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Assessment of MBR Facility in Alreehan Suburb for Wastewater Treatment and Reclaimed Water Recycling in Agricultural Irrigation

تقييم منشأة الأغشية الحيوية (MBR) في ضاحية الريحان لمعالجة مياه الصرف الصحي وتدوير المياه المستصلحة في الري الزراعي

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Examination Committee Approval

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

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Dedication

بسم الله الرحمن الرحيم

" قل اعملوا فسيرى الله عملكم ورسوله والمؤمنون "صدق الله العظيم.

إلهي لا يطيب الليل إلا بشكرك ولا يطيب النهار إلى بطاعتك .. ولا تطيب اللحظات إلا بذكرك .. ولا تطيب الآخرة إلا بعفوك.

إلى من بلغ الرسالة وأدى الأمانة .. ونصح الأمة .. إلى نبي الرحمة ونور العالمين .. الى معلم البشرية اجمع .. (سيدنا محمد صلى الله عليه وسلم)

إلى من كلله الله بالهيبة والوقار .. إلى من علمني العطاء بدون انتظار .. إلى من أحمل اسمه بكل افتخار .. (أبي العزيز).

إلى معنى الحب وإلى معنى الحنان والتفاني .. إلى بسمة الحياة وسر الوجود .. إلى من كان دعاؤها سراً لنجاحي .. (أمي الحبيبة).

إلى من هم اقرب إليّ من روحي .. إلى من شاركوني حضن الام وبهم أستمد عزتي وإصراري .. (اخوتي واخواتي).

إلى الذين بذلوا كل جهد وعطاء كي نصل إلى هذه اللحظة .. (دكاترتي الأعزاء).

الى من ضاقت السطور من ذكرهم فوسعهم قلبي .. (أصدقائي الأعزاء).

إلى هذه الصرح العلمي العريق والجبار .. (جامعتي بيرزيت).

إلى من ضحوا بحريتهم من أجل حرية غيرهم .. (الأسرى والمعتقلين).

إلى من هم أكرم منا مكانة .. (شهداء فلسطين).

إلى من احتضنتني كل هذه السنين .. (فلسطين الحبيبة).

أهدي هذا الجهد المتواضع.

Abstract

Due to climate change and increase in population in the Middle East and North Africa (MENA), exacerbated by COVID-19 pandemic, MENA region faces severe water gaps. Desalination and reclaimed water recycling could close the water gap as non-conventional water sources.

Considered as water resources recovery facilities, wastewater treatment plants (WWTPs) serve Palestinian communities, but they suffer from defective operations and a lack of operation and maintenance. If wastewater is not treated well, this source may have public health and environmental risks, and damage the physical and chemical properties of the soil and the quality of crops, in addition to limiting development Social and economic and reducing regional and international conflicts. Therefore, the sustainability of these facilities and maintaining their reliability are important to protect the environment, prevent health risks, and ensure their compliance with Palestinian standards for wastewater treatment and reuse in various uses.

This research aimed at investigating the efficacy of a full-scale submerged membrane bioreactor (MBR) for the treatment of domestic wastewater including hospital wastewater flow from Istishari Arab Hospital in Alreehan suburb. The treatment efficiency of the MBR system and appropriate operating conditions to comply with effluent reuse in irrigation were also considered. This thesis attempts to solve the problem by monitoring the efficiency of the Alreehan MBR facility, and the quality of treated wastewater and examining the physical, chemical and biological parameters and their compliance with the Palestinian standards for the reuse of wastewater in agriculture. During the period (August 2021 to November 2021), the MBR system was monitored with average concentrations for BOD (460-556 mg/L), COD (1137-1427 mg/L) and TKN (29-61 mg/L). The results of the research showed unexpected and unsatisfactory results for MBR technology, where

the removal efficiency of each of the BOD, COD, TSS, TKN, NO_3, NH_4, and total phosphate (TP) were 79%, 74%, 80%, 56%, 60 %, 89%, 82%, respectively. The achieved removal efficiencies did not comply with the Palestinian criteria for effluent reuse in irrigation.

About MLSS and SVI, design values were low and did not match the design parameters in the MBR Alreehan facility design report. Alreehan MBR system suffers from defects and problems in the operation and maintenance of the unit operations including membrane fouling. The MBR system handles a municipal wastewater (domestic wastewater and liquid waste flows from Istishari Arab Hospital and commercial wastewater from LACASA Mall). This unique mixture of liquid waste flows of variable hydraulic and organic pollution loads (large quantities of detergents, sterilizers and chemicals) has serious impacts on the MBR efficacy. Results obtained revealed that the MBR system suffered from non-compliance with local regulations and legislation for reuse wastewater in agriculture and green spaces irrigation. Overall, the study recommends development and enforcement of effective monitoring through a Central Control Department (CCD) for regular operation and maintenance of wastewater treatment facilities in Palestine. Regular process control, OM&R activities including training and raising knowledge and professional skills of the operating staff at wastewater treatment facilities. Long-term impacts of wastewater from Istishari Arab Hospital on the operation and efficacy of Alreehan MBR facility considering the effects and fate of emergent pollutants, antibiotics, disinfectants and pharmaceuticals warrants further research studies.

الملخص

نتيجة لتغير المناخ والزيادة في عدد سكان منطقة الشرق تعتبر منطقة شرق وشمال إفريقيا (MENA) أكثر مناطق العالم التي تعاني من الإجهاد المائي، حيث تعتبر اعادة اســتخدام المياه العادمة أحد الطرق لتخفيف من الإجهاد المائي واحد مصــادر المياه الغير تقليدية، تعتبر منشــئات معالجة المياه العادمة التي تخدم المجتمعات الفلســطينية مهمة في لاستعادة الموارد المائية الفلسطينية، لكنها تعاني من خلل في العمليات ونقص في التشغيل والصيانة، إذا لم تتم معالجة المياه العادمة بشكل جيد، فقد يكون لهذا المصدر مخاطر صحية وبيئية ، وتضر بالخصائص الفيزيائية والكيميائية للتربة وجودة المحاصــيل بالإضــافة الى الحد من التنمية الاجتماعية والاقتصــادية والتقليل من النزاعات الاقليمية والدولية. لذلك تعد اســتدامة هذه المنشــئات والحفاظ على موثوقيتها أمرا مهم لحماية البيئة ومنع المخاطر الصــحية وضمان امتثالها للمعايير الفلسطينية لمعالجة المياه العادمة واعادة استخدامها في الاستخدامات المختلفة.

تم إجراء تحليل لكفاءة معالجة محطة الريحان من مدخل ومخرج المحطة بالإضــافة بعض المعلمات التشــغيلية في المحطة والحصول على نتائج عينات لسنوات سابقة من المشغل السابق، من المتوقع ان تنتج المنشاة مياه معالجة تتوافق مع الاستخدامات الغير مقيدة.

تحاول الرســالة لحل المشكلة من خلال مراقبة كفاءة منشأة ضاحية الريحان MBR وجودة المياه العادمة المعالجة وفحص المعلمات الفيزيائية والكيميائية والبيولوجية ومدى توافقها مع المعايير الفلسطينية لإعادة استخدام المياه العادمة في الزراعة. ومساعدة صناع القرار في تطوير مشاريع اعادة استخدام المياه العادمة واتخاذ القرار في المزيد من مشاريع اعادة الاستخدام للمياه المعالجة بالإضافة الى البحث في المعلمات التشغيلية وظروف التشغيل واقتراح الممارسات التشغيلية الأمثل لتشغيل المحطات وتخفيف احداث تعطل المحطات. خلال الفترة (أغسطس 2021 إلى نوفمبر 2021)، تم رصد نظام MBR بمتوسط أحمال عضوية BOD (556-460 ملج/ لتر) و COD(1427 – 1137 ملج/لتر) و TKN(61 – 29 ملج/لتر).

أظهرت نتائج البحث نتائج غير متوقعة وغير مرضـــية لتكنولوجيا الأغشـــية الحيوية في المنشـــأة حيث كانت كفاءة الإزالـة لكل من ال BOD , COD , TSS, TKN, NO3, NH4 , TP على التوالي كـالتـالي: 79%, 74%, 80%, 56%, 60%, 89%, 82%. وكانت كفاءة الازالة لا تستوفي المعايير الفلسطينية لإعادة الاستخدام الزراعي.

أما بالنسـبة ل MLSS، SVI فقد كانت منخفضـــة ولا تتوافق من المعلمات التصــميم في تقرير التصــميم لمنشـــاة الريحان MBR. تعاني منشاة الريحان لمعالجة المياه العادمة من خلل ومشـاكل في التشـغيل وصيانة المنشاة والأغشية بالإضـافة لاستقبال المحطة المياه العادمة الخام من المستشفى الاستشاري التي تحتوي على كميات كبيرة من المنظفات والمعقمـات والمواد الكيميـائيـة، الأمر الـذي يؤثر بشـــكل واضـــح على كفـاءة معالجة المنشـــاة ومدى امتثالها للوائح والتشـريعات المحلية لإعادة استخدام المياه العادمة في الزراعة وري المساحات الخضـراء، بتطوير وإنفاذ إدارة فعالة لمراقبة تشـغيل وصـيانة مرافق معالجة مياه الصـرف الصـحي في فلسـطين ، والتحكم في تشـغيل هذه المرافق وتوفير التدريب ورفع مهارة الكادر التشـغيلي في تسـهيلات معالجة مياه الصـرف الصـحي ، وتقييم تأثير مياه الصـرف الصـحي التي يتم تصـريفها من قبل المسـتشـفى الاسـتشـاري على فعالية منشـأة الريحان MBR ووجود الملوثات المسـتجدة والمستحضرات الصيدلانية على مياه الصرف الصحي الخام ومياه الصرف الصحي المعالجة.

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List of Abbreviations

MBR	Membrane Bioreactor
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
D.O	Dissolved Oxygen
EC	Electrical Conductivity
MLSS	Mixed liquor suspended solids
FC	Fecal Coliform
TC	Total Coliform
MCM	Million Cubic Meter
MENA	Middle East and North Africa
WWTP	Wastewater Treatment Plant
NO_3	Nitrate
NH4	Ammonium
TKN	Total Kjeldahl Nitrogen
TP	Total Phosphorus
F/M	Food to Mass
WHO	Water Health Organization
UF	Ultra-Filtration
MF	Micro filtration
NF	Nano filtration
TSS	Total Suspended Solids
WHO	Water Health Organization
PWA	Palestinian Water Authority
HF	Hollow Fiber
FS	Flat Sheet
SRT	Sludge Retention Time
OLR	Organic Loading Rate
HRT	Hydraulic Retention Time

TOC	Total organic carbon
TMP	Trans-Membrane Pressure
EPS	Extra-cellular Polymer Substances
PCBS	Palestinian Central Bureau of Statistics
EPA	Environmental Protection Agency
SVI	Sludge Volume Index
RAS	Return Activated Sludge
CFU	Colony Forming Unit
PSI	PS Palestinian Standards

1. Introduction

1.1 General Background

According to the World Bank, due to climate change and the increase of population, the Middle East and North Africa (MENA) is the most region in the world that suffer from water stress, which may expose the region to instability and limitation of economic growth (World Bank, 2017). This constitutes a major challenge facing the MENA region due to the increase in population causes the increasing demand for freshwater, the limited supply of water, and the excessive exploitation of water (Haddadin, 2001). Palestine is one of these countries that suffer from water stress due to the Israeli control over the Palestinian water resources and preventing them from obtaining their water rights (Abu Madi et al., 2008). While the Palestinian National Authority reports from Israel indicate that more than 90 percent of the water resources shared between the two sides are being exploited, the Palestinians do not get more than 10 percent (Palestinian Water Authority, Palestine: The Right to Water, 2011). The average domestic water consumption is 96 liters per capita per day (l/c/d) in Gaza, 72 (l/c/d) in the West Bank and at the national level approx. 82 l/c/d (PWA, 2012).

The limitation of freshwater resources pushing toward non-conventional water resources such as desalination, water purchase and reuse of treated wastewater. Treated wastewater provides a sustainable source of water to relieve pressure on water sources. Where Then Treated wastewater is a good strategic solution can be utilized in several areas such as agriculture, green space irrigation, industrial uses, and ground water recharge (Aziz & Farissi, 2014).

The agricultural sector is the main consumer of water in Palestine, with the West Bank and Gaza Strip consuming 37% and 47%, respectively, of the available water (PWA, 2015).

The Palestinian sewage sector generally is characterized by weakness (McNeill et al., 2008), 70% of the Palestinian areas are still not served by central sewage networks in semi-urban and rural areas, and more than 50% of raw sewage water is discharged directly into receiving water bodies, including seasonal streams, or through cesspits (Al-Sa'ed, 2010).

Despite the tendency of the National Authority to develop the wastewater sector and establish treatment plants with modern and sometimes highly efficient technologies, it still suffers from a problem in proper operation and delays in maintenance. Most Palestinian communities face a problem due to limited funding and natural resources (Al-Sa'ed & Tomaleh, 2012),

In addition, the occupation also plays the important role in the inability of the Palestinian Authority to control the water sector. The sewage sector, placing obstacles and delaying the implementation of development projects in sanitation (Barceló & Petrovic, 2011).

Membrane bioreactors (MBR) have emerged as a promising technology, and have received global attention in recent years, as this technology is characterized by high treated wastewater quality, and a small area footprint compared to other technologies, but the weakness of this technology is high-energy consumption in addition to the biofouling (Lesjean & Huisjes, 2008).

Membrane bioreactors have gone beyond domestic wastewater, as they have shown high efficiency in treating wastewater with high organic loads such as food, beverage, textile, and olive mill wastewater (Hoinkis et al., 2012). In Palestine, there are three MBR stations operating on a large scale in Al-Tira neighborhood, Al-Reehan neighborhood and Bethlehem industrial zone. This expansion in the use of MBR technology in Palestine pushes to expand knowledge and build experiences in this field.

In this study, the operation of a large-scale MBR facility operating in the suburb of Al-Reehan will be evaluated for a period of four months. We argue that the MBR facility shows high efficacy in treating the wastewater generated from the suburb of Al-Reehan mixed with the wastewater from the Istishari Hospital and complies with the local regulations for municipal agricultural irrigation, in addition to researching some operational parameters of the facility that may affect the efficacy of the facility.

1.2 Problem statement

Water security is one of the most important global concerns, especially in countries that suffer from water shortages and is the main reason for searching for non-conventional sources of water, wherever treated wastewater is one of the most important non-conventional sources. Despite this, the lack of proper wastewater treatment will cause many problems in the soil, plants, human and animal health.

With the beginning of the establishment of wastewater treatment plants in Palestine, many challenges appeared in this aspect, wastewater treatment plants (WWTPs) in Palestinian communities plagued by process malfunctioning, lack of operation and maintenance and limited system control can severely affect public health, environment and socio-economic development (Al-Sa`ed, 2015). The sustainability, performance and process reliability of WWTPs are crucial to prevent health hazards, protect the environment, ensure compliance with national effluent guidelines for beneficial uses and reduce local and regional socio-political conflicts. This research will provide deep insights and more information on the efficiency of the MBR facility in Alreehan housing compound and the suitability of the reclaimed water in agricultural irrigation considering the local water reuse regulations. That will extend help to the decision-makers to decide and bush onto more water reuse projects in the agricultural sector, and enable the MBR operator to develop practical operational and feasible mitigation measures against possible process malfunctioning events.

1.3 Goals and objectives

The main goal of this study is to evaluate the performance of Alreehan MBR facility and the compliance of reclaimed water with the national regulations for agricultural irrigation. The specific objectives include:

- Investigate the efficacy of the MBR facility for municipal wastewater treatment with emphasis on the removal of physicochemical parameters and pathogens to accepted levels.
- Explore the compliance of treated water with the local regulations for safe agricultural irrigation.
- Evaluate and suggest operational practices for optimized operation of the MBR system.

1.4 Research questions

This research tries to answer the main question: what is the efficacy of Alreehan MBR facility? In addition, this research raises other important and specific questions:

- What is the efficacy of the MBR facility for treating municipal wastewater with removal physicochemical parameters and pathogens to acceptable levels?
- What effluent quality does Alreehan MBR produce? Moreover, the compatibility of quality with the national regulations for agricultural irrigation?
- What is the operational practices in the MBR system? In addition, how can the optimal operation of the MBR system under the current conditions?

2. Literature review

2.1 Introduction

Wastewater is defined the generated water from various human activities such as domestic, commercial, industrial, and agricultural use. In addition, it is one of the most important environmental matters that receive wide attention worldwide, due to its negative effects on the environment and humans (Xu et al., 2012).

Wastewater varies according to the source of domestic, industrial, commercial or hospital wastewater and this variation affect at the chemical and physical properties are varying in wastewater. Domestic wastewater contains organic matter and nutrients (N, P, K); dissolved minerals; toxic chemicals; and pathogens (Hanjra et al., 2012).

The presence of effective sewage and wastewater treatment system with high quality is important to protect freshwater sources from pollution; in addition, it is considered a reliable and sustainable water source for various activities including agricultural irrigation, aquifer recharge, car washing, and water for natural and recreational uses (Al-Sa'ed, 2015).

Membrane bioreactors are one of the most popular and modern systems that work on solid-liquid separation by pressure with membrane and are the most efficient in wastewater treatment, but technologists, operators and managers of WWTPs do not understand MBR technology and need extensive technical information training(Skoczko et al., 2020).

MBR systems demonstrate high treatment efficiency of hospitals effluent wastewater up to 80% in COD, BOD, TSS, and NH_3–N removal and fecal coliform less than 760 CFU/100 ml (Liu et al., 2010). The operating conditions and control of MBR plants are very important in order to obtain the best compatibility of MBR effluent with national standards for reuse with lower costs, and the operational parameters such as MLSS, HRT and aeration are critical factors in the operation of the facility (Yoon et al., 2004).

(Le-Clech, 2010) indicates the importance of pre-treatment treatment removing materials that can become entangled around the fibres such as hair, lint, and fibrous materials causing irreversible blockage of membranes, or blockage of aerators and lack of aeration in biological ponds, and removing them manually can cause membrane damage.

2.2 Wastewater types and characteristics

2.2.1 Domestic wastewater

The main source of sewage water is the domestic water generated from the various processes inside the house such as toilet, shower, laundry, cooking, etc. (Butler et al., 1995). Domestic wastewater is characterized by a low organic strength compared to industrial wastewater. The strength of the water is often judged by the concentrations of COD and BOD_5, which express the organic load of the wastewater, where the BOD_5 in general reaches from 200 - 800 in domestic wastewater and determines the strength of the resulting wastewater is the rate of wastewater consumption by the community. Therefore, in the United States, where water use reach (350–400 l/person day), wastewater is weak (BOD_5 = 200–250 mg/l), but in tropical regions, where water consumption is relatively lower (40–100 l/person day), wastewater is strong (BOD_5 = 300–700 mg/l) (Mara, 2013). The Palestinian consumption of water is considered to be very low due to the lack of a regular water supply, due to this, the wastewater is concentrated and its strength increases (Al-Sa'ed, 2000), Table (1) shows characteristics of wastewater of some Palestinian cities.

Table 1 Raw wastewater characteristics in some Palestinian cities (Al-Sa'ed, 2000.)

*Parameters**	*Ramallah*	*Nablus*	*Hebron*
COD_5	525	11850	1008
BOD	1390	2115	2886
TKN	79	120	278
NO_3	0.6	1.7	0.3
NH_4	51	104	113
TSS	1290	-	1188
SO_4	132	137	267
PO_4	13	7.5	20

*all parameters data in mg/L

2.2.2 Industrial wastewater

In industries, water is used in various fields such as drinking, washing, steam production, cooling etc. These activities industries produce industrial wastewater; the quality of wastewater depends on the types of industries which is characterised by colour, solids, high organic loads and heavy metals such as Cadmium (Cd), Nickel (Ni), Lead (Pb), Zinc (Zn) and Copper (Cu) it contributes to polluting the environment because of its high ability solubility in the aquatic environment and hazardous bio-accumulation (Shrestha et al.,2021). Table 2 shows the different industries and the different pollutants they produce in the wastewater. These pollutants are produced during the different production processes of the final product, and these wastewaters often comply with the standards set by local and global environmental organizations and institutions (Roy et al.,2022).

Table 2 Principal pollutant produce by some industries(Sinha et al., 2019, Awulachew, 2021, Nazzal, 2017, Garg, 2022).

Industries	**Major pollutants**
Dairy	Solids, high organic content, chlorides, sulphates, oil and grease
Olive mills	Inorganic salt, high organic content, phenols
Slaughterhouse	Pathogenic and non-pathogenic microorganisms, detergents &disinfectants, high organic content, heavy metals, colour, solids, nutrients.
leather tanning	High organic loading, High salinity and specific pollutants : sulphide and chromium

The economic growth and the increase in the demand for goods lead to increasing industrial development in various different fields, the production of larger quantities of wastewater to generate larger quantities of pollutants, in addition to the development of legislation and laws and the increase in strictness in them to the trend towards more efficient wastewater treatment such as membrane technologies, advanced oxidation processes and Nano filtration for industrial wastewater (Garg, 2022).

The author mentioned that modern technologies could be adopted as an alternative to conventional technologies such as membrane bioreactors, besides to one of the other technologies such as advanced oxidation or reverse osmosis to provide high performance and ease of operation (Priyanka et al., 2021).

2.2.3 Hospital wastewater

Hospitals' consumption of water leads to the production of different quantities of wastewater, as the wastewater generated from hospitals differs in its characteristics from domestic or industrial wastewater in that it contains pathogens and residues of medicines in addition, health care products that require special treatment due to the danger in human health (Kumari et al., 2020). The quantities of wastewater produced from hospitals vary according to the number of patients, different facilities, and sewage from the administration ward. Many research mentioned that the rate of water production in hospitals varies between developed and developing countries, where wastewater production in developed countries ranges from around 400-1200 L/capita/day. In developing countries 200-400 L/capita/day (Majumder et al., 2020).

When wastewater is discharged from hospitals without treatment or that does not comply with the standards and guidelines issued by relevant organizations and institutions such as the World Health Organization and others, it becomes a source of danger to the environment and public health (Kumari et al., 2020). The characteristics of effluents from hospitals differ, as they do not carry the same nature of pollutants, while the COD in hospital effluents ranges around 1200-2500 (Verlicchi et al., 2012).

Hospital Wastewater contains a variety of pollutants called emerging pollutants, such as disinfectants, surfactants, pharmaceuticals, personal care products, endocrine disruptors, illicit drugs etc. most of these materials are characterized by high stability in the environment Often, many of these substances' unregulated pollutants and the potential health effects are unknown (Verlicchi et al., 2010).

The high use of disinfectants and antibiotics has serious impacts on the environment and human health (Zhang et al., 2020). The danger to human health from the excessive use of antibiotics shows their transmission in the environment, their appearance in the food chain and their transmission to humans (Bandyopadhyay & Samanta, 2020).

Biological treatment is the cornerstone of organic load removal. The higher the SRT in the biological treatment system, the greater the ability to remove difficult contaminants such as emerging contaminants from hospital waste, and this is what MBR systems promise (Verlicchi et al., 2010). However high concentrations of pharmaceutical preparations inhibit the treatment in the aeration tank, resulting in less efficiency in the treatment process (Khan et al., 2020).

Since the emergence of the coronavirus infectious disease (COVID-19) at the end of 2019, the authorities worldwide have recommended the use of disinfectants and antibiotics to control the spread of the disease, as disinfectants have been widely used, especially in hospitals (Chen et al., 2021).

2.3 Membrane bioreactor (MBR) systems

The membrane bioreactor (MBR) process is a suspended growth activated sludge system that uses submerged membranes in the aeration tank to separate solids instead of the traditional activated sludge clarification process as shown in Fig. (1), some membranous systems have the ability to biologically remove nitrogen and phosphorous (Metcalf, G. J.2017). The first appear of use activated sludge treatment and the membrane separation in the United States in 1969 by Smith and others with ultrafiltration that aim of treating wastewater from factories, but it did not get very interest at that time (Al-Asheh et al., 2021).

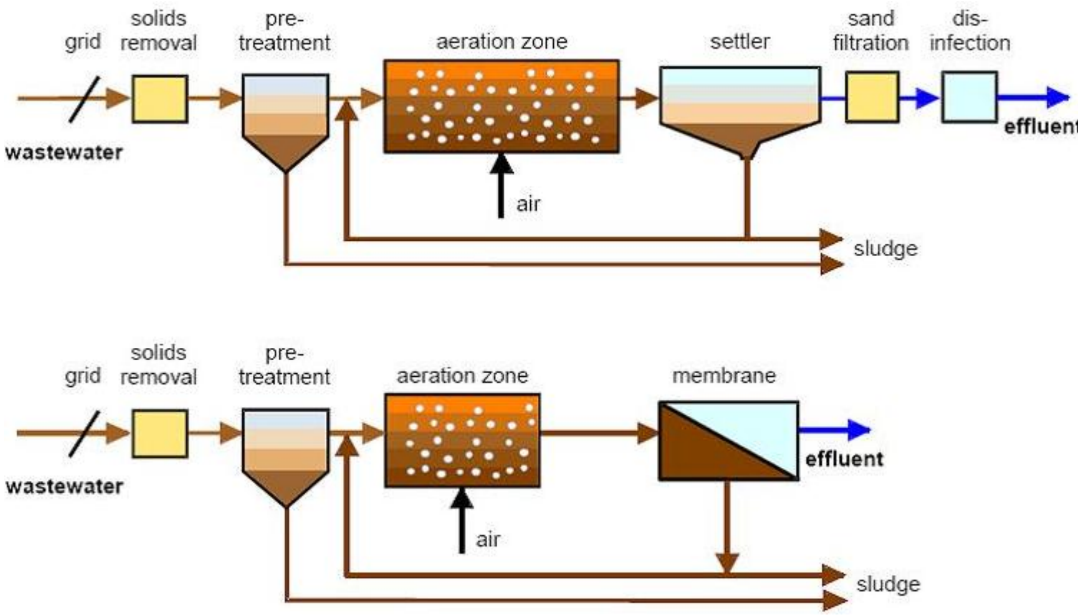

Figure 1 Schematic view of a conventional ASS & MBR (Karim & Mark, 2017)

2.3.1 Membrane bioreactor configurations classification.

The membrane separation is carried out through diverse configurations of MBR including side-stream MBR system, an external mode of installations, which typically requires a pressurized mixed liquor through the membrane, or as submerged membrane installations directly in the biological units as shown in Figure 2 (Melin et al., 2006).

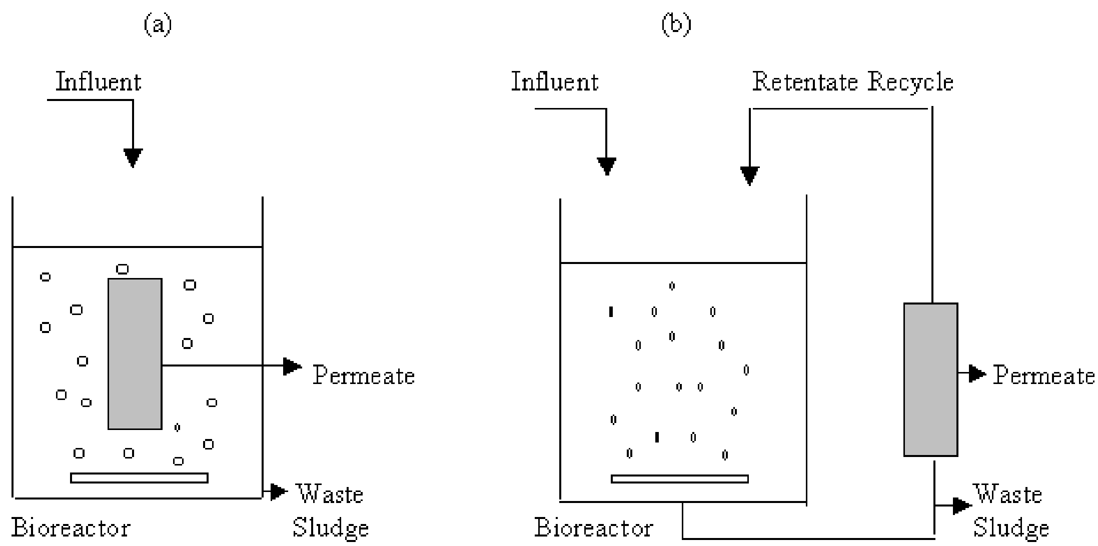

Figure 2 submerged system (a) and external MBR system (b), (Melin et al., 2006).

Membrane bioreactors can be divided into configurations that can be used in MBR: Hollow fibre (HF), Spiral-wound, Plate-and-frame (i.e., flat sheet (FS), Pleated filter cartridge and Tubular used in membrane bioreactors. Most membrane bioreactors configuration used in the treatment plant are hollow fibres indicating low cost compared to the flat plate membrane. Table 3 shows a comparison between the tubular with immersed MBRs (Radjenović et al., 2007).

Table 3 Tubular with immersed MBRs in filtration conditions (Radjenović et al., 2007).

	Side-stream tubular membrane	*Submerged membrane*

Manufacturer	Zenon	Zenon
Model	Permaflow Z-8	ZeeWeed ZW-500
Surface Area (m^2)	2	46
Permeate flux ($L/m^2.h$)	50-100	20-50
Air flow rate (m^3/h)	4	0.2-0.5
Energy (kWh/m^3)	4-12	0.3-0.6

The above table shows that the energy consumption in the submerged membranes is less, this can be explained by the occurrence of membrane fouling on the membranes and that need shear forces to separate the sludge from the membranes, where the aeration process provides shear in submerged, but in the side stream, the forces are through pumping.

Membrane bioreactors can also be classified based on the size of the pores into 1- Microfiltration 2-Ultrafiltration 3-Nanofiltration Table 4 shows the main characteristics of each of them (Han, 2013).

Table 4 main characteristics of the MBR classifications based on pore size

Parameter	**MF**	**UF**	**NF**
Operating Pressure(bar)	1-4	2-7	10-40
Pore size (µm)	0.1	0.01-0.05	0.001-0.01
Size-cut-off range (µm)	0.1-20	0.005-0.1	0.001-0.01

2.3.2 Operational parameter

MBRs provide highly effluent and efficiently treatment of wastewater (municipal, industrial, Hospital etc.) with a high content of organic and chemical contaminants, but like other membrane systems suffer from the potential for fouling or clogging (Gander et al., 2000). However, MBR systems are exposed to deflection to the operating conditions that lead to the failure of the treatment process, which is fully reflected in the quality of the treated wastewater (Trinh et al., 2014). MBR systems are sensitive to particles carried with wastewater such as sand, hair, tissues, etc., which can lead to breaking membranes and cause blockages in the membranes. Therefore, they must be protected from these materials through fine screening within range between 1-3 mm (Judd, 2010).

Main parameters factors effect on the operation of the MBR system: Hydraulic retention time (HRT), solids retention time (SRT), organic loading rate (OLR), food to microorganism ratio (F:M) and nutrients. HRT and SRT express the time it takes for liquid and solids respectively to pass through the wastewater treatment plant (WWTP).

The hydraulic retention time is an important operational parameter in the MBR system which has a direct impact on the efficiency of biological treatment, COD and BOD removal, turbidity, color, nitrogen and phosphorous. As the HRT increases, the treatment efficiency increases. However, the relationship between HRT and permeate flow is inversely proportional. Najmi et al. (2020) reported that the HRT must be adapted to the optimum to obtain the highest treatment efficiency while avoiding the membrane biofouling. HRT has directly affected the food-to-mass ratio (F:M) for example, an increase in the HRT will cause a decrease in the F:M ratio.

MBR systems work on a high solids retention time (SRT), which makes these systems have the ability to tolerate toxic compounds more than the other conventional systems (Najmi et al. 2020).

The SRT is associated with the MLSS concentration, where the increase of the SRT affects the increase in the concentration of MLSS and the viscosity of the mixed liquor, thus a higher need for aeration and an increased possibility of fouling; reaching the optimal SRT value is necessary to control the fouling phenomenon (Al-Asheh et al., 2021).

The sludge age can theoretically be controlled because the membranes reject all solids, MLSS affects the efficiency of wastewater treatment facilities, so the sludge life can be increased through increased MLSS to high levels, but in practice, the MLSS concentration was restricted due to the high cost of operation and repair and potential fouling. The lower MLSS in aeration tanks is an important and main factor in the decline in treatment performance (Fatima, & Khan, 2012).

The mixed liquor suspended solid (MLSS) is a factor expressing the concentration of biomass and solids in a given biological reactor. MLSS is a mixture of raw or settled sewage with biologically active fraction contained in the aeration tanks of WWTPs. At high sludge ages (SRT), one of the most important advantages of MBR, the high concentration of MLSS that distinguish it from conventional wastewater treatment technologies. Radjenović et al., (2007) reported that the MLSS concentration in MBR ranges from eight (8) to 10 g/L compared to 2 g/L to 3 g/L in conventional activated sludge systems.

The F: M ratio means the amount of food (measured as BOD, COD or TOC) relative to the amounts of microorganisms available to consume that food. This can be explained by the fact that the low percentage of food maintains biomass activity, through competition for food moreover, the high sludge age maintains the stability of biomass and its ability to adapt to various changes in wastewater quality (Radjenović et al., 2007).

MLSS is one of the key design factors affecting of the operation of MBR, where the optimum concentration of MLSS must be maintained in the basins for its effect on treatment efficiency. However, higher MLSS content could have negative effects on the occurrence of membrane fouling, it should be noted that the optimal concentration of MLSS depends on the operational process and membrane status (Hamedi et al., 2019).

2.3.2 Membrane fouling

Although MBR technology is well-established, mature and widely used in the world, it suffers from two main obstacles, which are the formation of fouling, high-energy consumption (Lin et al., 2012). Many researches around the world work to mitigate membrane fouling and make it more attractive (Krzeminski et al., 2017).

The problem of fouling is defined as a blockage or narrowing in the pores of the membranes due to the formation cake layer on the membrane surface and the absorption of soluble colloidal substances or micros smaller than the size of the pores, the fouling phenomenon is the main problem that suffers from MBR systems, there are many factors that cause or influence the formation of fouling: characteristics of wastewater, strategies for cleaning membranes and operation conditions (Al-Asheh et al.,2021; Metcalf, 2003). In addition, it can be recognized by decrease the flux with the trans-membrane pressure (TMP) be constant or increase (Krzeminski et al., 2017; Shi et al., 2021).

The phenomenon of fouling formation includes several mechanisms for its occurrence in MBR systems, this includes:

- Pore narrowing: a collection of fine colloidal substances that narrow the membrane pores.

Pore clogging: particles of a size close to the size of the pores that clog membrane pores

Cake layer formation: accumulation of a layer with a size larger than the size of the pores, forming a biofilm that closes the pores. Higher MLSS concentration, increased membrane flux and reduced air scouring in addition to high EPS and SMP contents are factors behind the cake layer formation (Hamediet al., 2019).

Membrane fouling is classified into three main types according to the type of foulants: which are organic fouling, inorganic fouling and biofouling. Biofouling is considered the main type of fouling, as the growth of microorganisms and bacteria and release of the extracellular polymeric substance (EPS) and by-products forms a cake layer on the surface of the membrane, and deposition of dissolved colloidal substances, biofilms cause more flow resistance (Zhang et al., 2012). In addition, membranous fouling can also be classified into three other categories based on the condition of the membranes: irremovable fouling, removal fouling, and irreversible fouling.

Many researches has focused on the process of mitigating the phenomenon of fouling through cleaning membranes. Three techniques prevalent in the membrane cleaning, i.e. chemical, physical and physico-chemical cleaning. Backwashing technology can be used in hollow fibre membranes, which is possible by pumping wastewater reversely, but it is not considered effective in flat sheet membranes. In general, physical cleaning is able to remove the cake layer, but it remains less efficient than chemical cleaning, where chemical cleaning is done inside and outside the site according to the strength of the foulants (Nguyen et al., 2022).

MBR is widely used in more than 200 countries around the world for various municipal and industrial uses (icon, 2008); the sales and installation of these technologies have grown around the world, especially in China (Srinivasan, 2007), where the market size of MBR reached about 1.2 billion dollars in the year 2016 and is expected to exceed 3 billion by the year 2023 (Judd, 2016).

The obvious increase in the demand for MBR systems shows the reliability of this technology due to its small footprint, the higher separation efficiency of organic matter compared to conventional activated sludge and the high quality of effluent and the possibility of reuse (Neoh et al., 2016), on the other hand, the key drivers being: stricter legislation and new laws by governments and the scarcity of water resources (Judd, 2010; Zhang et al., 2021).

Several studies have shown the high efficiency of the MBR system, which outperforms the conventional treatment systems, especially the conventional activated sludge system, in removing organic pollutants, nutrients and a wide range of microorganisms (Jadhao & Dawande, 2012).

MBR shows significant efficacy in removing various emerging and pharmaceutical micro pollutants from the aquatic environment. For example, the average removal rate of ibuprofen and acetaminophen from the aquatic environment with MBR is more than 90%, which is higher than other removal techniques (Nguyen et al., 2022).

Mutamim et al., 2012 refer to the ability of MBR efficiently treat high strength wastewater such as textiles, the food industry, the refinery, pharmacy, municipal etc. MBR has a high efficiency of up to 90% on removing COD, colour and turbidity MBR has a high efficiency of up to 90% on removing COD, colour and turbidity from wastewater generated by the textile industry thanks to the relatively long sludge age and HRT, but it remains limited to the disposal of salinity, which can be disposed of through the reverse osmosis unit (Zahraa & Gzar, 2019). However, a major drawback in the operation of MBR is membrane fouling, which leads to the decline in permeate flux and therefore requires membrane cleaning. Due to the high sludge age, MBR technology also has the potential to efficiently treat highly stable compounds that occur in industrial effluents (Hoinkis et al., 2012).

MBR systems provide high efficiency in treating hospital sewage and pathogens compared to conventional treatment systems (Liu et al., 2010) also the COD removal efficiency reached 80%, the turbidity was 90%, and the NH4 disposal was 82%(Wen et al., 2003).

During the recent Coronavirus pandemic, global attention appeared to viruses and infectious pathogenic removal in hospitals, some types of bacteria were resistant to antibiotics and some viruses appeared stable even after treatment inside the hospital, it was required to add larger doses of chlorine or ultraviolet rays to neutralise their effect (Majumder et al., 2021).

In Palestine, there is three large full-scale treatment plant with an MBR system Alteereh, Bethlehem industrial zone and al-Reehan, The first MBR treatment plant was commissioned in 2014 in the Alteereh west of Ramallah, with a flow of about 1,500 cubic meters per day. The plant's performance was excellent and the water quality was suitable for unrestricted uses (Al-Sa'ed, 2015).

2.4 Reuse of treated wastewater

2.4.1 Wastewater reuse

The increasing of population, it causes the increasing of demand fresh water, and the scarcity of drinkable water, that lead the countries with water shortages to use another water source like desalination of sea water, brackish water (Dhakal et al.,2022; Van Vliet et al., 2021).

The population of the West Bank is about 2.9 million people on an area of 5655 km, they consume about 184 MCM, and about 37% go to agriculture and the rest to other uses. While the population of the Gaza Strip is 1.9 million people who consume about 47% for agriculture and the rest for other uses (PWA, 2011; PCBS, 2016). In general, household consumption per person is 70 litters per day per person, while the minimum recommended by the World Health Organization is 100 litters per day per person.

The water shortage in the Middle East has led to the reuse of wastewater as a source of water to relieve pressure on water sources. Governments have gone to issue regulations and laws that include wastewater reuse, in addition, the regards quality of treated wastewater, where the main parameters that include (PH, BOD, turbidity, fecal coliform and residual chlorine), and there is no social acceptance of the reuse of treated wastewater that people do not want to consume products that irrigated with the sewage water (Bahadir et al,. 2016). For example, the Gulf countries suffer from water stress on groundwater sources, where the total withdrawal is five times the recharging, and where they are interested in searching for non-conventional sources of water, despite all that, the reuse of wastewater does not exceed 40% due to social, religious and health concerns (Qureshi, 2020).

The treated domestic wastewater reuse projects have featured as a potential non-conventional and sustainable resource of water. It is expected that the treated wastewater in the Palestinian territories will reach about 60 million cubic meters by 2035 (PWA, 2018). Treated wastewater had wide use, for example, in Agriculture, landscape irrigation (parks, green areas, golf courses, etc.), car washing, groundwater recharge fire fighting, and industrial sector (Besbes, 2019).

2.4.2 Wastewater reuse regulations and guidelines

Policymakers went to enact laws to encourage management and regulation of the water sector and to move towards optimal water use, including the exploitation of treated wastewater. In addition, there are no unified standards for the reuse of treated water for the whole world, due to the different social, economic, and political conditions and water resources in various countries (Cipolletta et al., 2021), where many countries have gone to include wastewater as a water resource such as the United States of America, Spain, Germany, and Israel (Kamizoulis, 2003).

Many organizations and countries have set guidelines for the reuse of treated water, such as the World Health Organization (WHO), the Environmental Protection Agency (EPA) and The Food and Agriculture Organization (FAO).

The WHO issued the document "Reuse of effluents: methods of wastewater treatment and health safeguards" to maintain public health and proper sanitary use of waste in agriculture in 1973 where drafted the first guidelines Then, in 1986, all available epidemiological studies and their risks were analyzed, and in 1989, the guidelines were updated and new criteria were included (Carr, 2005).

EPA extended the scope of indirect drinking reuse and industrial reuse to include several new and revised case studies, new knowledge on treatment and is infection technologies, emerging chemicals and pathogens of concern, economics, user rates and funding alternatives, public involvement and acceptance, research activities and sources of information (EPA, 2004). These guidelines have been the basis for the formulation of the regulations in different countries in the world. The possibility of reusing treated wastewater depends on the quality of treatment in different uses such as agriculture, industry and etc., according to the criteria for reusing treated wastewater published by the U.S. EPA and WHO there are different criteria for each use as shown in the table 5 (Kellis et al., 2013).

Table 5 U.S. EPA and WHO criteria for treated wastewater throughout different uses (Kellis et al., 2013).

Water use	Type of use	BOD	Turbidity	TSS	FC	Cl	PH	Filtration & Disinfection
Agriculture	Food crops (fresh consumed)	≤10 mg\l	≤2 NTU	-	ND /100 mL	1 mg\l	6-9	Yes
	Non-food crops & crops consumed after processing	≤30 mg\l	-	≤30 mg\l	≤200 /100 mL		6-9	No
Landscape	Parks, School, Yards, Playgrounds	≤10 mg\l	≤2 NTU	-	ND /100 mL	1 mg\l	6-9	Yes
	Golf Courses, Cemeteries, Greenbelts, Residential	≤30 mg\l	-	≤30 mg\l	≤200 /100 mL	1 mg\l	6-9	yes
Industrial	Cooling Water, Boiler Feed, Heavy Construction	≤30 mg\l	-	≤30 mg\l	≤200 /100 mL	-	-	yes

Recreational	Lakes and ponds, Marsh enhancement, Stream flow augmentation, Fisheries, Snowmaking	≤10 mg\l	≤2 NTU	-	ND /100 mL	1 mg\l	6-9	Yes

In 1999, the Palestinian Law was issued, which stipulated in Article 29 that: "The Ministry of Environmental Affairs (MENA), in coordination with the competent agencies, shall set standards and norms for collecting, treating, reusing, or disposing of wastewater and storm water in a sound manner, which complies with the preservation of the environment and public health" (EQA, 1999).

Then, the Palestinian standards for the reuse of wastewater in agriculture were set in 2003, but they were restricted to general standards and technical principles for irrigation, which are:

- Wastewater must be collected, treated and used in accordance with the guidelines to reduce the water deficit.
- The treated domestic, commercial or industrial wastewater to be reused must comply with the standards assigned to each reuse plan.
- Lined channels and pipes must be used to transport wastewater, and it is strictly forbidden to use sprinkler irrigation in treated wastewater.
- Irrigation with treated wastewater must be stopped two weeks before the harvest, and fruits that have fallen on the ground should not be eaten and must be destroyed.

- Irrigation with treated wastewater for all crops prevents crops that are eaten raw such as vegetables
- It is prohibited to dilute wastewater by mixing it with fresh water in treatment plants to comply with the requirements of this standard for reuse (EQA, 2003).

In 2012, the Standards and Metrology Institution in cooperation with the Ministry of Agriculture and the Water Authority issued mandatory technical instructions 2012 - 34 for the reuse of treated wastewater for agricultural irrigation. These instructions included the definition of wastewater and the administrative instructions governing the reuse of wastewater, the table () below shows the Palestinian specification No. 2012-34.

- The treated wastewater was divided according to its quality into four categories, high quality (A), Good quality (B), Moderate quality (C) and Poor quality (D).
- The specification requires the approval of the Ministry of Agriculture for this use in accordance with the instructions issued by it for this purpose and allocating the violet colour to the water-carrying pipes.
- It is prohibited to water livestock, irrigate vegetables, and directly feed groundwater and fish farming.

Table 6 Technical instructions No. 2012 - 34 for the reuse of treated wastewater for agricultural irrigation.

Parameter	**Treated water quality**			
	High quality (A)	**Good quality (B)**	**Medium quality (C)**	**Low quality (D)**
DO	>1	>1	>1	>1
BOD	20	20	40	60
COD	50	50	100	150
TSS	30	30	50	90
TDS	1200	1500	1500	1500
NH4	5	5	10	15
PH	6 - 9	6 - 9	6 - 9	6 - 9
SO4	300	300	300	300
NO3	20	20	30	40
FC	200	1000	1000	1000

3. Materials and Methods

3.1 Study design

This study opted for an applied research type, which entails two stages. The first stage entails information and data collection about Alreehan suburb including technical data on the residential and commercial zones including AL-Istishari Arab Hospital. Through personal interviews, the technical data covered the unit operations of the hospital including water consumption, wastewater discharge, and number of employees, departments, beds, and patients. The number of residents served by the MBR facility, MBR technical design, domestic water consumption in the suburb and hospital. The collected data on quantities of volumes of used chemicals and detergent in hospital.

The second stage comprised fieldwork and lab analysis. In this study, sampling was done during August to November 2021 from the inlet, biological tank (anoxic, oxic, and anoxic) and outlet. The samples were collected biweekly basis at the Alreehan MBR facility, with lab analysis for selective parameters including physical {pH, temperature, conductivity (EC), turbidity, total suspended solids (TSS), mixed liquor suspended solid (MLSS), sludge volume index (SVI) }, chemical {chemical oxygen demand (COD), biological oxygen demand (BOD), NH4, NO3, total Keldgal nitrogen (TKN), total P}, biological parameters (total and faecal coliforms). All samples were prepared and analysed according to the Standard Methods (APHA, 2017).

3.2 Site description

Al-Reehan Suburb

Al-Reehan Suburb is a newly established Suburb owned by the Palestine Investment Fund and developed by Ammar Company, located about 8 km northwest of Ramallah and to the southwest of Abu Qash town, at an altitude of 800 meters above sea level. Administratively, Al-Reehan Suburb is affiliated with the Ramallah Municipality. The total area of the Suburb is 250,000 square meters; AL-Reehan Suburb see figure no.3, is used predominantly for residential and some commercial purposes and the Istishari Arab Hospital is located in the Suburb. AL-Reehan Suburb includes about 1,800 housing units to accommodate 8,000 residents. Wastewater from the Suburb is completely discharged through a sewage network to a sewage treatment plant designated for the Suburb using membrane bioreactor technology (MBR).

Figure 3 General overview of Alreehan Suburb

The Istishari Arab Hospital (IAH) is located in Alreehan suburb and is considered the largest in terms of investment in the Palestinian health sector. The hospital had 14 floors with a total area of 25,000 square meters, contains 19 departments including most medical specialties, internal, heart, neurosurgery, obstetrics, pediatrics, daily cancer treatment unit, with a special department for coronavirus, the total number of the hospital beds now reaches 220 beds moreover, 490 employees clinical and non-clinical caregiver. Currently, the hospital is establishing an entirely new building specialising for cancerous tumors, which will include a department for treating radioactive, chemical, biological and hormonal tumors for adults and children, and bone marrow transplantation.

The Istishari Arab Hospital (IAH) consumes about 1,000 cubic meters of water per month and disposes of about a, while the hospital annually consumes about 1824 litters as for detergents, 5424 litters and washing powder (laundry) 768 kg. Without prior pre-treatment, all wastewater streams from Istishari Arab Hospital (IAH) are directly connected to the sewerage network of Alreehan Suburb, where a full-scale membrane bioreactor (MBR) system is operational for treatment and water recycling of reclaimed water in agricultural purposes (Figure 4).

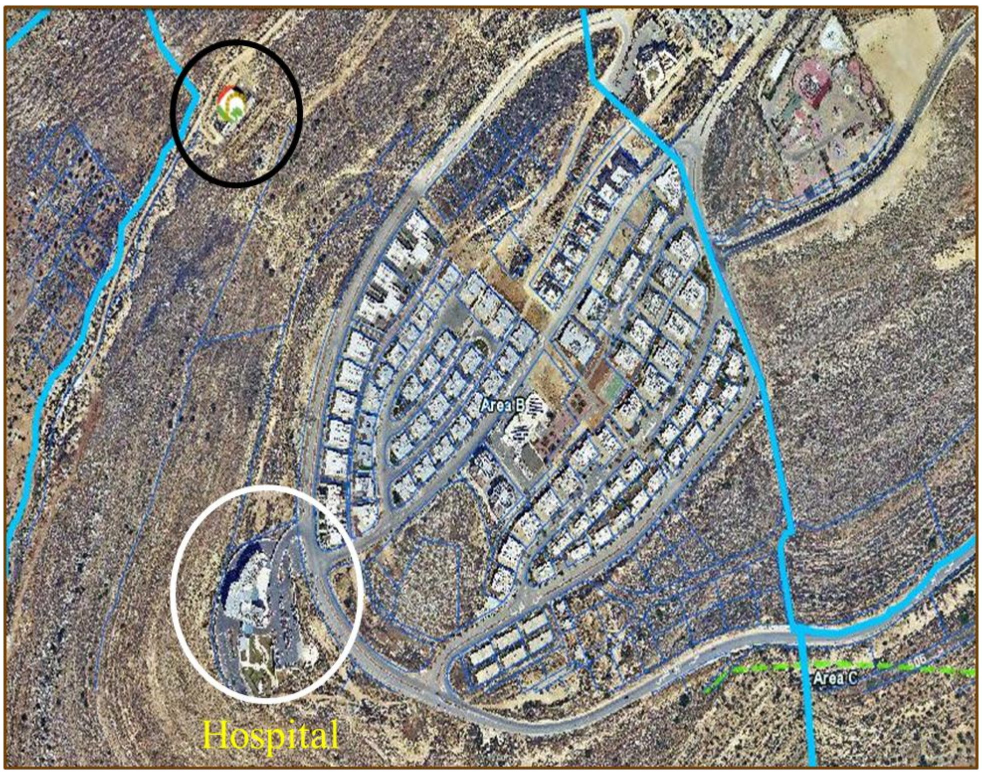

Figure 4 Al-Reehan suburb with AL-Istishari Hospital and MBR facility

MBR wastewater treatment facility

The MBR system, a wastewater treatment plant serving the neighborhood of Alreehan suburb on the side of the valley. During this study, the MBR system received an average daily flow of about 180 m^3. The origin and volumes of wastewater is variable with domestic wastewater from households of Alreehan housing compound, hospital liquid waste streams from IAH, and recently commercial wastewater from the LACASA Mall. The Mall extends over 65,000 m^2 with hundreds of shops, restaurants, central supermarket and diverse services.

Before entering the biological treatment, the incoming wastewater undergoes a preliminary treatment stage and will screen to at least 2 mm and then the biological treatment (anoxic tank, balancing tank, oxic or aeration tank.

The mixed liquid flows by gravity to the membrane tanks from the biological process tanks, and a pump recirculates to the beginning of the biological treatment tanks in a process called return activated sludge (RAS). The membrane system is submerged membrane type ZW500d made with hollow fibre and gives a pore size of 0.4 microns, two cassettes installed in the membrane tank, a chlorination disinfection unit, and dewatering sludge unit, and an effluent collection tank.

Typical operation of the membranes will involve a cycling of filtration (between 6 – 15 minutes the system will permeate producing clean water), backwash and relaxation subroutines. The purpose of the backwash and relaxation steps is to minimize solids build up on the membrane surface thereby maintaining the system performance over a long period without the need for excessive chemical. It is recommended to chemically clean the membranes every two months periodically to maintain the membranes. The cleaning process includes draining the mixed liquid in the membranes basin and filling the basin with clean water and sodium hypochlorite, then leaving the membrane soaked for 4-6 hours. It is preferable to clean continuously and not wait until failures.

Table 7 Technical Operational Parameters for the MBR system

Parameter	**Value**
Average Daily Flow	500 m^3 /day
Biological tank (oxic, anoxic)	113.4
Membrane Type	ZW500d
Membrane Tank volume	20.5 m^3
Total Number of Trains	1
Number of full cassettes/Train	2
Surface Area	41 m^2
Wastewater Temp.	T max: 25 °C T min: 15 °C
MLSS	≤ 8,000 mg\l (in biological tanks) ≤ 10,000 mg\l (in membrane tank)
PH	6-9
F/M ratio	0.148 d^{-1}

Table 8 designed parameters for inlet and outlet Al-Reehan facility

Parameter	**Inlet** (**Raw Wastewater**)	**Designed Outlet** (**Treated Wastewater**)	**Unit**
COD	1200	30	mg\l
BOD	600	5	mg\l
TSS	610	5	mg\l
TN	-	30	mg\l
TKN	80	5	mg\l
NH_4	60	1	mg\l
TP	10	-	mg\l
PH	6-9	6-8	mg\l
EC	≤ 1500	≤1500	mg\l
Total coliform (TC)	-	2.2 cfu\100 ml	


2013/02/18

3.3 Sampling

All samples analysed in lab with the methods used in the testing laboratories at the University of Birzeit to physical, chemical and biological parameters mentioned in the table no.9 below.

Physical tests

The Electrical Conductivity (EC) and pH were analysed by instrument WTW (Germany) pH/Oximeter.

Dissolved Oxygen (DO) were analysed by instrument (DO-meter 98196)

Turbidity measured in NTU: Nephelometric Turbidity Units. The measuring is taken by instrument (Turbidity meter).

Total Suspended Solids (TSS) samples were well mixed and filtered with weighted glass-fibre filter paper and dried at 105 °C. The difference in weight is the total suspended solids.

For the MLSS test, we used a standard pre-weighed glass fiber filter. The residue remaining on the filter was dried at temperatures between 105°C; the increase in weight represents the MLSS. Sludge volume index (SVI) means measuring the sludge settling ability. In addition, it is valued by reading the volume of sludge settled within 30 minutes from a volume of one litter of sample in a graduated cylinder.

SVI = volume of sludge stabilized after 30 minutes in (ml/L) divided by MLSS mixed liquid suspended solids (mg/L).

Chemical tests

BOD_5, COD, TP, NO_3-N and Ammonium (NH_4) were measured according to Standard methods (APHA, 2017).

Biological Tests

Total coliform (TC) and faecal (FC) coliform analysis was determined according to standard method (APHA 2017).

Table 9 Standard methods used for the determination of chemical, physical and biological parameters (APHA, 2017)

Parameters measured	***Instruments used for analysis***	***Methods of analysis***	***Location of analysis***
PH	WTW (Germany) pH/Oximeter	4500-H+ A	BZU Lab
DO	DO-meter 98196		BZU Lab
Temp.	Temperature meter	2550B	Onsite
EC	Portable EC meter	2520B	BZU Lab
Turbidity	2100P TURBIDIMETER	2130B	IEWS Lab
TSS	Filtration and drying	2540D	IEWS Lab
COD	Hach COD reactor	5220D	IEWS Lab
BOD	DO meter – Oxi 197	5210B	IEWS Lab
NO_3	HPIC	4500-NO3	BZU Lab
TKN	Gerhardt, kjeldatherm Gerhardt, Vapodest 30.	4500B	BZU Lab
NH_4	UV-VIS spectrophotometer	4500C	BZU Lab

TP	ICP-AES	-	BZU Lab
MLSS& SVI	Filtration and drying, Imhoff cone 1L	-	IEWS Lab
TC & FC	Vacuum Filtering Apparatus	9222B, 9222D	BZU Lab

4. Result and Discussion

This section presents and discusses the results on physical, chemical and biological parameters obtained from the Al-Reehan MBR system. The water samples were taken from the water inlet of the treatment plant and from outlet the station and biological tanks in the station. The operational variables in the treatment plant will be evaluated to reflect the performance of the MBR system in compliance with local standards for agricultural reuse.

4.1 Physical control parameters of Alreehan MBR facility

4.1.1 pH

The pH values as shown in Figure (5) in Alreehan MBR system whether in raw or treated wastewater, looking at the operational parameters Table (7), and the pH value is within the allowable range in the design; That is, it has no effect on the operation of the system. Nevertheless, it has slight differences, as the average pH value remained at 7.7 in raw wastewater and treated wastewater at 7.94 where pH value showed a slight increase in value in the treated wastewater. According to the Palestinian standards for agriculture reuse (PSI) and the agriculture ministry, this treated wastewater can be reused in agriculture due to the range of pH.

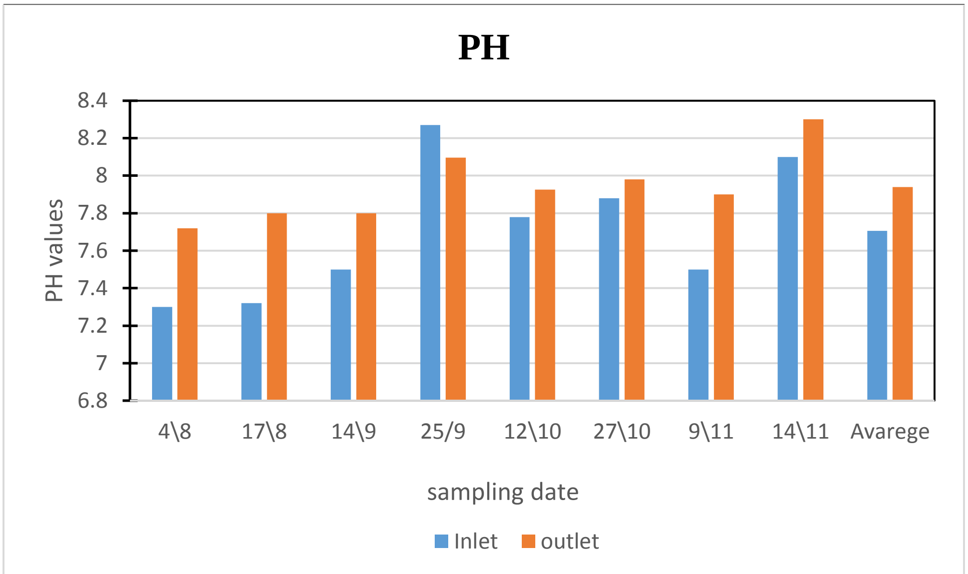

Figure 5 pH values for MBR inlet & outlet

4.1.2 Electrical Conductivity (EC)

The average electrical conductivity (EC) values in the raw wastewater ranged around 1547 µs\cm, while in the treated wastewater it was at a rate of 1517 µs\cm, where the results did not show a clear change in the EC values, due to the inability of MBR technology to remove salts from the wastewater (Zahraa & Gzar, 2019). According to the Palestinian standards for agriculture reuse (PSI) and the agriculture ministry, this treated wastewater can be reused in agriculture.

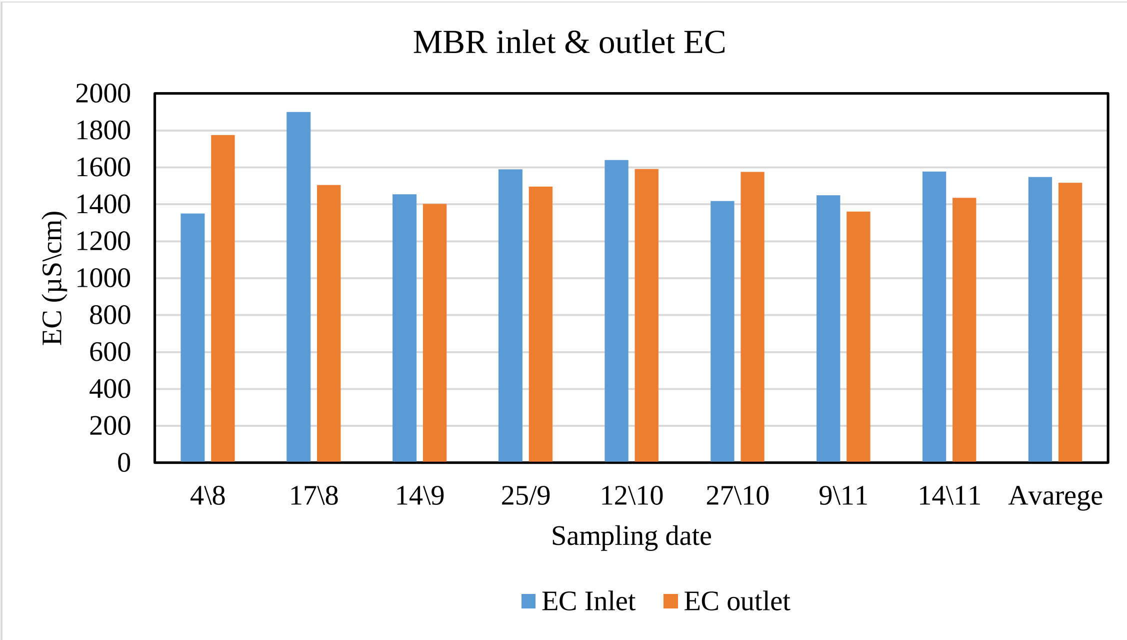

Figure 6 EC values Of MBR inlet and outlet

4.1.3 Dissolved Oxygen (DO)

In this study, the results of the DO showed a significant increase in the treated wastewater than the raw wastewater. The average values of DO in the raw wastewater were about 0.26 mg\l , while the average values in the treated wastewater were 2.44 mg\l, which corresponds to the Palestinian standards for agricultural reuse. The noticeable rise in DO as shown in figure (7) due to the occurrence of treatment in the biological process and air supply via diffusers in the biological tanks. According to the Palestinian standards for agriculture reuse (PSI) and the agriculture ministry, this treated wastewater can be reused in agriculture.

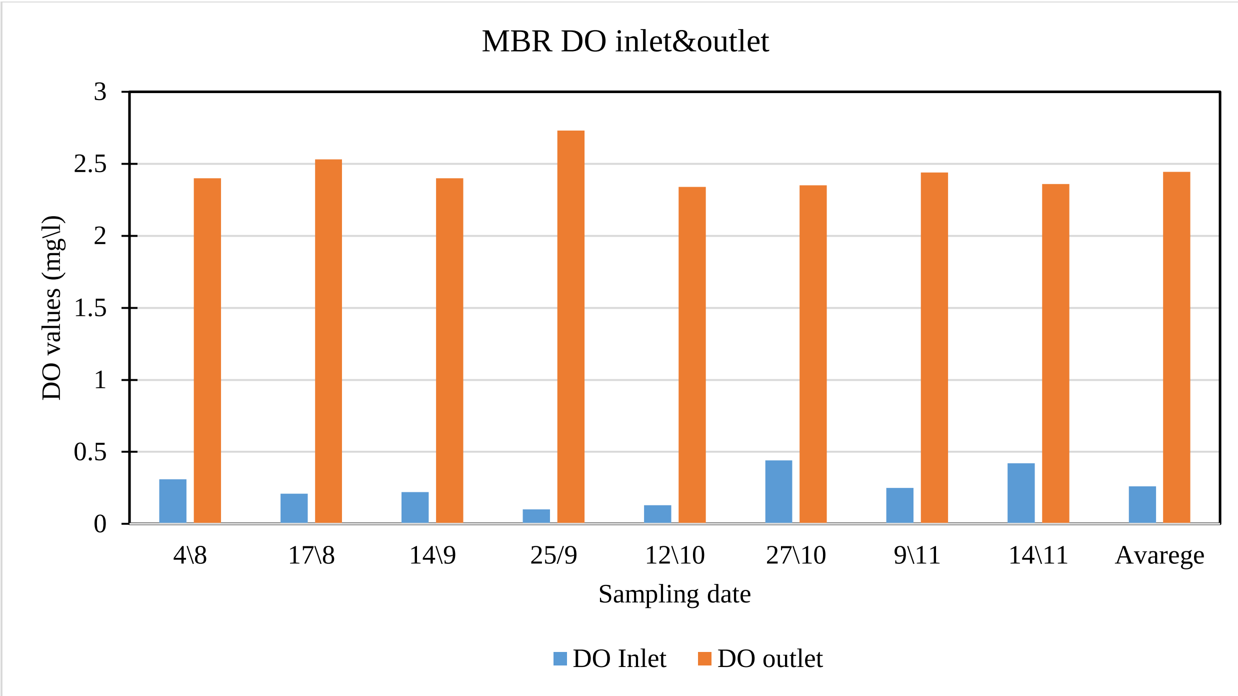

Figure 7 the DO of MBR inlet and outlet

4.1.4 Turbidity

Membrane bioreactor (MBR) systems are considered highly efficient in removing turbidity due to their use of a microfiltration system (Yigit et at., 2007), Our study showed the turbidity as shown in figure(8) below the average value of the raw wastewater ranged from 372 NTU, while the average value of the treated wastewater reached 30 NTU.

Although the high-efficiency turbidity removal expected in the MBR system can be reached 90%. these results do not appear as expected from the efficiency of MBR systems, as the results of previous studies showed high efficiency in getting rid of turbidity that does be within the range of 1.5 - 0.5 NTU (Naghizadeh et al., 2011; Nazzal,. 2017).

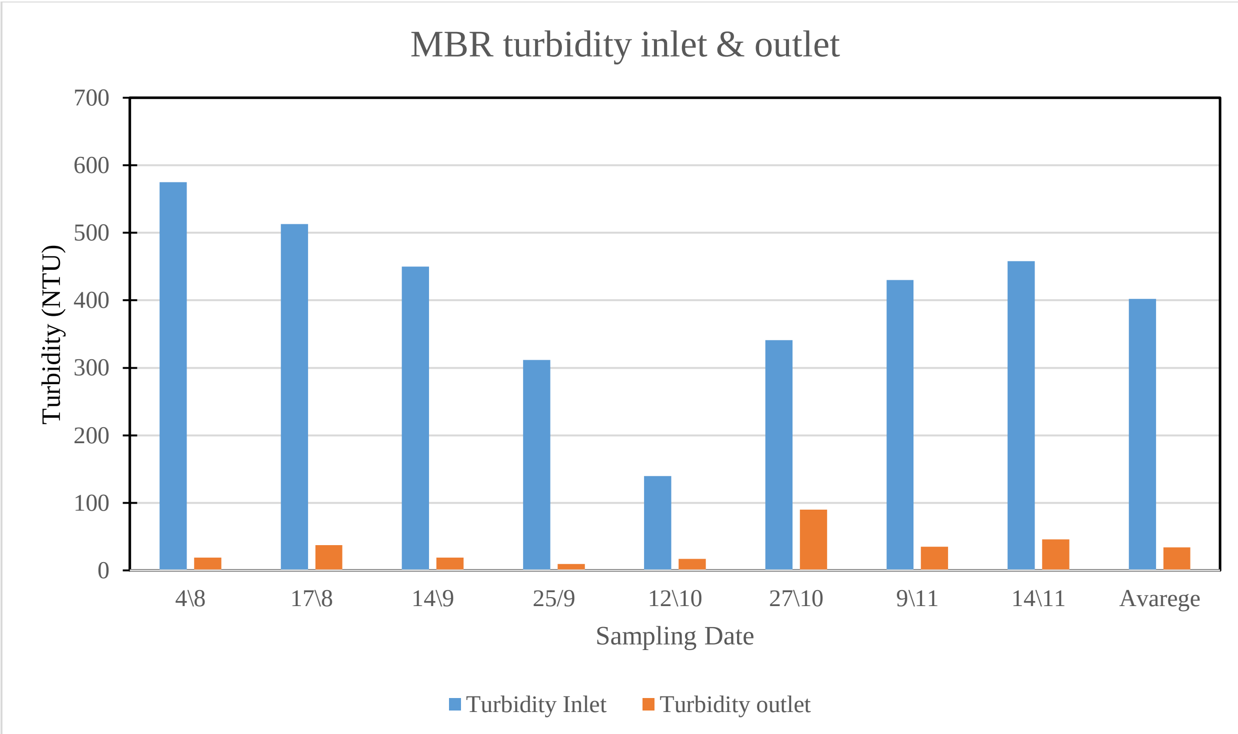

Figure 8 turbidity of MBR system inlet &outlet

4.1.5 Water temperature

The temperature play important role in biological treatment, such as the higher temperature in summer positively affects the efficiency of MBR systems like organic matter removal, as well as the removal of persistent pollutants such as pharmaceuticals residues and others that are expected to be present in the wastewater removal (Cirja et al., 2008).

In our study, the water temperature results showed within the normal range with an average of 24 for raw wastewater and about 25 for treated wastewater. Whereas, temperatures of around 25 C are more efficient in the process of removing pollutants (Cirja et al., 2008).

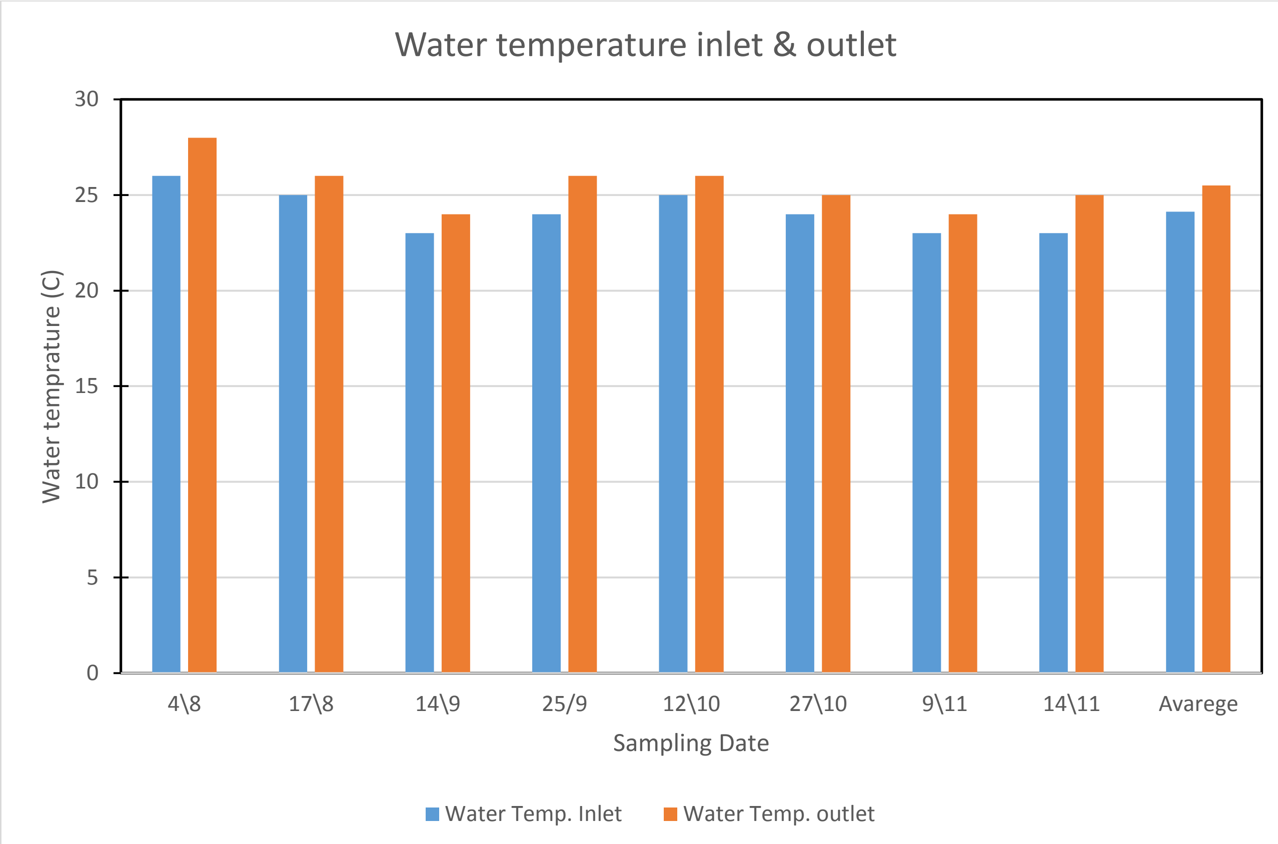

Figure 9 water temperature of MBR inlet & outlet

4.2 Alreehan facility operational parameters (MLSS & Sludge Volume Index (SVI))

The operation of wastewater treatment plants in high mixed liquid suspended solids (MLSS), which raises the hydraulic retention rate, which leads directly to reducing the space needed for the stations (Judd, 2008). Although the MLSS in the design report should be about 8000 mg/L, the results in biological treatment ranged between 1967 - 2938 mg/l, this means that there is not enough biomass that can degrade organic matter and feed on it, therefore the biological treatment is not sufficiently effective, while the optimum values in MBR systems range from 4000-8000 mg/l (Ren et al., 2005, Le-Clech et al., 2003).

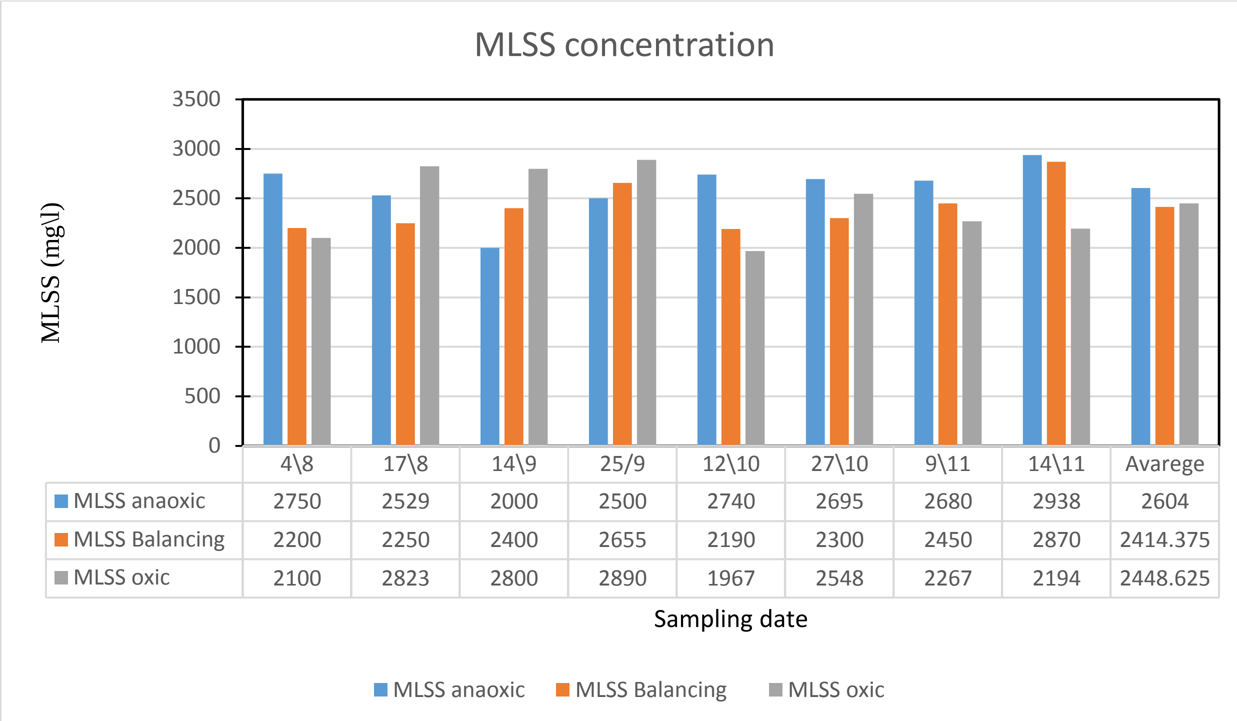

Figure 10 MLSS concentration of the biological tanks

The sludge volume index (SVI) was studied to assess the compaction and stability of the sludge, the optimum compaction leads to an increase in the porosity of the cake layer, thus enhancing membrane flow (Gkotsis et al., 2021), and although MBR systems do not depend on sedimentation, the SVI provides information about the quality of the sludge (Qin et al., 2012). Where the results showed in the figure that the SVI in biological treatment ponds is around 30 ml/g, which SVI value is low, and the sludge is high settled and indicates fast compressive properties and no filamentous bacteria or bulking sludge.

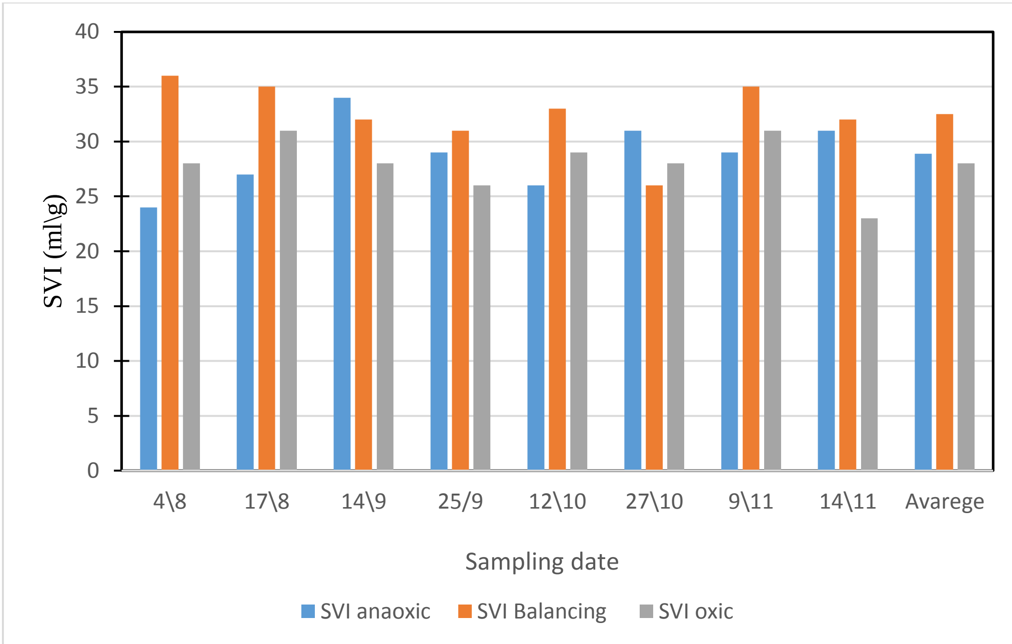

Figure 11 SVI values in the biological tanks

Al-Istishari hospital uses large quantities of sterilizers, detergents and various chemicals used from laboratories, in addition to containing a section for treating cancer patients. Kumari et al., 2020 indicates that wastewater from hospitals contains dangerous substances such as the residues of pharmaceutical preparations, pathogens, heavy elements, and chemicals different radionuclides. Due to this, the wastewater generated from hospital wastewater contributes significantly to the impact on the treatment processes in wastewater (Al Aukidy et al., 2014). These flows of heavy loads of organic and inorganic materials lead to a decrease in the efficiency of the MBR system and the possibility of using it in agriculture (Nazzal, 2017).

4.3 Treatment Efficiency of Alreehan MBR System

4.3.1 Removal of BOD & COD

The results of BOD and COD, as shown in the figure (11, 13), BOD ranged from 460 - 556 mg/l in the inlet wastewater facility with BOD loading rate 85 kg/day. The BOD concentrations in the outlet wastewater facility ranged between 70 – 140 mg\l, while the results of the chemical oxygen demand (COD) in inlet wastewater facility appear from 1137 - 1427 mg/l with COD loading rate 226 kg COD/day, and the COD in the outlet of wastewater facility ranged from 239 - 470 mg/l.

The average removal rate of BOD and COD is shown in the figure (12, 14) 79.9 %, and 74.4% respectively. According to Judd (2016), higher removal rates (90%) for COD were reported by similar MBR facilities treating domestic wastewater.

The removal rate reached, this is inconsistent with what has been published in most literature (Naghizadeh et al., 2011; Wang et al.,2021; Kitanou et al.,2021), because of the low concentration of MLSS in the biological treatment tanks affects the efficiency of wastewater treatment in the MBR facility, as the number of bacteria is small and cannot digest all the organic loads.

This treated wastewater can't be reused in agriculture according to the agriculture ministry and the Palestinian standards for agriculture reuse (PSI).

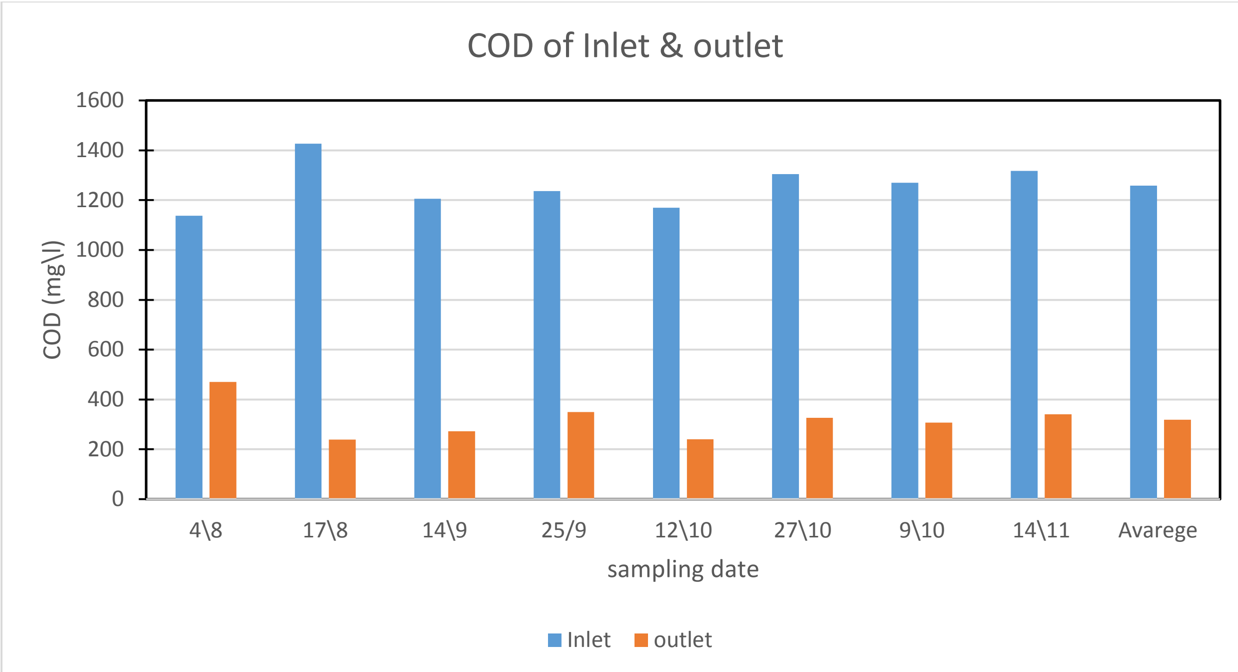

Figure 12 COD of MBR Inlet and outlet

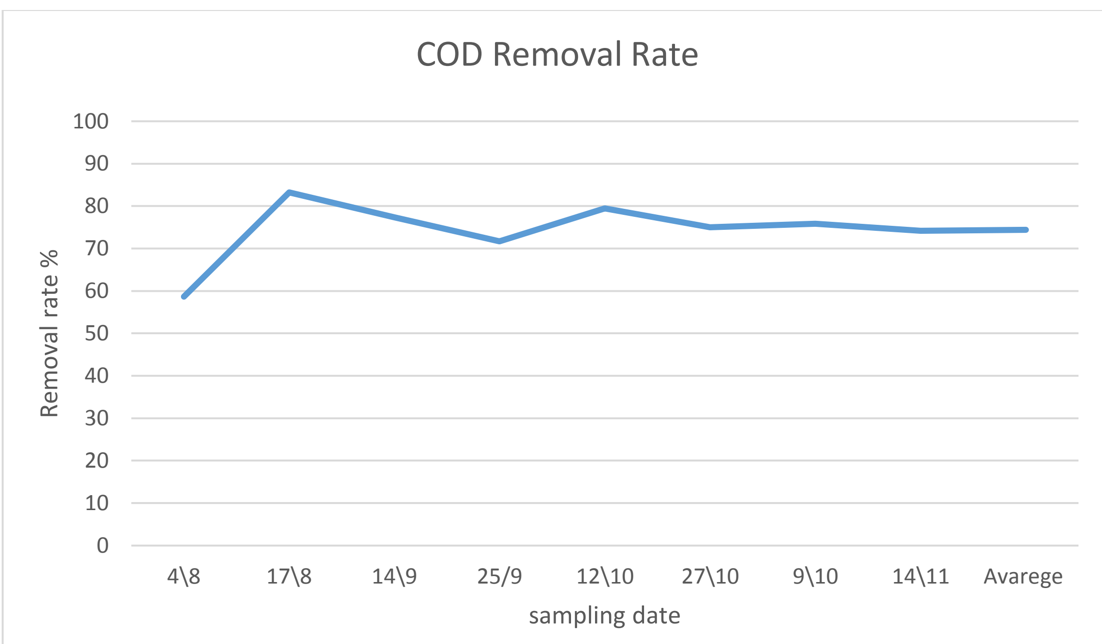

Figure 13 MBR removal rate of COD

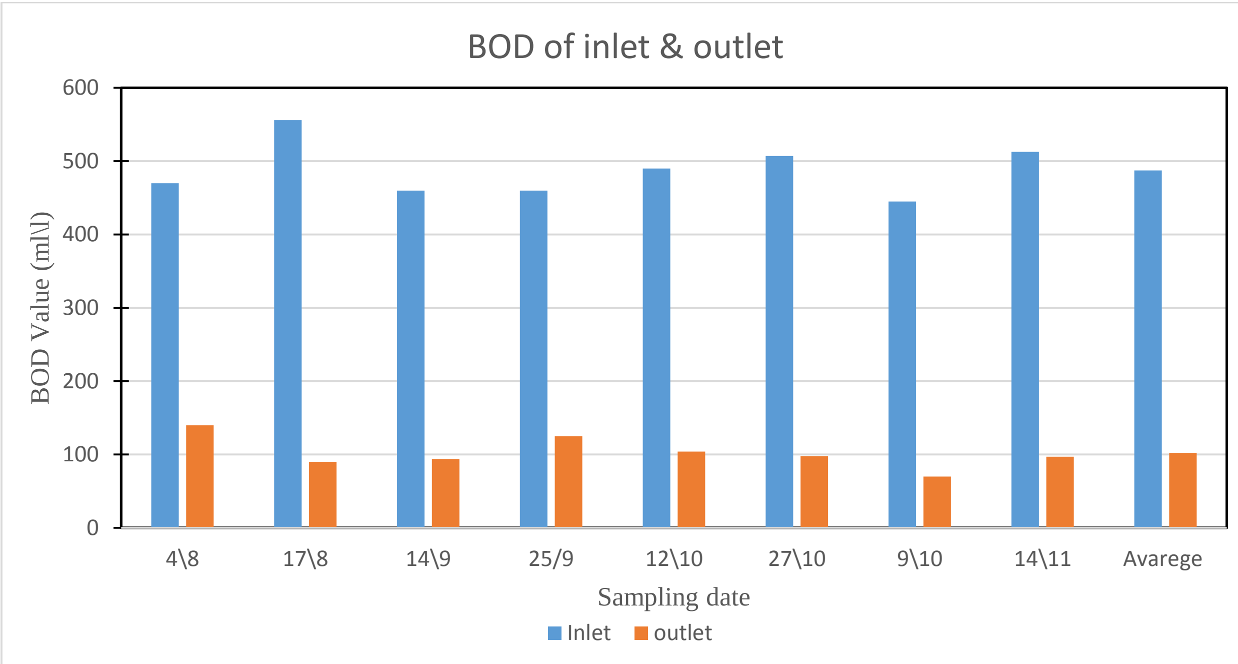

Figure 14 BOD of MBR inlet & outlet

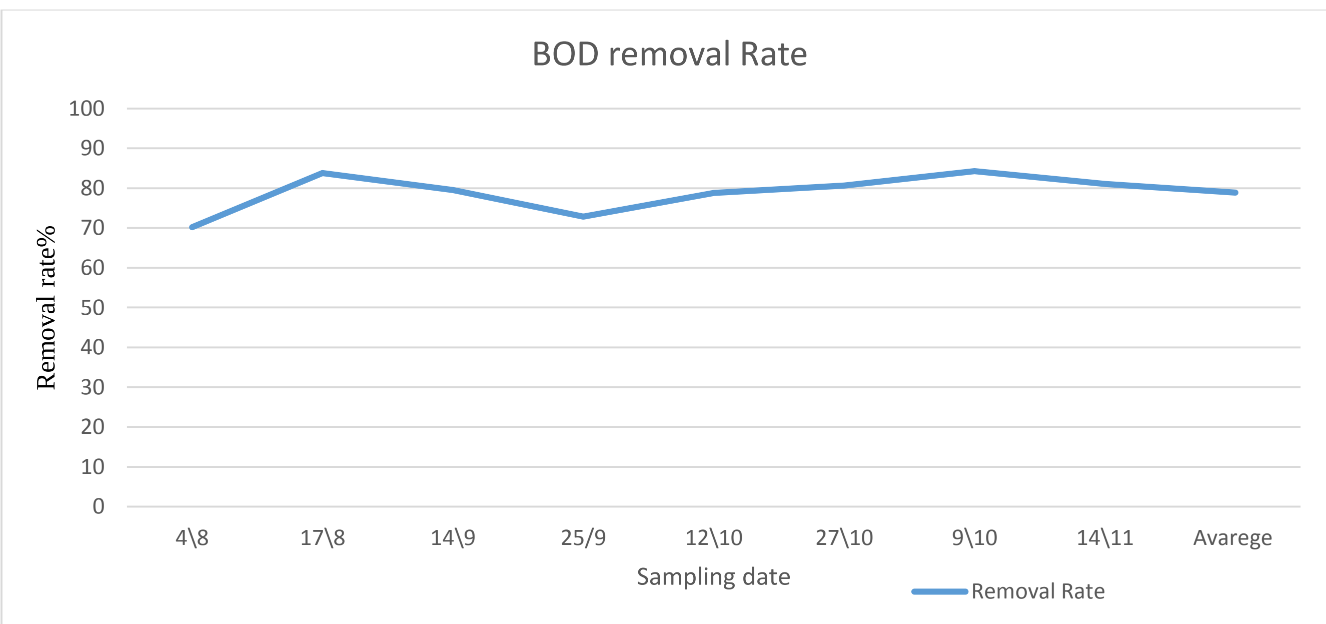

Figure 15 MBR removal rate of BOD

The figures (15,16) show the COD & BOD results: 505, 10.9 mg\l the average BOD inlet and outlet respectively. and the average COD 885, 28 mg\l from inlet and outlet, these results were obtained for previous operator for the MBR facility, which shows high efficiency in wastewater treatment, reaching a rate of 97% and 96% BOD, and COD, respectively as shown in figures (17,18),

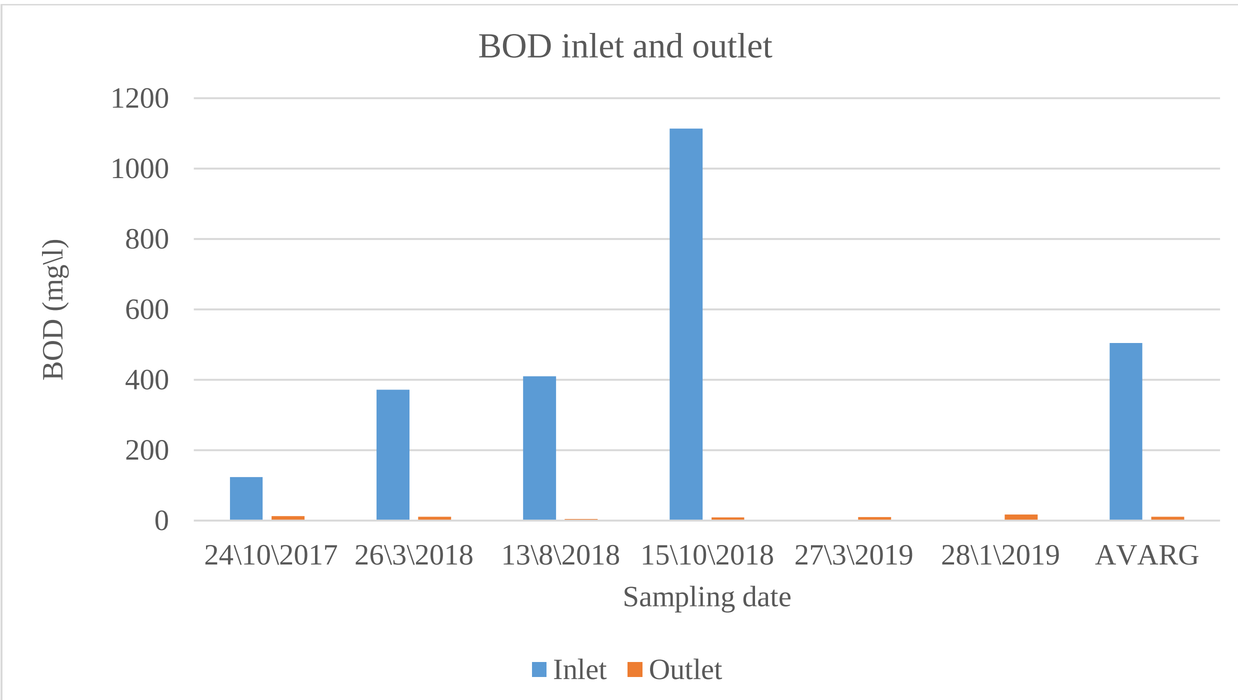

Figure 16 BOD inlet & outlet for previous years for the MBR facility

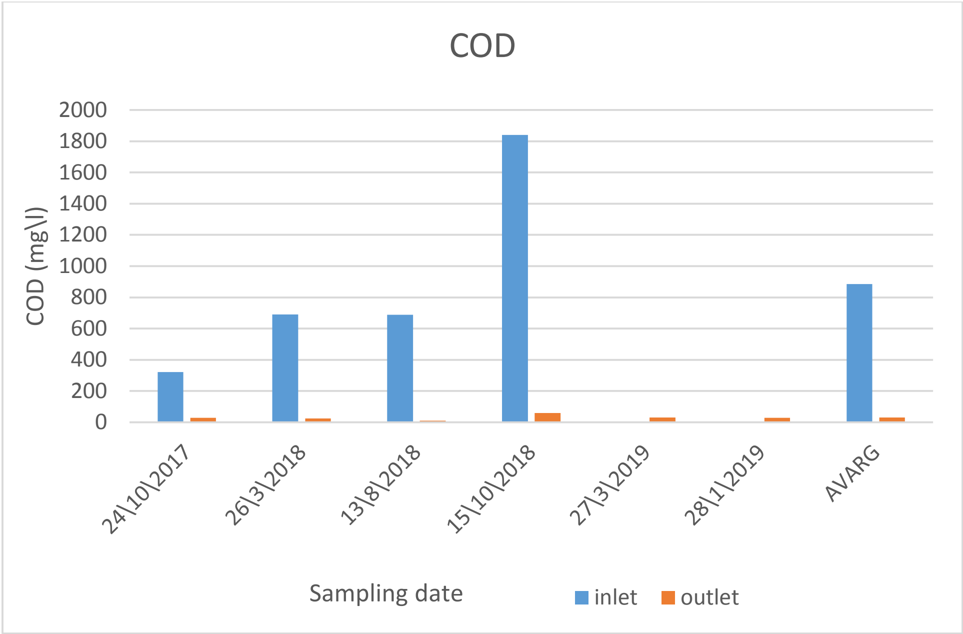

Figure 17 COD inlet & outlet for previous years for the MBR facility

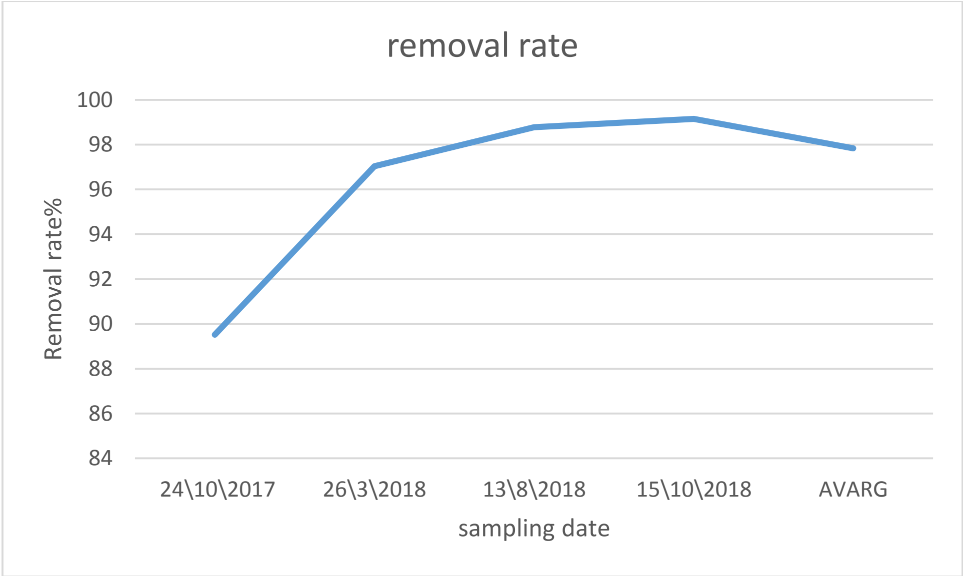

Figure 18 BOD removal rate from previous years for MBR facility

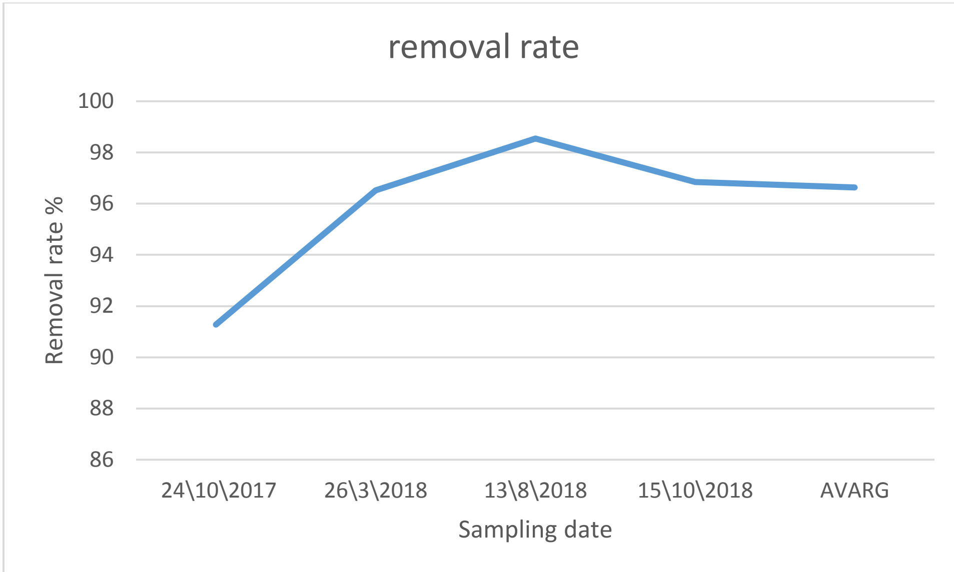

Figure 19 Figure 17 COD removal rate from previous years for MBR facility

4.3.2 Total Nitrogen (TN)

The results as shown in figure (20,22,,24) below of Total Kjeldahl Nitrogen (TKN) in raw wastewater about 78 - 127 mg/l, while the results of TKN coming outlet of the MBR facility were 29 - 61 mg\l and in nitrate (NO3) in raw wastewater 0.34 - 0.92 mg\l and reduced to reach 0.16 - 0.41 mg\l in the outlet and the results were ammonium (NH4) in the raw wastewater 14 - 60 mg\l and reduced to reach 2 -5 mg\l with a removal rate of TKN 56.1%, 60.4% in NO3 and 89.1% in NH4. According to the Palestinian standards for agriculture reuse (PSI) and the agriculture ministry, this treated wastewater can be reused in agriculture.

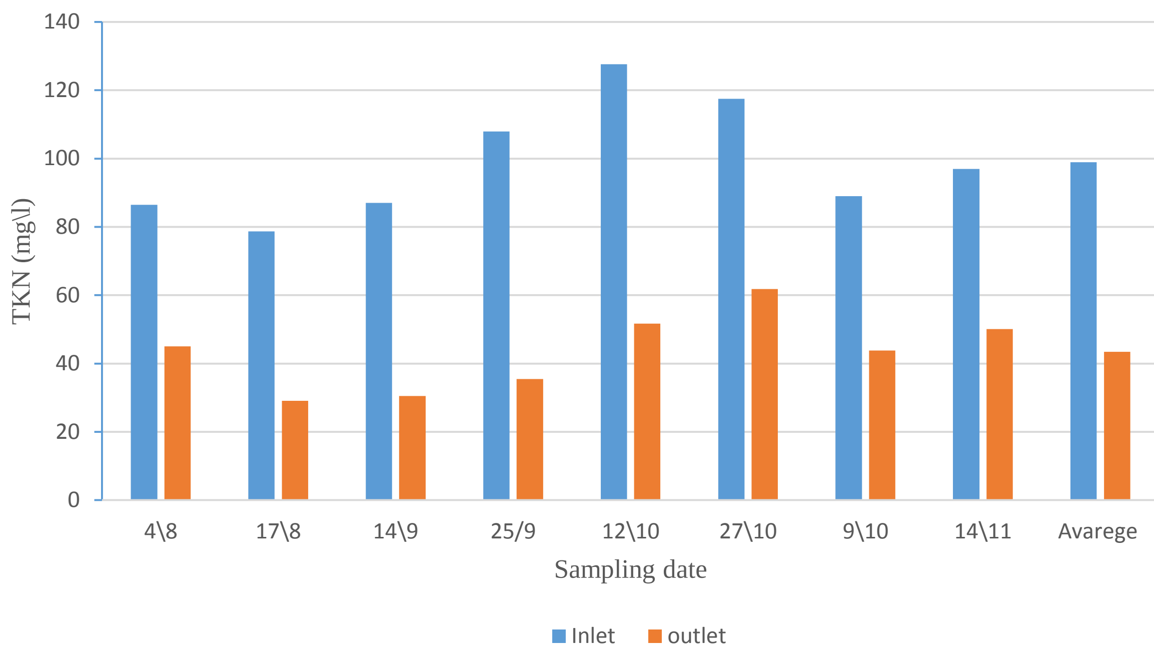

Figure 20 TKN of MBR inlet & outlet

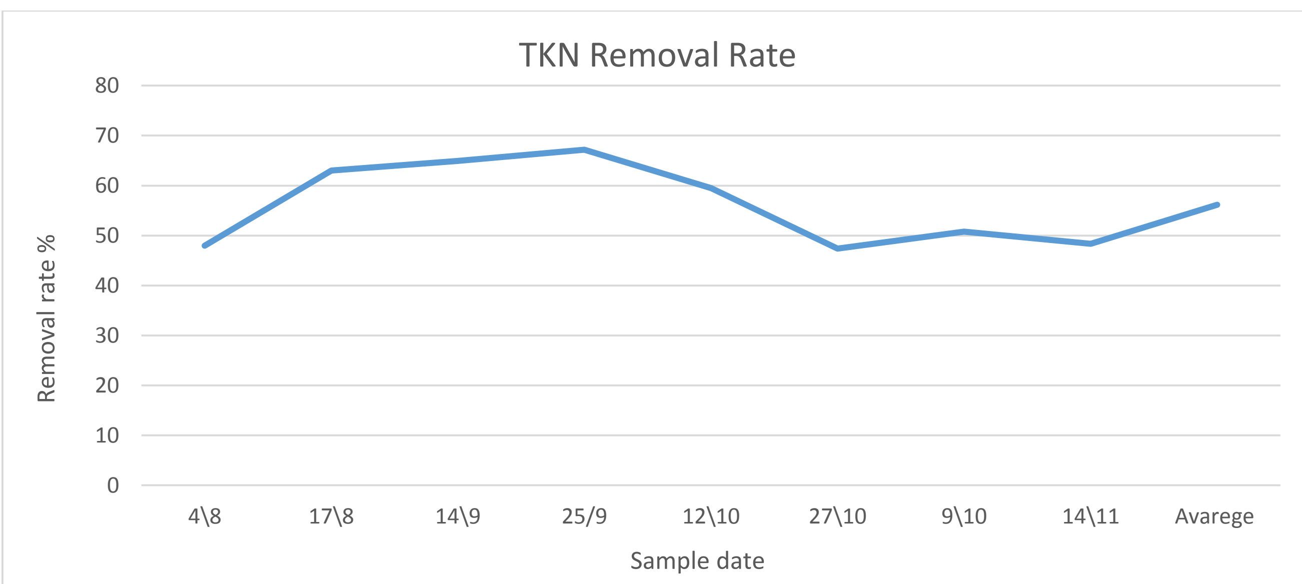

Figure 21 TKN removal rate in MBR

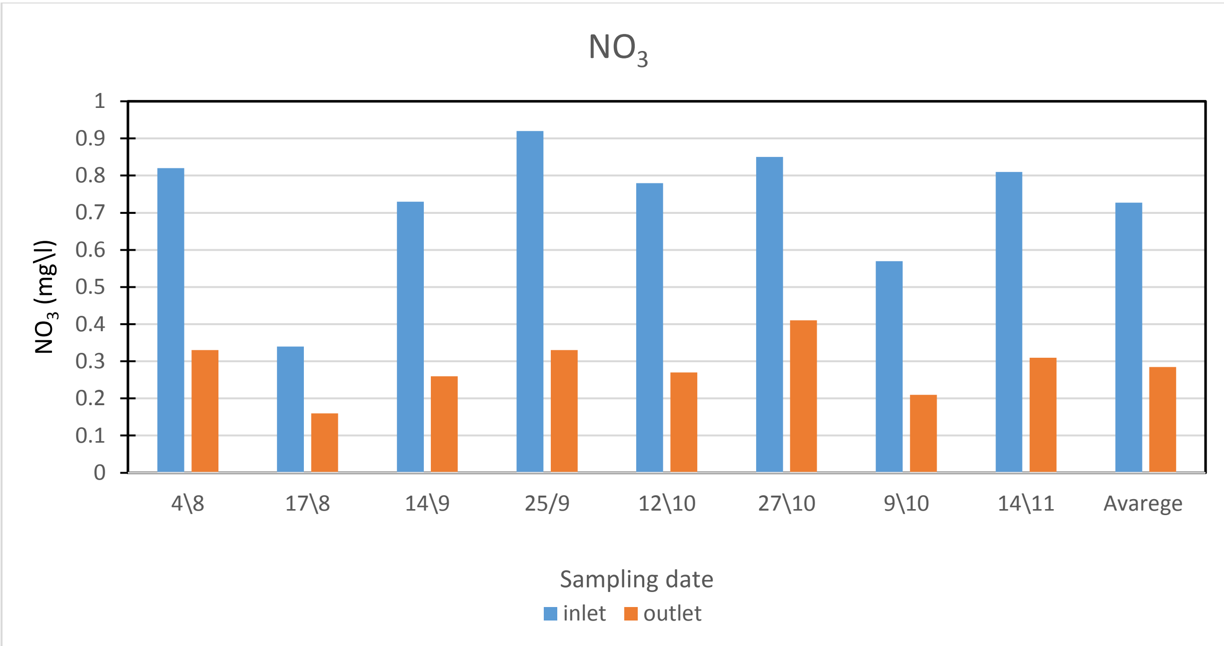

Figure 22 NO_3 of MBR inlet and outlet

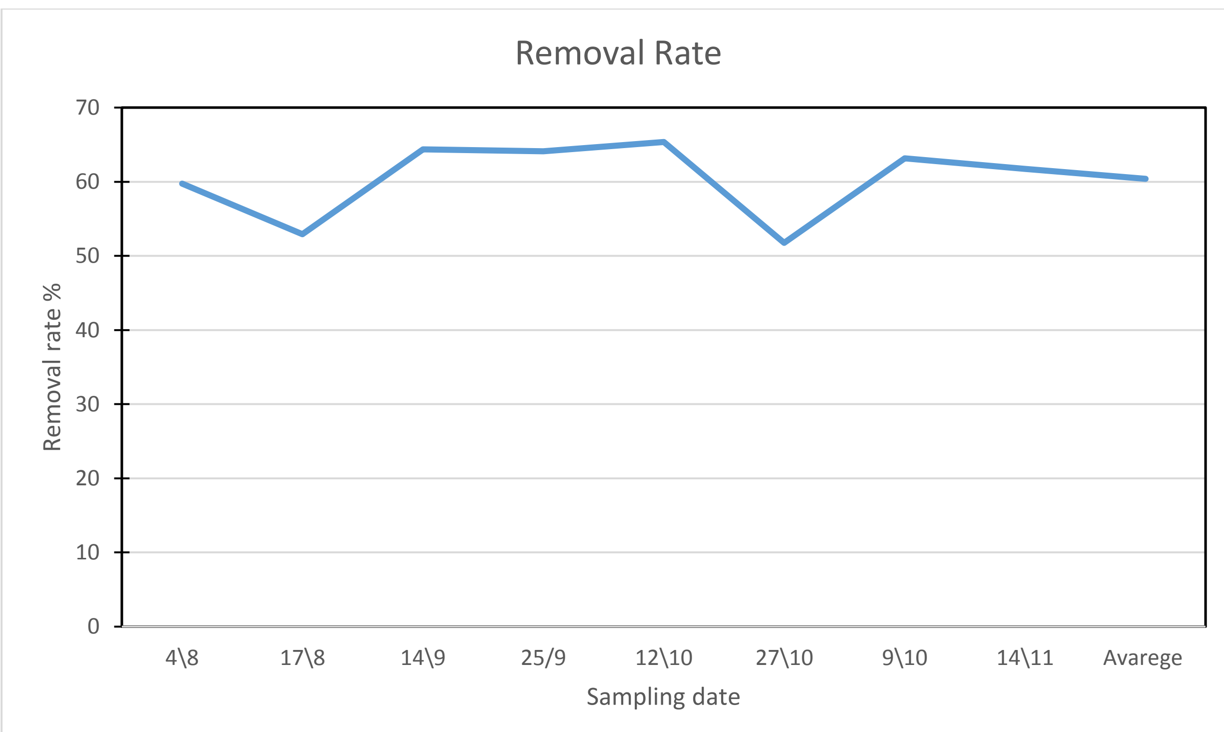

Figure 23 MBR removal rate of NO3

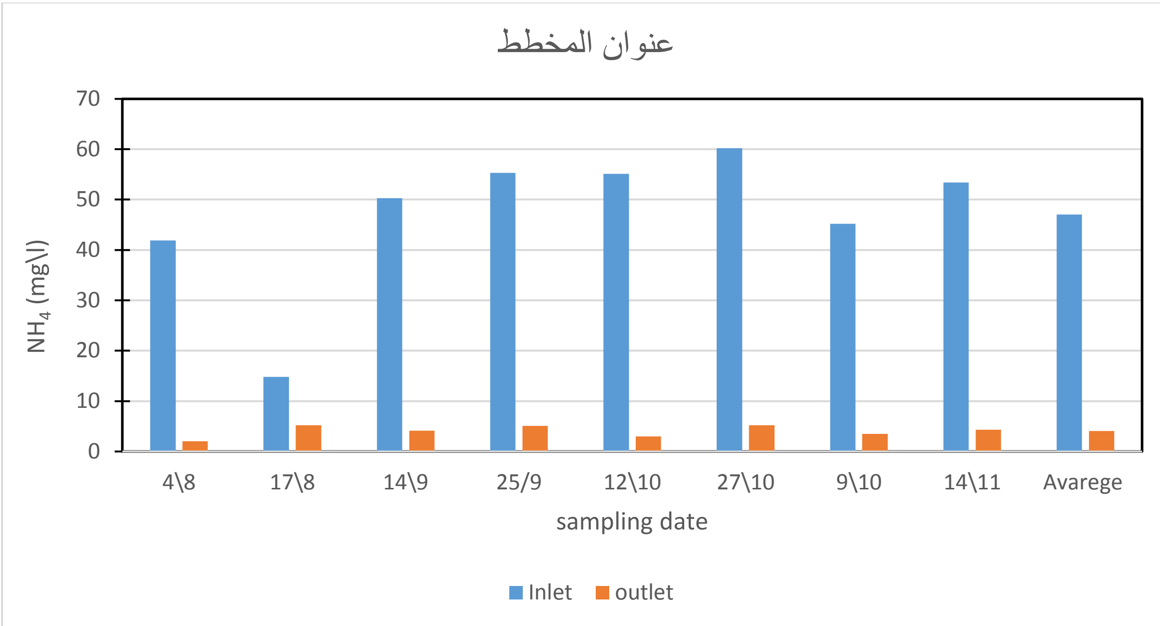

Figure 24 NH4 of MBR inlet & outlet

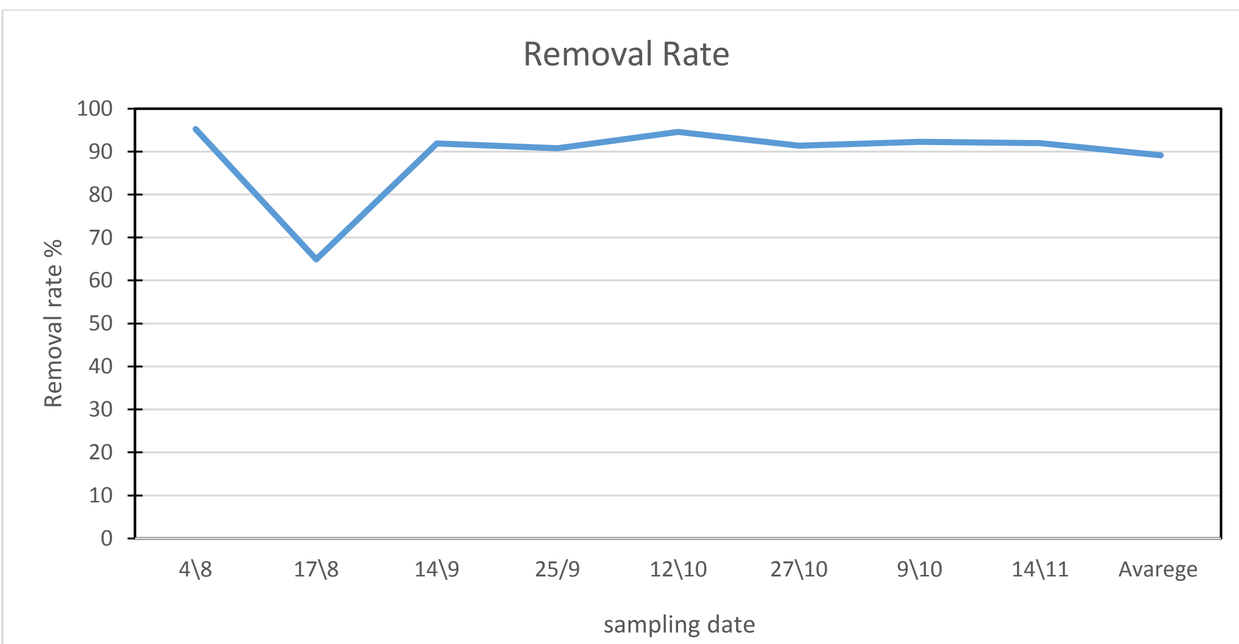

Figure 25 MBR removal rate of NH_4

4.3.3 Total Phosphorous (TP)

After analysing the wastewater samples from the Al-Reehan MBR facility, the results of total phosphorous were found, as shown in the figure below. The results of total phosphorous in raw wastewater ranged from 10.65 -16.4 mg/l, while in the outside water it was 9.35 - 0.55 mg/l, where the removal rate was 82.25%.

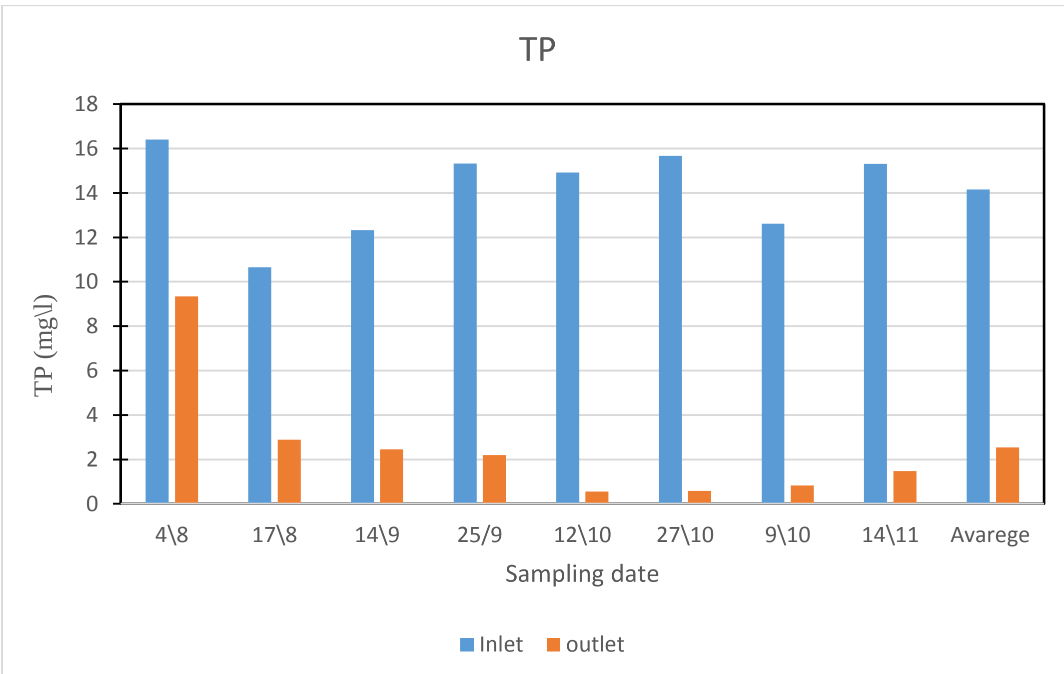

Figure 26 TP of MBR inlet & outlet

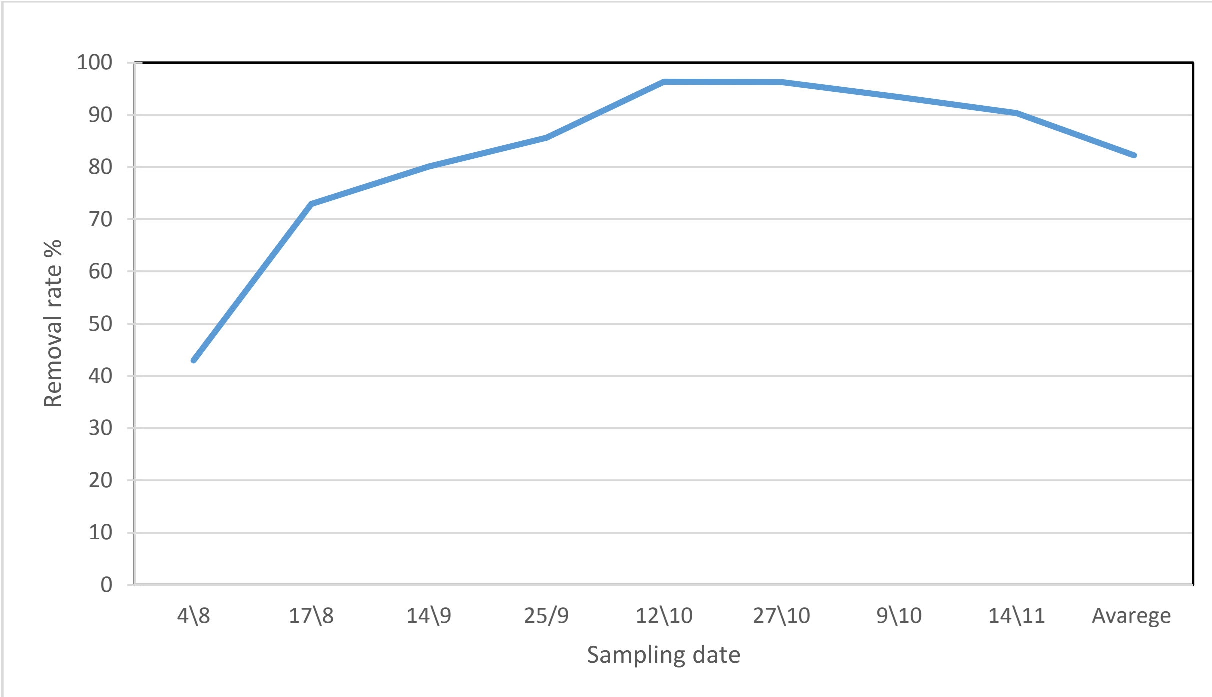

Figure 27 MBR removal rate of TP

4.3.4 Total suspended solids (TSS)

Total suspended solids (TSS) as shown in the figure below, the concentration of TSS in the influent was 240 - 760 mg / l and the concentration of effluent 0 - 160 mg / l with a removal efficiency of more than 80.4% According to the Palestinian Ministry of Agriculture, in this parameter the values is high that means this treated water can't be used As a water source for irrigation because the values of some samples are high and do not comply with the Palestinian standards for reuse.

In this study, results appear surprisingly contrary to what was published in the previous literature, and it appears that there are problems in the membranes that may have been damaged.

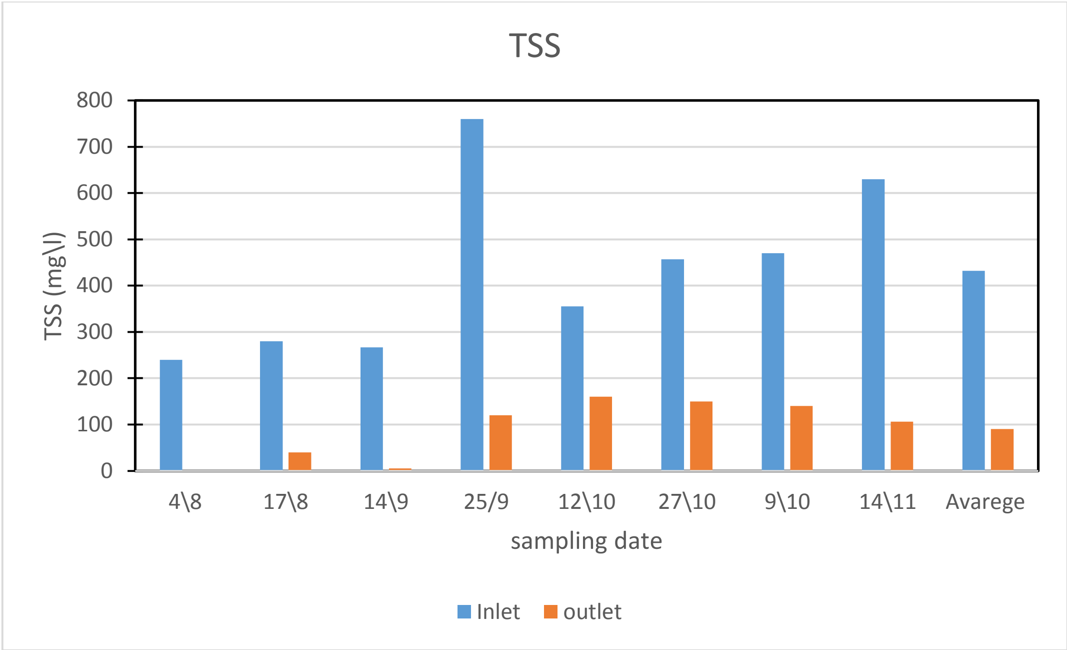

Figure 28 TSS of MBR inlet & outlet

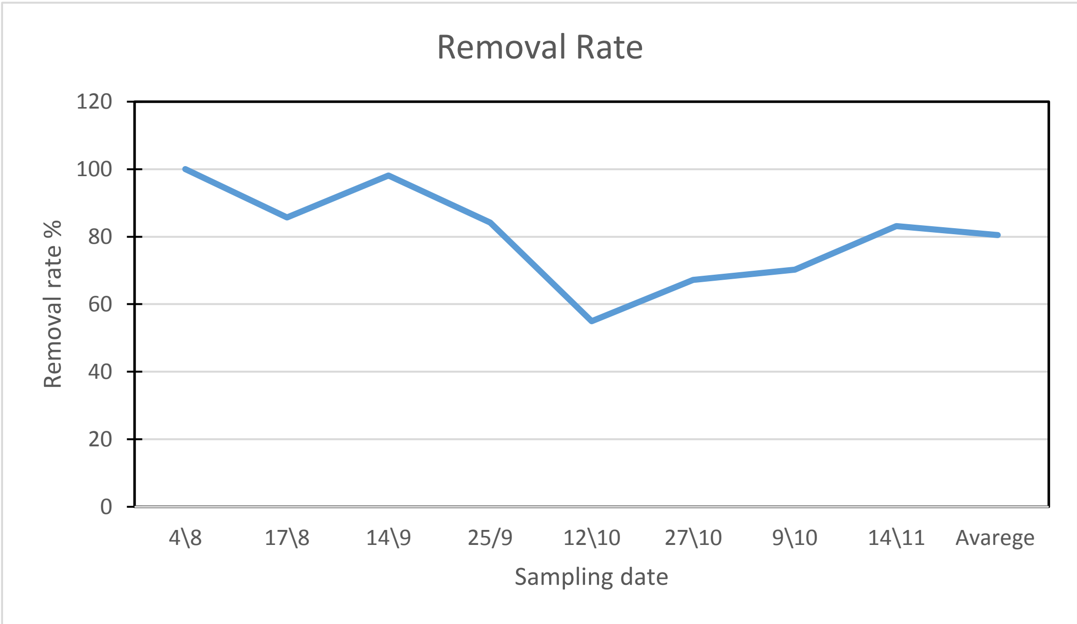

Figure 29 TSS removal rate of MBR

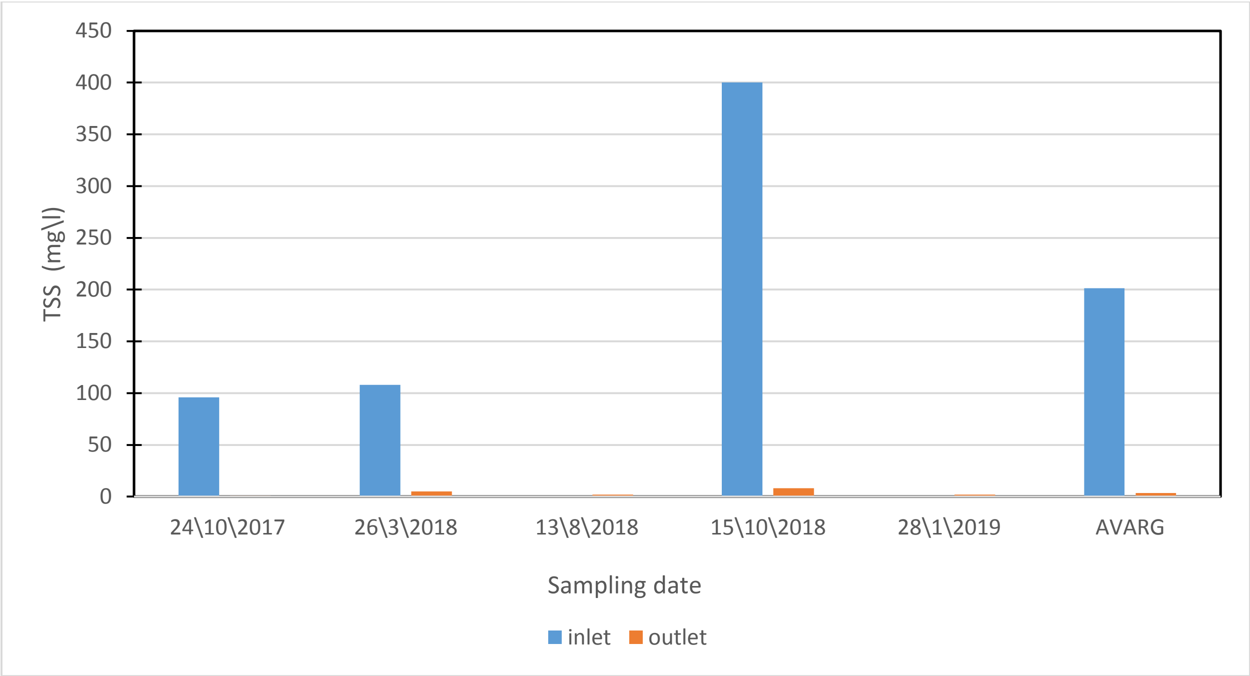

Figure 30 TSS inlet & outlet for previous years for the MBR facility

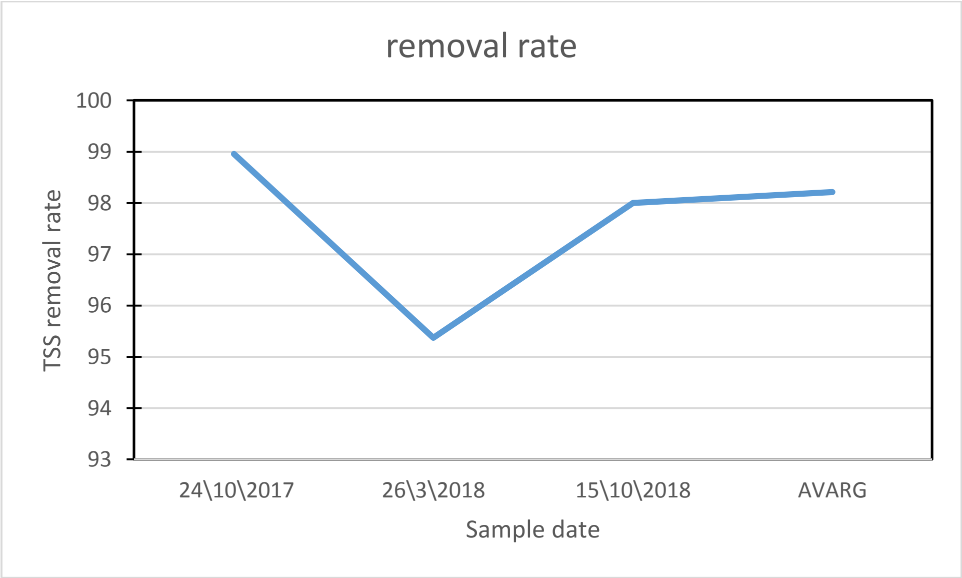

Figure 31 MBR removal rate of TSS for previous years for the MBR facility

4.4 Biological Parameters

Biological parameters are considered important parameters in the wastewater treatment process, as wastewater carries many pathogenic cusses such as bacteria, viruses and worms, pathogens pose a threat to human health and in wastewater reuse, it poses a direct danger to farms workers. There are many approaches to microbiologically assessing treated water for wastewater reuse.

In this study, two parameters we investigated, total coliform and fecal coliform, The absence of total and fecal coliform is based on the premise that it is feasible to monitor wastewater for all pathogenic microorganisms and that the use of alternative parameters is acceptable (Blumenthal et al., 2000).

4.4.1 Total coliform & fecal coliform

The analysis of samples of Total and Faecal Coliform bacteria showed high results in the outlet of MBR facility, which may be a result of a failure in the integrity of the membranes or a failure in the disinfection process (Zhang et al,. 2015), as this treated water poses a health hazard and cannot be used in agriculture, according to the Palestinian standards for agriculture reuse (PSI) and the agriculture ministry.

Table 10 Total and fecal coliform results

FC		TC		sample No.
Outlet	**Inlet**	**Outlet**	**Inlet**	
1300	700,000	500000	TMTC	***1***
66.8	1400000	TMTC	TMTC	***2***
34000	900000	1500000	TMTC	***3***
10000	14000000	TMTC	TMTC	***4***
21000	6900000	710000	90000000	***5***
11000	12000000	2400000	79000000	***6***
15000	8600000	1500000	78000000	***7***
24000	64000000	1700000	67000000	***8***
14545.85	15400000	1385000	78500000	***Average***

*all parameters data in CFU

5. Conclusions

The study aimed at investigating the efficiency of the Alreehan MBR facility and assessing its compliance with local effluent reuse guidelines. According to the results obtained in the study, the following points can be concluded:

- The of poor operation and maintenance within the MBR facility effected onto effluent low quality, which is have negative impact to the environment and public health.

- The quality of treated wastewater from the Al-Reehan MBR facility with Palestinian technical instructions No. 2012 - 34 for the reuse of treated wastewater for agricultural irrigation.

- Direct discharges containing large quantities of chemicals, detergent, etc. from the hospital affect the quality of the wastewater arriving at the MBR facility and cause treatment failures.

6. Recommendations

In order to get a better overview about the Alreehan facility, it is necessary to analyze more samples over a long period. It would be good for a year to get more information about the efficiency of the plant's work and changes related to climate change and system modifications and a greater understanding of the disturbances that could occur in addition to studying the parameters Additional operational like Flux, HRT, SRT, RAS.

In addition, based on the results obtained in this study described in the thesis, the following points are worthwhile and require further research:

- Research and assessment of the impact of wastewater discharged by Istishari Hospital on the effectiveness Alreehan MBR facility and the presence of emerging and pharmaceutical on the raw wastewater and treated wastewater and the removal efficiency MBR facility.

- Develop and enforce effective department for monitoring to the operation and maintenance of wastewater treatment facilities in Palestine, and control the operation of these facilities in addition to providing training and raising the skill of the operating staff in wastewater treatment facilities.

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