Bank which are considered low cost wastewater treatment plants to provide pollutants removal. Zeita WWTP has a rated capacity of 80 m^3/day, Sarra WWTP has a rated capacity of 460 m^3/d, Hajjah has a rated capacity of 70 m^3/d, and BeitHasan has a rated capacity of 70 m^3/d (MoA, 2016).



ID	Description	Technology
0	Beit Dajan WWTP	AS
1	Nablus West WWTP	AS
2	Sarra Constructed Wetland WWTP	Reedbeds
3	Hajja Constructed Wetland WWTP	Reedbeds
4	Anza WWTP	AS
5	Jenin Aerated Ponds WWTP	Aerobic Ponds
6	Tulkarm Anaerobic Ponds WWTP	Anaerobic Ponds
7	Beit Hassan Constructed Wetland WWTP	Reedbeds
8	Ramalah WWTP	Anaerobic Ponds
9	Al-Reehan WWTP	MBR
10	Al Bireh WWTP	AS
11	Taybeh & Rammoun WWTP	RBCs
12	Alteereh-Ramallah WWTP	MBR
13	Jericho WWTP	AS
14	Bethlehem Industrial Zone WWTP	MBR
15	Beit Lahya WWTP	Anaerobic Ponds
17	Shiekh Ejleen WWTP	HS
19	Wadi Gaza WWTP	HS
24	Rafah WWTP	HS
22	Khan Younis WWTP	Anaerobic Ponds

Figure (2.1). Key Map of The WWTPs Distribution in West Bank & Gaza Strip

(source: MoA, 2016)**.**

2.2 International Standards for Reuse Reclaimed Wastewater

2.2.1 Jordanian Standards

Jordan’s Department for Standards issued a first comprehensive standard for reusing the treated domestic wastewater in 1995, this standard was mended in 2002 for expand the reuse activities. The final version of this standard was published in 2006 (Seder and Abdel-Jabbar, 2011). The standard consists of two essential components depending on the final use of the treated wastewater as follow (Ulimat 2012, Seder and Abdel-Jabbar 2011):

a. Reclaiming the water for reuse.

b. Reclaiming the water discharge into streams, wadis or the water bodies.

- Reclaiming the water for reuse:

This component of the standards includes the following two categories:

A) The artificial recharge of the groundwater aquifers.

B) The reuse for irrigation purposes.

The allowed limit per final use for the categories and the criteria for reusing in irrigation is tabulated in the following table (2.1) (Ulimat 2012, Seder and Abdel-Jabbar 2011).

Table 0:1 Jordanian Standards for Wastewater Reuse in Irrigation

Allowable limits per end use						
	Irrigation				Artificial Recharge	Discharge to water bodies and valleys
Parameter	Cooked Vegetables, Parks, Playgrounds and Sides of Roads within city boundaries	Fruit Trees, Sides of Roads outside city limits, and landscape	Field Crops, Industrial Crops, Forest Trees	Cut Flowers		
Treatment Grade Requirements	A	B	C	-	-	-
BOD_5(mg/L)	30	200	300	30	15	60
COD(mg/L)	100	500	500	100	50	150
DO(mg/L)	>2	-	-	>2	>2	>2
TSS(mg/L)	50	200	300	15	50	60
PH	(6-9)	(6-9)	(6-9)	(6-9)	(6-9)	(6-9)
NO_3(mg/L)	30	45	70	45	30	70
T. N(mg/L)	45	70	100	70	30	70
E.coli (cfu/100mL)	100	1000	unlimited	<1.1	<1.1	1000
Intestinal Helminthes eggs/L	≤1	≤1	≤1	≤1	≤1	≤1
FOG (mg/L)	8	8	8	2	8	8.0

Source: JISM, 893/2006

2.2.2 Egyptian Standards for Reusing The Treated Wastewater in Agriculture

The Ministry of Housing Utilities and New Communities (MHPUNC); issued in 2015 Egyptian Code (501/2005) for reusing the treated wastewater in agriculture. According to the code regardless of the treatment level prohibited the use of the treated wastewater for producing of vegetables whether eaten raw or cooked, export-oriented crops “such as cotton, rice, onions, potatoes, medical and aromatic plants", as well as citrus fruit, or irrigating the school gardens, respectively (Abdel Shafy and Mansour, 2013).The code classified treated wastewater into three grades (A, B, and C) according to the level of the treatment, the allowed maximum contaminants level for each grade, and the allowed crops to be irrigated for each grade as shown in tables (2.2 & 2.3). The code determine the conditions for the irrigation methods the health protection methods for farm workers, consumers, and the neighboring farms (El-Zanfaly, 2015, Abdel Shafy and Mansour, 2013, MHPUNC, 2005).

Table 0:2 Egyptian Code: Allowable Limit Values for Treated Wastewater Reused in Agriculture

Treatment Grade Requirements		A	B	C
Effluent limit values for BOD and Suspended Solids (SS) parameters (mg/L)	BOD_5	<20	<50	<250
	SS	<20	<60	<400
Effluent limit values for biological parameters	Fecal coliform / 100 mL	<1000	<5000	Unspecified
	Nematode cells or Eggs / liter	< 1	< 1	Unspecified

Source: MHPUNC, Egyptian Code 2005.

- Grade A: involves tertiary treatment which can be achieved by developing the secondary treatment plants to include sand filtration, disinfection and other measures.

- Grade B: includes the secondary treatment which is performed in the most Egyptian plants. It is carried out through activated sludge, oxidation ditches, trickling filters, and stabilization ponds.

- Grade C: include the primary treatment which is restricted to sand and oil removal basins and using sedimentation basins.

Table 2:3 Egyptian Code: Classification of Plants and Crops Irrigable with Treated Wastewater.

Grade	The agricultural Group	The Plants or The Crops
A	G1-1: Plants and trees grown for greenery at touristic villages and hotels.	The Palm, Saint Augustin grass, cactaceous plants, ornamental palm trees, climbing plants, fencing bushes and trees, wood trees and theshade trees.
	G1-2: Plants and trees grown for greenery inside residential areasat the new cities.	Palm, Saint Augustin grass, the cetaceous plants, ornamental palm trees, climbing plants, fencing bushes and trees, wood trees and shade trees.
B	G2-1: Fodder/feed Crops.	Sorghum sp.
	G2-2: Trees producing fruits with epicarp.	On condition that they are produced for processing purpose such as lemon, mango, date palm and almonds.
	G2-3: Trees used for green belts around cities and a forestation of high ways or roads.	Casuarina, camphor, atheltamarix (salt tree), oleander, fruit producing trees, date palm and olive trees.
	G2-4: Nursery Plants	The nursery plants of wood trees, ornamental plants and fruit trees.
	G2-5: Roses & Cut Flowers	Local rose, eagle rose, onions (e.g. gladiolus).
	G2-6: Fiber Crops	Flax, jute, hibiscus, sisal.
	G2-7: Mulberry for the production of silk.	Japanese mulberry.
C	G3-1: Industrial Oil Crops.	Jojoba and Jatropha.
	G3-2: Wood Trees.	Caya, camphor and other wood trees.

Source: MHPUNC, Egyptian Code 2005.

2.2.3 Emirate of Abu Dhabi Standards for Reusing Reclaimed Wastewater

In 2018 the Regulation and Supervision Bureau (RSB, 2018) issued amended regulations and quality standards for the Recycled Water and the Biosolids (Second Edition). According to the RSB 2018 the use of the recycled water for drinking, cooking, bathing, or swimming purposes is strictly prohibited (RSB, 2018). The minimum requirements for treating the wastewater to be transfered or discharged to the marine environment or for the land uses should be complied with the quality criteria summarized in the table (2.4).

Table 0:4 Standards for Reuse Reclaimed Wastewater in Abu Dhabi.

Parameter	P1	P2
	Unrestricted Reuse	Restricted Reuse
pH	6 to 8.5	6 to 8.5
BOD_5 (mg/L)	10	10
Total Suspended Solids (mg/L)	10	20
Turbidity	5	10
Residual Chlorine (total available)(mg/L)	0.5 to 1	0.5 to 1
DO (mg/L)	≥ 1	≥ 1
Faecal Coliform or E. Coli CFU /100ml	23	800
Intestinal Enterococci CFU /100ml	24	104
Helminth Ova No./L	0	0
Legionella (in circulating water)CFU /ml	100	N/A

Source: RSB2018 in the Emirate of Abu Dhabi.

- Unrestricted Reuse: referred to as P1which involves frequent and uncontrolled exposure of the general public to the Recycled Water i.e. the public access is not restricted;

- Restricted Reuse: referred to as P2 which involves infrequent and controlled exposure of the general public to the Recycled Water; i.e. the public access is restricted.

2.2.4 The Palestinian Specifications for Reusing treated Wastewater in Agriculture

The Palestinian specifications for reclaiming the wastewater has been developed by the Palestinian Standards Institute (PSI) in 2003, in order to regulate the reuse of the reclaimed wastewater via methods and the practices for protecting and maintaining the environmental soundness. However, the limit values have been set for the effluent characteristics of the wastewater treatment plants, as reference-conditions for reusing the treated wastewater. The institute in cooperation with the relevant authorities issued in 2012 an obligatory technical specifications for reusing the treated wastewater in agriculture (PSI 34-2012). These obligatory technical specifications are aimed at the following:

a. Set foundations for reusing the treated water in agriculture in a way that does not harm human and animal health or crops.

b. Ensure that the treated wastewater for agriculture does not damage the environmental elements.

According to (PSI 34-2012) the effluent of the treated wastewater from the domestic wastewater treatment plants which will be discharged or reused must be complied to (PSI 742-2003).

The use of the treated water for agriculture is prohibited in the following cases (PSI 34-2012):

a. The use to drink the livestock and the poultry.

b. Irrigating all kinds of the vegetables.

c. The groundwater recharge through direct injection.

d. The use for aquaculture.

The Palestinian specifications (PSI 742-2003) classified the treated wastewater into three grades (A, B, and C) according to the quality of the treated wastewater, the allowed maximum pollutants of each grade, as well as identifying the barriers approach which are required for each grade in the reusing for different crops as shown in tables (2.5 2.6). (PSI 742-2003) characterized the barriers which must be taking into account for reusing the treated wastewater and specifying the number of the barriers for each one based on their characterizations as shown in the table (2.7), these barriers must be used for all the allowed irrigated crops by the treated wastewater except the following crops (PSI 742-2003):

a) The cultivated crops for the seeds - production.

b) Forest trees which have no contact with the public.

c) The ornamentals plants.

d) The forest and the fruit seedlings in the nurseries.

e) The industrial crops such as cotton.

Table 0:5 Characterization of Barriers According to Palestinian Specifications.

Characterization of Barrier	Number of considered Barriers
An over ground surface spacing not less than 50cm between emitters(drip irrigation) and the crop.	two barriers
An over ground surface spacing not less than 25cm between the emitters(drip irrigation) and the crop.	one barrier
A distance not less than 50cm between sprinkler irrigation and fruits.	one barrier
Plastic mulch between the treated wastewater and fruits.	one barrier
The Subsurface irrigation.	two barriers
The Crops or the fruits with uneatable skin.	one barrier
A crop or a fruit which eaten cocked only	one barrier
Existing a Sand filter.	one barrier
A retention time for treating the wastewater in 15 days or more.	one barrier
The water storage ponds with at most 10% treated wastewater.	one barrier
TAny disinfection method of the treated wastewater.	one barrier

Source: PSI 742-2003.

Table 0:6 Classification of the treated Wastewater According to the Palestinian Specifications.

Grade Quality	Parameter (mg/L Unless otherwise stated)							
	pH	BOD_5	COD	TSS	TDS	Total-N	NO3-N	F. Coliforms cfu/100m
A High quality	9-6	20	50	30	1200	30	20	200
B Good quality	9-6	20	50	30	1500	30	20	1000
C medium quality	9-6	40	100	50	1500	45	30	1000
D Low quality	9-6	60	150	90	1500	60	40	1000

Source: PSI 34-2012.

Table 0:7 Number of Required Barriers for Irrigated Crops with Treated Wastewater According to Palestinian Specifications.

Cultivated Crop	Number of required barriers			
	Grad A	Grade B	Grade C	Grade D
Gardens, sports fields, parks	0	Prohibited	Prohibited	Prohibited
Groundwater recharge by infiltration	0	0	0	Prohibited
Discharge into seas at least 500 m in sea	0	0	0	Prohibited
Corn	0	2	2	4
Green fodders	0	0	0	Prohibited
Dry fodders	0	0	0	0
Citrus (drip irrigation method)	0	2	2	3
Irrigated Citrus without drip	0	3	3	4
Fruit Crops eaten dry; such as dry almonds, pomegranate, pistachios etc.	0	2	2	3
Fruits: apples, peaches, cherries, apricots	0	2	2	3
Tropical fruits: mangos, coco	0	2	2	3
Grapes with high frames	0	2	2	3
Grapes with regular frames	0	2	2	3
Cactus	0	2	2	3
Palms	0	2	2	3
Olives	0	2	2	3

Source: PSI 742-2003.

2.3 Constructed Wetland Plants for Wastewater Treatment

2.3.1 Constructed Wetland Systems Background

Constructed treatment wetlands are artificial engineered systems which mimic natural processes composed of a shallow basin filled with some sort of filter material such as soil or gravel and planted with tolerant vegetation of saturated conditions (Abou-Elela, 2017). The constructed wetlands rely on chemical, physical and biological mechanisms to reduce the pollutants within a waste stream. These processes are depend on the size, the shape, the temperature, the loading and the vegetation used within the wetland process (Miller, 2007). The wastewater is fed into the basin of the constructed wetland and inflows over the surface or through the filter medium, and is discharged out of the basin through a structure which controls the depth of the wastewater in the wetland (UN Habitat, 2008).

The Constructed wetland systems for the wastewater treatment are considered an effective technology of reducing the pathogens, the organic pollutants, and the toxic metals. The removal efficiency of the CWs can be controlled by altering the hydraulic retention time and temperature (Sehar *et al*., 2013).

The more comprehensive performance information about the existing full-scale constructed wetlands can lead to more efficiency in applying this technology from site to site, the success or the failure of the constructed wetlands treatment is commonly characterized by the simple measures of the performance. However, in many cases, the targeted constituents are measured from the inflow, the outflow of the constructed wetland treatment system and the performance of the system is expressed as a relative removal (Murray-Gulde *et al*., 2008).

However, the long-term effective treatment performance in the CWs and the sustainable operation remains a challenge for the related agencies and the environmentalists. In the last few decades, the constructed wetlands had been considered a green treatment technology by imitating the natural wetlands. It has been widely used to treat various types of wastewater (Abou-Elela, 2017). The Constructed wetlands has long proven technology being an effective, low-cost and easily maintained treatment method for various types of wastewater in removing the organic matter, the nutrients and the suspended solids (Shuib *et al*., 2011).

The wetlands removal of biochemical oxygen demand (BOD_5) and total suspended solids (TSS) is very high (Dong *et al*., 2015). The traditional wastewater treatment systems have been used successfully for remediating the water pollution in the most countries. However, those wastewater treatment technologies such as the activated sludge process have disadvantages such as expensiveness and being not entirely feasible to be applied in the rural areas. Therefore, selecting low-cost and efficient alternative technologies for treating the wastewater is useful and practical especially in the developing regions (Abou-Elela, 2017).

The conventional wastewater treatment systems consist of an intensive energy and a mechanized treatment components which require high investment and high operating costs. Thus, the experiences has shown that the existing wastewater treatment systems in most of the developing countries which are built through funding by the international donor-agencies failed to treat the wastewater adequately. The reasons for this inadequate treatment can be summarized in the high maintenance costs, the lack of the local expertise and the poor governance. Compared to the conventional treatment systems, constructed wetlands are low cost, easily to be operated and maintained, and can be applied in the developing countries. The Constructed wetlands are accepted as a reliable wastewater treatment technology and represent an appropriate solution for treatment many wastewater types (Mustafa, 2013).

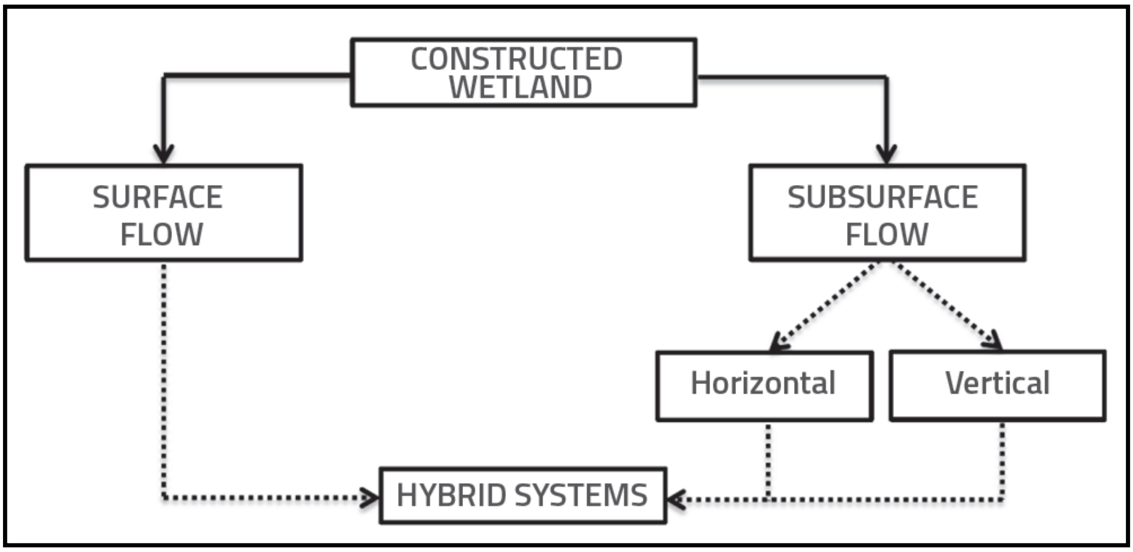
2.3.2 Wetlands Characteristics

The monitoring of the water treatment in the natural wetlands for many years led to developing the constructed wetlands as an attempt to improve the water quality and to create habitat benefits of the natural wetlands in a constructed ecosystem (EPA, 2000). Wetlands either natural or constructed provide alternative cheaper and low cost technology for treating the wastewater (Wetlands International-2003). The Constructed wetlands are engineered designed systems that are utilized for domestic and industrial wastewater treatment involving substrates such as soil, gravel, specific types of vegetation which are tolerant to the saturated conditions, and associated microbial assemblage for enhancing the wastewater treatment, they are designed to imitate the same processes in the natural wetlands but in a controlled environment (Vymazal, 2010).

The vegetation contributes essential role for purifying the wastewater through their roots which provide a huge surface area for the attaching microbial growths which have function of degradation and uptake the pollutants (nutrients) from the wastewater, and diffuse the oxygen from the roots to the rhizosphere, as well as it provides aesthetical value and wildlife habitat area (Elzein *et al*., 2016). The typical constructed wetland consists of the following five major components: the basin, the substrate, the vegetation, the liner, and the inlet/outlet points (UN Habitat, 2008).

2.3.3 Classification of Constructed Wetlands for Treating Wastewater

Several types of the constructed wetlands are applied for treating the wastewater, the Constructed wetlands are generally classified based on the water flow pattern in the basin into two major types as shown in figure(2.2); free water surface (FWS), and Sub surface flow water (SSF) (Farooqi *et al*., 2008). The free water surface is a shallow flow water on the surface of a basin over the saturated substrate; it's similar to the natural wetlands, while the subsurface flow CWs is designed to keep the water level totally beneath the surface of the filter bed (Haiming *et al*., 2015).



Figure(2.2). Classification of Constructed Wetland Systems (Stanković, 2017).

- **Free Water Surface (FWS)**

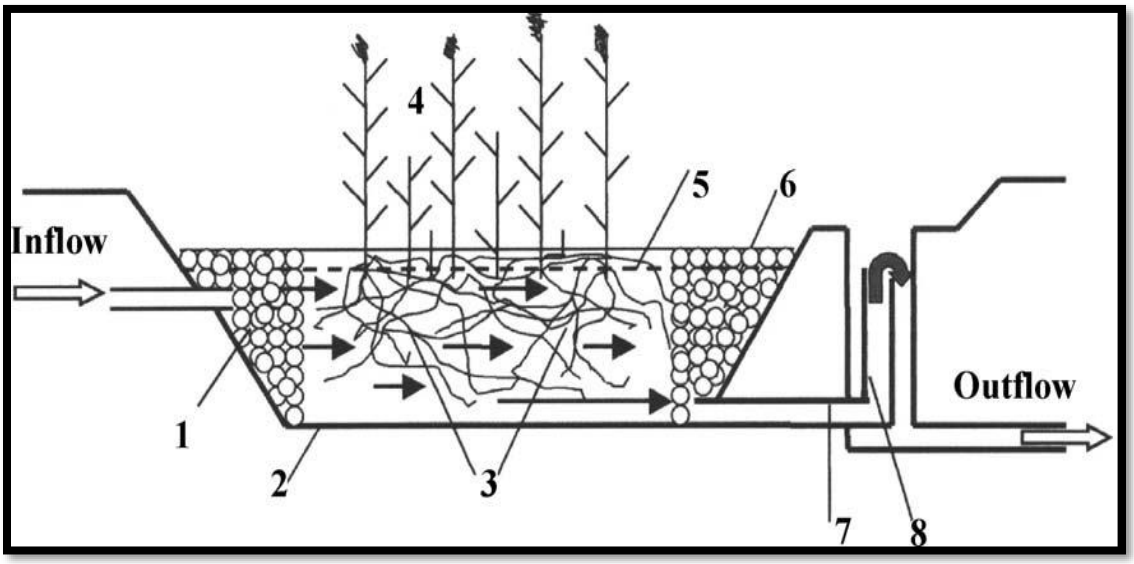
FWS wetlands which are also known as the surface flow wetlands are defined as wetland systems similar in the appearance to the natural marshes and have areas of open water which allows the water to flow above the ground therefore the water surface is visible and is exposed to the atmosphere (EPA, 2000).

- **Subsurface Water Flow (SSF)**

The wastewater is intended in the SWF system to stay beneath the surface of the media and flows in ,around the roots and the rhizomes of the plants (Kadlec and Wallace, 2009). On the basis of the direction of the water movement in the basin of the CW system; the constructed wetlands are classified into horizontal flow (HF) and vertical flow (VF). Furthermore the hybrid system is a combination of the horizontal flow or vertical flow constructed wetlands in order to achieve the maximum advantages from the both flows in reducing the wastewater pollutants (Vymazal, 2013).

I. Horizontal Flow (HF)

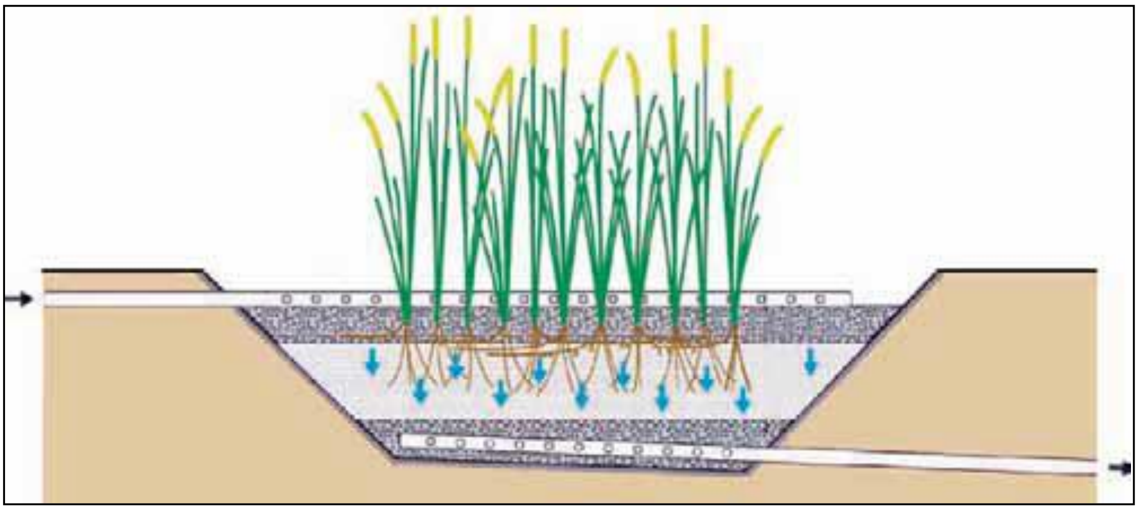
The wastewater is entered at the inlet point of the bed of the HF system and flow slowly through the pores of the substrate beneath the surface of the bed at the horizontal path until it reaches the outlet zone where it is collected as shown in figure(2.3), due to the limited oxygen transfer inside of the HF bed the major removal mechanism of the nitrogen in HF CW is denitrification (UN Habitat, 2008, and Vymazal, 2001).



Figure(2.3) Horizontal Flow Wetland (Vymazal, 2005)**.**

II. Vertical Flow (VF)

In the vertical flow wetlands, the wastewater is dosed intermittently in large batch over the surface of bed using a mechanical dosing system and then it percolates down slowly through the substrate until reaching the bottom, then collected in drainage pipes at the bottom then to outlet zone, after that the next batch is fed only after all the water percolates and the bed is free of the water as shown in figure (2.4) (Maiga *et al*., 2017). This enables diffusion of oxygen from air into the bed and provide suitable aerobic conditions for the nitrification process. The VF CWs are very effective in removing organics and suspended solids. However, removal of phosphorus is low unless media with high sorption capacity is used (Vymazal, 2010).



Figure(2.4) Vertical Flow Wetland (UN HABITAT, 2008).

III. Hybrid Flow Constructed Wetlands

The system consists of various types of constructed wetlands stages which can be combined to complement each other in series have been introduced in order to exploit the advantages of each type of the wetland and complete each other. However, most of the hybrid systems are comprised of VF and HF systems arranged in a staged manner, the major reason for the use of the hybrid CWs is the more stringent requirements for improving the effluent water quality especially nitrogen (Šereš *et.al*, 2017).

IV. French Vertical Flow Wetlands (French VF)

The origin of this system is France where the VF wetlands have been introduced to treat raw wastewater directly in a single step, the system consists of two stages, and each stage contain alternating operated cells. The function of the first stage is to treat the primary sludge in addition to a partial removal of the organic matter, while the function of the second stage is final removal of organic matter and nitrification occurs. (Troesch *et al*., 2014).

2.3.4 Mechanisms of Pollutants Removal by Constructed Wetlands

The main mechanisms of the pollutants reduction in a constructed wetland can be achieved by the following mechanisms as shown in table (2.9).

Table 0:8 Main Removal Mechanisms for Pollutants and Pathogens in CWs (Stanković, 2017).

Parameter	Main Removal Mechanisms
Organic matter (expressed as BOD or COD)	Undissolved organic matter is removed by sedimentation and filtration and converted into dissolved BOD. Biofilm fixes the dissolved organic matter that is then removed by attached bacteria (biofilm on plants, roots, substrate particles, etc.).
Suspended solids	Filtration. Decomposition by special bacteria in soil over a long period of time.
Nitrogen	Nitrification, denitrification, and plant uptake.
Phosphorus	Adsorption, precipitation mechanisms driven by filter media properties, plant uptake.
Pathogens	Sedimentation, filtration, natural die-off, predation (carried out by protozoa and metazoa)

2.3.4.1 Organic Matter Reduction Mechanism

The reduction of coarse organic matter in constructed wetlands is performed through gravity settling in opened pores of the substrate medium (EPA, 1993). While the oxygen can be supplied through atmospheric oxygen diffusion and macrophyte root, transfer of the oxygen into the plant - rhizosphere through pores of the substrate media in the subsurface CW. Therefore, BOD removal is mainly due to aerobic microbial degradation, the sedimentation and the filtration processes, as well as the removal of soluble organic substances is achieved through growth of microorganisms on the media, the adhered on the rhizomes and roots of the macrophytes (Abou-Elela, 2017). These microorganisms grow on the surface of substrate and root particles, where they form an active biofilm (Stanković, 2017). Furthermore, anaerobic organic degradation can be predominant inside the CW beds where pores of the substrate media lack oxygen (Song *et al*., 2006).

2.3.4.2 Total Suspended Solids Removal Mechanism

The total suspended solids are defined as all the particles in wastewater sample which include all of organic and inorganic matter that cannot pass through a fiber filter, such as silt, industrial waste,sewage, and nutrients or the metals that could be attached to the particles(Zhang *et al*., 2013).The major function which is achieved by the constructed wetland system is the removal of suspended solids from the pollutants water influx through wetland, these removals are the final result of a complicated set of physical chemical and biological processes in the wetland system (Kadlec and Wallance, 2009).

2.3.4.3 Nitrogen Reduction Mechanism

The nitrogen removal mechanism in the constructed wetlands includes five principal processes: ammonification (mineralization), nitrification, denitrification, plant uptake, and decomposition (Gajewska *et al*., 2018). The ammonification process is the first step of nitrogen conversion to nitrate and/or removal which consist of conversion of organic nitrogen to ammonium through microbial activity (Vymazal, 2007). Nitrification-denitrification process is considered the main source of nitrogen loss in the constructed wetlands (Wen *et al.*, 2011). Nitrification process is oxidation of ammonium to nitrate through microorganisms in the presence of oxygen, It's almost take place in VF wetlands due to availability of oxygen, sometimes this process can take place in HF especially when lightly loaded with organic matter, denitrification converts nitrate to the nitrogen gas which is released to atmosphere (Vymazal and Kröpfelová, 2008).

2.3.4.4 Phosphorus Reduction Mechanism

Phosphorus inflows most of wetlands primarily as organic phosphorus and orthophosphate. When organic matter decomposes most of organic phosphorus is converted into orthophosphate. The methods of phosphorus removal in wetland systems include chemical precipitation, sedimentation, and adsorption, uptake through plant and microbes (Dotro *et al*., 2017). removal of phosphorus in SSF wetlands depend on the characteristics of the substrate used for wetland system (Vymazal, 2007).

2.3.4.5 Pathogenic Reduction Mechanism

Pathogens are removed in wetland systems mainly by sedimentation, the filtration and absorption, by biomass, by natural die-off and predation (Dotro *et al*., 2017).

Chapter Three

Methodology

3.1 Introduction

The study was carried out in four rural communities in the West Bank which have constructed wetland systems for treating the wastewater and are currently operated. The same technology for treating the wastewater had been employed in Sarra, Hajjah, and BietHasan wastewater treatment plants and used hybrid wetland system for treating the wastewater. However, the technology employed in the fourth plant in Misillya village is French vertical wetland system. The following methodology was applied to achieve the objectives of research. The methods and experimental procedures used for collecting the data are explained below.

3.2 Background of The Studied Sites

3.2.1 Sarra Wetland Plant

Sarra wetland plant is situated at Sarra village; Sarra is a Palestinian village in Nablus Governorate, located 17.8 km in the west of Nablus City. The total population of Sarra in 2017 was 3384 (PCBS, 2018). Sarra is considered famous of the olive cultivation and there is about 393.5 hectares of the land planted with olive trees in the village (ARIJ, 2014).

3.2.1.1 Treatment Plant Description

Sarra wetland plant has been constructed since 2012 on the north side of Sarra village. The treatment plant is located 11 km in the south west of Nablus on total area of about 9250 m^2. The designed technology that has been constructed is the large-scale hybrid constructed wetlands planted with common reed/Fragment Astuaries from the Jordan Valley. It is considered a low-cost wastewater treatment plant, where a local sewage network connected to all housing units approximately. Thus, the domestic wastewater is discharged into the WWTP. The plant has been designed for a maximum average of 465m^3 of the wastewater flow (PHG plant documents, 2012). The actual flow rate of the wastewater into the treatment plant is about 248 m^3/day.

3.2.1.2 The Main Components of The Treatment Plant

- Preliminary treatment system

The mechanical treatment is considered the first unit operation used in wastewater treatment plants; where disturbing coarse material is removed in order to protect the subsequent processes. The raw wastewater passes through a bar screen followed by a grit removal channel to remove the solid parts. Mechanically the downstream of the screened sewage is divided into two streams by a partition manhole. The water from the partition manhole flows in the Imhoff tank.

- The Primary treatment system

The system consists of two Imhoff septic tanks operated in parallel. The Imhoff consists of an upper chamber in which the sedimentation occurs and the collected solids slide down the inclined bottom slopes to an entrance into the lower chamber. The Imhoff provides sedimentation and sludge digestion in one unit and is designed to produce a satisfied primary effluent.

- The constructed Wetlands Treatment - Plant

Sarra CW consist of six lines (figure 3.1). Each one is operated independently and is composed of two different stages working in series:

1) The first Stage –Vertical Flow bed (VF): fully planted with common reed/ Phragmites Australis. The surface area of the bed is 1500 m^2. The bed is filled with filter media at an average height of 0.70m of the substrate. The VF bed is divided by 6 beds operated in parallel; where every bed is fed by a wastewater independently and intermittently by a siphon device.

2) The Partition manhole: for collecting the treated wastewater which is discharged from vertical CW bed.

3) The second Stage–Horizontal flow bed (HF): fully planted with common reed/ Phragmites Australis; the surface area of the bed is 3000 m^2. The bed is filled with filter media at average depth of 0.8 of the substrate, and the bed slope 0.5%. The HF bed is composed of 6 beds, operated in parallel, and every bed is independently operated.

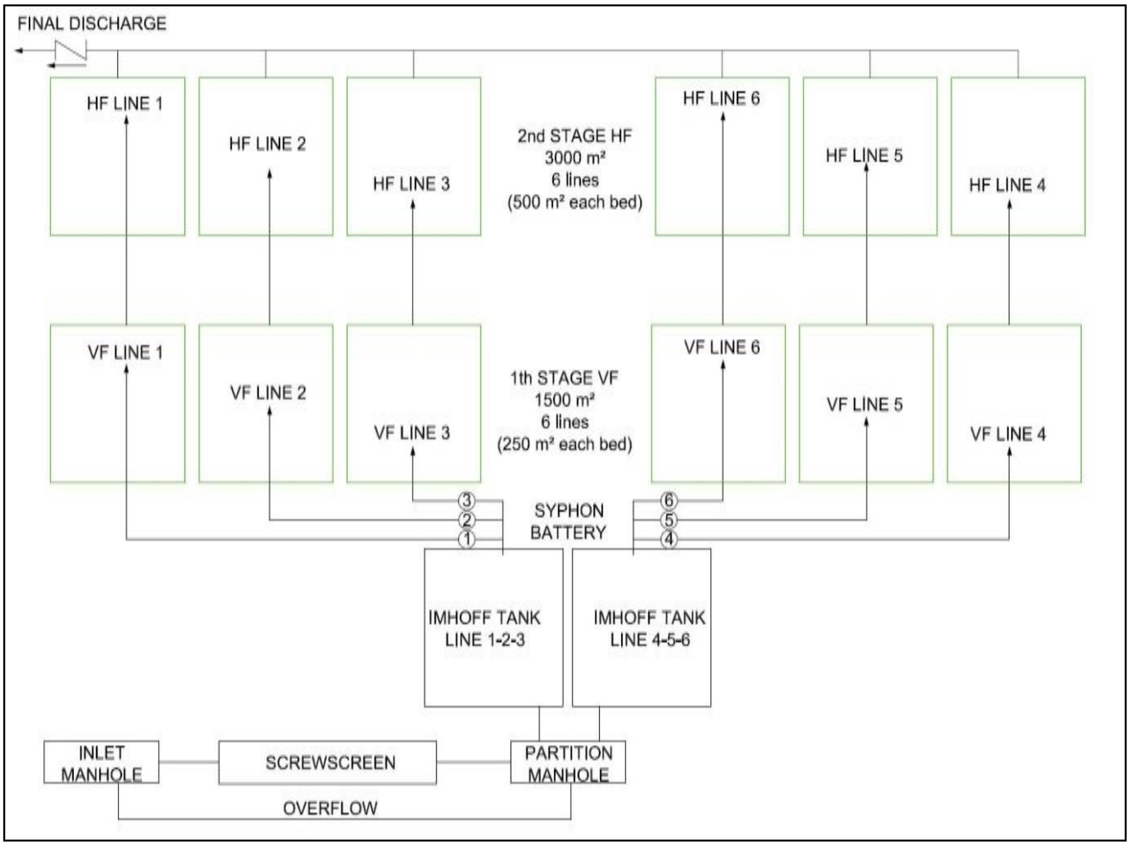
4) Partition manhole: for collecting the treated wastewater which is discharged from the horizontal CW bed.

3.2.1.3 Operation of Vertical Wetland Beds

In the vertical flow systems (VF) the wastewater is discharged through a siphon device and into a distribution system on the whole surface area to passes through the filter medium in the vertical path. The filter medium is filled in arranged layers as follow: the upper layer gravel is 1-5 mm with 50 cm depth, the next layer gravel is 10mm with 10cm depth, and the last layer gravel is 40-70 mm depth of about 10 cm. the wastewater is dosed on the bed in large batches (intermittently feeding by a siphon device). The time between the doses enables the pores within the filter to be fed with air which is trapped by the next dose of the wastewater. Thus, the required oxygen by nitrifying bacteria is favored and full nitrification can be performed. However, a small part of the formed nitrate is denitrified under the aerobic conditions. The treated wastewater is withdrawn through the perforated pipes on the bottom, parallel to the long axis in the bottom of the bed drainage system to be discharged into the partition manhole.

3.2.1.4 Operation of Horizontal Wetland Beds

The HF beds are comprised of the inlet feeding system, the synthetic liner, the filter medium; the common reed and the outlet piping with water level- control. The bed filled with substrate arranged as follow: the inlet zone filled with coarse gravel 80-120mm, the treatment zone filled with gravel 10 mm and coarse sands in the bottom of the layer at the depth of 5 cm; with an average water level of 0.7m, the outlet zone filled with coarse gravel 80-120mm with an average porosity of 0.35. The wastewater is fed by the inlet device and flows slowly in and around the root, the rhizomes of the plant and through the porous medium under the surface of the bed in a horizontal path until it reaches the outlet zone. The treated water is collected in partition manhole which include water level control- device to maintain the water level under the surface of the bed. The treated wastewater is discharged by the gravity into the collecting reservoir.



Figure(3.1). Layout of Sarra Wetland Plant (PHG plant documents, 2012)**.**

3.2.2 Hajjah Wetland Plant

Hajjah wetland plant is situated at Hajja village. Hajjah is a Palestinian village in the Qalqiliya Governorate located 15.9 km east of Qalqiliya City. The total population of Hajjah in 2017 was 2.659 (PCBS, 2018). Hajjah is considered famous of olive cultivation where 700 hectares of the cultivated area is planted with olive trees in addition to the field crops and the forage. The area is cultivated with cereals particularly wheat and barley of about 16 hectares (ARIJ, 2013).

3.2.2.1 Treatment Plant Description

Hajjah village has its own wastewater treatment system since 2012. The project has been carried out by the Palestinian Hydrology Group (PHG). The existent WWTP is in the south west of the village 1km away from the nearby houses. The project aim to reduced the health risks which is linked with the presence of the untreated wastewater in the villages, and to create a non-conventional source of water for irrigating the olive trees, to improve the productivity and the livelihood for the smallholder farmers. The technology employed in this treatment plant is the hybrid constructed wetlands planted with common reed. A local sewage network connected to 150 housing units only. The plant has been designed for a maximum average of 173m^3/day of the wastewater flow (PHG plant documents). However, the domestic wastewater of these housing units is discharged into the WWTP with an actual daily flow rate of about 65 m^3/day.

3.2.2.2 The Main Components of The Treatment Plant

- The Preliminary treatment system:

Mechanical treatment is considered the first operation unit used in the wastewater treatment plant to remove the disturbing coarse material in order to protect the subsequent processes. The raw wastewater passes through a bar screen followed by a grit removal channel to achieve the mechanical removal of the solid parts.

- The Primary treatment system:

The system comprises of one Imhoff septic tank at net volume about 88 m^3. The Imhoff tank consists of two separate compartments, the sedimentation compartment and the digestion compartment placed below the sedimentation one.

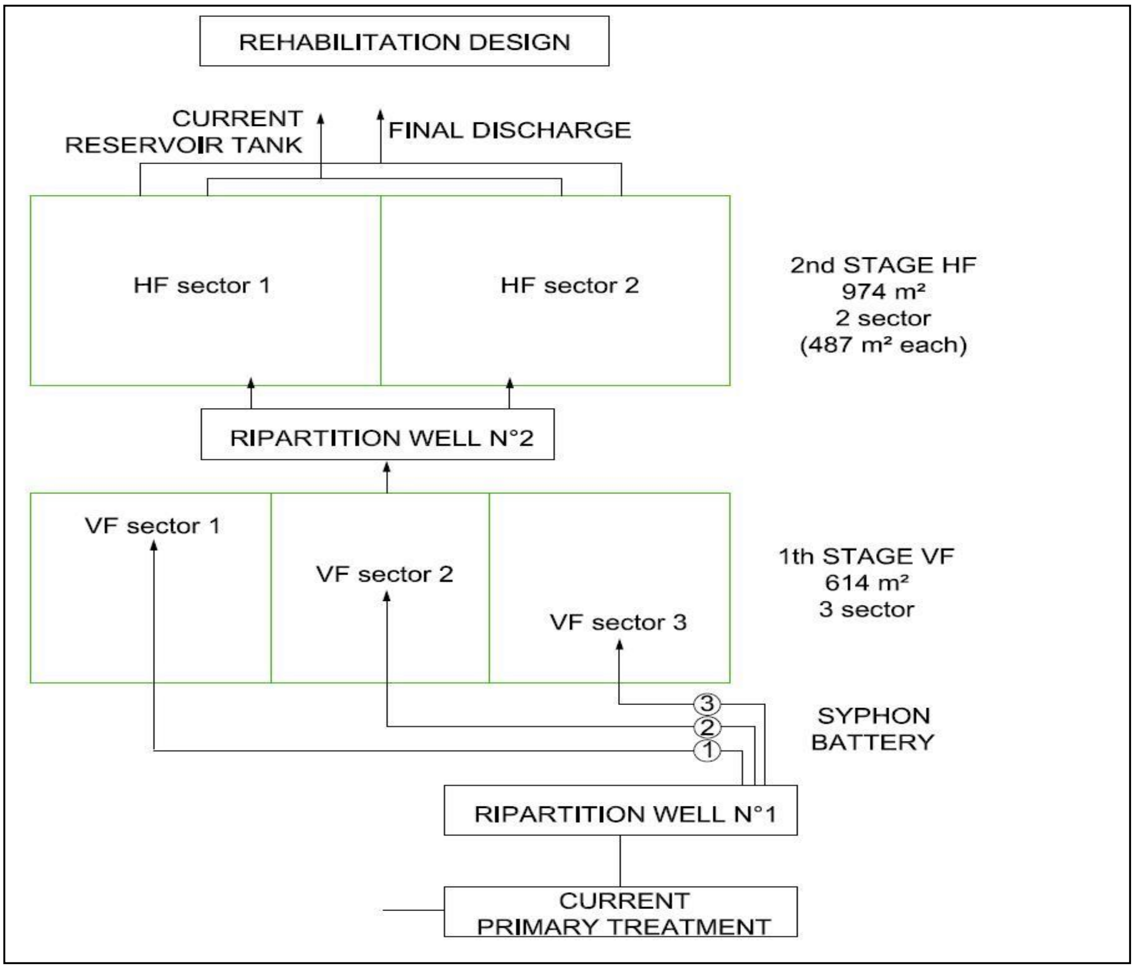
- The Constructed Wetlands Treatment Plant (CW):

The plant is composed of two different stages operated in series, and each stage is consisted as given bellow:

1. The first Stage - Vertical Flow Bed (VF): fully planted with common reed. The surface area of the bed is 615 m^2; filled with filter medium (pea gravel 15 mm) at an average depth of 0.70 m. The VF bed is intermittently fed of the wastewater by a siphon device.

2. The Partition manhole for collecting the treated wastewater which is discharged from the vertical CW bed.

3. The second Stage - Horizontal flow Bed (HF): fully planted with common reed. The surface area of the bed is 975m^2; filled with filter media (pea gravel 15 mm; porosity 0.35); with an average depth of 0.80 m, and a bed slope of 1%.



Figure(3.2). Layout of Hajjah Wetland Plant (PHG plant documents, 2012)**.**

3.2.3 Misillya Wetland Plant

Misillya wetland plant is situated at Misillya village; Misillya is a Palestinian village in Jenin Governorate, located 14 km south east Jenin City with a total population of 2.884 (PCBS, 2018). Misillya is famous with olive, vegetable, and fodder crops cultivation.

3.2.3.1 Treatment Plant Description

Misillya wetland plant has been constructed and operated in 2018. It's located in the North side of the village, the project carried out by the Palestinian Water Authority (PWA). The treatment system of the plant relies on the French vertical CW, the plant design has a maximum capacity flow rate of about 267 m^3/day in the dry weather and 370 m^3/day in the wet weather (PWA). When the samples were taken the flow rate of the inlet wastewater measurement was 170 m^3/day.

3.2.3.2 The Main Components of The Treatment Plant

- The Septage receiving station:

The system includes inlet truck connection- pipe, a bar screen, the storage tank has volume of 6 m^3. The storage tank receive the screened septage sludge and discharge them into the inlet pumping station with a maximum load of 1 m^3/day.

- The Inlet pumping station:

The system include feeding pump and float levels. The inlet pumping receive water from the sewage network and the sludge from the septage receiving station and discharge them into the network for the CW beds surface distribution.

- The vertical flow CW reed beds:

The system comprises of nine vertical CW reed beds with a total area of 4324.5 m^2 subdivided into three independent beds whence one unit with an area of 480.5 m^2 planted with common reed/ Phragmites Australis. Three hydraulically independent beds operated with 3.5 days/7days as a feeding period/rest period alteration. The filter media arranged inside the bed into layers as the following:

- The Unsaturated filtering layer with 70 cm length of a large dolomite gravel 20-50 mm size.
- The unsaturated transition layer with aeration pipes, with 15 cm length and medium dolomite gravel of 10-15 mm size.
- The saturated drainage layer, with 75 cm length and fine dolomite gravel of 3-6 mm size.

The inlet wastewater percolate vertically through the unsaturated and the saturated layers inside the bed then is discharged and collected in the level control manhole.

- The recirculation/ feeding manhole:

The recirculation/ feeding manhole controls the recirculation rate up to 100% of the treated wastewater, when the samples had been taken the recirculation rate was up of 50% of the treated wastewater rate which is recycled into recirculation manhole.

- The disinfection and the storage lagoon with a total area of 4500 m².

Figure(3.3). Misillya Wetland Plant.

3.2.3.3 BeitHasan Wetland Plant

BeitHasan wetland plant is situated at BeitHasan village. Beit Hasan is a Palestinian village in Nablus Governorate. The designed technology that has been constructed is large-scale hybrid constructed wetlands for wastewater treatment planted with common reed/ Fragment Astuaries.

3.3 Research Operation

1. The field visits were conducted to identify the technology which is employed for the following constructed wastewater treatment plants

that are currently operated in the West Bank: Sarra; Hajjah; Mesillya and BietHasan village.

2. Wastewater samples had been collected from the selected plants between 10 am and 13:00 pm, the samples had been taken three times over the period (October/ 2018 to February/ 2019), the samples had been collected in clean plastic bottles; labeled and stored in ice box in the site, then immediately transferred to the laboratory.
3. The collected samples had been analyzed in the same day in the laboratory of National Agricultural Research Center (NARC) for the following parameters: EC, pH, BOD_5, COD, T. Phosphorus, T. Nitrogen, TDS, TSS, E. coli, T. coliform.
4. The dissolved oxygen and the temperature of the wastewater had been recorded in the site by the DO meter in the same time of collecting the samples.
5. The four composite samples had been collected from Sarra and Hajjah treatment plants from different locations every time to represent all the treatment stages in the plant in the following way (the inlet wastewater point, after primary treatment point, after vertical beds, and after horizontal beds point).
6. The three grab samples had been collected from Mesillya treatment plant to represent all the treatment stages in the plant in the following way (the inlet waste water, the recirculation stage, and after vertical bed).

7. The two grab samples had been collected from BeitHasan treatment plant to represent all the treatment stages (the inlet wastewater of the plant, after primary treatment stage, and the outlet of the plant).

8. Quantitative data had been collected in three different month dates for the selected plants, the calculated average and the standard deviation was performed by an excel sheet for every parameter.

9. The SPSS version 23 package was used to perform the correlation analysis between the obtained results of the physical parameters for the selected treatment plants.

10. The obtained results is used to assess the performance efficiency of the studied wastewater treatment plants (WWTPs) and comparing their effluent characteristics with the Palestinian obligatory technical specifications (PSI 34-2012).

11. An Assessment of the performance efficiency as a percentage for the studied wastewater treatment plants was performed by the following equation (Gajewska *et al*., 2018):

$$\textbf{Overall removal efficiency of pollutant}\ (\%) = \frac{(\mathrm{Cin} - \mathrm{Cout})}{\mathrm{Cin}} \times 100$$

Where

C_{in}, C_{out} : Concentration of the pollutant in the influent wastewater, and the effluent (mg/L) respectively of the selected WWTP.

12. An assessment and comparison of the performance efficiency for the treatment stages of the selected WWTP.

13. An estimation of the mass removal rate of Sarra and Hajjah WWTPs is performed by the following equation (Gajewska *et al*., 2018):

Mass removal rate (MRR)= $q\times[C_{in}-C_{out}]$ ($g.m^{-2}.d^{-1}$)

14. Estimation of the rat constant (K_{BOD}) of Sarra and Hajjah WWTPs is performed by the following equation (Gajewska *et al*., 2018; Abdelhakeem *et al*., 2016):

$$\frac{\mathbf{Cout}}{\mathbf{Cin}} = \mathbf{e}^{-(\frac{\mathbf{KA}}{\mathbf{q}})}$$

Where

C_{out}, C_{in} : Concentration of the pollutant (mg/L) in the effluent and the influent respectively of the selected WWTP.

K_A : Decomposition constant rate area-based ($m.d^{-1}$).

q : The hydraulic loading rate ($m.d^{-1}$).

3.4 Analytical Methods and Instruments

The methods, instruments, tools that is used to measure different parameters during the research are explained in the table below:

Table 3:1 Methods and instruments used for measurement water quality parameters of the wastewater samples

Parameter	Analytical method	Instrument used for analysis
EC	The electrical conductivity	JENWAY 4510 Conductivity meter
pH	The electrometric method	JENWAY 3510 pH meter
BOD_5	Incubation of samples in amber jars at 20 ^oC for five days	BOD sensor, VELP Scientifica
COD	The colorimetric method	LaMotte COD3 plus colorimeter.
DO and temperature	The dissolved Oxygen Meter	DO-5512SD
Total Nitrogen	The Kjeldahl method	Gerhardt Turbotherm (Digester), Gerhardt Vapodest (steam distillation apparatus)
Total phosphorus	The Persulfate Digestion method	JENWAY 7305 Spectrophotometer at 882 nm
TDS	The Gravimetric method	Filtration apparatus
TSS	The Gravimetric method	Filtration apparatus
Biological parameters	The Culture method	Pure Plate

Chapter Four

Results and Data Analysis

4.1 General

The presentation and interpretation of the results analysis and discussing the performance of the studied wetland plants are presented in the following sections.

The main physical, chemical and biological results for the collected samples from the studied wetland plants represent an average data value and a standard deviation in the following sections.

4.2 Sarra Wetland Plant for Wastewater Treatment

4.2.1 Physical Parameters

Table (4.1) presents the results of the samples analysis for the physical parameters of Sarra wetland plant. The parameters present analysis results of the wastewater samples which had been taken from four points during three different dates of three months to represent all the treatment stages inside the plant (from Oct 2018 to Feb. 2019).

Table 4:1 Results of physical parameters for Sarra plant.

Parameter	Treatment Stage	Average Value	STDEV
EC (ms/cm)	S1	1.77	0.094
	S2	1.99	0.15
	S3	1.80	0.13
	S4	1.83	0.17
pH	S1	6.98	0.085
	S2	7.06	0.04
	S3	7.13	0.060
	S4	7.24	0.052
TDS (mg/L)	S1	1184.6	54.24
	S2	1328	42.2
	S3	1245	44.5
	S4	1276.3	83.26
DO (mg/L)	S1	0.466	0.20
	S2	0.63	0.15
	S3	0.93	0.75
	S4	1.26	1.02
Temperature ^{0}C	S1	21.63	5.75
	S2	21.13	6.15
	S3	20.43	6.95
	S4	17.63	4.97

S1: the influent wastewater, S2: after primary treatment and before VF beds stage, S3: after VF beds and before HF beds stage, S4: after HF beds stages (effluent).

As presented in table (4.1), for pH, the mean value increased slightly between the influent and the effluent. The average of pH value in the influent was 6.98 and the average effluent value was 7.24 tend to be slightly base may be due to the increase of TDS. In terms of EC value also it increased slightly between the influent and the effluent. The average of EC value in the influent was 1.77 ms/cm and the average effluent value was 1.83 ms/cm. The average influent value of TDS was 1184.6 mg/L, the average value increased after the primary treatment stage to 1328 mg/L due to the mineralization process and the degradation of organic matter, while the average effluent value decreased to 1276.3 mg/L may be due to the uptake of the elements through roots of the plant. The mean influent value of DO was 0.466 mg/L and the mean effluent value was 1.26 mg/L.

4.2.1.1 Correlation of The Physical Parameters

As presented in table (4.2) the SPSS version 23 package was used to assess the statistical significant correlation between the physical parameters.

Table 4:2 Correlation of physical parameters for Sarra WWTP.

		EC	pH	TDS	DO	Temp.
EC	Pearson Correlation	1	-.008	.904*	-.122	.106
	Sig. (2-tailed)		.992	.050	.878	.894
pH	Pearson Correlation	-.008	1	.412	.994**	-.951*
	Sig. (2-tailed)	.992		.588	.006	.049
TDS	Pearson Correlation	.904*	.412	1	.307	-.280
	Sig. (2-tailed)	.050	.588		.693	.720
DO	Pearson Correlation	-.122	.994**	.307	1	-.954*
	Sig. (2-tailed)	.878	.006	.693		.046
Temp.	Pearson Correlation	.106	-.951*	-.280	-.954*	1
	Sig. (2-tailed)	.894	.049	.720	.046	
**. Correlation is significant at the 0.01 level (2-tailed).						
*. Correlation is significant at the 0.05 level (2-tailed).						

From table (4.2). For pH no significant correlation at the level of ($\alpha \leq 0.05$) with EC and TDS; while it's found a significant correlation at the level of ($\alpha \leq 0.05$) with DO, and an inverse significant correlation at the level of ($\alpha \leq 0.05$) with temperature. For the DO inverse significant correlation at the level of ($\alpha \leq 0.05$) with temperature. For EC no significant correlation at the level of ($\alpha \leq 0.05$) with DO and temperature; while it's found significant correlation at the level of ($\alpha \leq 0.05$) with TDS. For TDS no significant correlation at the level ($\alpha \leq 0.05$) with DO and temperature.

4.2.2 Chemical Parameters

The results analysis of the chemical parameters for Sarra wetland plant are presented in the following sections.

4.2.2.1 Biochemical Oxygen Demand (BOD_5)

From figure (4.1) the mean influent BOD_5 value was 746 mg/L and decreased to 503 mg/L after the primary treatment stage with difference in the average values between before and after treatment stage which was 243 mg/L. The mean value of the effluent VF beds was125.6 mg/L. The difference in the mean values between before and after every one of the treatment stage achieved highest value in the effluent of the VF beds which was 377.4 mg/L due to the removal efficiency of the treatment stage. The mean effluent value of the final treatment stage (HF beds) was 43 mg/L with difference in the mean values between before and after the treatment stage was 82.6 mg/L. According to the Palestinian obligatory technical specifications (PSI 34-2012) the mean effluent value was found above the maximum value of grade C and below grade D, which means that the effluent characteristics of this WWTP related to the BOD_5 is low quality.

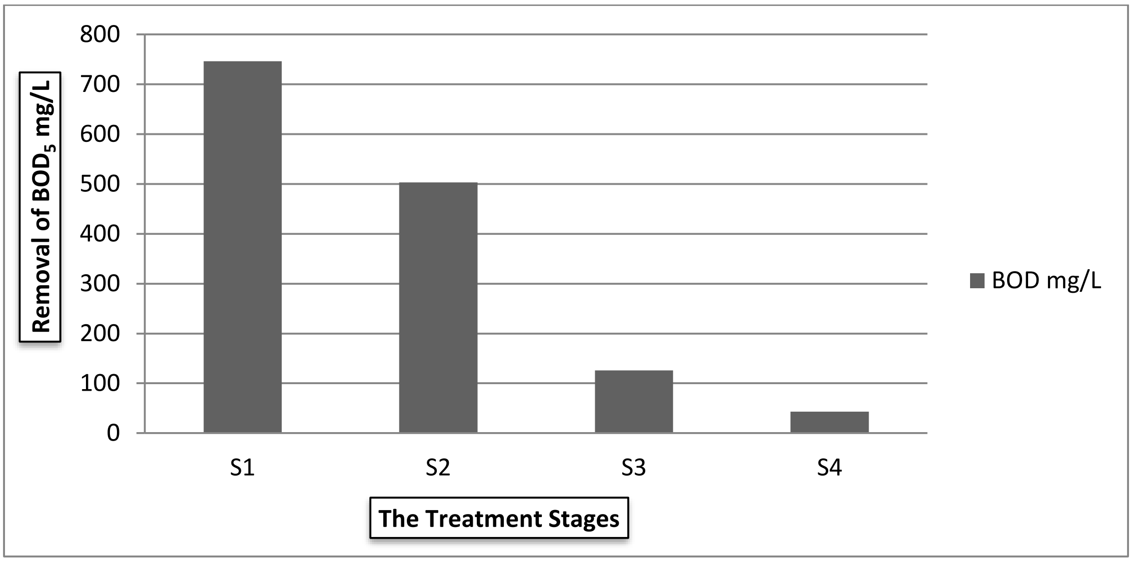


Figure (4.1). Removal of BOD_5 across the treatment stages of Sarra WWTP.

4.2.2.2 Chemical Oxygen Demand (COD)

From figure (4.2) the mean influent of COD value was 1562 mg/L and decreased to 1035 mg/L after the primary treatment stage with difference in the average values between before and after the treatment stage which was 527 mg/L. The mean value of the effluent VF beds was 265 mg/L. The difference in the mean values between before and after for every one of the treatment stage achieved highest value in the effluent of the VF beds which was 770 mg/L due to the removal efficiency of the treatment stage. The mean effluent value of the final treatment stage (HF beds) was 94.3 mg/L with difference in the mean values between before and after the treatment stage which was 170.7 mg/L. According to the Palestinian obligatory technical specifications (PSI 34-2012) the mean effluent value was found below the maximum value of the grade C, which means that the effluent characteristics of this WWTP related to COD is medium quality.

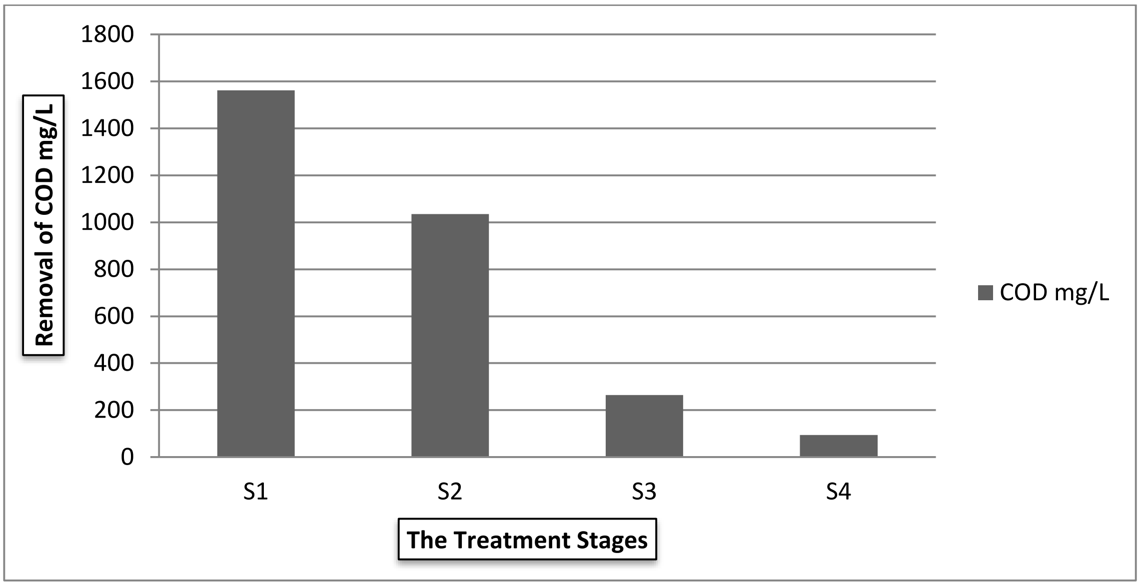


Figure (4.2). Removal of COD across the treatment stages of Sarra WWTP.

4.2.2.3 Total Suspended Solids (TSS)

From figure (4.3) the mean influent TSS value was 1283 mg/L and decreased to 868.3 mg/L after the primary treatment stage with difference in the average values which was 414.7 mg/L. The mean value of the effluent VF beds was 169.3 mg/L. The difference in the mean values between before and after for each one of the treatment stage achieved highest value in the effluent of the VF beds which was 699 mg/L due to the removal efficiency of the treatment stage. The mean effluent value of the final treatment stage (HF beds) was 83.3 mg/L with difference in the mean values between before and after the treatment stage was 86 mg/L. According to the Palestinian obligatory technical specifications (PSI 34-2012) the mean effluent value was found below the allowed maximum value of grade D, which means that the effluent characteristics of this WWTP related to TSS is low quality.

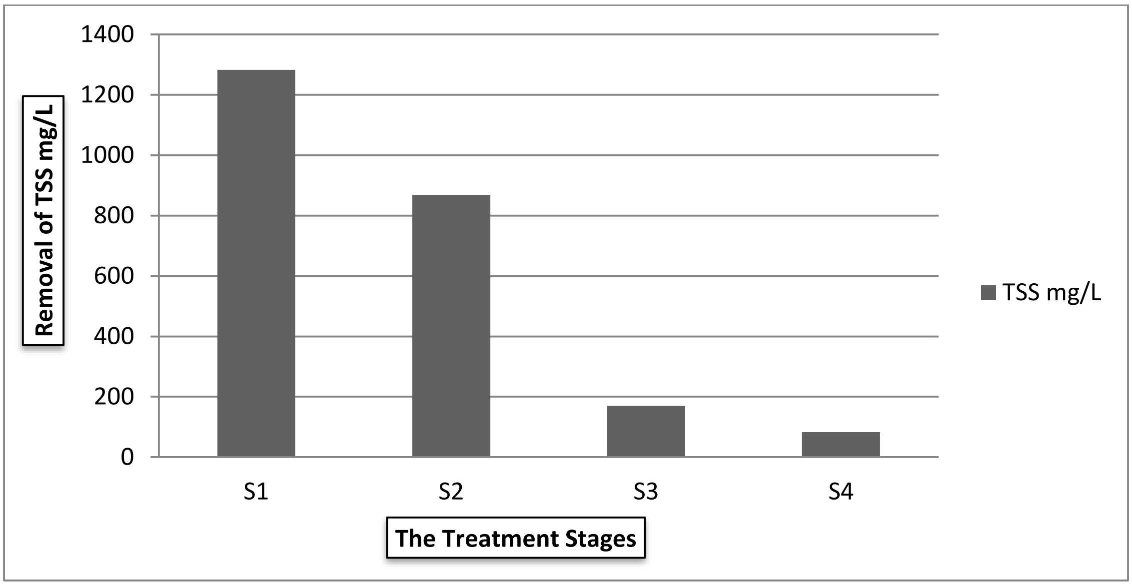


Figure (4.3). Removal of TSS across the treatment stages of Sarra WWTP.

4.2.2.4 Removal of Total Nitrogen (TN)

The high concentrations in TN were detected in the influent and effluent throughout the research period; the average influent concentration was 177.7 mg/L and decreased to 154 mg/L after the primary treatment stage with difference in the average values which was 23.7 mg/L. The mean value of the effluent VF beds was 135.3 mg/L with difference in the average values between before and after the treatment stage was 18.7 mg/L. The difference in the mean values between before and after for each one of the treatment stage achieved the highest value in the Primary treatment due to the biodegradation of the organic nitrogen; nitrogen removal was not only due to ammonia removal but also due to the organic nitrogen removal. The mean effluent of the final treatment stage (HF beds) was 119.4 mg/L with difference in the mean values between before and after the treatment stage was 15.9 mg/L. According to the Palestinian obligatory technical specifications (PSI 34-2012) the mean effluent value was found above the allowed maximum value, which means that the effluent characteristics of this WWTP related to TN is failed to meet (PSI 34-2012); the efficiency of this WWTP in removing the TN from the wastewater is very low.

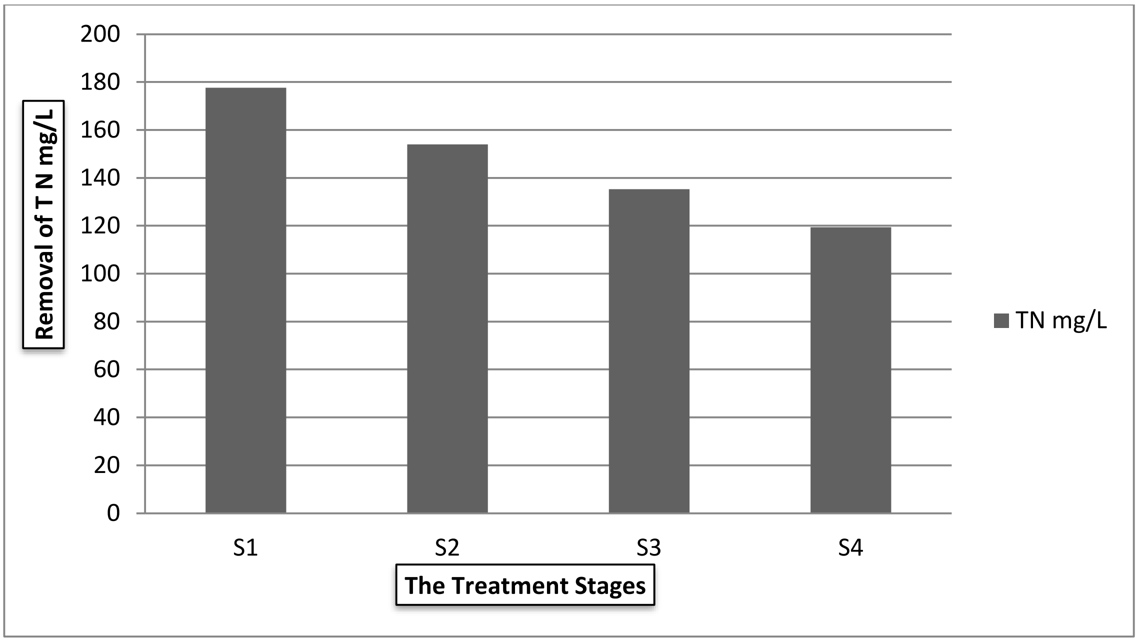


Figure (4.4). Removal of TN across the treatment stages of Sarra WWTP.

4.2.2.5 Removal of Total Phosphorus (TP)

A low concentrations of TP were detected in the influent and the effluent values throughout the research period; the average influent and effluent concentrations were 28.7 mg/L, 20 mg/L respectively. According to the Palestinian obligatory technical specifications (PSI 34-2012) the allowed maximum value of ($P\text{-}PO_4^{-3}$) is 30 mg/L, which means that the effluent characteristics of this WWTP related to TP is high quality.

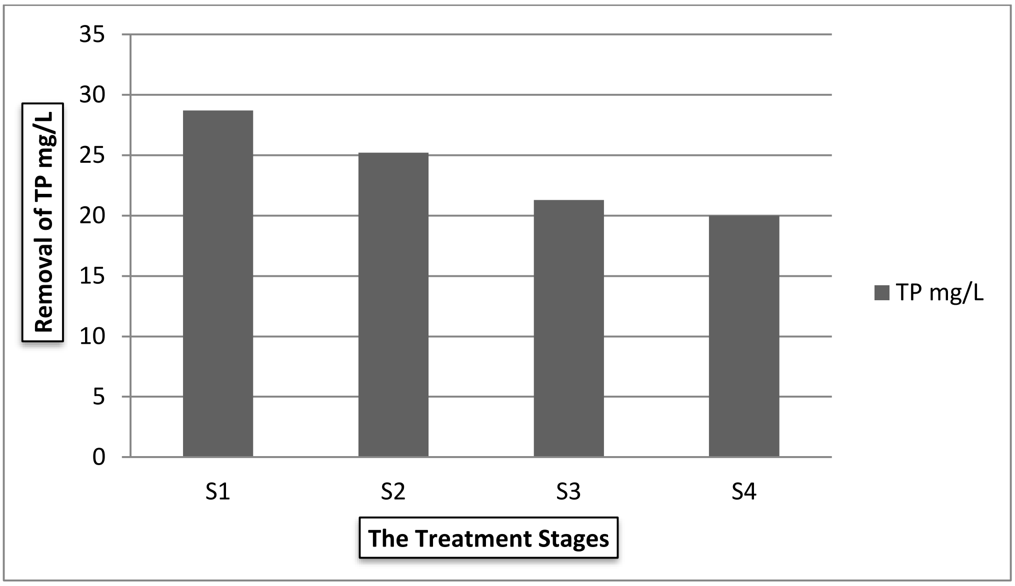


Figure (4.5). Removal of TP across the treatment stages of Sarra WWTP.

4.3 Hajjah Wetland Plant for Wastewater Treatment

4.3.1 Physical Parameters

Table (4.3) presents the samples results analysis for the physical parameters of Hajjah wetland plant. The parameters present the analysis of the wastewater samples results which had been taken from four points during three different months to represent all the treatment stages inside the plant (from Oct 2018 to Feb. 2019).

Table 4:3 Results of physical parameters for Hajjah plant

Parameter	Treatment Stage	Average Value	STDEV
EC (ms/cm)	H1	1.585	0.127
	H2	1.556	0.127
	H3	1.635	0.140
	H4	1.660	0.117
pH	H1	6.91	0.090
	H2	7.23	0.078
	H3	7.3	0.086
	H4	7.54	0.068
TDS (mg/L)	H1	1088.3	36.5
	H2	1043.6	73.9
	H3	1069	98.2
	H4	1074.3	125.5
DO (mg/L)	H1	0.83	0.15
	H2	0.7	0.2
	H3	1.03	0.4
	H4	1.57	1.4
Temperature ^{0}C	H1	21.5	4.9
	H2	18.6	4.2
	H3	18.8	4.3
	H4	18.3	4.6

H1: influent wastewater, H2: after primary treatment and before VF beds stage, H3: after VF beds and before HF beds stage, H4: after HF beds stages (effluent).

As shown in table (4.3), for pH, the mean value increased between the influent and the effluent. The average of pH value in the influent was 6.91 and the average effluent value was 7.54. In the terms of EC value also slightly increased between the influent and the effluent. The average of EC value in the influent was 1.585 ms/cm and the average of the effluent value was 1.660 ms/cm. the average of the influent value of TDS was 1088.3 mg/L, the mean value decreased after the primary treatment stage to 1043.6 mg/L could be due to the sedimentation process, while the average of the effluent increased to 1074.3 mg/L. The mean influent value of DO was 0.83 mg/L and the mean effluent value was 1.57 mg/L.

4.3.1.1 Correlation of The Physical Parameters

As presents in table (4.4) the SPSS version 23 package was used to assess the statistical significant correlation between the physical parameters.

Table 4:4 Correlations of physical parameters

		pH	EC	TDS	DO	Temp.
pH	Pearson Correlation	1	.689	-.311	.923	-.909
	Sig. (2-tailed)		.311	.689	.252	.091
EC	Pearson Correlation	.689	1	.437	.901	-.381
	Sig. (2-tailed)	.311		.563	.286	.619
TDS	Pearson Correlation	-.311	.437	1	-.496	.662
	Sig. (2-tailed)	.689	.563		.670	.338
DO	Pearson Correlation	.923	.901	-.496	1	-.804
	Sig. (2-tailed)	.252	.286	.670		.406
Temp.	Pearson Correlation	-.909	-.381	.662	-.804	1
	Sig. (2-tailed)	.091	.619	.338	.406	

From in table (4.4). No significant correlation at the level of ($\alpha \leq 0.05$) between the results of the physical parameters for the Hajjah WWTP.

4.3.2 Chemical Parameters

The results analysis of the chemical parameters for Hajjah wetland plant are presented in the following sections.

4.3.2.1 Biochemical Oxygen Demand (BOD_5)

From the figure (4.6) the mean influent of BOD_5 value was 506 mg/L and decreased to 373.6 mg/L after the primary treatment stage with difference in the average values between before and after treatment stage was 132.4 mg/L. The mean value of the effluent VF beds which was 100.3 mg/L. The difference in the mean values between before and after for each one of the treatment stage achieved the highest value in the effluent of the VF beds which was 273.3 mg/L due to the removal efficiency of the treatment stage. The mean effluent value of the final treatment stage (HF beds) was 39 mg/L with difference in the mean values between before and after the treatment stage which was 61.3 mg/L. According to the Palestinian obligatory technical specifications (PSI 34-2012) the mean effluent value was found below the maximum value of grade C, which means that the effluent characteristics of this WWTP related to BOD_5 is medium quality.

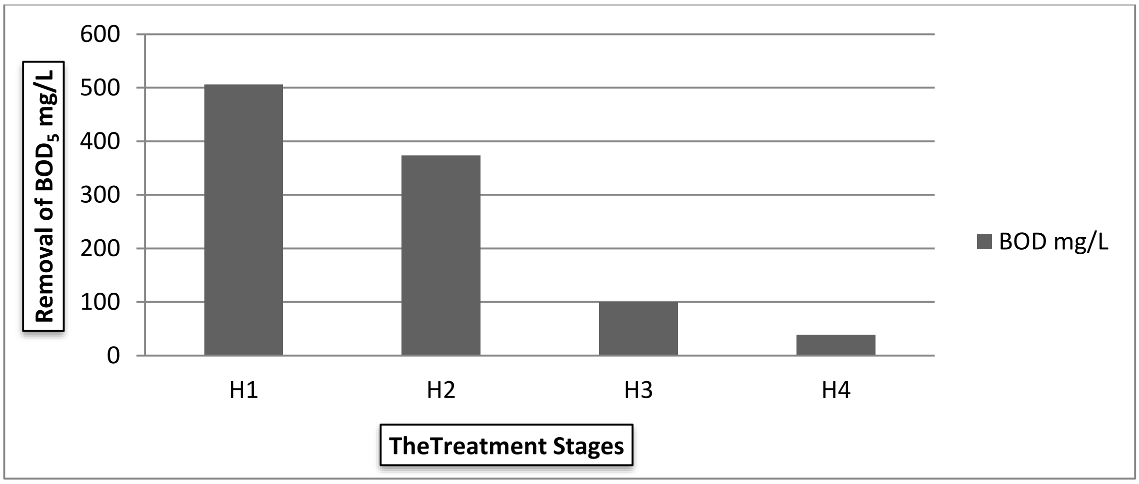


Figure (4.6). Removal of BOD_5 across the treatment stages of Hajjah WWTP.

4.3.2.2 Chemical Oxygen Demand (COD)

From figure (4.7) the mean influent of COD value was 1074.6 mg/L and decreased to 791.6 mg/L after the primary treatment stage with difference in the average values between before and after treatment stage was 283 mg/L. The mean value of the effluent VF beds was 178.3 mg/L. The difference in the mean values between before and after for each one of the treatment stage achieved the highest value in the effluent of the VF beds which was 613.3 mg/L due to the removal efficiency of the treatment stage. The mean effluent value of the final treatment stage (HF beds) was 74.6 mg/L with difference in the mean values between before and after treatment stage which was 103.7 mg/L. According to the Palestinian obligatory technical specifications (PSI 34-2012) the mean effluent value was found below the maximum value of grade C, which means that the effluent characteristics of this WWTP related to the COD is medium quality.

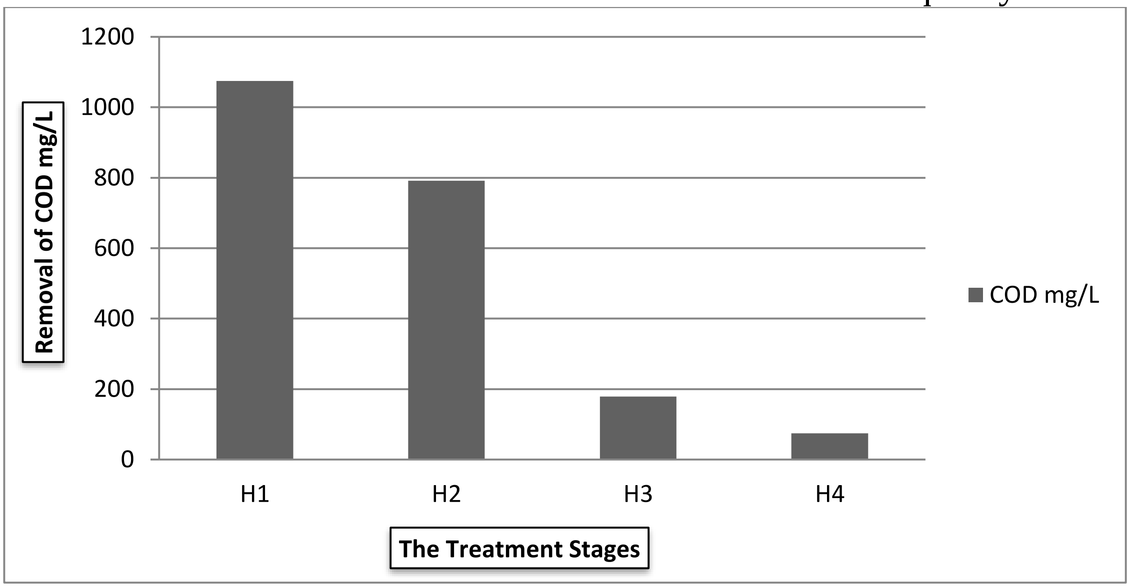


Figure (4.7). Removal of COD across the treatment stages of Hajjah WWTP.

4.3.2.3 Total Suspended Solids (TSS)

From the figure (4.8) the mean influent of TSS value was 1016.3 mg/L and decreased to 796.6 mg/L after the primary treatment stage with difference in the average values was 219.7 mg/L. The mean value of effluent VF beds was 232.3 mg/L. The difference in the mean values between before and after for each one of the treatment stage achieved the highest value in the effluent of the VF beds which was 564.3 mg/L due to the removal efficiency of the treatment stage. The mean effluent value of the final treatment stage (HF beds) was 82.3 mg/L with difference in the mean values between before and after the treatment stage was 150 mg/L. According to the Palestinian obligatory technical specifications (PSI 34-2012) the mean effluent value was found below the allowed maximum value of the grade D, which means that the effluent characteristics of this WWTP related to the TSS is low quality.

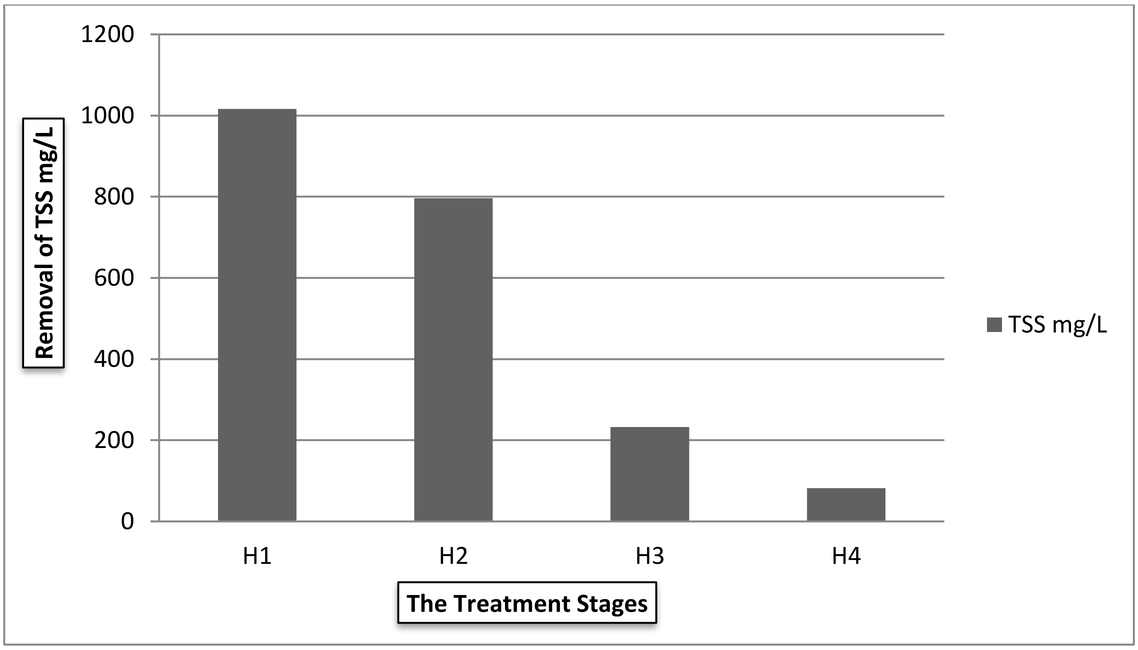


Figure (4.8). Removal of TSS across the treatment stages of Hajjah WWTP.

4.3.2.4 Removal of Total Nitrogen (TN)

From figure (4.9) the average influent concentration of TN was 168.3 mg/L and decreased to142.4 mg/L after the primary treatment stage with difference in the average values which was 25.9 mg/L. The mean value of the effluent VF CW was 114.9 mg/L with difference in the average values between before and after treatment stage was 27.7 mg/L. The mean effluent of the final treatment stage (HF beds) was 72 mg/L with difference in the mean values between before and after the treatment stage was 42.7 mg/L. The difference in the mean values between before and after for each one of the treatment stage achieved the highest value in the treatment stage of HF beds could be due to the de-nitrification process because of the prevailing of anaerobic conditions. According to the Palestinian obligatory technical specifications (PSI 34-2012) the mean effluent value was found bellow the maximum value of the grade D, which means that the effluent characteristics of this WWTP related to the TN is low quality.

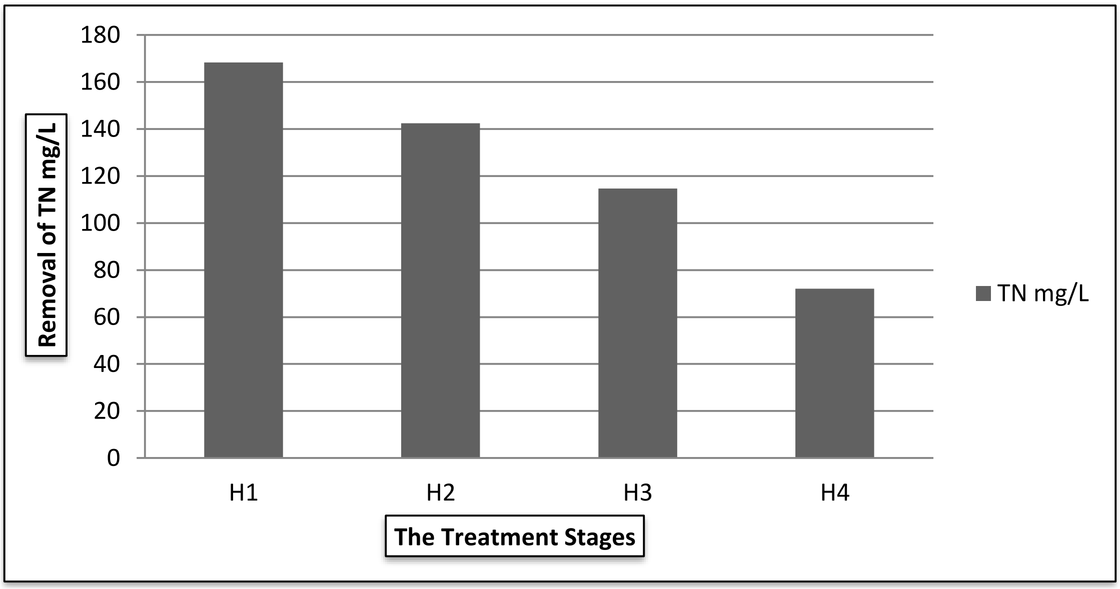


Figure (4.9). Removal of TN across the treatment stages of Hajjah WWTP.

4.3.2.5 Removal of Total Phosphorus (TP)

From figure (4.10) low concentrations of TP were detected in the influent and the effluent values throughout the research period; the average of the influent and the effluent concentrations were 22.4 mg/L, 13.8 mg/L respectively. According to the Palestinian obligatory technical specifications (PSI 34-2012) the allowed maximum value of the ($P\text{-}PO_4^{-3}$) is 30 mg/L, which means that the effluent characteristics of this WWTP related to the TP is high quality.

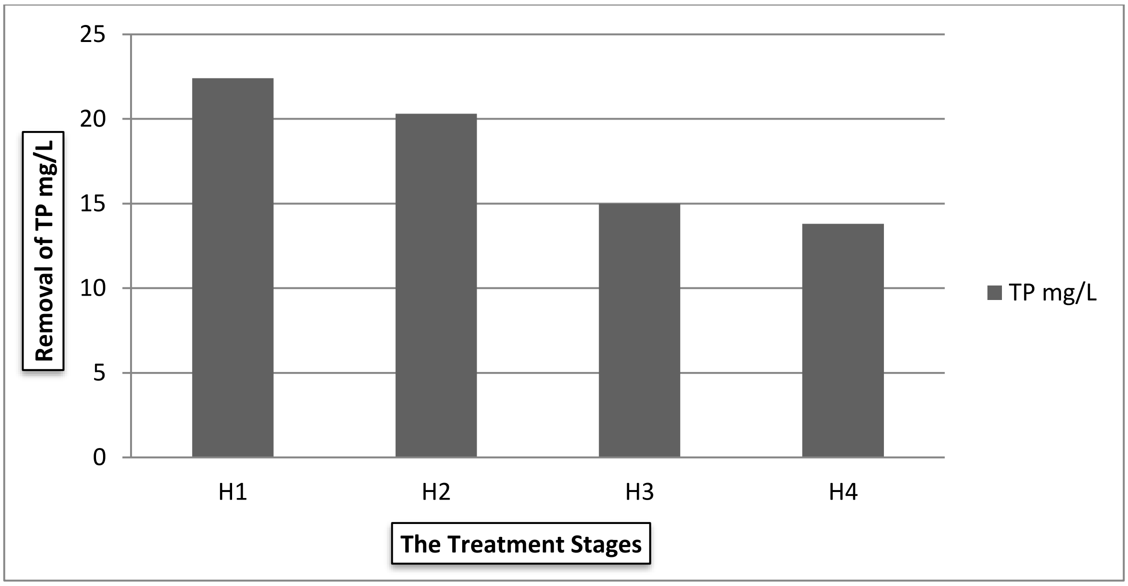


Figure (4.10). Removal of TP across the treatment stages of Hajjah WWTP.

4.4 Misillya Wetland Plant for Wastewater Treatment

4.4.1 Physical Parameters

Table (4.5) presents the results of the samples analysis for the physical parameters of Misillya wetland plant. The parameters present the analysis results of the wastewater samples which had been taken from four points during three different months to represent all the treatment stages inside the plant (from Sep. to Nov. 2018).

Table 4:5 Results of physical parameters for Misillya plant

Parameter	Treatment Stage	Average Value	STDEV
EC (ms/cm)	M1	2.143	0.211
	M2	2.002	0.066
	M3	1.879	0.088
pH	M1	7.53	0.332
	M2	7.89	0.257
	M3	7.58	0.136
TDS (mg/L)	M1	1590.1	116.5
	M2	1200.4	74.6
	M3	1079.4	84.1
DO (mg/L)	M1	0.6	0.1
	M2	0.86	0.25
	M3	1.26	1.4
Temperature ^{0}C	M1	24.8	2.3
	M2	23.7	3.0
	M3	23.8	2.9

M1: influent wastewater, M2: From recirculation/feeding manhole, M3: effluent wastewater from CWs.

As shown in table (4.5) for pH; the mean value in the influent was 7.52; and increased after the recirculation stage in the feeding manhole to 7.89; and the mean effluent value of the CWs decreased to 7.58. In terms of EC; the mean value in the influent was 2.143 ms/cm and the mean value decreased after the recirculation stage to 2.002 ms/cm, the mean effluent value of the CWs was 1.879 ms/cm. For TDS; the mean influent value was 1590.1 mg/L, mean value increased after the recirculation stage to 1200.4 mg/L, while the mean effluent value of the CWs was 1079.4 mg/L. The mean influent value of DO was 0.60 mg/L and increased after the recirculation stage to 0.86 mg/L while the mean effluent value was 1.26 mg/L.

4.4.1.1 Correlation of The Physical Parameters

As presents in table (4.6) the SPSS version 23 package was used to assess the statistical significant correlation between the physical parameters.

Table 4:6 Correlations of physical parameters

		pH	EC	TDS	DO	Temp.
pH	Pearson Correlation	1	-.167	-.411	.007	-.670
	Sig. (2-tailed)		.893	.730	.996	.532
EC	Pearson Correlation	-.167	1	.968	-.987	.844
	Sig. (2-tailed)	.893		.163	.103	.361
TDS	Pearson Correlation	-.411	.968	1	-.914	.952
	Sig. (2-tailed)	.730	.163		.265	.198
DO	Pearson Correlation	.007	-.987	-.914	1	-.747
	Sig. (2-tailed)	.996	.103	.265		.463
Temp.	Pearson Correlation	-.670	.844	.952	-.747	1
	Sig. (2-tailed)	.532	.361	.198	.463	

From table (4.6). No significant correlation at the level ($\alpha \leq 0.05$) between the results of the physical parameters for Misillya WWTP.

4.4.2 Chemical Parameters

The results analysis of the chemical parameters for Misillya wetland plant are presented in the following sections.

4.4.2.1 Biochemical Oxygen Demand (BOD_5)

From the figure (4.11) the mean influent of BOD_5 value was 916.6 mg/L and decreased to 189 mg/L after the recirculation stage with difference in the average values between before and after the recirculation stage which was 727.6 mg/L. The mean value of the effluent of the CW beds was 66.6 mg/L. The difference in the mean values between before and after the CW beds was 122.4 mg/L due to the removal efficiency of the treatment stage in the CW beds. According to the Palestinian obligatory technical specifications (PSI 34-2012) the mean effluent value was above the maximum value of the grade D, which means that the effluent characteristics of this WWTP regarding the BOD_5 fail to meet with the (PSI 34-2012). The reasonable explanation for these results may be due to the uncompleted maturity of the beds which mean it's still not reached the steady-state.

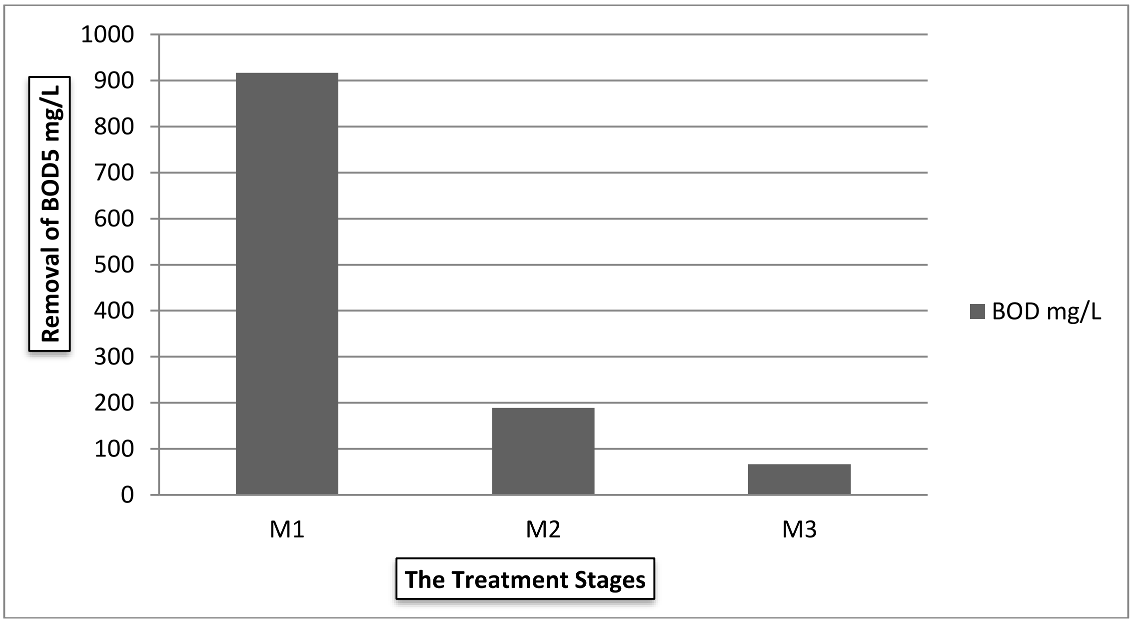


Figure (4.11). Removal of BOD_5 across the treatment stages of Misillya WWTP.

4.4.2.2 Chemical Oxygen Demand (COD)

From Figure (4.12) the mean influent of COD value was 975.7 mg/L and decreased to 534.2 mg/L after the recirculation stage with difference in the average values between before and after the treatment stage which was 441.5 mg/L. The mean value in the effluent of the CW beds was 78.4 mg/L. The difference in the mean values between before and after the CW beds was 455.8 mg/L due to the removal efficiency of the treatment stage. According to Palestinian obligatory technical specifications (PSI 34-2012) the mean effluent value was below the maximum value of grade C, which means that the effluent characteristics of this WWTP regarding the COD is medium quality.

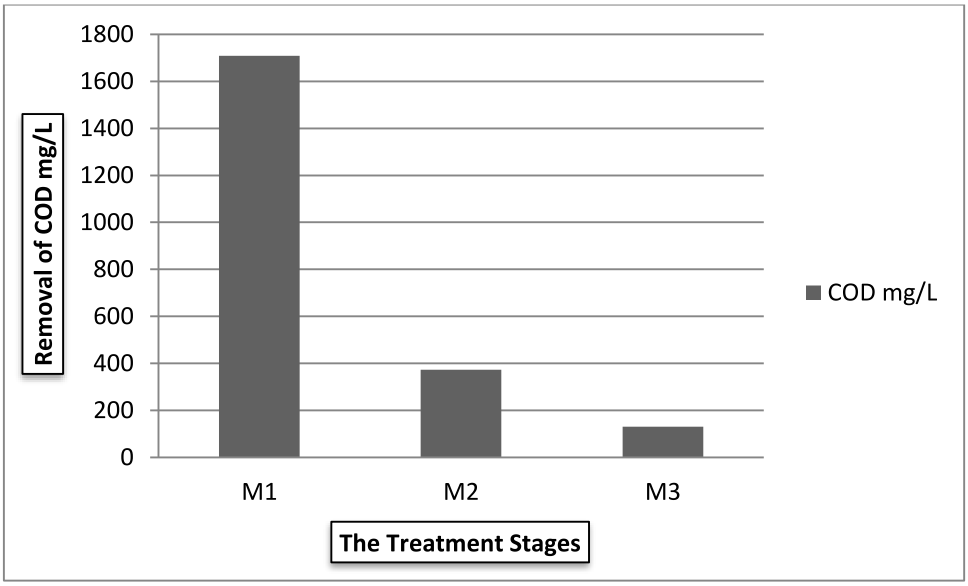


Figure (4.12). Removal of COD across the treatment stages of Misillya WWTP.

4.4.2.3 Total Suspended Solids (TSS)

From Figure (4.13) the mean influent of TSS value was 975.7 mg/L and decreased to 534.2 mg/L after the recirculation stage with difference in the average values which was 441.5 mg/L. The mean effluent value of the CW beds was 78.4 mg/L. The difference in the mean values between before and after the CW beds was 455.8 mg/L due to the removal efficiency of the treatment stage. According to the Palestinian obligatory technical specifications (PSI 34-2012) the mean effluent value was below the allowed maximum value of the grade D, which means that the effluent characteristics of this WWTP regarding the TSS is low quality.

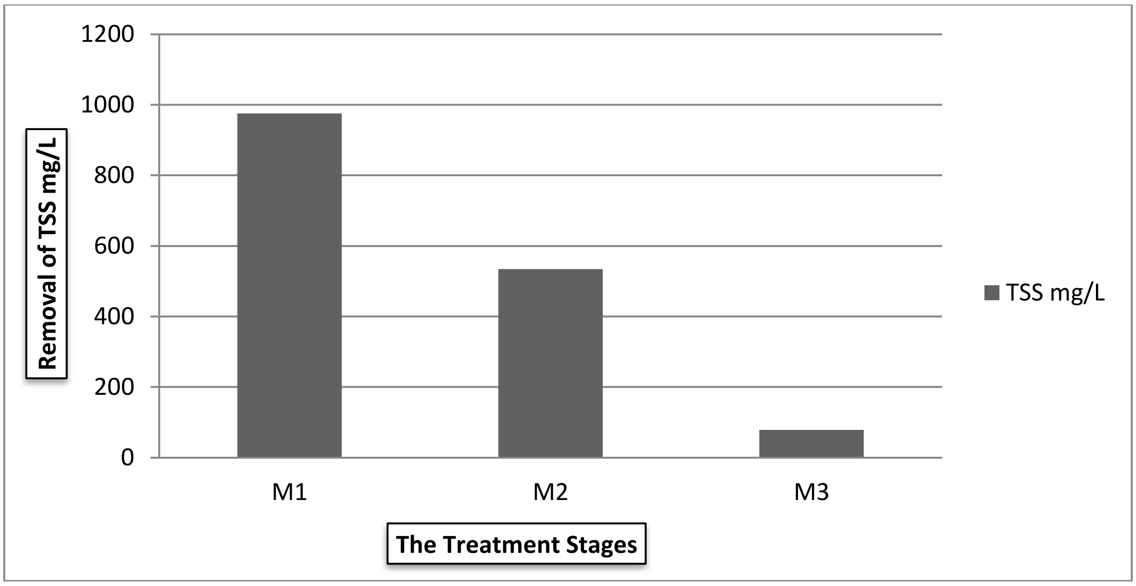


Figure (4.13). Removal of TSS across the treatment stages of Misillya WWTP.

4.4.2.4 Removal of Total Nitrogen (TN)

From figure (4.14) the average influent concentration of TN was 125.7 mg/L and decreased to 94.7 mg/L after the recirculation stage with difference in the average values which was 31 mg/L. The mean effluent value of the CW beds was 44.5 mg/L with difference in the average values between before and after the treatment stage was 50.2 mg/L. According to the Palestinian obligatory technical specifications (PSI 34-2012) the mean effluent value was bellow the maximum value of grade C, which means that the effluent characteristics of this WWTP regarding the TN is medium quality.

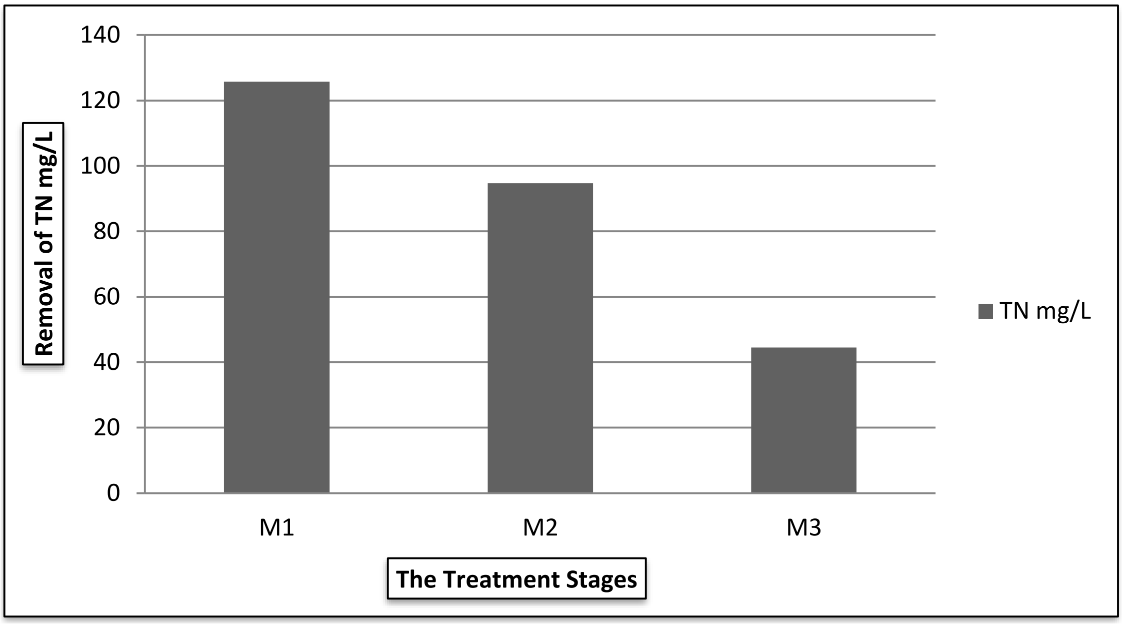


Figure (4.14). Removal of TN across the treatment stages of Misillya WWTP.

4.4.2.5 Removal of Total Phosphorus (TP)

Low concentrations of TP were detected in the influent and the effluent values throughout the research period; the average of the influent and the effluent concentrations was19.7 mg/L, 6.26 mg/L respectively. According to the Palestinian obligatory technical specifications (PSI 34-2012) the allowed maximum value of the ($P\text{-}PO_4^{-3}$) is 30 mg/L, which means that the effluent characteristics of this WWTP regarding the TP is high quality.

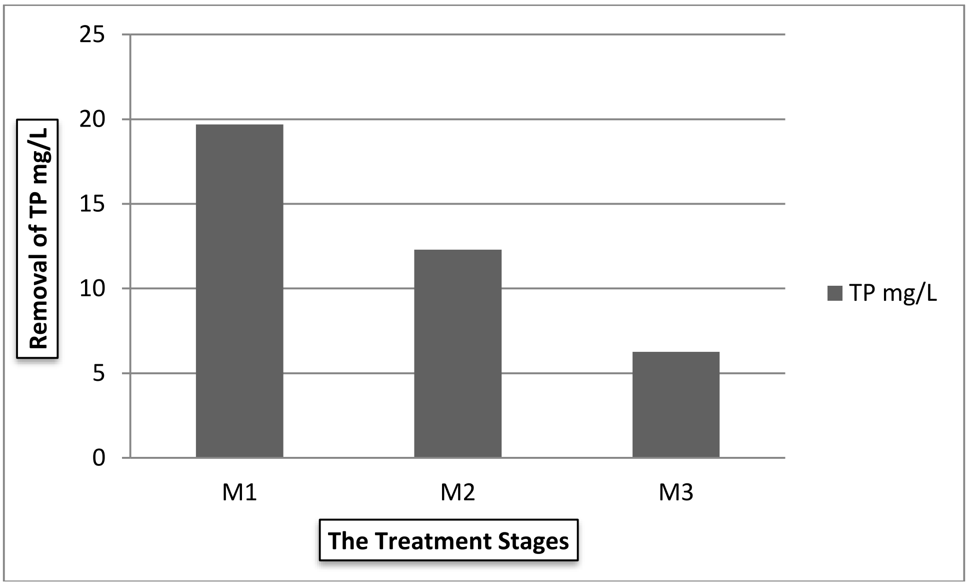


Figure (4.15). Removal of TP across the treatment stages of Misillya WWTP.

4.5 BietHasan Wetland Plant for Wastewater Treatment

4.5.1 Physical Parameters

Table (4.7) presents the results of the samples analysis for the physical parameters of BeitHasan wetland plant. The parameters present the result analysis of the wastewater samples which had been collected during three different months (from Oct 2018 to Feb. 2019).

Table 4:1 Results of physical parameters for Biet Hasan plant

Parameter	Treatment Stage	Average Value	STDEV
EC (ms/cm)	Influent	2.1	0.34
	Effluent	2.97	0.07
pH	Influent	7.01	0.22
	Effluent	7.93	0.03
TDS (mg/L)	Influent	1254.6	74.2
	Effluent	1859.3	58.4
DO (mg/L)	Influent	0.56	0.11
	Effluent	1	0.10
Temperature ^{0}C	Influent	27.7	3.23
	Effluent	22.9	2.59

As shown in table (4.7) for pH; the mean value in the influent was 7.01 and the mean effluent value increased to 7.58. In terms of EC; the mean value in the influent was 2.1 ms/cm and the mean effluent value was 2.97 ms/cm. For TDS; the mean influent value was 1254.6 mg/L, the mean effluent value was 1859.3 mg/L. The mean influent of DO was 0.56 mg/L and the mean effluent value was 1 mg/L.

4.5.2 Chemical Parameters

The results analysis of the chemical parameters for BeitHasan wetland plant are presented in the following sections.

4.5.2.1 Biochemical Oxygen Demand (BOD_5)

From Figure (4.16) the mean influent of BOD_5 value was 481.6 mg/L. The mean effluent value of the CW beds was 65 mg/L. The difference in the mean values between the influent and the effluent of the plant was 416.6 mg/L due to the efficiency treatment of the plant. According to the Palestinian obligatory technical specifications (PSI 34-2012) the mean effluent value was above the maximum value of the grade D, which means that the effluent characteristics of this WWTP regarding the BOD_5 failed to meet with (PSI 34-2012).

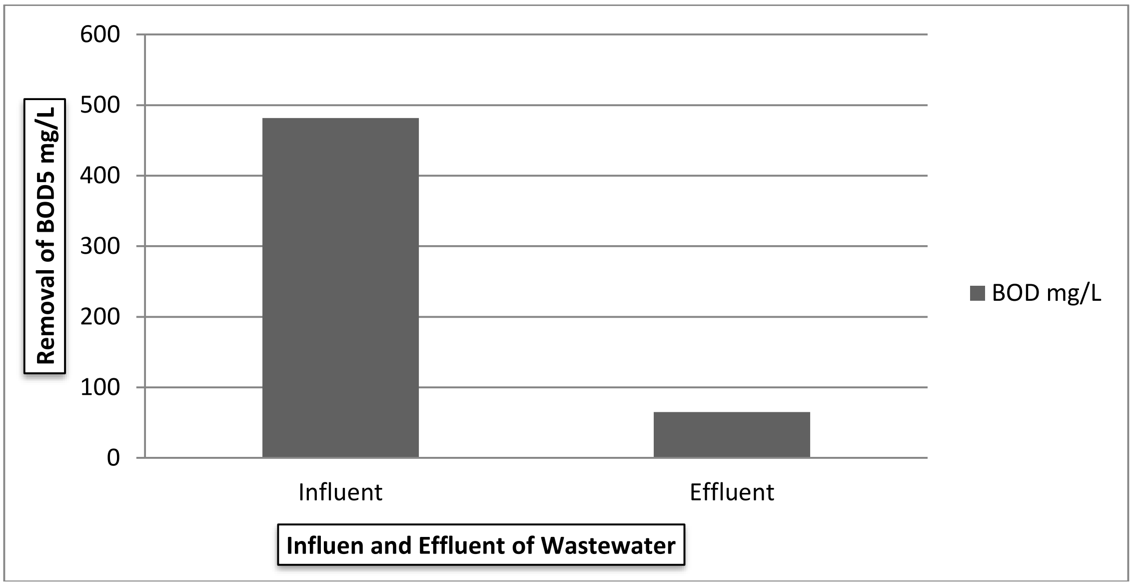


Figure (4.16) Performance of BeitHasan WWTP for BOD_5 removal.

4.5.2.2 Chemical Oxygen Demand (COD)

From figure (4.17) the mean influent of COD value was 948.6 mg/L. The mean effluent value of the CW beds was 150.6 mg/L. The difference in the mean values between the influent and the effluent of the plant was 789 mg/L due to the efficiency treatment of the plant . According to the Palestinian obligatory technical specifications (PSI 34-2012) the mean effluent value was around the maximum value of the grade D, which means that the effluent characteristics of this WWTP regarding the COD is low quality.

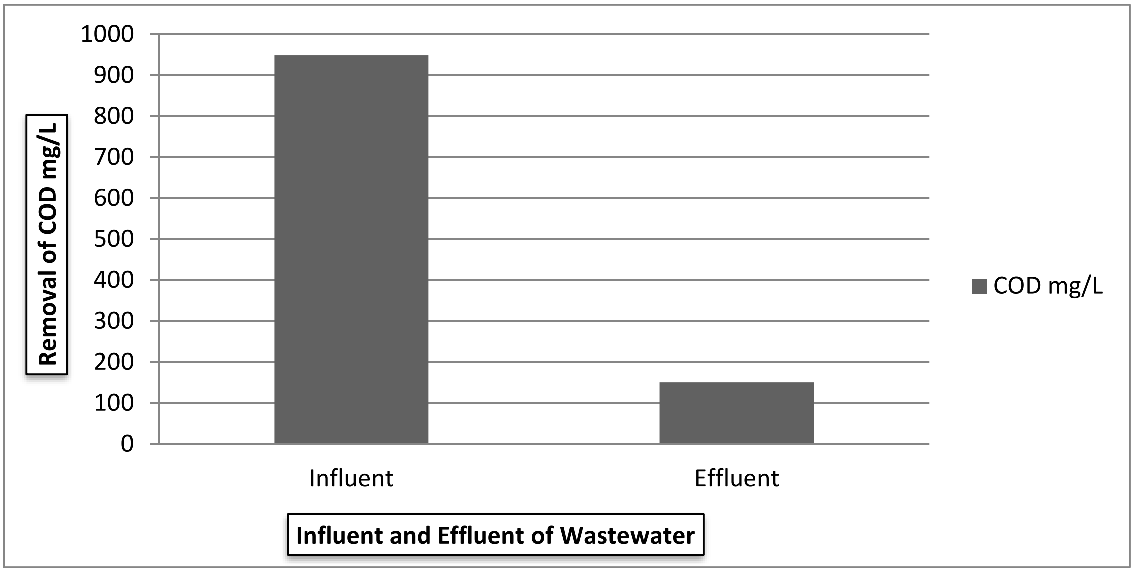


Figure (4.17). Performance of Beit Hasan WWTP for COD removal.

4.5.2.3 Total Suspended Solids (TSS)

From figure (4.18) the mean influent of TSS value was 1175.3 mg/L. The mean effluent value of the CW beds was 180 mg/L. The difference in the mean values between the influent and the effluent of the plant was 995.3 mg/L due to the efficiency treatment of the plant. According to the Palestinian obligatory technical specifications (PSI 34-2012) the mean effluent value was above the maximum value of the grade D, which means that the effluent characteristics of this WWTP regarding the TSS fail to meet with (PSI 34-2012).

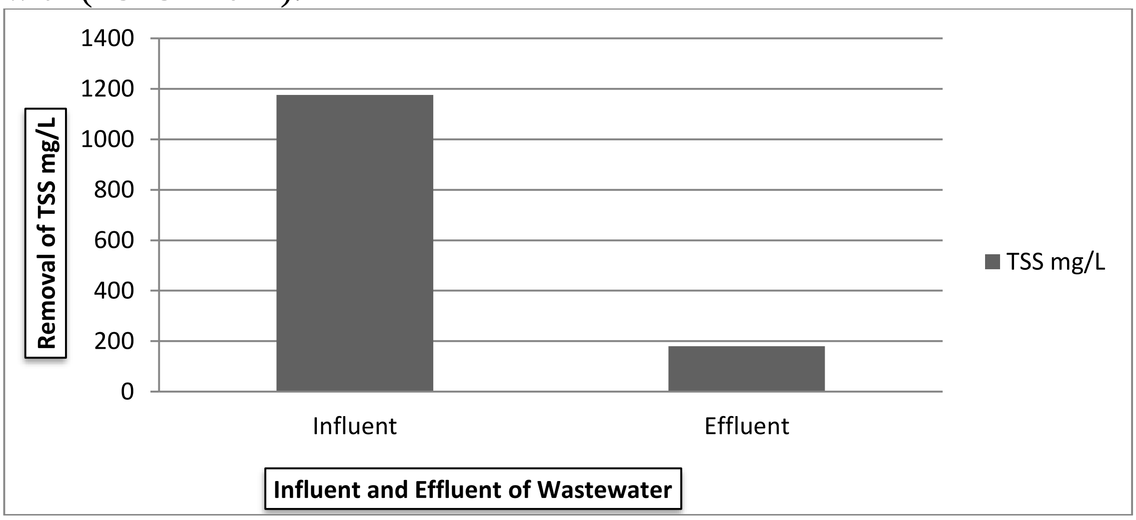


Figure (4.18). Performance of BeitHasan WWTP for TSS removal.

4.5.2.4 Removal of Total Nitrogen (TN)

From figure (4.19) the mean influent concentration of TN was 128.4 mg/L. The mean effluent value of the CW beds was 54.5 mg/L. The difference in the mean values between the influent and the effluent of the plant was 73.9 mg/L due to the efficiency treatment of the plant. According to the Palestinian obligatory technical specifications (PSI 34-2012) the mean effluent value was bellow the maximum value of the grade D, which means that the effluent characteristics of this WWTP regarding the TN is low quality.

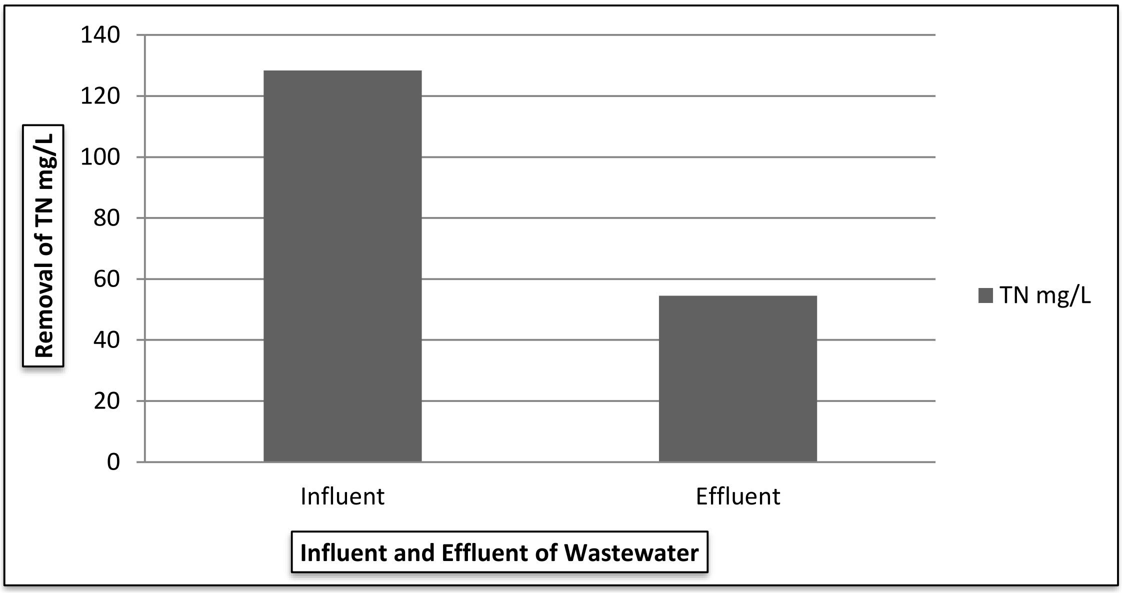


Figure (4.19) Performance of Beit Hasan WWTP for TN removal.

4.5.2.5 Removal of Total Phosphorus (TP)

Low concentrations in TP were detected in the influent and the effluent throughout the research period; the average of the influent and the effluent concentrations was 20.9 mg/L, 13.2 mg/L respectively. According to the Palestinian obligatory technical specifications (PSI 34-2012) the allowed maximum value of ($P\text{-}PO_4^{-3}$) is 30 mg/L, which means that the effluent characteristics of this WWTP regarding the TP is high quality.

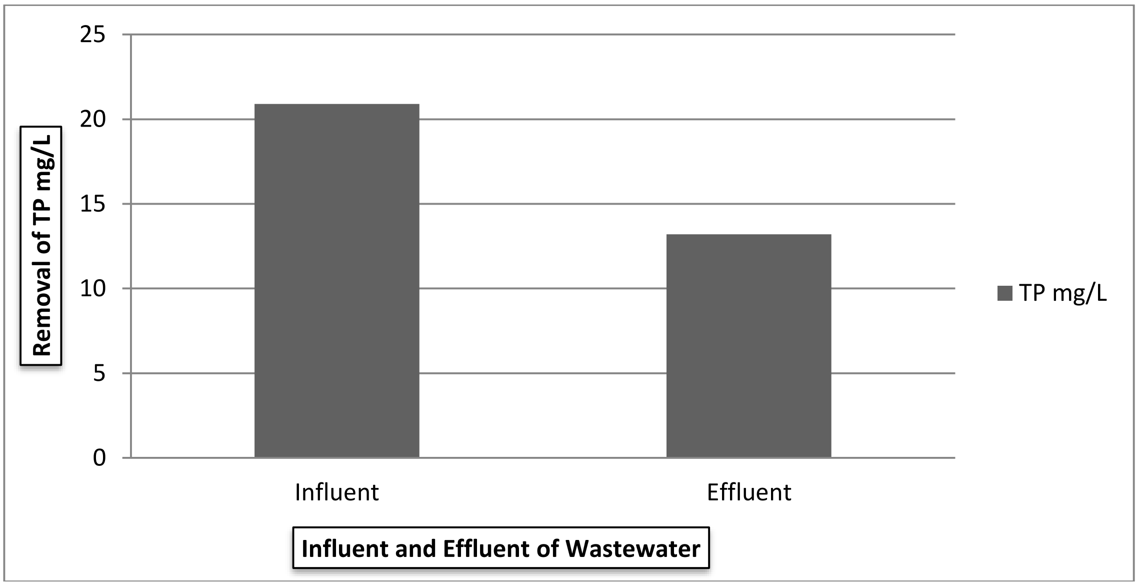


Figure (4.20) Performance of BeitHasan WWTP for TP removal.

4.6 The Performance Assessment of The Studied Wetland Plants for Removing Pollutants

4.6.1 Removal Efficiency of Biochemical Oxygen Demand (BOD_5)

From figure (4.21). In general, the performance efficiency of BOD_5 removal for the studied WWTPs was close between 92% to 94% except of BeitHasan WWTP. The removal efficiency achieved the highest performance in Sarra plant which was 94%, Misilliya plant came in the second and achieved 92% in the removal efficiency of BOD_5 compared to the other studied WWTPs was, then Hajjah plant achieved 92% in the removal efficiency of BOD_5. However, BeitHasan plant achieved the lowest performance compared to the other studied WWTPs; the removal efficiency of BOD_5 for BietHasan plant was 86.5%. Vymazal (2005) reported that the hybrid CW in case of the VF-HF system showed high removal efficiency of BOD_5. Dong *et al*., (2015) reported that the removal efficiency of the BOD_5 in case of the VF-HF hybrid CW was 97.6%. Xinshan *et al*., (2010) reported that the removal efficiency of the BOD_5 in case of the VF-HF hybrid CW was 94%. Öövel *et al*., (2007) reported that the removal efficiency of BOD_5 in case of the VF-HF hybrid CW was 94%. Troesch *et al*., (2014) reported that the removal efficiency of BOD_5 in the effluent of the French VF CW system was 97%.

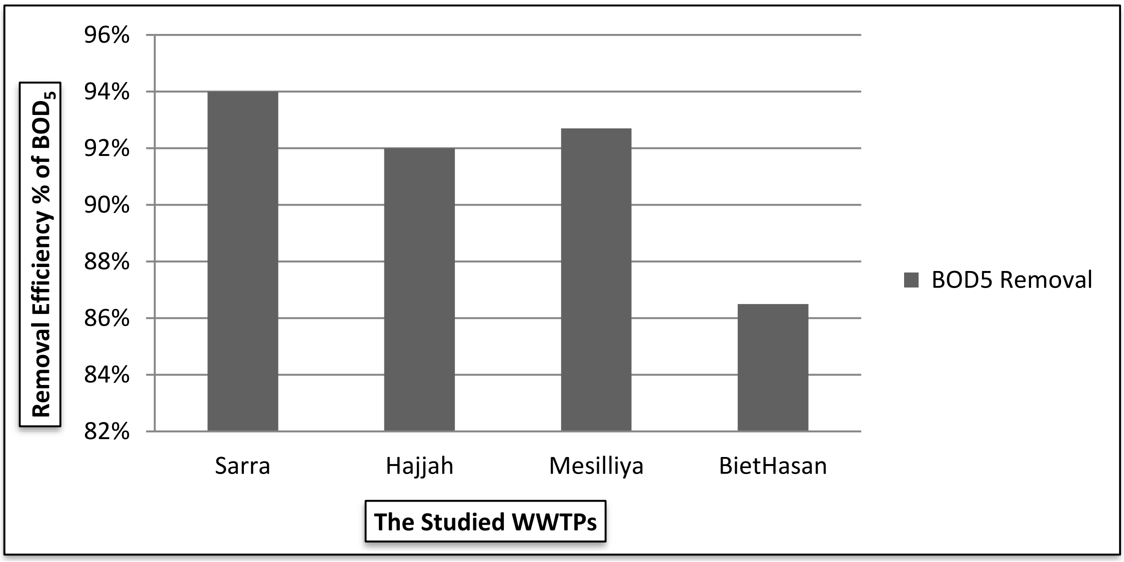


Figure (4.21). Performance efficiency of the studied WWTPs for BOD_5 removal.

4.6.2 Removal Efficiency of Chemical Oxygen Demand (COD)

From figure (4.22). In general, the performance efficiency of COD removal for the studied WWTPs was close to 92% and 94% except for BeitHasan plant.

The removal efficiency achieved the highest performance in Sarra plant which was 93.9%, Hajjah plant came in the second rank and achieved 92% in the removal efficiency of COD compared to the other studied WWTPs, then Misillya plant achieved 92% in the removal efficiency of COD. However, Beit Hasan plant achieved the lowest performance compared to the other studied WWTPs; the removal efficiency of COD for Biet Hasan plant was 84%. Xinshan *et al*., (2010) reported that the removal efficiency of COD in case of the VF-HF hybrid CW was 94%. Troesch *et al*., (2014) reported that the removal efficiency of COD in case of the French VF CW system was 92%.

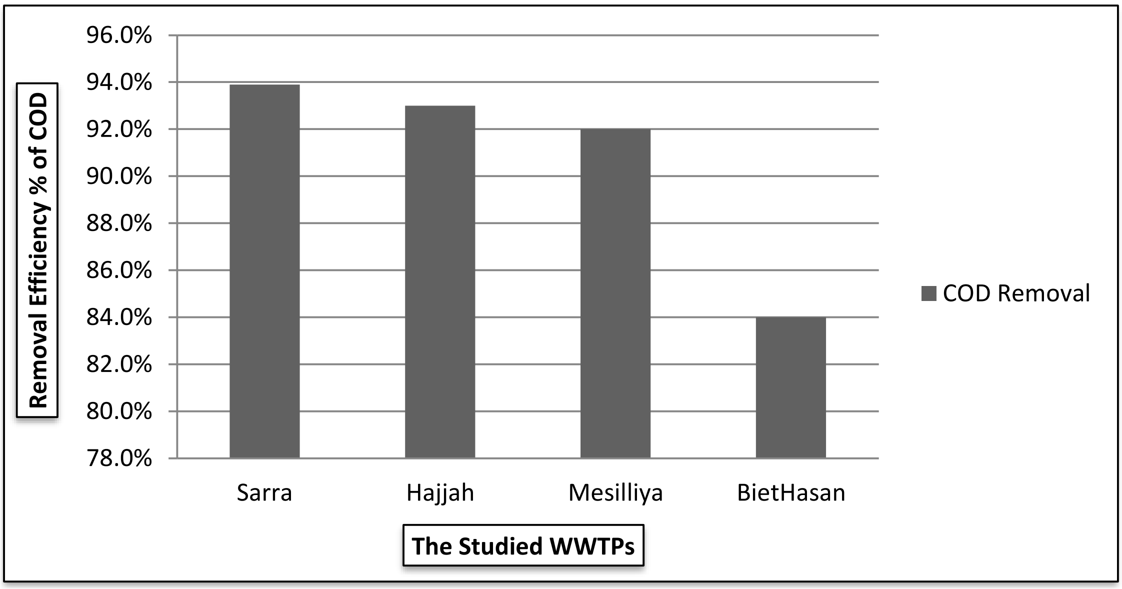
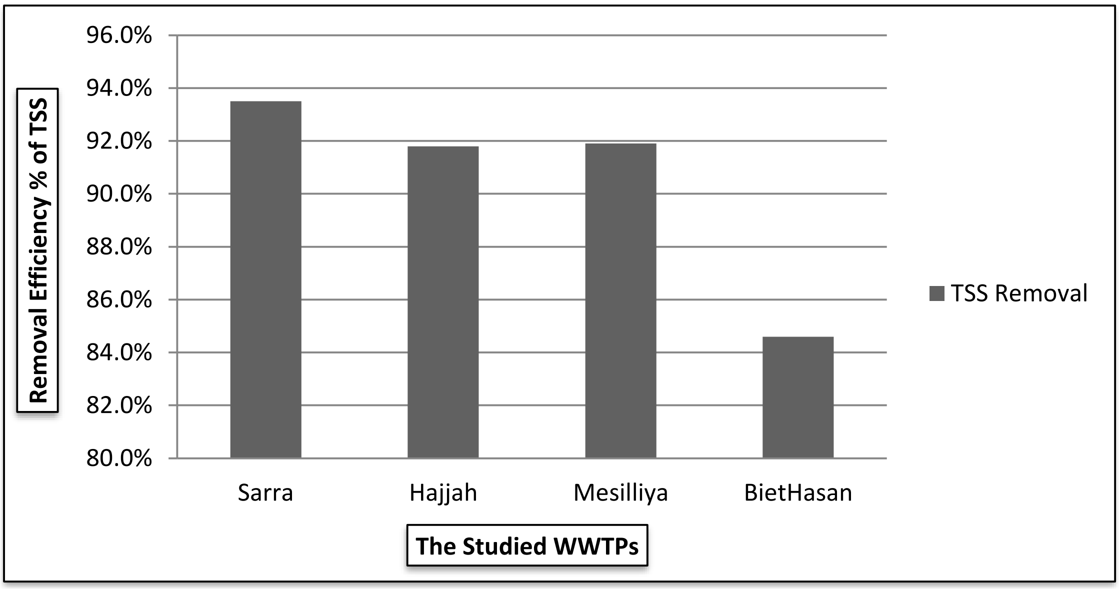


Figure (4.22). Performance efficiency of the studied WWTPs for COD removal.

4.6.3 Removal Efficiency of Total Suspended Solids (TSS)

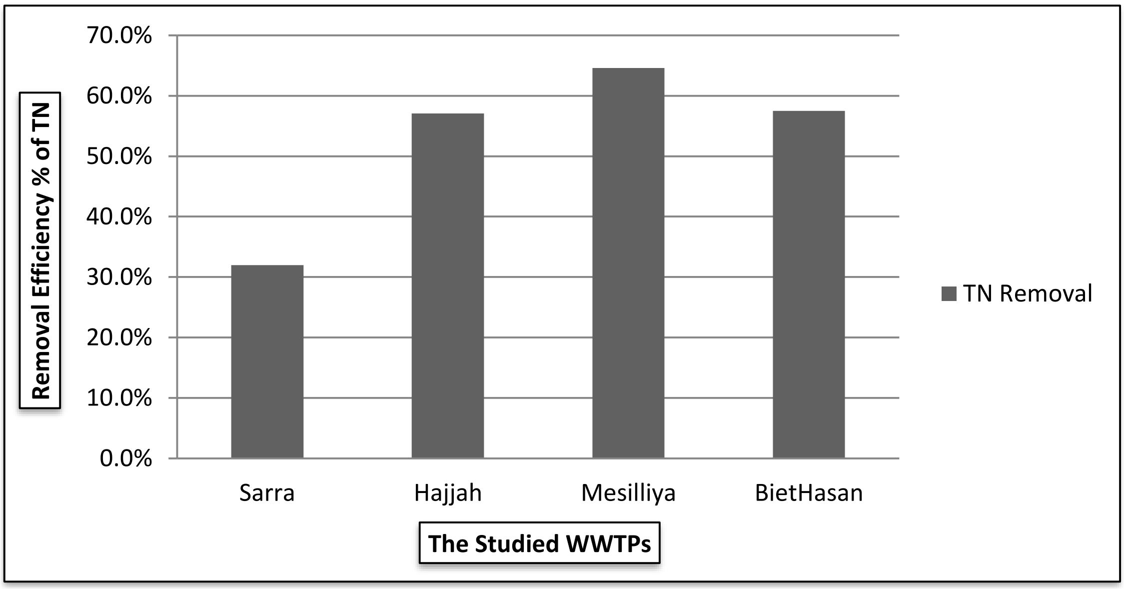
From figure (4.23). The removal efficiency of TSS achieved the highest performance in Sarra plant was 93.5%. The performance efficiency of TSS removal for Misillya and Hajjah plants was close to 92%, Misillya plant achieved removal efficiency of 91.9%, then Hajjah plant achieved removal efficiency of 91.8%. However, BeitHasan plant achieved the lowest performance compared to the other studied WWTPs; the removal efficiency of TSS for BietHasan plant was 84.6%. Vymazal (2005), reported that the hybrid CW in case of the VF-HF system showed high removal efficiency of TSS. Dong *et al*., (2015) reported that the removal efficiency of TSS in case of the VF-HF hybrid CW was 96.8%. Öövel *et al*., (2007) reported that the removal efficiency of TSS was 87%. Troesch *et al*., (2014) reported that the removal efficiency of TSS in the effluent of the French VF CW system was 97%.



Figure(4.23). Performance efficiency of the studied WWTPs for TSS removal.

4.6.4 Removal Efficiency of Total Nitrogen (TN)

From figure (4.24). The removal efficiency achieved the highest performance in Misillya plant which was 64.6%. The performance efficiency of TN removal for Hajjah and BietHasan plants was close to 57%, Beit Hasan plant came in the second rank achieved 57,5% removal efficiency of TN compared to the other studied WWTPs, then Hajjah plant achieved 57,1% in the removal efficiency of TN. However, Sarra plant achieved the lowest performance compared to the other studied WWTPs; the removal efficiency of TN for Sarra plant was 32%. Dong *et al*., (2015) reported that the removal efficiency of TN in case of the VF-HF hybrid CW was 41.4%. Xinshan *et al*., (2010) reported that the removal efficiency of TN in case of the VF-HF hybrid CW was 93%. Öövel *et al*., (2007) reported that the removal efficiency of TN in case of the VF-HF hybrid CW was 70%. Troesch *et al*., (2014) reported that the removal efficiency of TKN in the effluent of the French VF CW system was 90%.

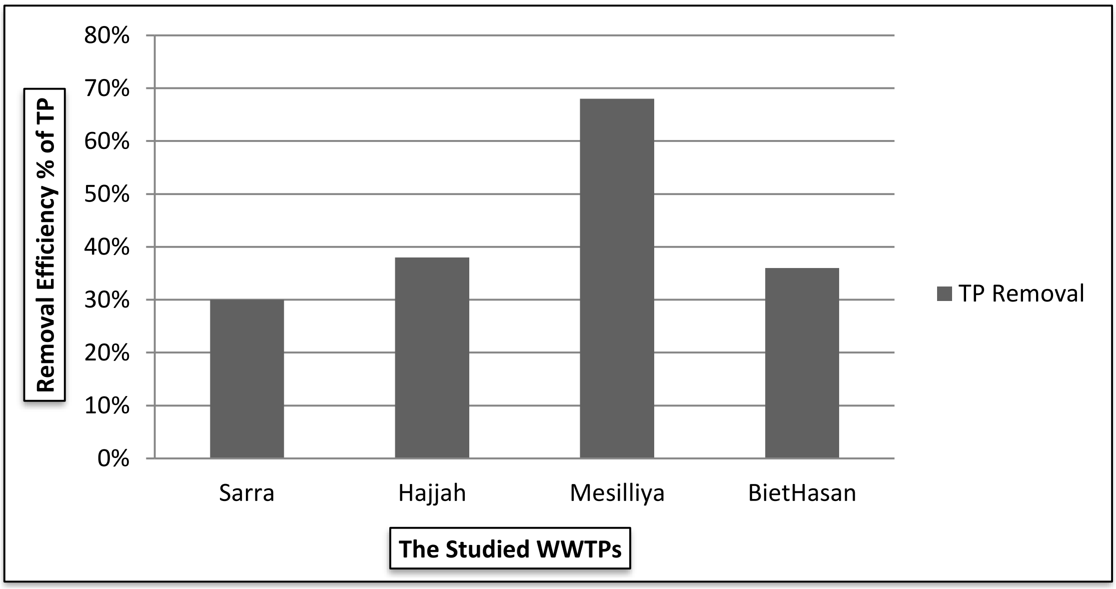


Figure(4.24). Performance efficiency of the studied WWTPs for TN removal.

4.6.5 Removal Efficiency of Total Phosphorus (TP)

From figure (4.25). In general, the performance efficiency of TP removal for the studied WWTPs was close between 30% to 38% except Misillya plant.

The removal efficiency achieved the highest performance in Msillya plant was 68%. Hajjah plant achieved 38% in the removal efficiency of TP, then BeitHasan plant achieved removal efficiency of 36%. However, Sarra plant achieved the lowest performance compared to the other studied WWTPs; the removal efficiency of TP for Sarra plant was 30%. Dong *et al*., (2015) reported that the removal efficiency of the TP in case of the VF-HF hybrid CW was 47%. Öövel *et al*., (2007) reported that the removal efficiency of TP in case of the VF-HF hybrid CW was 91%. . Troesch *et al*., (2014) reported that the removal efficiency of the TP in the effluent of the French VF CW system was 32%.



Figure(4.25). Performance efficiency of the studied WWTPs for TP removal.

4.7 The Performance Assessment for Treatment Stages of The Studied Wetland Plants

To compare the performance efficiency for the treatment stages of the studied WWTPs; the researcher divided the treatment stages for every studied WWTP into two main treatment stages as the following:

T1: the treatment stage of the primary treatment or the recirculation stage.

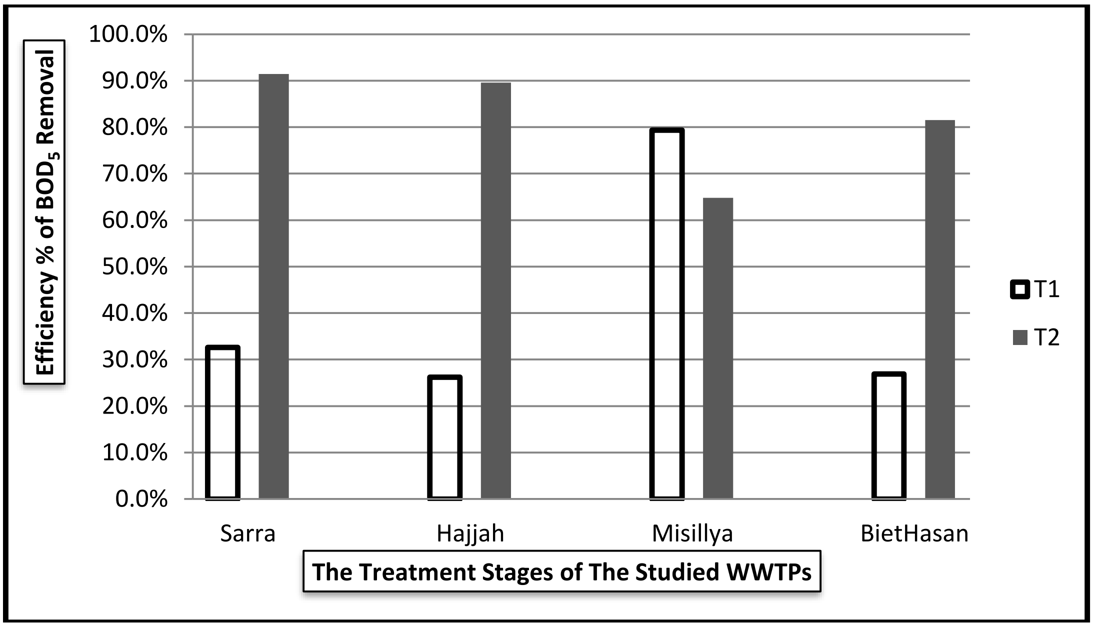
T2: the treatment stage of the CW beds as a single treatment stage (the wastewater effluent).

4.7.1 Removal efficiency of Biochemical Oxygen Demand (BOD_5)

From figure(4.26). In case of the T1 treatment stage, the removal efficiency achieved the highest performance compared to the other studied WWTPs in Misillya plant (where T1 represents the recirculation treatment stage) which was 79.4%. The performance efficiency for BOD_5 removal in Sarra, Hajjah and BietHasan plants (where T1 represents primary treatment stage) ranged between 26% and 32.6%. Depending on the above results, the treatment of the wastewater in the recirculation stage has the highest performance compared to the primary treatment stage for BOD_5 removal.

In case of the T2 treatment stage (CWs), the removal efficiency achieved the highest performance compared to the other studied WWTPs in Sarra plant was 91.5%. Hajjah WWTP came in the second rank and achieved 89.6% in the removal efficiency of BOD_5 compared to the other studied

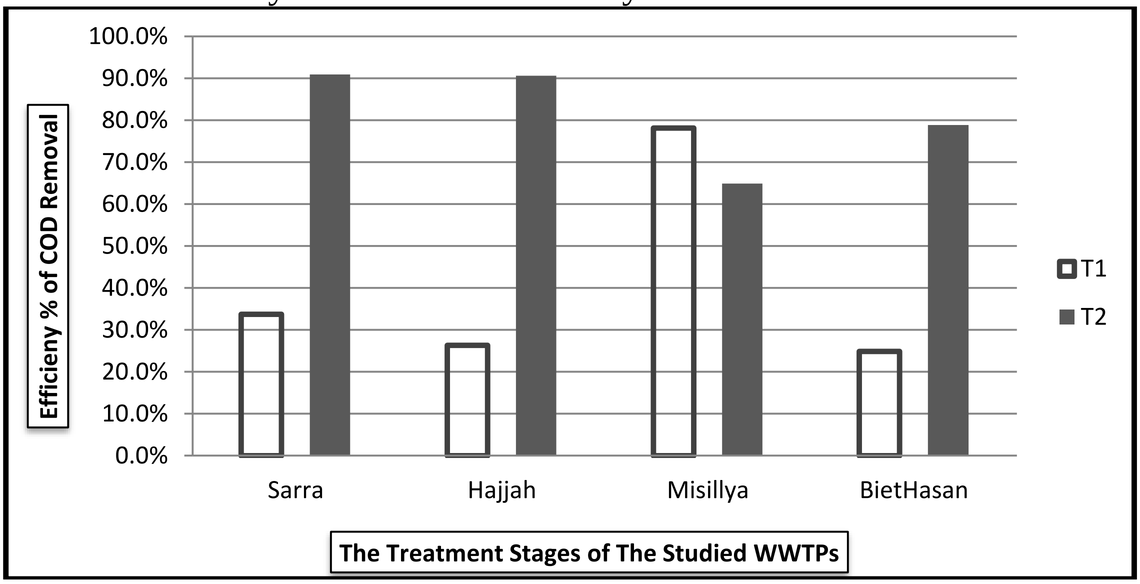
WWTPs, then BietHasan WWTP achieved 81.5% in the removal efficiency of BOD_5. Misillya WWTP achieved the lowest performance compared to the other studied WWTPs; the removal efficiency of BOD_5 for Misillya WWTP was 64.8%. Vymazal, (2005) reported that the performance efficiency for the primary treatment of BOD_5 in case of the hybrid CW plant at Dhulikhel, Nepal was 43%. Sun, *et al*., (2003) reported that the efficiency assessment for treating the agricultural wastewater after comparison between with recirculation and without recirculation in the whole system; the investigation results revealed that the average removal efficiency of BOD_5 without recirculation was 71.8%, whereas results was 96,7% when recirculation was employed. (Sun, *et al*., 2003). Prost- Boucle and Molle, (2012) reported that BOD_5 removal efficiency in recirculation stage for the French vertical CW with 50% flow rate was 86%.



Figure(4.26) Performance Efficiency of the treatment stages for BOD_5 removal.

4.7.2 Removal Efficiency of Chemical Oxygen Demand (COD)

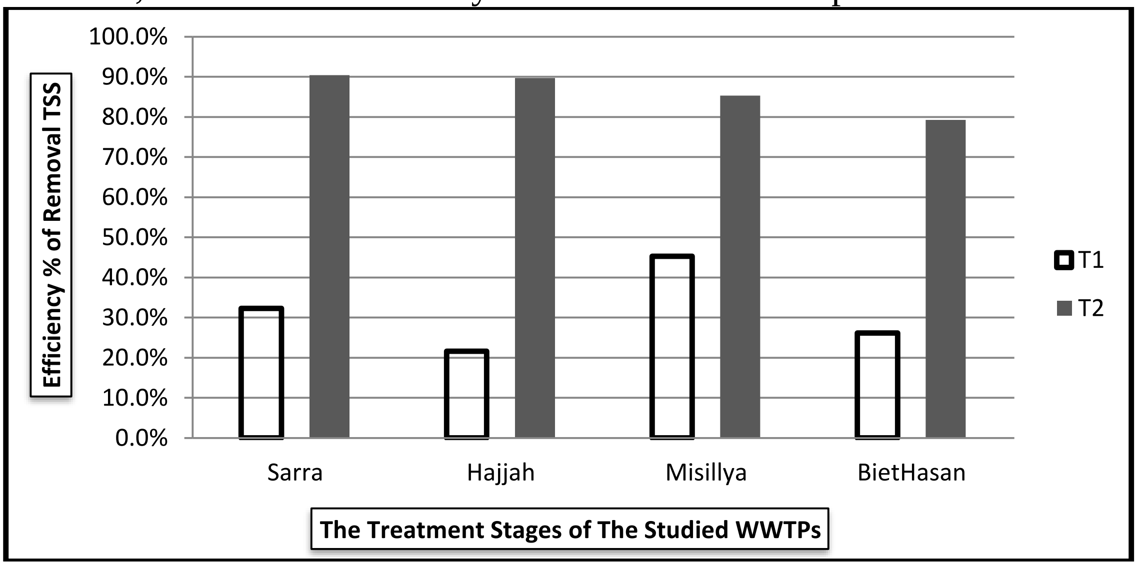
From figure(4.27). In case of the T1 treatment stage, the removal efficiency achieved the highest performance compared to the other studied WWTPs in Misillya WWTP (where T1 represents the recirculation treatment stage) which was 78.2%. The performance efficiency of COD removal in Sarra, Hajjah and BietHasan WWTPs (where the T1 represents primary treatment stage) ranged between 26% to 33.7%. Depending on the above results, the wastewater treatment in the recirculation stage has the highest performance compared to the primary treatment stage for COD removal. In case of the T2 treatment stage (CWs), the removal efficiency of COD for Sarra and Hajjah WWTPs was close 90.9%, 90.6% respectively. BietHasan WWTP achieved 78,9% in the removal efficiency of COD. Misillya WWTP achieved the lowest performance compared to the other studied WWTPs; the removal efficiency of the COD for Misillya WWTP was 64.9%.



Figure(4.27). Performance Efficiency of the treatment stages for COD removal.

4.7.3 Removal Efficiency of Total Suspended Solids (TSS)

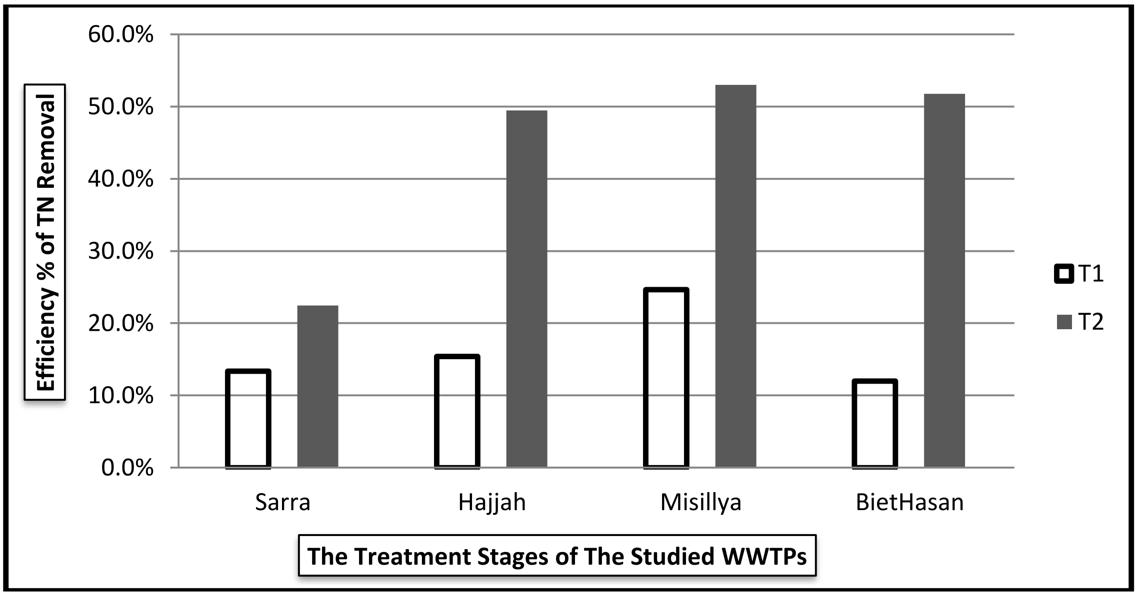
From figure(4.28). In case of theT1 treatment stage, the removal efficiency achieved the highest performance compared to the other studied WWTPs in Misillya plant (where T1 represents recirculation treatment stage) which was 45.2%. The performance efficiency of TSS removal in Sarra, Hajjah and BietHasan WWTPs (where the T1 represents the primary treatment stage) ranged between 21.1% to 32.3%. Depending on the above results, the wastewater treatment in the recirculation stage has the highest performance compared to the primary treatment stage for TSS removal. In case of the T2 treatment stage (CWs), the removal efficiency achieved the highest performance compared to the other studied WWTPs in Sarra plant was 90.4%. Hajjah plant came in the second rank and achieved 899.7% in the removal efficiency of TSS compared to the other studied WWTPs, then Misillya plant achieved 85.3% in the removal efficiency of TSS. BietHasan plant achieved the lowest performance compared to the other studied WWTPs; the removal efficiency of TSS for BietHasan plant was 79.3%.



Figure(4.28). Performance Efficiency of the treatment stages for TSS removal.

4.7.4 Removal Efficiency of Total Nitrogen (TN)

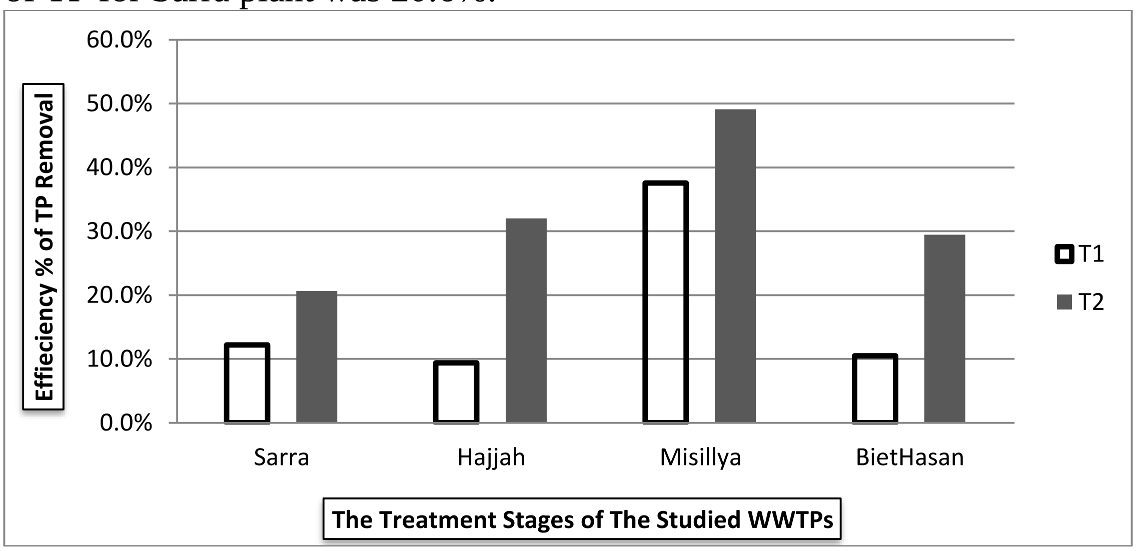
From figure(4.29). In case of the T1 treatment stage, the removal efficiency achieved the highest performance compared to the other studied WWTPs in Misillya plant (where T1 represents the recirculation treatment stage) which was 24.7%. The performance efficiency of TN removal in Sarra, Hajjah and BietHasan plants (where T1 represents the primary treatment stage) ranged between 12% to 15.4%. Depending on the above results, the wastewater treatment in the recirculation stage has the highest performance compared to the primary treatment stage for the TN removal. In case of the T2 treatment stage (CWs), the removal efficiency achieved the highest performance compared to the other studied WWTPs in Misillya plant was 53%. BietHasan plant came in the second rank and achieved 51.8% in the removal efficiency of the TN compared to the other studied WWTPs. then Hajjah plant achieved 49.4% in the removal efficiency of the TN. However, Sarra plant achieved the lowest performance compared to the other studied WWTPs; the removal efficiency of the TN for Sarra WWTP was 22.5%.



Figure(4.29). Performance Efficiency of the treatment stages for TN removal.

4.7.5 Removal Efficiency of Total Phosphorus (TP)

From figure(4.30). In case of the T1 treatment stage, the removal efficiency achieved the highest performance compared to the other studied WWTPs in Misillya plant (where the T1 represents the recirculation treatment stage) which was 37.6%. The performance efficiency of removal the TP in Sarra, Hajjah and BietHasan plants (where the T1 represents the primary treatment stage) ranged between 9.4% to 12.2%. Depending on the above results, the wastewater treatment in the recirculation stage has the highest performance compared to the primary treatment stage for TP removal. In case of the T2 treatment stage (CWs), the removal efficiency achieved the highest performance compared to the other studied WWTPs in Misillya plant was 49.1%. Hajjah plant came in the second rank and achieved 32% in the removal efficiency of TP, then BietHasan plant achieved 29,4% in the removal efficiency of TP. However, Sarra plant achieved the lowest performance compared to the other studied WWTPs; the removal efficiency of TP for Sarra plant was 20.6%.



Figure(4.30). Performance Efficiency of the treatment stages for TP removal.

4.8 Comparison of The Performance Efficiency for HF, VF CW Beds of Sarra and Hajjah Wetland Plants

Figure (4.31) present the removal efficiency of Sarra and Hajah plants in removing organic pollutants through VF and HF CW beds by the mean values of the parameters.

4.8.1 Removal Efficiency of Organic Pollutants (BOD_5, COD, TSS)

From figure (4.31). the VF beds were more effective in removing the BOD_5, COD, TSS than the HF beds of Sarra and Hajjah plants. The removal efficiency in the primary treatment in terms of the BOD_5, COD, TSS for the both plants ranged between (21%- 34%). Vymazal, (2005) reported that the performance efficiency in the primary treatment for the BOD_5, COD, TSS in case of the hybrid CW plant at Dhulikhel, Nepal was43%, 37.9%, 64% respectively (Vymazal, 2005).

The VF CW treatment stage achieved the highest performance efficiency which ranged between (73%-77%) for the BOD_5, COD, in terms of the TSS removal it ranged between (71%-80%). The Removal efficiency in the HF treatment stage (effluent) of BOD_5, COD, TSS ranged between (61%-65%), (58%-64%), (51%-64%) respectively. The reasonable explanation for these results could be due to the suitable conditions for the aerobic conditions inside the beds. However, Gajewska *et al.*, (2018) reported that the configuration with the vertical flow bed at the beginning of the treatment process VF-HF in case of the hybrid CW produces suitable conditions for degradating and transforming the pollutants which provide higher efficiency and higher removal of the pollutants,. However, the investigation results revealed that the removal efficiency of the BOD_5, COD, TN in the hybrid CW VF-HF in case of the VF bed was 89%, 86.6%, 46.6% respectively, and in case of the HF bed was 36%, 25.7%, 24% respectively (Gajewska *et al.*, 2018). Melián *et al.*, (2010) reported that the removal efficiency of the BOD_5, COD, TSS in the hybrid CW VF-HF in case of the VF bed which filled with gravel ranged between (78%-89%), (55%-73%), (81%-83%) and the removal efficiency of the COD, TSS in case of the HF bed ranged between (40%-43%), (73%-75%) respectively (Melián *et al.*, 2010).

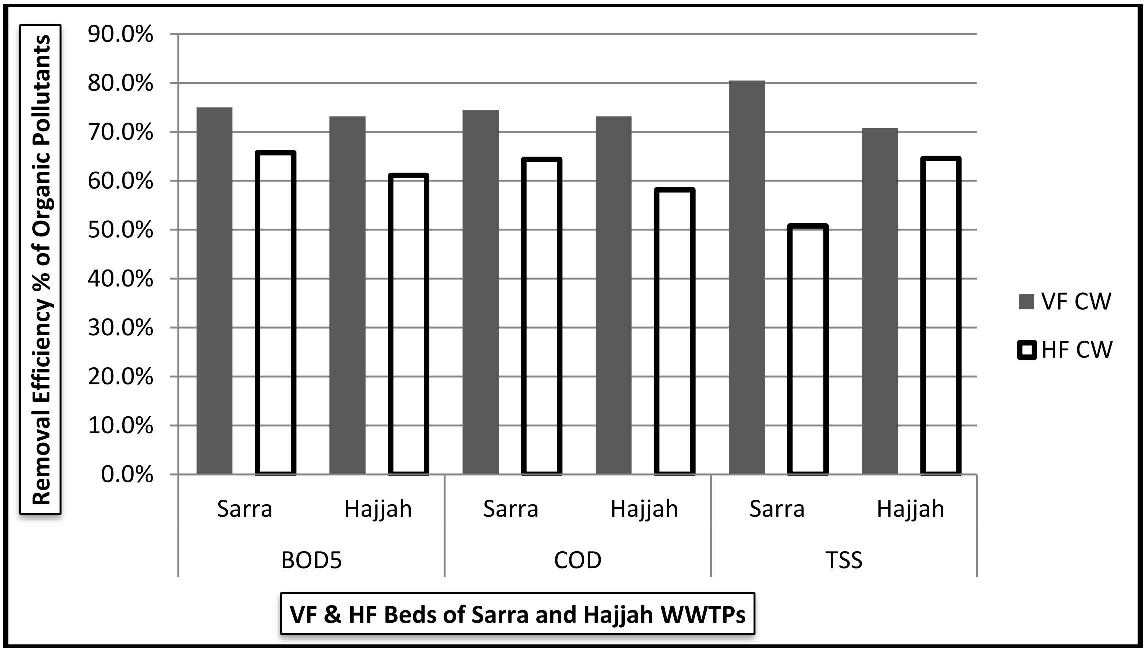
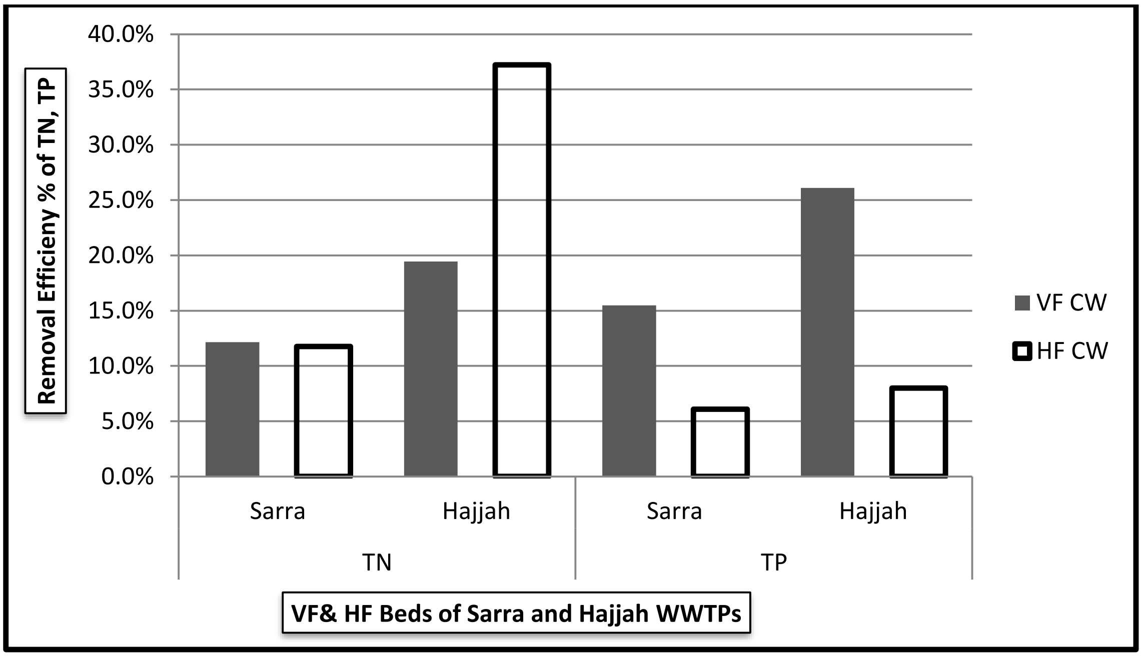


Figure (4.31) Performance of VF & HF CW beds for removing BOD_5, COD, TSS.

4.8.2 Removal efficiency of Nutrient Pollutants (TN,TP)

From figure (4.32). The removal efficiency of the nutrient pollutants was low compared to the organic pollutants. the removal of the TN and the

TP nutrients depend on the system properties and the operational conditions (Dong Jin et al., 2015). However, the removal efficiency of the TN, TP was higher in Hajjah WWTP compared to Sarra WWTP. regarding Hajjah WWTP, in case of the VF treatment stage the removal efficiency of the TN, TP was 19.4%, 25.9% respectively. regarding Sarra WWTP, in case of the VF treatment beds the removal efficiency of the TN, TP was 12.1%, 15.5% respectively. However, for Hajjah WWTP, in case of the HF beds the removal efficiency of the TN, TP was 37.2%, 8% respectively. For Sarra WWTP, the removal efficiency of the TN, TP was 11.8%, 5.9% respectively. Dong *et al*., (2015) showed that the removal efficiency of the TN, TP in the hybrid constructed wetland VF-HF in case of the VF treatment stage beds was 16.9%, 21.5% respectively, and in case of the HF was 33.6%, 35% respectively.



Figure(4.32). Performance of VF & HF CW beds for removing TN& TP.

4.8.3 Estimate Degradation Rate Constant and Mass Removal Rate of Sarra and Hajjah Wetland Plants

The wetland performance is often reported on a percentage removal basis. This can leads to inaccuracy, since it provides no indication for the mass removal of the pollutant. The analysis in terms of the mass removal rates and the removal rate constant is surely more instructive (Mitchell and Mcnevin, 2001). The removal rate constants: A first-order degradation approach has been used to predict the removal performance of the pollutants in the constructed wetlands. The rate constants for this model can be defined on either a areal (k_A) or a volumetric (k_V) basis (Abdelhakeem *et al*., 2016).

Most of the processes in the wetlands are depend on the wetland area. However, k(BOD) rates which are used in the wetland literature are mostly area-based coefficients (k_A) (Gajewska *et al*., 2018). The first order area-based an assumption of plug flow movement of the water through the wetland with first-order reaction kinetics primarily by biological degradation (Frazer-Williams, 2010). This approach has been used for design and predict the removal performance of the pollutants in the constructed wetlands (Mitchell and Mcnevin, 2001). The most common form - first order equation which was used to calculate the removal rate constants areal (k_A) is presented by following (Gajewska *et al*., 2018, Abdelhakeem *et al*., 2016):

$$\frac{\mathrm{Cout}}{\mathrm{Cin}} = \mathrm{e}^{-\left(\frac{\mathrm{KA}}{\mathrm{q}}\right)}$$

Where:

C_{out}, C_{in} = Concentration of pollutant in effluent wastewater and inflow wastewater (mg/L) respectively.

K_A : Pollutant degradation rate constant area-based ($m.d^{-1}$).

q : Hydraulic loading rate ($m.d^{-1}$).

On the other hand mass removal rate was calculated on the basis of the following equation (Gajewska, *et al*., 2018):

Mass removal rate (MRR)= $q \times [C_{in}-C_{out}]$ ($g.m^{-2}.d^{-1}$)

Table (4.8) Mass removal rate and removal rate constant (K_{BOD}) area-based of Sarra and Hajjah wetland plants.

Treatment stage	MRR ($g.m^{-2}.d^{-1}$) of Sarra plant	MRR ($g.m^{-2}.d^{-1}$) of Hajjah plant	K_A(BOD) ($m.d^{-1}$) of Sarra plant	K_A(BOD) ($m.d^{-1}$) of Hajjah plant
VF beds	62.2	33.3	0.22	0.16
HF beds	6.7	4.7	0.088	0.072

As presented in tables (4.8) the removal rate constant K_A(BOD) and the mass removal rate were higher in case of the VF than HF beds for both WWTPs. However, in terms of Sarra WWTP both of K_A(BOD) and MRR achieved higher values than Hajjah WWTP in the case of the VF and HF beds. Abdelhakeem *et al*., (2016) reported that the K_A(BOD) of the VF wetland performance assessment for the sewage water treatment was 0.27 $m.d^{-1}$. Frazer-Williams (2010) reported that the literature of the constructed wetlands performance in the different countries K_A(BOD) of HF in Denmark was 0.068 $m.d^{-1}$, and UK were 0.060 $m.d^{-1}$. Rousseaua *et al*.,(2004) reported that literature of the K_A(BOD) for HF was kadlec and knight reported that it ranged from 0.085 m.d^{-1} to 1 m.d^{-1}. UN Habitat (2008) suggested the value of the k(BOD) for HF 0.15 m.d^{-1} and VF 0.2 m.d^{-1}.

4.9 Comparison of effluent treated wastewater characteristics of the studied wetland plants with Palestinian obligatory technical specifications for reuse treated wastewater in agriculture

The reusing of the reclaimed wastewater is a major priority to meet the increase water demands in the agricultural sector due to the water scarcity in the West Bank. According to the results which is obtained from this study, and comparison of the effluent characteristics for the main parameters (BOD_5, COD, TSS, TN, TDS, pH) with the Palestinian obligatory technical specifications (PSI 34-2012) for the studied wetland plants as shown in the table (4.9).

Table(4.9) Parameters of effluent wastewater of the studied Wetland Plants and Palestinian obligatory technical specifications

Parameter	Effluent of Wetland Plants				Palestinian Specifications			
	BietHasan Plant	**Mesillya Plant**	**Hajjah Plant**	**Sarra Plant**	A	B	C	D
BOD_5 (mg/L)	65	66.6	39	43	20	20	40	60
COD (mg/L)	150.6	131	74.6	94.3	50	50	100	150
TSS (mg/L)	180	78.4	82.3	83.3	30	30	50	90
TN (mg/L)	54.5	44.5	72	119.4	30	30	45	60
TDS (mg/L)	1259.3	1079.4	1054.3	1276.3	1200	1500	1500	1500
pH	7.93	7.58	7.54	7.24	6-9	6-9	6-9	6-9

Chapter Five

Conclusion and Recommendations

5.1 Conclusions

This research study was carried out in four rural communities in the West Bank; Sarra, Hajjah, Misillya, and BietHasan villages, which have constructed wetland plants for treating the wastewater and are currently operated, the research focuses on evaluating the performance efficiency of those selected constructed wetlands. According to the results obtained from this study and compared with previous studies results, the following conclusions can be drawn for the studied constructed wetland WWTPs:

1. Although the removal efficiency of Sarra and Hajjah plants in terms of removing the organic pollutants (BOD_5, COD, TSS) was overall good above 90% and the daily flow rate did not parallel with the maximum capacity of the plants, the effluent characteristic of the (BOD_5, COD, TSS) for both of them failed to achieve good quality grade (achieved Grade C-D) compared to the Palestinian obligatory technical specifications (PSI 34-2012).

2. TN concentration of the effluent characteristics of Sarra and Hajjah plants failed to meet with the Palestinian obligatory technical specifications (PSI 34-2012). However, it was relatively high concentration in Sarra plant; the reason may be due to bad operation

of the plant, in addition to low denitrificaion through HF beds may be because of the beds affected by clogging.

3. The organic pollutants (BOD_5, COD, TSS) of the effluent characteristics of Biet Hasan failed to meet with the Palestinian obligatory technical specifications (PSI 34-2012).

4. Based on the removal rate constant (K_ABOD) as was presented in the previous sections, the performance of Sarra plant was better than Hajjah plant.

5. Enhancement of the performance efficiency is necessary for Sarra, Hajjah and BietHasan in order to improve the quality of the effluent characteristics.

6. The constructed wetlands beds of Sarra, Hajjah and BeitHasan need maintenance by avoided clogging and vegetation management.

7. The effluent characteristics of Misillya WWTP; BOD_5 failed to meet with the obligatory Palestinian specifications (PSI 34-2012), in terms of the COD, achieved Grade D (low quality).

8. The low performance efficiency for the reed beds of Misillya WWTP may be due to the uncompleted maturity of the bed which mean it's still not reached the steady-state to build enough microbial population and biofilm on the filter.

9. It was shown high reduction in terms of TN, TP concentration in Misillya WWTP compared to other studied WWTPs, the reasonable explanation may be due to the type of the filter which is used for its beds (Dolomite), as well as the uniformity and the good management of the vegetation growth.

10. Recirculation treatment stage probably achieve better performance for removal pollutants compared to primary treatment in case of the constructed wetland plants.

5.2 Recommendations

An enhancement of the performance of the studied CWs must be done to achieve high-quality grade meet with the Palestinian specifications (PSI 34-2012) by improving the management and operation, and by the maintenance of the studied WWPs. In terms of the systems management the capacity building for the operator's WWTP may play an important role in improving the WWPs performance, as well as maintenance must be conducted as continuously by monitoring the inlets and outlets of CWs, which must be cleaned from any debris because this may result in clogging, while the influent suspended solids which are accumulated at the inlet of CW bed require removal from time to time because the accumulations may result in reducing the hydraulic retention time so reducing the performance of CWs, Washing or replacing the substrate is also needed to maintain the hydraulic conductivity. Furthermore the percent cover of the dominant plant species (common reed) must be also monitored continuously. Thus, the removal of the undesirable vegetation, harvesting and replanting the dominant plant could be needed continuously to maintain the flow patterns and the treatment functions.

Further research is recommended to investigate the long term - performance and improve the pollutants removal efficiency for the studied WWTPs.

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Annexes

Annexes A

Table(1.A) Obtained results of Sarra Treatment Plant.

Parameter	Treatment Stage	Average	STDEV	Difference
BOD_5 (mg/L)	S1	746	110	-
	S2	503	70.15	243
	S3	125.6	18.6	377.4
	S4	43	10.6	82.6
COD (mg/L)	S1	1562	147.5	-
	S2	1035	104.3	527
	S3	265	32.8	770
	S4	94.3	17.2	170.7
TSS (mg/L)	S1	1283	145	-
	S2	868.3	63.3	414.7
	S3	169.3	36.4	699
	S4	83.3	15.5	86
T. Nitrogen (mg/L)	S1	177.7	11.4	-
	S2	154	13.1	23.7
	S3	135.3	21.8	18.7
	S4	119.4	14	15.9
T. Phosphorus (mg/L)	S1	28.7	3.68	-
	S2	25.2	1.75	3.5
	S3	21.3	0.75	3.9
	S4	20	0.89	1.3
T. Coliform CFU/ml00	Inlet	$12.7*10^5$	$4.1*10^5$	-
	Outlet	$3.77*10^3$	$1.20*10^3$	-
E. Coli/100ml	Inlet	$149*10^3$	$26.8*10^3$	-
	Outlet	197	32	-

S1: inflow wastewater, S2: after primary treatment and before VF beds stage, S3: after VF beds and before horizontal beds stage, S4: after HF beds stages (effluent).

Table(2.A). Obtained Results of Hajjah Treatment Plant.

Parameter	Treatment Stage	Average	STDEV	Difference
BOD_5 (mg/L)	H1	506	83.8	-
	H2	373.6	53.6	132.4
	H3	100.3	16.16	273.3
	H4	39	9	61.3
COD (mg/L)	H1	1074.6	117.2	-
	H2	791.6	77.5	283
	H3	178.3	35.6	613.3
	H4	74.6	18.3	103.7
TSS (mg/L)	H1	1016.3	123.7	-
	H2	796.6	86.9	219.7
	H3	232.3	10.2	564.3
	H4	82.3	8.50	150
T. Nitrogen (mg/L)	H1	168.3	17.6	-
	H2	142.4	13	25.9
	H3	114.7	7.7	27.7
	H4	72	12.4	42.7
T. Phosphorus (mg/L)	H1	22.4	4.39	-
	H2	20.3	4.47	2.1
	H3	15	4.44	5.3
	H4	13.8	3.85	1.2
T. Coliform CFU/ml00	Inlet	$11.89*10^5$	-	-
	Outlet	$25.53*10^3$	-	-
E. Coli/100ml	Inlet	$73*10^3$	-	-
	Outlet	320	-	-

H1: inflow wastewater, H2: after primary treatment and before VF beds stage, H3: after VF beds and before HF beds stage, H4: after HF beds stage (final effluent).

Table(3.A). Obtained Results of Misillya Treatment Plant.

Parameter	Treatment Stage	Average	STDEV	Difference
BOD_5 (mg/L)	M1	916.6	161.7	-
	M2	189	14.9	727.6
	M3	66.6	33.7	122.4
COD (mg/L)	M1	1709.3	165.4	-
	M2	373.3	38.4	1336
	M3	131	71.1	242.3
TSS (mg/L)	M1	975.7	71.6	-
	M2	534.2	205.9	441.5
	M3	78.4	14.6	455.8
T. Nitrogen (mg/L)	M1	125.7	39.9	-
	M2	94.7	12.2	31
	M3	44.5	17.2	50.2
T. Phosphorus (mg/L)	M1	19.7	4.2	-
	M2	12.3	3.7	7.4
	M3	6.26	1.0	6.04
T. Coliform CFU/ml00	Inlet	$39.2*10^4$	-	-
	Outlet	$34.6*10^3$	-	-

M1: inflow wastewater, M2:From feeding manhole(recirculation wastewater with flow rate 30%), M3: effluent wastewater.

Table(4.A). Obtained Results of Biet Hasan Treatment Plant.

Parameter	Treatment Stage	Average Value	STDEV	Difference
BOD_5 (mg/L)	Influent	481.6	64.1	-
	Primary Treatment	352	24.6	129.6
	Effluent	65	11.5	416.6
COD (mg/L)	Influent	948.6	51.4	-
	Primary Treatment	713	43.2	235.6
	Effluent	150.6	11.0	798
TSS (mg/L)	Influent	1175.3	86.7	-
	Primary Treatment	868	31.8	307.3
	Effluent	180	9.16	995.3
T. Nitrogen (mg/L)	Influent	128.4	17.6	-
	Primary Treatment	113	12.7	15.4
	Effluent	54.5	7.4	73.9
T. Phosphorus (mg/L)	Influent	20.9	2.6	-
	Primary Treatment	18.71	3.4	2.19
	Effluent	13.2	2.19	5.51
T. Coliform CFU/ml00	Influent	$3.37*10^4$	-	-
	Effluent	$5.943*10^3$	-	-

Annex B:

Calculations

(Table1.B) Mass Removal Rate and Removal Rate Constant (K_A) BOD of Sarra Wetland Plant.

Treatment stage	Average Value BOD (mg/L)	Flow rate (m^3/d)	Hydraulic load rate ($m.d^{-1}$)	MRR ($g.m^{-2}.d^{-1}$)	K_A ($m.d^{-1}$)
Influent wastewater of VF bed	503	248	-	-	-
VF bed	125.6		0.165	62.2	0.22
HF bed	43.3		0.082	6.7	0.088

Table (2.B) Mass Removal Rate and Removal Rate Constant (K_A) BOD of Hajjah Wetland Plant.

Treatment stage	Average Value BOD(mg/L)	Flow rate (m^3/d)	Hydraulic load rate ($m.d^{-1}$)	MRR ($g.m^{-2}.d^{-1}$)	K_A ($m.d^{-1}$)
Influent wastewater of VF bed	373.6	75	-	-	-
VF bed	100.3		0.122	33.3	0.16
HF bed	39		0.077	4.7	0.072

These values were calculated depending on measured concentration the influent and effluent BOD_5 of VF and HF beds of CWs using the following equations:

$$\frac{\text{Cout}}{\text{Cin}} = e^{-(\frac{KA}{q})}$$

Mass removal rate (MRR)= $q \times [C_{in}-C_{out}]$ ($g.m^{-2}.d^{-1}$)

Where:

C_{out} : Concentration of pollutant in the effluent wastewater (mg/L).

C_{in} : Concentration of pollutant in the influent wastewater (mg/L).

K_A : Pollutant degradation rate constant area-based ($m.d^{-1}$).

q : Hydraulic loading rate ($m.d^{-1}$).

جامعة النجاح الوطنية
كلية الدراسات العليا

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قُدمت هذه الأطروحة إستكمالاً لمتطلبات الحصول على درجة الماجستير في علوم البيئة بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين

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إشراف

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د. عبد الله العمري

الملخص

تعتبر الاراضي الرطبة المنشأة تكنولوجيا فعالة وصديقة للبيئة لمعالجة المياه العادمة، بالإضافة لكونها غير مكلفة اقتصاديا ، تعمل الأراضي الرطبة المنشأة على ازالة الملوثات من المياه العادمة وذلك باستخدام العمليات الفيزيائية والكيميائية والحيوية ومع ذلك يعتمد اداء هذه الانظمة على خصائص الموقع ونوعية المياه والظروف التشغيلية. يتضمن هذا البحث مراجعة علمية واسعة النطاق تستعرض المعرفة العلمية المتعلقة بهذه التكنولوجيا. ركزت هذه الدراسة على تقييم كفاءة الاداء لأربعة محطات مركزية تعمل بواسطة تكنولوجيا الاراضي الرطبة المنشأة لمعالجة المياه العادمة تم انشاؤها في اربعة قرى ريفية فلسطينية هي صرة وحجة وبيت حسن ومسلية ،بالإضافة لمقارنة المياه المعالجة التي تنتجها هذه المحطات مع التعليمات الفنية الالزامية الفلسطينية الخاصة بإعادة استخدام المياه العادمة المعالجة في الزراعة (PSI 34-2012).

تم تنفيذ زيارات ميدانية لهده المحطات في بداية الدراسة حيث وجد ان محطات صرة وحجة وبيت حسن تعمل بنظام الاراضي الرطبة المنشأة المهجنة اما محطة مسلية فوجد انها تعمل بنظام الاراضي الرطبة العمودية الفرنسية. تم اخذ عينات من المحطات الاربعة خلال ثلاثة فترات مختلفة من السنة لإجراء الفحوصات المخبرية للعينات. اشتملت الفحوصات بالإضافة لفحص الاكسجين الذائب (DO) والذي تم اجراؤه داخل المحطة ودرجة حرارة المياه العادمة، على الفحوصات المخبرية

التي تم اجراءها داخل المختبر بهدف تحديد كفاءة الاداء لكل محطة تضمنتها الدراسة على النحو التالي:

EC, pH, DO, BOD_5, COD, T. P, T. N, TDS, TSS, E.coli, T. coliform.

بيت نتائج الدراسة ان كفاءة الاداء العامة للمحطات كانت تعمل بشكل عام بأداء جيد حيث بلغت كفاءة الاداء العامة المتعلقة بتخفيض او بإزالة الملوثات العضوية والتي تشمل متطلب الاكسجين الحيوي (BOD_5) ومتطلب الاكسجين الكيميائي (COD) والمواد غير الراشحة الكلية (TSS) في محطات صرة وحجة ومسلية اكبر من 90%، اما محطة بيت حسن فبلغت كفاءة الاداء العامة لإزالة الملوثات العضوية اكبر من 85%.

ينصح الباحث بضرورة عمل صيانة دورية للمحطات التي شملتها الدراسة لتحسين كفاءة الاداء لهذه المحطات .