

## APPLICABILITY OF USING REVERSE OSMOSIS MEMBRANE TECHNOLOGY FOR WASTEWATER RECLAMATION IN THE GAZA STRIP

Mazen Abuatayef<sup>a,\*</sup>, Abdelmajeed Kahail<sup>b</sup>, Hassan Al-Najjar,<sup>c</sup> and Thaer AbuShbak<sup>d</sup>

<sup>a,\*</sup> Environmental Engineering Department, the Islamic University of Gaza, Gaza, Palestine

<sup>b</sup> CTG-United Nations Office for Project Services, CTG-UNOPS, Gaza, Palestine

<sup>c</sup> Civil Engineering Department, Institute of Natural Sciences, Sakarya University, Sakarya, Turkey

<sup>d</sup> Central Laboratory for Water and Soil, Ministry of Agriculture, Gaza, Palestine

**ABSTRACT:** Reverse osmosis (RO) technology shows common popularity in the field of water treatment as an advanced stage to eliminate the residual biogenic elements and dissolved impurities after the traditional treatment processes. This article highlights the applicability of using RO membrane technology as a post-treatment stage to treat the discharged effluent from the Gaza wastewater treatment plant. The designed experimental model reveals optimal removal efficiency between 92 and 100% for a number of physical, chemical and biological pollutants. The RO membrane unit demonstrates significant removal efficiency compared to the sand filter where the RO removal efficiency for BOD, TSS, TDS, Fecal Coliform and NO<sub>3</sub> were 100, 97.5, 92, 100 and 100%, respectively. The quality of reclaimed wastewater was idealistic where the contents of BOD, Fecal Coliform and NO<sub>3</sub> in the permeate were nil, and the concentrations of TDS and TSS were 20 and 296 ppm, respectively. Practically, the results confirm that the wastewater with the reclaimed quality could be used for agricultural activities with no degree of restriction according to FAO's guidelines water quality for irrigation. According to the Palestinian Standard (PS), the quality of reclaimed wastewater is high, class (A), and it could be used without restrictions to irrigate many crops and for the purposes of groundwater replenishment. Related to energy estimation and cost analysis, the numerical model and the market analysis study demonstrate the energy of 1.23 kWh and total cost, i.e. fixed and energy costs, of 0.58 USD to produce 1 m<sup>3</sup> of reclaimed wastewater using the RO membrane in the Gaza Strip over a projected lifespan of 5 years.

**Keywords:** Gaza Strip; Wastewater; Reclamation; Reverse osmosis; Post-treatment; Agriculture.

### المياه العادمة في قطاع غزة مدى قابلية تطبيق تقنية التناضح العكسي لاستصلاح

مازن أبو اللطيف<sup>\*</sup>، عبدالمجيد كحيل، حسن النجار و ثائر أبو شباك

**المخلص:** في ضوء التطور السريع في تكنولوجيا معالجة المياه، أصبح توجه استصلاح المياه العادمة خياراً واعداً لتخفيف أزمة المياه ولزيادة الاستدامة في نظام إدارة المياه في المناطق التي تعاني عجز حقيقي في مصادر المياه. تكنولوجيا التناضح العكسي تشكل التقنية الأكثر رواجاً في مجال معالجة المياه وإزالة العوالق والملوثات البيولوجية وغيرها. نسلط الضوء في هذا المقال على استخدام أغشية التناضح العكسي لمعالجة المياه العادمة الخارجة من محطة غزة للمياه العادمة وذلك للوصول إلى مياه قابلة للاستخدام في مجال الزراعة وحقن الخزان الجوفي حسب المعايير الفلسطينية للمياه. أظهر النموذج المصمم باستخدام أغشية التناضح العكسي كفاءة تتراوح بين 92 إلى 100% في إزالة الملوثات الفيزيائية، الكيميائية والبيولوجية. وكانت كفاءة إزالة BOD، TSS، TDS، Fecal Coliform، NO<sub>3</sub> كالتالي 100، 97.5، 92، 100، 100% على التوالي. عملياً يمكن الاستنتاج أن جودة المياه المعالجة بهذه التقنية يمكن تصنيفها بدرجة (A) حسب المعايير الفلسطينية، وهذا يعني أنه يمكن استخدامها بدون محددات في الزراعة والري وحقن الخزان الجوفي. من ناحية أخرى أظهرت النتائج أن كمية الطاقة اللازمة يومياً هي 1.23 كيلو وات لكل متر مكعب و تبلغ تكلفة معالجة المتر المكعب 0.58 دولار أمريكي حساباً على فترة عمر 5 سنوات للمشروع.

**الكلمات المفتاحية:** قطاع غزة؛ مياه عادمة؛ استصلاح؛ تناضح عكسي؛ ما بعد المعالجة؛ زراعة.

\*Corresponding author's e-mail: mabualtayef@iugaza.edu.ps



## 1. INTRODUCTION

The water scarcity crisis has raised as one of the most pressing problems on the sustainability of life due to the effect of population growth, climate change, water abuse, pollution of water resources, improper management of water and other factors (Mehta, 2007; Karagiannis and Soldatos, 2008; Vörösmarty *et al.* 2010; Jacobson *et al.* 2011 Ang *et al.* 2015). The water crisis threatens about four out of every five persons of the human communities and more than two-thirds of the environmental habitats (Jacobson *et al.* 2010; Vörösmarty *et al.* 2010). In an effort to alleviate the water shortage, new water sources have been identified and supplied through desalination of seawater or brackish water, and by reclaiming wastewater (Zhang and He, 2013). However, the utilizing of treated wastewater in agriculture and in the replenishment of water resources (i.e., surface and groundwater) is less expensive than using the desalinated water and it is more affordable for most crops (FAO 2006; Zhang and He, 2013; Jaramillo and Restrepo 2017). Moreover, the worth of wastewater comes from being a promising constituent in promoting smart sustainable development especially in arid and semi-arid areas and many counties worldwide. The merit of wastewater as an efficient alternative water source is derived from the fact that about 99% of its ingredients are water and only less than 1% is solid wastes and hence the waste components reduction of wastewater to acceptable levels by means of water recycling could be worthy environmentally and economically to the sustainability of water resource management.

Nowadays, the rapid development in membrane manufacturing technologies, such as micro, ultra, nanofiltration, and reverse osmosis (RO) membrane technologies plays a significant role in enhancing the feasibility of water and wastewater reclamation by adding a quaternary-post-treatment process to remove the remaining pollutants, e.g. pyrogens, color, submicron colloidal matter, bacteria, and viruses, after the tertiary treatment (Metcalf and Eddy, 2013). In comparison to other membrane technologies, the use of RO technology is the most prestigious in the purification of wastewater due to the low energy consumption and the high rate of pollutant and contaminant removal. Edwards and Schubert (1974) and Fang and Chian (1976) reported that the RO membrane technology could eliminate 51% up to 99% of various pesticides. Al Jilil and Sajid (2014) found that the RO water treatment process could remove all the cations and anions from wastewater or seawater especially removing the monovalent ions such as chloride (Cl<sup>-</sup>) with a removing efficiency of 94.4%. Suzuki and Minami (1991) revealed through several experiments that RO membranes could remove up to 99%, 90% and 99.9% of total dissolved solids (TDS), total organic carbon (TOC) and fecal coliform, respectively. Abid *et al.* (2012) addressed the dye removal efficiency of more than 97% from industrial wastewater by membrane technologies of RO.

Practically, agriculture shows a huge demand for water as it is considered the biggest consumer of water in volume among all other water sectors. The possibility of using

reclaimed wastewater forms an attractive water source to farmers for several reasons such as its reliability, its low or zero cost and its valuable nutrient content, which increases crop production without adding artificial fertilizers (U.S. EPA, 2004; Jiménez, 2005; Qadir *et al.* 2010). In specific, the typical domestic wastewater is a rich source of the nitrogen, phosphorus, potassium, micronutrients and organic matters that are naturally required for agricultural harvesting (FAO 1992). However, the main challenge that faces the sustainability of any wastewater reclamation activity is compromised by public health assurances. The wastewater is most likely to contain pathogenic organisms similar to those in the original human excreta such wastes: bacteria, viruses, protozoa, and helminth (FAO 1992). Depending on the harsh effects of sunlight and desiccation, almost all excreted pathogens can survive in soil and on crop surfaces for a sufficient length of time ranges between two days and many months which is a sufficient to indicate that public health risk and infections by Diarrhea, Typhoid, Salmonella type and other virus diseases could be conjugated (WHO 1989). Moreover, the accumulation of heavy metals the wastewater demonstrates a major potential risk to consumers and farmers (Jaradat, 2016). Gumbo *et al.* (2010) found significant public health risks for using wastewater for agricultural irrigation. Jan *et al.* (2010) detected heavy metals concentrations in a number of tested food crop samples irrigated with wastewater. Generally, the long term using of partially treated wastewater in irrigation can degrade soil and cause public health risks through the transmission of enteric diseases and heavy metal accumulation (Jamil *et al.* 2010). Obviously, the different water activities and uses in terms of public health and environmental protections are principally governed by specific guidelines and frameworks that are set and adopted by the World Health Organization (WHO) or by the national legislation of countries. In Palestine, the relevant policies, legislation, and regulation related to water quality are set and adopted by the Palestinian Water Authority (PWA) with direct negotiations and discussion with the related ministries such as the ministry of health, ministry of agriculture and the environmental quality affairs (PWL, 2002). Generally, the wastewater treatment passes through a tertiary treatment process which contains an Ultraviolet (UV) disinfection stage to eliminate the pathogenic organisms from the treated wastewater. Unfortunately, the technique of UV is unavailable in most of the regions that suffer from a lack of facilities and energy resources. The wastewater is a valuable source of water to balance the water deficit in the Gaza Strip, therefore, this study demonstrates the applicability of using the RO membrane technology as a post-treatment stage instead of the UV stage to eliminate the remained nutrients and pathogenic organisms from the reclaimed wastewater in order to be efficient in term of quality to be applicable in different water sectors according to specified Palestinian water standards and guidelines. Moreover, not only in the Gaza Strip, the applicability of RO membrane technology as a post-treatment stage could be a potential unique solution for different countries in the Middle East and North Africa

which suffer from poor facilities and energy resources to overcome the need to tertiary treatment stage of UV which needs a well-established preparations and facilities.

## 2. ENVIRONMENTAL STANDARDS AND REGULATIONS

Investigating the efficiency of any water treatment systems is performed in terms of the produced quality of water and its coinciding with the adopted guidelines and standards. Water quality, which is as significant and important as quantity, has been overlooked for decades in terms of legislation, investment and public awareness. Water and sanitation infrastructure, water and sanitation policies, good governance and practice, proper legislation, regulations, and standards are key issues to safeguard humans and their surrounding environment. Various legislations and regulations were designed worldwide to regulate water resource protection, water supply, sanitation, protection of the environment, and prevention of pollution. Standards have been adopted for different purposes of water uses and reuse. Monitoring systems have been put in place to ensure responding to these regulations and standards. The availability of adopted water quality standards and regulatory aspects in forms of national or international standards is important to control and restrict the arbitrary use or disposal of wastewater. There are no unified criteria for wastewater reuse in the world and each country proposes its own best practices criteria based on different environmental, economic, social and political conditions. Globally, many organizations and agencies like the World Health Organization (WHO), Food and Agriculture Organization (FAO) and Environmental Protection Agencies (EPAs) suggest guidance standards for wastewater reuse for different purposes. In the 1970s, the WHO started developing guidelines, shown in Table 1, for wastewater reuse in agricultural irrigation to ensure human health and environmental integrity. These guidelines are based on the consensus view that the actual risk associated with irrigation with treated wastewater is much lower than previously thought and that earlier standards and guidelines for effluent quality (WHO, 2006). Traditionally, irrigation water is grouped into various quality classes in order to guide the user to the potential advantages as well as problems associated with its use and to achieve optimum crop production. The water quality classifications are only indicative guidelines and their application has to be adjusted to conditions that prevail in the field. This is so because the conditions of water use in irrigation are very complex and difficult to predict (WHO, 2006). The suitability of water for irrigation greatly depends on the climatic conditions, physical and chemical properties of the soil, the salt tolerance of the crop grown and the management practices. Thus, the classification of water for irrigation will always be general in nature and applicable under average use conditions. Many schemes of classification for irrigation water have been proposed. FAO (1985) classified irrigation water into three groups based on salinity, sodicity, toxicity, and miscellaneous hazards. These general water quality classification guidelines help to identify potential crop

production problems associated with the use of conventional water sources. The guidelines are equally applicable to evaluate wastewaters for irrigation purposes in terms of their chemical constituents, such as dissolved salts, relative sodium content and toxic ions. Depending on the sodium ion concentration relative to the concentrations of calcium and magnesium ions (as indicated by SAR) and the total salt concentration, the potential content of sodium ions in the irrigation water affects the infiltration rate and the soil permeability. Obviously, it is clear to indicate that for a given SAR value, an increase in total salt concentration is likely to increase soil permeability and, for a given total salt concentration, an increase in SAR will decrease soil permeability. This illustrates the fact that soil permeability (including infiltration rate and surface crusting) hazards caused by sodium in irrigation water cannot be predicted independently of the dissolved salt content of the irrigation water or that of the surface layer of the soil (FAO 1985). In Palestine, the Palestinian water laws clearly declare the responsibility of the PWA, in consultation with the ministry of health, ministry of agriculture and environmental quality authority, to establish guidelines and framework for monitoring the water-related practices, protecting the water resources and ensuring the safety of Palestinian public health (PWL 2002, 2014). The Palestinian Standard (PS 2003) imposes a set of mandatory technical instructions for using treated wastewater in agricultural irrigation to maintain the safety of humans, animal health and the crops as well as to sustain environmental constituents. The PS prohibits the usage of treated wastewater for watering livestock and poultry, irrigation of all types of vegetables, groundwater recharge through direct injection and fish farming. Based on the quality of treated wastewater, the PS categorizes the effluents into four classes based on the water quality as shown in Table 2. The PS states that “the irrigation using reclaimed wastewater should be stopped before three weeks of the yield time for the fruit crops and before two weeks for field and feeding crops” to take into consideration the sensitivity of some crops to the properties and the elements of treated wastewater. The PS permits the use of treated wastewater, without any restrictions on the irrigation activities, for harvesting the yields of Cotton, Luffa, Brooms and other crops that are not in direct contact with the public. However, concerning the crops that are in direct contact with the public through touch or eating, the PS imposes intensive preventive restrictions and protective procedures for using the treated wastewater in irrigation. The PS adopts eleven irrigation methods that enable the farming activities from using the reclaimed wastewater for irrigating specific types of crops. Each of these methods is classified as a two-way or a one-way restriction method (PS, 2003).

One-way restriction irrigation methods:

- A distance  $\geq 25$  cm above the ground between the dripping point and the crop or fruits.
- A distance  $\geq 50$  cm between the level of sprinklers and the fruits.
- A ground plastic cover between the treated wastewater and the fruits.
- Crops or fruits with a single crust or an uneaten shell.

**Table 1.** WHO microbiological quality guidelines for wastewater use in agriculture (WHO, 2006).

Category	Reuse conditions	Exposed Group	Intestinal nematodes (arithmetic mean no. of eggs per liter)	Fecal coliforms (geometric mean no. per 100 ml)	Treatment to meet the micro-biological guidelines
A	Irrigation of crops probably to be consumed uncooked, sports fields, public parks	Farmers, consumers, public	≤ 1	≤ 1000	A series of stabilization ponds designed to attain micro-biological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees	Farmers	≤ 1	No standard recommended	Retention in stabilization ponds for 8–10 days or equivalent helminths and fecal coliform elimination
C	Localized irrigation of crops in category B if exposure to workers and the public does not occur	None	Not Applicable	Not applicable	Pretreatment as essential by irrigation technology but not less than primary sedimentation

**Table 2.** Classification of wastewater quality (PS, 2003).

Parameter	Unit	Class (A)	Class (B)	Class (C)	Class (D)
Quality	Type	High	Good	Medium	Low
BOD <sub>5</sub>	mg/l	20	20	40	60
TSS	mg/l	30	30	50	90
Fecal coliform	CFU /100 ml	200	1,000	1,000	1,000
COD	mg/l	50	50	100	150
DO	mg/l	> 1	> 1	> 1	> 1
TDS	mg/l	1,200	1,500	1,500	1,500
pH	-	6.00 to 9.00	6.00 to 9.00	6.00 to 9.00	6.00 to 9.00
Fat, Oil & Grease	mg/l	5.00	5.00	5.00	5.00
Phenol	mg/l	0.002	0.002	0.002	0.002
Methylene Blue Active Substance (MBAS)	mg/l	15	15	15	25
NO <sub>3</sub> -N	mg/l	20	20	30	40
NH <sub>4</sub> -N	mg/l	5	5	10	15
Total-N	mg/l	30	30	45	60
Cl	mg/l	400	400	400	400
SO <sub>4</sub>	mg/l	300	300	300	300
Na	mg/l	200	200	200	200
Mg	mg/l	60	60	60	60
Ca	mg/l	300	300	300	300
SAR	-	5.83	5.83	5.83	5.83
PO <sub>4</sub> -P	mg/l	30	30	30	30
Al; Fe	mg/l	5	5	5	5
As; Cr	mg/l	0.1	0.1	0.1	0.1
Cu, Mn, Ni, Pb	mg/l	0.2	0.2	0.2	0.2
Se	mg/l	0.02	0.02	0.02	0.02
Cd	mg/l	0.01	0.01	0.01	0.01
Zn	mg/l	2	2	2	2
CN; Co	mg/l	0.05	0.05	0.05	0.05
Hg	mg/l	0.001	0.001	0.001	0.001
B	mg/l	0.7	0.7	0.7	0.7
E. coli	CFU /100 ml	100	1,000	1,000	1,000
Nematodes	Eggs/l	≤ 1	≤ 1	≤ 1	≤ 1

- Crops or fruits eaten only cooked.
- Sand filter detain the wastewater for at least 15 days or water ponds that contain less than 10% of treated wastewater.
- Disinfection by chlorine so that the residual chlorine is not less than 0.5 mg/l and the contact time is not less than an hour half or by using any other sterilization method.

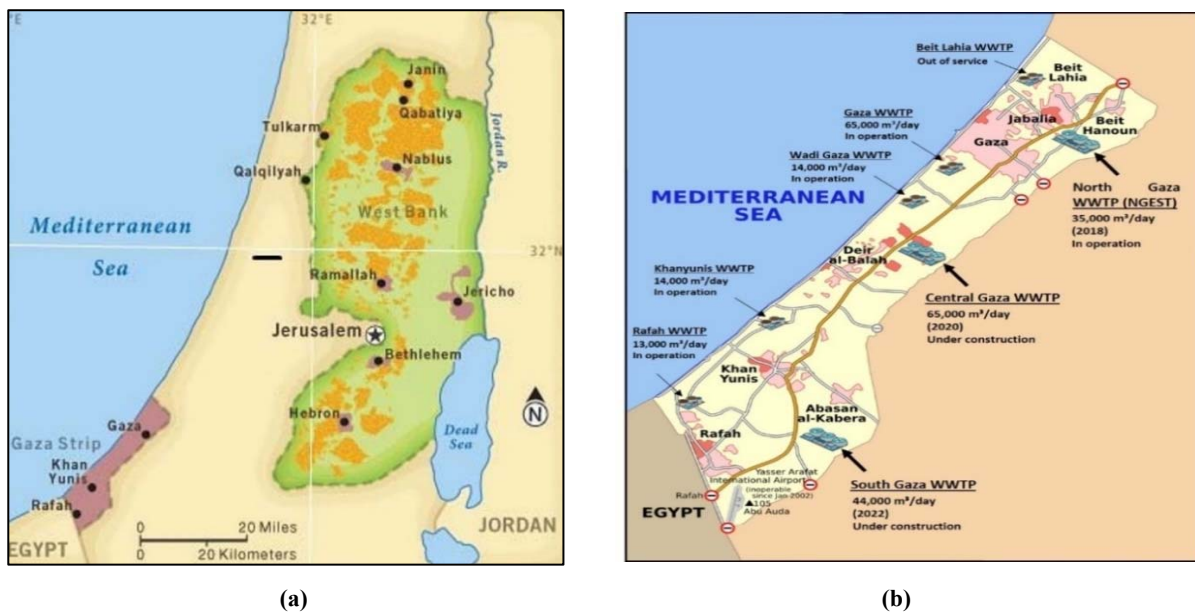
Two-way restriction:

- A distance ≥ 50 cm above the ground between the dripping point and the crop or fruits.

Irrigation methods:

- Underground drip irrigation.

The PS requires specific standard considerations to irrigate crops by the reclaimed wastewater. The PS restricts the irrigation activities for gardens, playgrounds, and parks to be by a reclaimed wastewater quality of class (A). However, the processes of groundwater replenishment by infiltration and the offshore disposal of about 500 m into the sea should be by wastewater quality of not less than class (C). The standards permit the irrigation of crops of seeds production, dry feeds, forest trees, industrial corps



**Figure 1** (a). Geographical location of the Gaza Strip, and (b) Positions of wastewater treatment plants in the Gaza Strip.

and grains using low quality of treated wastewater. The PS allow using treated wastewater with class quality of (A), or other quality with suitable one-way or two-way restriction irrigation methods to irrigate the crops of artichoke, eaten corns, citrus fruits, uneaten shell fruits, falling leaves trees, tropical crops, grapes, cactus, dates, olives, and flowers (PS, 2003). In the area of the Gaza Strip, four types of crops are cultivated and harvested: (a) field crops: wheat, potatoes, and onions; (b) vegetables: tomatoes, cucumbers, eggplants, squash, green beans, and paprika; (c) fruit trees: citrus fruits, guava, dates, and almonds; and (d) olives (ARIJ, 2015). Generally, drip irrigation remains the domain irrigation system and widely used for agricultural production by farmers in the Gaza Strip (ARIJ, 2015).

### 3. WATER ISSUES OF THE STUDY AREA

The Gaza Strip (shown in Fig. 1(a)) is a stretch of area that extends on the coast of the eastern Mediterranean with about 42 km long, between 6 and 12 km wide, and an area of 365 km<sup>2</sup>. The Gaza Strip is recognized as one of the most densely populated areas in the world. The estimations of the Palestinian Central Bureau of Statistics (PCBS) for the year 2018 revealed that the population of the Gaza Strip was more than two million inhabitants (PCBS, 2018). Concerning the current situation of the water sector, the region of the Gaza Strip is characterized by many parties as an area in a continuous humanitarian crisis due to the lack of both quantity and quality of water resources for different uses (PWA, 2011, 2013, 2014).

The underlying coastal aquifer is the only water resource that is exploited in the Gaza Strip for the domestic, industrial and agricultural uses. The status of the coastal aquifer shows permanent deterioration on both quantity and quality. The annual replenishment volume of the aquifer is between 55 and 60 million cubic meters while the

Palestinian abstraction from the aquifer in the Gaza Strip is quantified by about 180 million cubic meters per annum. The agricultural sector consumes the largest portion of nearly 50% of the entire pumped groundwater water from the aquifer comparing to the other remaining domestic and industrial sectors that tighter use the second half of the extracted groundwater. Accordingly, the records of water balance show a severe and continuous deficit of about more than 120 million cubic meters per annum (PWA, 2013). In terms of quality, the present rate of deterioration demonstrates that over 95% of the coastal aquifer is contaminated with unacceptably high levels of either nitrate (NO<sub>3</sub>) or chloride (Cl), posing significant health risks to Gaza's residents (PWA, 2014). The sustainability of coastal aquifer became a crucial and sensitive issue for the Palestinian Water Authority (PWA) and other Palestinian water-related organizations and agencies. Hence, in order to alleviate the huge pressing on the coastal aquifer, the PWA pays more attention to using new alternative and other non-conventional water sources.

- i. Purchased water: the water sector in the Gaza Strip is supplied by 10 million cubic meters per year. This quantity is bought from Israeli water utility (Mekorot). In addition, under the negotiation's agreement of Oslo II, there is a commitment to increase the supplied quantity by 10 million cubic meters (PWA, 2014).
- ii. Desalination of seawater: desalination of seawater became a strategic option for the PWA to overcome the shortage in the water supply. Hence, the PWA provided a strategic plan for water supply along with the short and long terms. Nowadays, short-term low-volume (STLV) seawater desalination plants, the overall capacity of 13 million cubic meters per annum, are built to enhance the quality and quantity supply of water in the Gaza Strip. From a long-term perspective, a plan to construct a regional strategic large-scale

seawater desalination was adopted. The first phase of the regional seawater is intended to provide water sector by 55 million cubic meters yearly while the second phase will lift the plant's capacity to 120 million cubic meters per annum (PWA, 2015).

- iii. Treated wastewater reuse: the reclamation of wastewater draws the attention of PWA as a potential source that could be used to maintain the coastal aquifer sustainable. Exploiting the reclaimed wastewater can achieve the sustainability of groundwater by 50%. Practically, the PWA starts studying the willingness of using reclaimed wastewater for irrigating agriculture (PWA, 2013).

On average, the water services suppliers estimate the total amount of produced wastewater in the Gaza Strip by approximately 50 million cubic meters per annum (ARIJ 2015; PCBS, 2018). Currently, there are four small scale and one large scale operating wastewater treatment plants, geographically demonstrated in Fig. 1(b), in the Gaza Strip. The four small scale wastewater treatment plants of Gaza, Wadi Gaza, Khanyunis and Rafah have the capacity to treat partially, and not in an acceptable level of quality, about 38.7 million cubic meters of the collected wastewaters in the Gaza Strip. This quantity which forms a ratio of about 75-80% of the total generated municipal effluents in the Gaza Strip is directly disposed into the marine ecosystem without enough proper treatment and without any mitigation measures. As well, the operating large scale of north Gaza (NGEST) wastewater treatment plant treats about 12.8 million cubic meters of wastewater which is utilized to recover the coastal aquifer through a number of wastewater infiltration basins.

The characteristic properties of raw wastewater quality for different governorates in the Gaza Strip, as depicted in Table 3, show that the effluent of wastewater has high organic matter, i.e. BOD<sub>5</sub> of 724 mg/l, compared with the average BOD<sub>5</sub> levels in the developing countries which range from 200-300 mg/l (Polprasert, 2007). These high pollutant contents affect adversely the treatment efficiency of the in-operation wastewater treatment plant. The high growth in the population of the Gaza Strip increases the load on the capacity and affects the initial quality design parameters that have been used to plan the current wastewater treatment plants which affect the treatment efficiency. Therefore, the sanitation services in the Gaza Strip are in curial crisis and the existing wastewater treatment plants work under overloaded flow rates and so some wastewater is being treated and the large amount is returned raw and pumped into the sea. Based on the design parameters of BOD, COD, and TSS, illustrated in Table 4, the designed efficiency of the small-scale wastewater treatment plants is about 75% (CMWU, 2012). However, nowadays, and due to over rates of wastewater and the continuous deterioration in the treatment efficiency of the small-scale wastewater treatment plants, the PWA suggested closing these plants and constructing instead three large scale wastewater treatment plants on the eastern border of the Gaza Strip (PWA, 2014). To enhance the status of public health and sanitation services, the PWA plans to replace the current over-loaded wastewater

treatment facilities by three new large-scale high-efficiency wastewater treatment plants located as shown in Fig. 1(b) in the North, Central, and South of the Gaza Strip. Recently, as shown in the provided timeline plan in Table 5, the wastewater treatment plant of North Gaza entered the service to replace the old plant at Beit Lahia. Also, the Gaza central and south wastewater treatment plants are under construction and the decision-makers confirm that they will be ready to operate by 2022. The efficiency of the three planned large-scale wastewater treatment plants will be very acceptable, where, the effluent characteristics are between 10 to 20 mg/l for BOD<sub>5</sub>, 15-20 mg/l for suspended solids, 10 to 15 mg/l for total nitrogen, less than 1 eggs per liter from Helminths and less than 200 CFU per 100 ml for Fecal Coliforms (PWA, 2011). The quality of effluent indicates that these strategic plants were designed to provide treated wastewater of class (A). According to the monitoring records of the PWA, the volume of treated wastewater that was used in 2012 is 1 million cubic meters which represent only 3% of the available partially treated wastewater. The PWA put a strategic plan, shown in Table 6, extends to the year 2032 to enhance the water management system in the Gaza Strip (PWA, 2013). According to this plan, by 2022, in the short-term strategy plan, it is expected to lift the exploited treated wastewater to more than 25% of the available partially treated wastewater. However, by 2032, the expectations of the long-term strategy plan address that about 25 million cubic meters per annum and nearly 75 million cubic meters of treated wastewater are going to be used for agriculture and aquifer recharging, respectively.

In order to alleviate the deterioration in the coastal aquifer, the long-term plan aims to decrease the overall groundwater abstraction in the Gaza Strip from the present rate of 180 million cubic meters per annum to about 70 million cubic meters per annum in 2032. As shown in Table 6, the long-term strategic plan aims to increase the sustainability of the coastal aquifer by using the reclaimed wastewater as a new water source for agricultural purposes. The plan expects that the total anticipated demands of water for agriculture will be reduced as a result of urbanization and population growth, hence, the projected potential irrigated lands will be about 90,000 dunums by 2032.

#### 4. MATERIALS AND METHODS

This article highlights the performance of RO membrane technology as a post-treatment stage in enhancing the treatment efficiency to improve the quality of wastewater reclamation. The performance of this technology was investigated by setting up an experimental model and by testing and analyzing, in the laboratory, the quality of wastewater before and after the RO treatment. The experimental physical model, shown in Fig. 2, consists of: (1) Collecting tanks: High-density polyethylene (HDPE) feeder, permeate and concentrate tanks each of cubic meter volume were exploited to collect the raw and the reclaimed wastewater before and after the treatment process; (2) Sand filter: a composite of sand and well-graded sizes of gravels range from 2.37 and 9.5 mm was prepared to configure a cylindrical sand filter with a length of 50 cm and

**Table 3.** Characteristics of wastewater in the Gaza Strip (CMWU, 2012).

Parameter	Unit	Characteristics of wastewater according to area			
		North Area	Gaza	Rafah	Average
Biochemical Oxygen Demand (BOD <sub>5</sub> )	(mg/L)	728	667	777	724
Chemical Oxygen Demand (COD)	(mg/L)	1385	1306	1399	1,363
Suspended Solids (SS)	(mg/L)	663	617	540	607
SS/BOD	ratio	0.9	0.95	0.69	0.85
BOD/COD	ratio	0.526	0.51	0.56	0.532

**Table 4.** Efficiency of wastewater treatment in the Gaza Strip (CMWU, 2012).

Wastewater Plant	Biochemical Oxygen Demand (BOD <sub>5</sub> )			Chemical Oxygen Demand (COD)			Suspended Solids (SS)		
	Influent	Effluent	Removal	Influent	Effluent	Removal	Influent	Effluent	Removal
	mg/l	mg/l	%	mg/l	mg/l	%	mg/l	mg/l	%
Gaza	500	105	79	1020	220	78	550	110	80
Rafah	560	120	81	1160	255	78	550	122	79
KhanYunis	520	155	70	1090	322	70	580	141	76
Beit Lahia	440	133	70	980	250	74	480	222	71
<b>Average</b>	<b>505</b>	<b>128</b>	<b>75</b>	<b>1,063</b>	<b>262</b>	<b>75</b>	<b>540</b>	<b>149</b>	<b>77</b>

**Table 5.** Characteristics of large-scale wastewater treatment plant in Gaza Strip (PWA, 2011).

Facility	Flow (m <sup>3</sup> /day)	Current status	Future status	Final destination
North Gaza	35,000	North Gaza wastewater treatment plant; opened in 2018 to replace Bait Lahia treatment plant which is now out of service	Northern Gaza Emergency Sewage Treatment (NGEST) will be upgraded to a capacity of 70,000 m <sup>3</sup> /d	Infiltration Basins
Central Gaza	65,000	Gaza wastewater treatment plant; established in 1979; now the plant is overloaded with a capacity of 65,000 m <sup>3</sup> /day	Central Gaza treatment facility with a capacity of 65,000 m <sup>3</sup> /d to replace the current plant; it will be operated in 2020	Seawater
	14,000	Middle Gaza wastewater treatment plant; established in 2014 with a capacity of 12,000 m <sup>3</sup> /day		
South Gaza	14,000	Khan Yunis wastewater treatment plant; consists of three lagoons were built in to collect and treat wastewater during 2003 – 2009	South Gaza treatment plant with a capacity of 26,000 m <sup>3</sup> /d as phase I operated in 2019 and 44,000 m <sup>3</sup> /d operated in 2022 to replace the current treatment plant	Infiltration Basins

**Table 6.** Potential reuse of treated wastewater (PWA, 2013).

Items	Years			
	2012	2022	2027	2032
<b>Quantity of reclaimed wastewater</b>	33.2	59.3	75.8	99.9
Irrigation portion (million m <sup>3</sup> /year)	1	14.8	19	25
Aquifer Recharge (million m <sup>3</sup> /year)	32.2	44.5	56.9	75
<b>Portion of groundwater for irrigation (million m<sup>3</sup>/year)</b>	86	59	45.5	32
<b>Potion of constructed dams for Irrigation (million m<sup>3</sup>/year)</b>	0	5	7.5	10
<b>Total Available quantity for Irrigation (million m<sup>3</sup>/year)</b>	87	78.8	72	67
<b>Irrigation needs (million m<sup>3</sup>/year)</b>	74.1	74.1	74.1	74.1
<b>Irrigable land (dunum)</b>	133,000	123,000	118,000	113,000
<b>Potential irrigated land (dunum)</b>	117,403	106,383	97,112	90,401
<b>Percent of irrigable land (dunum)</b>	88.3%	86.5%	82.3%	80%

a diameter of 30 cm to eliminate the content of large suspended solids before the RO unit; (3) Microfiltration (MF) and Ultrafiltration (UF) unit: are cellulose acetate semipermeable membranes that remove too large solids before the RO unit, the microfiltration membranes range from 0.1 to 10 µm, and ultrafiltration membranes range from 0.1 to 0.01 µm; and (4) RO unit: consists of a semipermeable membrane thin polyamide layer (< 200 nm) deposited on top of a polyethersulfone or polysulfide porous layer (about 50 microns) on top of a non-woven fabric support sheet. These semipermeable membranes have the ability to remove ions, molecules and larger particles from water by applying pressure to

overcome the osmotic pressure. Regarding, quality control and quality assurance (QC/QA), many experimental trials were executed during February and April of 2018 to take into consideration the seasonal change in the characteristics of wastewater that reaches the wastewater treatment plants in the Gaza Strip.

For each experimental trial, approximately 500 liters of wastewater sample was collected from the effluent of Gaza wastewater treatment plant and transported to the laboratory of the Islamic University of Gaza using barrels. The barrels were preserved into an icebox to inhibit the metabolic derangements of the wastewater organic content. In the laboratory, the collected wastewater samples from the Gaza

wastewater treatment plant were poured into the feeder tank. The wastewater was passed through the sand filter, which composes of graded-size gravel, the flow of wastewater inside the sand filter is governed by the force of gravity. The general design criteria for the slow sand filter recommend a filtration rate between 0.1 and 0.2 m per hour through the filter layers (Kawamura 2000). However, the filtration treatment through the designed sand filter demonstrated a slow sand filtration, hence, the water head reached about 20 cm above the sand filter layers with a filtration rate of 0.5 liters per minute. The passed

wastewater through the sand filter is entered into the three stages of MF/UF membrane unit with 5- and 1-micron pores diameter which was selected as a second pretreatment unit after sand filter to protect the RO device from fouling and to reduce suspended solids. After sufficient pretreatment, the water was pumped by a main pump of 130 psi (8.844 bar) through the RO unit with a flow of the filter was 1.8 liters per minute, the recovery rate was 50% from the fed water. In order to enhance the recovery efficiency of the system, a repass cycle was inserted into the system, where, a small repass pump of 4.23 bar was operated

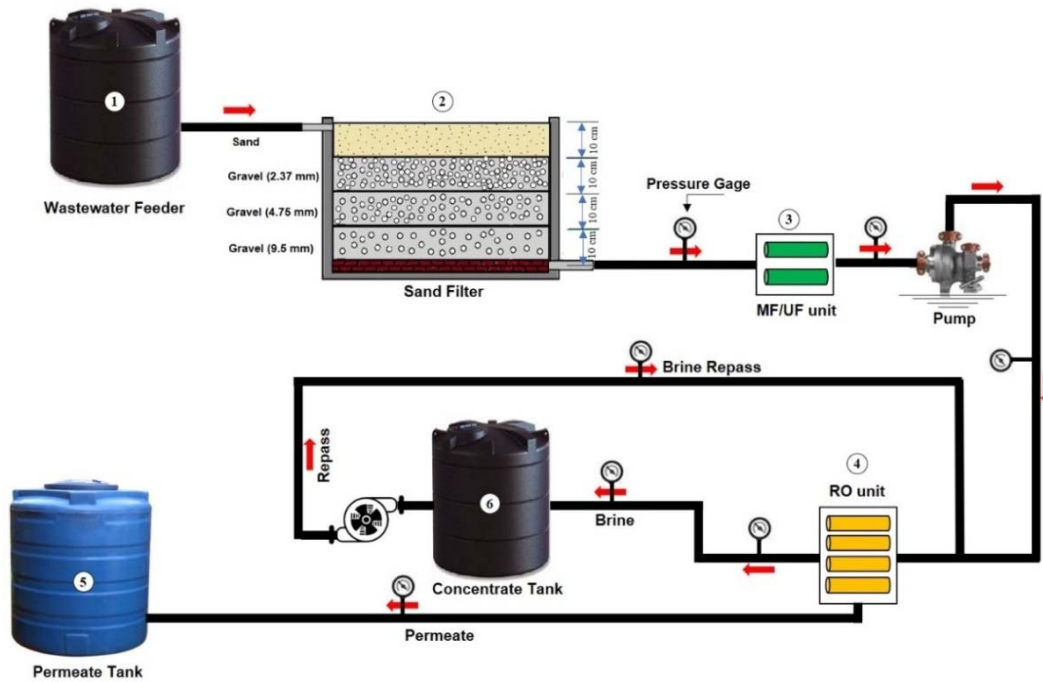


Figure 2. Scheme of the experimental physical model.

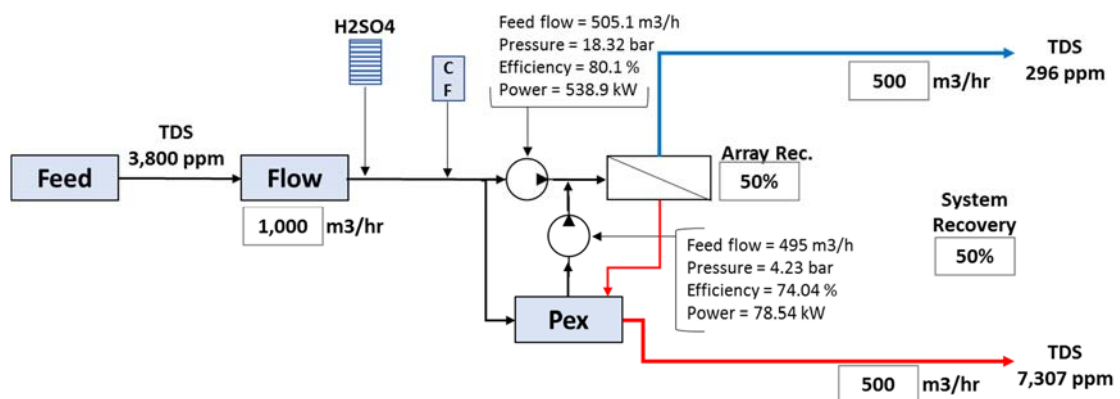


Figure 3. Model configuration of Winflows.



to repump the concentrate through the RO unit. The operation of the repass cycle was designed to operate when the concentrate in the concentrate tank reaches a volume of 250 liters or more. Finally, the treated water i.e., permeate water, was collected into the permeate tank (5) which is the treatment product that was tested in the lab. For each experimental trial, four samples were taken in every stage of filtration in each of the two experimental trials for testing and analysis purposes. The samples were put in polythene bottles that were pre-washed with acid and distilled water and then were dried. The first sample was taken from the feeder tank and before sand filter, the second was taken after the sand filter, and finally, the last two samples were taken from RO concentrate and permeate tanks, respectively. The four gathered samples were preserved at 4°C in an icebox and brought to the testing department of the laboratory for testing and results declaration. The quality of the treated wastewater in every phase of the treatment process was tested in order to examine the efficiency of each component in the experimental model in terms of Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Hydrogen Ion Concentration (pH), Electrical Conductivity (EC), Fecal Coliform (FC) and Nitrate (NO<sub>3</sub>-N). The described standard methods for the examination of water and wastewater by the American Public Health Association, American Water Works Association, and the Water Environmental Federation (2017) have been employed to examine the water quality parameters. The content of the organic matters has been tested in terms of the 5-day BOD test according to the procedure of the 5210 B. The described standard method in the procedure of 2540 D and 2520 B were applied to measure the TDS and the EC in the reclaimed wastewater samples, respectively. Furthermore, the acidity of the treated wastewater in term of pH was determined according to the procedure of 4500-H<sup>+</sup>. Concerning the pathogenic content, the FC concentration was detected according to the procedure of the 9211 B seven-hour fecal coliform test. Else, the concentration of NO<sub>3</sub> in the wastewater was determined using the Nitrate Electrode method according to the procedure of 4500-NO<sub>3</sub> D. Practically, testing the efficiency of membrane technology as a post-treatment in wastewater reclamation from the view of quality is not sufficient to judge on the whole efficiency of this technology. Principally, the main challenge governs the development and the popularity of membrane technology is the challenge of energy. Thus, it is critical to estimate the feasibility of this system from the views of cost and energy consumption. It is difficult to address the cost and energy consumption through the experimental physical model. Hence, with the rapid increase in computer power, it is not surprising to note the highly dependent on numerical simulation as a prediction tool in the pre-design and design stages. In this article, the simulation model of Win-flows RO system design and simulation software was used to estimate numerically the cost and energy consumption of wastewater reclamation through the designed experimental model. To ensure better simulation results, the software was run several times and a cartridge-filter-pre-treatment unit was added to the simulation system to provide a better

presentation of the reality. The Win-flows has some distinctive features like three pass systems, permeate split and recycle, anti-scalant dosing, energy recovery devices and ability to combine stages that make its ability higher than other similar software. The best presentation Win-flows model for the experimental model of this study, shown in Fig. 3, was designed to treat 1,000 m<sup>3</sup> per hour of tertiary treated wastewater with a TDS of 3,800, pH of 7.8 at a temperature of 16°C. After a series of trials and errors, the final design of the model system consisted of Cartridge filter as pretreatment and two stages of RO elements, 90 pressure vessels, and 65 pressure vessels, every vessel contains 7 elements of Duraslick anti-fouling membranes that are designed especially for wastewater treatment. The selected membrane model was DSL RO8040 to maintain the continuity of membrane efficiency for 5 years. In the numerical model, the water is pumped through the system using two pumps. In the first treatment stage, the main pump, which has a pressure of about 18 bar draws the feedwater by a capacity of 505 m<sup>3</sup> per hour and pumps it into the RO membrane system. However, the rejected water from the first stage is mixed with a flow of feedwater and repumped again into the membrane system using a repass pump with a pressure of 4.23 bar and a capacity of 495 m<sup>3</sup> per hour. The numerical model demonstrates that the system gives a recovery ratio of 50% which is acceptable and similar to the recovery ratio of the experimental model.

## 5. RESULTS DISCUSSION AND COST ESTIMATION

Reusing of reclaimed wastewater is expected to overcome the deficit in the water management system as a new proper water source. The advance development in membrane technology supports the progress in reusing wastewater; however, the energy challenges could be the main obstacle to make these technologies practical. The applicability of RO membrane technology as a post-treatment unit to recycle wastewater was investigated based on the quality of the reclaimed wastewater and on the energy efficiency of the whole system. The quality of reclaimed wastewater was addressed by the experimental examination for the efficiency of using RO membrane technology in treating wastewater. The experimental trials and laboratory testing were performed several times to ensure better QC/QA and to present precise results and decisions. Table 7 illustrates the average removal efficiencies of impurities and pollutants through the RO experimental model in terms of different physical, chemical and biological parameters for all runs. The quality of collected wastewater from Gaza wastewater treatment shows higher concentrations than designed quality effluent by about 138%, and excess concentrations above the average designed concentrations for three operating wastewater treatment plant in the Gaza Strip by 95%. The tested samples provide practical evidence that the treatment plants in the Gaza Strip operate with an unacceptable quality level. Thus, this article demonstrates efficiency investigation for the applicability of using membrane technology to reclaim wastewater in a region suffers from inefficient wastewater treatment plants. The

depicted experimental model results demonstrate that the treated wastewater using RO membrane technology achieves acceptable water quality levels for the agricultural and groundwater replenishment activities. The quality of the treated effluent wastewater through the designed experimental model was examined in terms of the physical, i.e. BOD<sub>5</sub>, TSS and TDS, the biological, i.e. FC and NO<sub>3</sub>, and the acidity or basicity index of pH. In the light of BOD<sub>5</sub>, the whole system shows a high overall efficiency of 100% for organic contaminants rejection, and the efficiency of the sand filter and RO unit were 59% and 100%, respectively. The system units and the whole system reveal lower removal efficiency for TSS and TDS than other parameters. The capacity of the system in eliminating TSS was higher than that of TDS by about 5%. The sand filter contribution in the whole eliminating of TSS and TDS is insignificant and the efficiency of sand filter in removing TDS is almost 0%. The RO unit forms the main removing part by the efficiency of 97.5 and 92% for TSS and TDS rejection, respectively. The contents of FC in the tested wastewater samples were about within 1300 CFU per 100 ml. The ability of sand filters to eliminate the FC from the samples was about 95% and the RO unit shows full ability to remove the remaining FC after the primary treatment by a sand filter. The nitrification process takes a significant place in the experimental system; hence, the sand filter trends to increase the concentration of NO<sub>3</sub> in reclaimed water as a result of conversion from NH<sub>4</sub> into NO<sub>3</sub> through the nitrification process. The NO<sub>3</sub> is a rich nutrient to plant growth and it is considered as a valuable element to the agricultural activities. However, the RO unit has a high ability to remove NO<sub>3</sub> and in all the whole system was able

to fully remove all NO<sub>3</sub> from the permeate.

Related to the pH, the nitrification process trends to convert the state of water into more alkalinity, hence, the results show that the pH of the treated wastewater rises from 7.7 to 8.7 after treatment so for the purposes of agricultural activities the treated wastewater must be adjusted to be within a pH value of 6.5 to 8.4 by adding a point entry injection system to pump an acid solution of acetic acid (white vinegar), citric acid or alum to reduce the basicity of treated water. The energy and cost estimations are two linked tasks, the specific energy consumption (SEC) for the RO system is commonly calculated using over simple analyses depending on the average operation tasks for the specific plant. The results of the built numerical model through the Winflows RO system design and simulation software indicate that the SEC of the whole experimental system is about 1.23 kWh per one cubic meter of permeate. However, the local membrane technology market indicates to set up a membrane-based treatment facility with a capacity of one million cubic meters of permeate per year over a five years lifespan is approximately 6 million United States dollars (USD) as shown in Table 8. Thus, the fixed cost estimation addresses that the loaded fixed costs on the unit volume of treated wastewater are about 0.4 USD per cubic meter of permeate. In the Gaza Strip, the cost of the municipal energy is approximated quantified by 0.15 USD for 1 kWh. Hence, the total cost to reclaim one cubic meter of wastewater is about 0.6 USD. Reviewing the cost and energy consumption estimations for similar RO wastewater treatment plants worldwide could introduce better indication about the expected cost and energy to produce one cubic meter of reclaimed wastewater. Facing all the challenges

**Table 7.** Experimental results of RO wastewater reclamation.

	BOD <sub>5</sub> (mg/l)	TSS (mg/l)	TDS (mg/l)	pH	FC (CFU/100 ml)	NO <sub>3</sub> (mg/l)
<b>Raw wastewater</b>	250	1,070	3,800	7.7	1,250	0.4
<b>After sand filter</b>	<b>103</b>	<b>837</b>	<b>3,800</b>	<b>7.8</b>	<b>67</b>	<b>15</b>
<b>Concentrate</b>	230	1,700	7,300	7.8	10	2
<b>Permeate</b>	<b>Nil</b>	<b>20</b>	<b>296</b>	<b>8.7</b>	<b>Nil</b>	<b>Nil</b>
<b>Sand filter efficiency (%)</b>	59	22	0	Increases pH	95	Increases NO <sub>3</sub>
<b>RO-unit efficiency (%)</b>	100	97.5	92	Increases pH	100	100
<b>System efficiency (%)</b>	<b>100</b>	<b>98</b>	<b>92</b>	Increases pH	<b>100</b>	<b>100</b>

**Table 8.** Estimated fixed cost for applying the model.

Series	Item	Unit	No.	Unit Price (USD)	Total price (USD)
1	8-inch low fouling DUASLICK membrane	No.	1,085	1,900	2,061,500
2	8-inch vessels (7 elements per vessel)	No.	155	4,000	620,000
3	Cartridge filter	No.	8	3,000	24,000
4	Primary pump	No.	10	5,000	50,000
5	High pressure pump	No.	10	15,000	150,000
6	Pressure exchange	No.	2	50,000	100,000
7	Dossing pump with tanks	No.	2	10,000	20,000
8	Pressure exchange	No.	2	50,000	100,000
9	Dual media filters	No.	4	7,000	28,000
10	Backwash pumps	No.	4	3,000	12,000
11	Flow meters	No.	4	1,000	4,000
12	Skids	No.	1	30,000	30,000
13	PLC	No.	1	200,000	200,000
14	Fittings and connections	No.	1	100,000	100,000
15	H <sub>2</sub> SO <sub>4</sub> along five years	kg.	45,000	2	90,000
16	Hanger and other plant structure	No.	1	750,000	750,000
17	Effluent and permeate tanks 4000 m <sup>3</sup>	No.	2	800,000	1,600,000
<b>18</b>	<b>Total price</b>	<b>USD</b>	-	-	<b>5,939,500</b>
19	Amount of permeate along five years	m <sup>3</sup>	-	-	15,000,000
<b>20</b>	<b>Total cost per 1 m<sup>3</sup> of permeate</b>	<b>USD</b>			<b>0.394</b>

and constrains relating to using RO in the reclamation of wastewater as new technology, the main two largest membrane-based treatment plants in the world, Sulaibiya wastewater treatment plant in Kuwait and Orange Country wastewater treatment plants in the United States (USA) produce daily hundreds of thousands cubic meters of reclaimed wastewater with stability and continuance. Sulaibiya wastewater treatment plant was opened in 2004; the plant is the biggest membrane-based water treatment plant. Currently, the capacity of SULAIBIYA wastewater treatment plant is about 375,000 m<sup>3</sup> per day and it is planned to expand it to reach a capacity of 600,000 m<sup>3</sup> per day and it is anticipated to cover 26% of Kuwait's gross water needs, and is expected to reduce the demand from 140 to 25 million cubic meters per annum (Pearce, 2008). The Orange Country plant was opened in 2004, the facility treats 320,000 m<sup>3</sup> daily of wastewater effluent using RO membrane technology. The plant is going to be expanded to a capacity of 590,000 m<sup>3</sup> per day (Water Technology, 2018). Generally, the estimations reveal that the conventional treatment of wastewater by the RO membrane technology, the costs about 85 to 90 cents per cubic meter of permeate (Pearce, 2008; Water technology, 2018). On the other hand, the requirement of energy to purify water depends on the quality of raw water and the applied treatment technique. The energy consumption for the purification of natural sources such as surface water and groundwater using membrane filtration is about 0.1 kWh per cubic meter. However, the energy consumption for treating surface water using both conventional treatment and UF/MF membrane is estimated by about 0.25 to 0.35 kWh per cubic meter. In general, the energy of water treatment could be estimated based on the TDS of the raw water, for TDS of less than 3,000 ppm about kWh of energy is needed to purify one cubic meter however for TDS between 3,000 and 11,000 ppm nearly 1.7 kWh of power is required to treat a cubic meter of water. Regarding, wastewater reclamation the energy requirement to recycle wastewater using dual membrane filtration of MF/UF and RO needs from 0.8 to 1.2 kWh per cubic meter. However, the use of a membrane bioreactor followed by RO requires energy between 1.2 and 1.5 kWh per cubic meter. In the countries of the Mediterranean Sea, the RO seawater desalination technique consumes about 2.3 to 4 kWh per cubic meter of freshwater (Pearce, 2008).

## 6. CONCLUSION

Reclamation of wastewater is a promising source to meet the increasing water demands in the arid and semi-arid regions. The agricultural sectors consume more than 50% of the water budget and providing treated wastewater with acceptable quality levels for irrigation can increase the sustainability of the water system and the fertility of agricultural lands. The rapid advance in the membrane technology draws the attention toward using RO membrane technology as a post-treatment process for wastewater treatment. The pollutants removal efficiency of RO

technology, as well as the low cost of operation and maintenance, makes this technology dominant in water treatment. This study experimentally concludes that the RO-membrane technology system has the ability to remove more than 90% of solids pollutants and the efficiency of eliminating the other bacterial and ionic pollutants could reach 100%. The study estimates the energy consumption for wastewater treatment using RO by around 1.23 kWh per cubic meter of permeate which is far less than the consumption of other alternative solutions brackish water and seawater desalination that consume about 1.7 kWh and up to 4 kWh per cubic meter, respectively. This technology provides a sustainable treatment process for countries suffering from a lack of electrical sources since the experimental model of this study estimates that the fixed cost to treat one cubic meter of permeate costs approximately 40 cents, compared to other comparison studies, the described model of this study could save more than 50% of the fixed costs to treat one cubic of wastewater.

Therefore, the findings of this study clarify that the RO-membrane technology system as a post-treatment stage in the wastewater treatment plants of the Gaza Strip could improve the wastewater quality to meet PS guidelines and produce a reclaimed wastewater of class (A) that could be used without restrictions to irrigate gardens, playgrounds, parks, groundwater replenishment and for the offshore disposal at about 500 m into the sea. Moreover, the quality of the reclaimed wastewater could be used for planting crops of seeds production, dry feeds, forest trees, industrial crops and grains, crops of artichoke, eaten corns, citrus fruits, uneaten shell fruits, falling leaves trees, tropical crops, grapes, cactus, dates, olives, and flowers. Regarding the existing drip irrigation system in the Gaza Strip which is widely common, this study recommends the use of the reclaimed wastewater using RO membrane technology to irrigate the crops of citrus, guava, dates, almonds, and olives under a two-way restriction measures by lifting the irrigation system by at least 0.5 meters from the ground. In conclusion, the applicability of the RO treatment system could be a significant component to enhance the strategic water development plan of the PWA to maintain the sustainability of the coastal aquifer.

## CONFLICT OF INTEREST

The authors declare no conflicts of interest.

## FUNDING

No funding was received for this project.

## REFERENCES

- Abid MF, Zablouk MA, Abid-Alameer AM (2012), Experimental study of dye removal from industrial wastewater by membrane technologies of reverse osmosis and nanofiltration. *Iranian J Environ Health Sci Eng* 9(1): 1-17.
- Al Jilil S, Sajid M (2014), Study of Wastewater Treatment Plant. *Applied Numerical Mathematics and Scientific Computation, Proceedings of the 2<sup>nd</sup> International*

- Conference on Applied Mathematics and Computational Methods*:132-140.
- Alhumoud JM, Al-Humaidi H, Al-Ghusain IN, Alhumoud AM (2010), Cost/Benefit Evaluation of Sulaibiya Wastewater Treatment Plant in Kuwait. *International Business & Economics Research Journal* 9(2): 23-32.
- American Public Health, American Water Works Association, Water Environment Federation (2017), Standard Methods for the Examination of Water and Wastewater 23<sup>rd</sup> edition. Baird RB, Eaton AD, Rice EW (Eds). *Publication office, American Public Health Association*, Washington, DC.
- Ang WL, Mohammad AW, Hilal N, Leo CP (2015), Review on the applicability of integrated/hybrid membrane processes in water treatment. *Desalination* 363 (1): 2-18.
- ARIJ (2015), Status of the environment in the state of Palestine. *Applied Research Institute – Jerusalem*.
- CMWU (2012), Environmental and social impact assessment (ESIA) and environmental and social management plan (ESMP) for Gaza water supply and sewage systems improvement project (WSSSIP) phase 1 and additional financing (AF). *Coastal municipalities water utility*.
- Edwards VH, Schubert PF (1974), Removal of 2,4-D and other persistent organic molecules from water supplies by reverse osmosis. *J Am Waterworks Assoc* 12: 610-616.
- Fang H, Chian E (1976), Optimization of NS-100 membrane for reverse osmosis. *Applied Polymer Science* 20(2): 303-314.
- FAO (1985), The state of Food and Agriculture. *Food and Agriculture Organization*.
- FAO (1992), Wastewater treatment and use in agriculture. *Food and Agriculture Organization*.
- FAO (2006), Water desalination for agricultural applications. Proceedings of the FAO Expert Consultation on Water Desalination for Agricultural Applications, *Food and Agriculture Organization*.
- FAO-AQUASTAT (2018), Global information system on water and agriculture. <http://www.fao.org/nr/water/aquastat/main/index.stm> (Accessed in June 2018).
- Gumbo JR, Malaka EM, Odiyo JO, Nare L (2010), The Health Implications of Wastewater Reuse in Vegetable: a case study from Malamulele, South Africa. *International Journal of Environmental Health Research* 20(3): 201-211.
- Jacobson KS, Drew DM, He Z (2011), Efficient salt removal in a continuously operated up-flow microbial desalination cell with an air cathode. *Bioresour Technol* 102 (1): 376–380.
- Jamil M, Zia MS, Qasim M (2010), Contamination of Agro-Ecosystem and Human Health Hazards from Wastewater Used for Irrigation. *Journal of Chemical Society of Pakistan* 32(3): 370-378.
- Jan FA, Ishaq M, Khan S, Ihsanullah I, Ahmad I, Shakirullah M (2010), A Comparative Study of Human Health Risks Via Consumption of Food Crops Grown on Wastewater Irrigated Soil (Peshawar) and Relatively Clean Water Irrigated Soil (Lower Dir). *J. Hazard Mater* 179: 612-621.
- Jaradat D. (2016), Reality and Challenges of Water Quality in Palestine: Focus on Regulations and Monitoring of Wastewater Treatment and Reclaimed Water Use. *Master Thesis*. Birzeit University, Palestine
- Jaramillo MF, Restrepo I (2017), Wastewater Reuse in Agriculture: A Review about Its Limitations and Benefits. *Sustainability* 9(10): 1-19.
- Jiménez B (2005), Treatment technology and standards for agricultural wastewater reuse: a case study in Mexico. *Irrigation and Drainage* 54 (1): 23-33.
- Karagiannis IC, Soldatos PG (2008), Water desalination cost literature: review and assessment. *Desalination* 223 (1-3): 448–456.
- Kawamura S. (2000), Integrated design and operation of water treatment facilities. 2nd edition, Canada, *John Wiley & Sons, Inc.*
- Mehta L (2007), Whose scarcity? Whose property? The case of water in western India. *Land Use Policy* 24 (4): 654–663.
- Metcalf and Eddy (2013), Wastewater engineering treatment and reuse. 4th edition. *McGraw-Hill: USA*.
- Middle East and North Africa. *Irrigation and Drainage Systems* 24(1-2): 37–51.
- PCBS (2018), Water and wastewater in Palestine. *IOP Publishing Physics Web*. <http://www.pcbs.gov.ps> Accessed 25 June 2018.
- Pearce GK (2008), UF/MF pre-treatment to RO in seawater and wastewater reuse applications: a comparison of energy costs. *Desalination*, 222(1-3): 66-73.
- Polprasert C. (2007), Organic waste recycling technology and management. 3rd edition, London, UK, *IWA Publishing*.
- PS (2003), The Palestinian standards for treated wastewater. *Palestinian Standard*.
- PWA (2011), The comparative study of options for an additional supply of water for the Gaza strip (CSO-G). The
- PWA (2013), Status report of water resources in the occupied state of Palestine-2012. *Palestinian Water Authority*, Ramallah, Palestine.
- PWA (2014), Gaza water resources status report, 2013/2014. *Palestinian Water Authority*, Gaza, Palestine.
- PWA (2015), Gaza Strip: Desalination facility project: necessity, politics and energy. *Palestinian Water Authority*, Gaza, Palestine.
- PWL (2002). *Palestinian water law*, Decree No 3: 2002.
- PWL (2014) *Palestinian water law*, Decree No 14: 2014.
- Qadir M, Bahri A, Sato T, Al-Karadsheh E (2010), Wastewater production, treatment, and irrigation in the production, treatment, and irrigation in the Middle East and North Africa. *Irrigation and Drainage Systems* 24(1-2): 37–51.
- Suzuki Y, Minami T (1991), Technological Development of a Wastewater Reclamation Process for Recreational Reuse: An Approach to Advanced Wastewater Treatment Featuring Reverse Osmosis Membrane. *Water Science and Technology* 23: 16-29.
- U.S. EPA (2004), Guidelines for water reuse. EPA/625/R-

- 04/108. U.S. Environmental Protection Agency, Washington.  
updated final report, *Palestinian Water Authority*, Gaza, Palestine.
- Vörösmarty CJ, McIntyre PB, Gessner MO, Dudgeon D, Prusevich A, Green P, Glidden S, Bunn SE, Sullivan CA, Reidy Liermann C, Davies PM (2010), Global threats to human water security and river biodiversity. *Nature* 467: 555–561
- Water Technology (2018), Groundwater Replenishment System (GWRS), *Orange County, California*. <https://www.water-technology.net/projects> Retrieved 15 July 2018.
- WHO (1989), Health guidelines for the use of wastewater in agriculture and aquaculture. The report of the scientific group on health aspects of the use of treated wastewater for Agriculture and Aquaculture. *The World Health Organization*, Geneva.
- WHO (2006), A compendium of standards for wastewater reuse in the Eastern Mediterranean Region. *The World Health Organization, Regional Office for the Eastern Mediterranean, Regional Centre for Environmental Health Activities*, CEHA.
- Zhang B, He Z (2013), Improving water desalination by hydraulically coupling an osmotic microbial fuel cell with amicrobial desalination cell. *Journal of Membrane Science* 441: 18–24.