The status of freshwater and reused treated wastewater for agricultural irrigation in the Occupied Palestinian Territories
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ABSTRACT
Global freshwater scarcity is imposing the demand for using non-conventional water resources for irrigation and non-irrigation purposes. Direct reuse of treated wastewater for agricultural irrigation is a widespread practice in arid and semi-arid regions, because of water shortage and scarcity. Water scarcity and the need for ecological sustainability have led to the introduction of treated wastewater as an additional water resource in the national water resources' management plans of Mediterranean countries. The use of wastewater for irrigation is an important tool for water resources’ supplement. However, the reuse of effluent in irrigation can have negative impacts on crop quality and soil conditions, as well as on public health and the environment. Furthermore, inappropriate management of agricultural irrigation with treated wastewater can also pose problems for plant production and the physical and chemical properties of soils. This paper presents some approaches to understand the impacts of reusing treated wastewater. It also presents a critical analysis of the treated wastewater’s reuse for irrigation in the Occupied Palestinian Territories (OPT), while shedding light on the water status in the OPT. The paper investigates the wastewater treatment and reuse for agricultural irrigation, especially in the lack of control of Palestinians on their own freshwater resources in the OPT.

Key words | agricultural irrigation, freshwater resources, health and environmental impacts of reusing treated wastewater, Occupied Palestinian Territories (OPT), wastewater characteristics, water shortage and scarcity

HIGHLIGHTS
- This paper is novel because it is the first of its kind that thoroughly investigates, analyzes, and discusses several issues related to the status of freshwater and wastewater in the Occupied Palestinian Territories (OPT).
- In particular, it investigates the status of wastewater treatment and reuse (WWTR) in agriculture in the OPT.
- It discusses the geopolitical circumstances affecting freshwater, wastewater, and WWTR in the OPT.
- It presents important recommendations to those concerned, including policy- and decision-makers, at governmental, nongovernmental, and academic institutions, as well as in the sectors of agriculture, industry, health, and the environment.

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INTRODUCTION

The increase in demand for using water resources can have remarkable effects on the environment, socio-economics, and agricultural production, as well as on sustainable development (Andrews et al. 2016). Water shortage and scarcity represent a critical issue in drier areas, i.e., in semi-arid and arid regions of the world, in particular. In the regions where water resources are limited, the use of wastewater is an important strategy for supplementing water resources. The reuse of treated wastewater for agricultural irrigation can reduce the problems associated with water scarcity and shortage, as well as with surface water and groundwater pollution.

This work deals with wastewater and its reuse in agriculture, after being treated. Wastewater treatment and reuse (WWTR) may need further treatment to satisfy various criteria, depending on a country’s regulations and guidelines (Zaidi 2010; Barceló & Petrovic 2011; Agrafioti & Diamadopoulos 2012; Fatta-Kassinos et al. 2016; Ghosh 2019). Therefore, when wastewater is reused for agricultural irrigation can reduce the problems associated with water scarcity and shortage, as well as with surface water and groundwater pollution.

However, recycling of wastewater is encouraged as an important part of integrated water resources management (IWRM), because it can benefit farmers and nature at the same time (Winpenny et al. 2010; Maaß & Grundmann 2016). Treated wastewater cannot be used to irrigate crops that are sensitive to wastewater, but it can successfully be used to irrigate salt-tolerant and wastewater-tolerant crops, such as some kinds of trees, shrubs, and fodders. Therefore, wastewater quality should be a major concern when reusing wastewater, as it determines which crops can be irrigated with it.
Various trace elements and salts play a major role in the reuse of wastewater. Above a certain level, high concentration of trace elements harmfully affect the crop growth, while individual salts may disorder plants’ nutrient uptake. However, if improper practices are taking place, water reuse can result in negative impacts, such as soil’s salinization and contaminated crops with chemical and biological contents (Christou et al. 2014; Hülsmann & Arakani 2018). High sodium to calcium and magnesium concentration ratio (Na/Ca + Mg) may cause unstable soil structure, as discussed later in further detail. The unstable structures of soils are subject to compaction, crustling, and quality degrading of soils, which all affect crop growth. Furthermore, long-term irrigation farms with wastewater can have the potential to make changes in physical properties of soils and chemical composition of organic and mineral pollutants (Oort et al. 2017). Wastewater, containing various concentrations of nutrients and metals, impacts soil productivity and quality, with the consideration of environmental risks. This means that when crops are irrigated with wastewater, containing above-threshold concentration of toxic elements, the toxic elements might enter the food chain, affecting the food taken by humans and animals.

These are some examples on WWTR for agricultural irrigation, and its impacts on soils and crops in the Mediterranean region, including Morocco, Tunisia, Jordan, and Palestine, as they share the same Mediterranean climate. In Morocco, treated wastewater was reused to irrigate cereals (wheat and barley), vegetable crops (beans, cauliflower, and artichoke), fodder crops (alfalfa), and fruit trees (olive and palm trees). Accordingly, Malki et al. (2017) indicated that treated wastewater reuse in Morocco can be safe and reliable, commercially viable, socially acceptable, and environmentally sustainable. In Tunisia, where olive trees are considered a national wealth, Bedbabis et al. (2015) reused treated wastewater to irrigate olive trees over a period of ten years. They found that standard quality indices (free acidity, K232, and K270) of virgin olive oil and oil content were not affected significantly by water quality. Instead, chlorophyll, total phenols, induction time, and δ-tocopherol values decreased significantly after ten years of irrigation with treated wastewater. However, both fruit water content, and the concentrations of β-carotene and tocopherols (α, β, and γ) in virgin olive oil increased (Bedbabis et al. 2015). In Jordan, where approximately 85% of treated wastewater is used for crops’ irrigation (Almanaseer et al. 2020), Rusan et al. (2007) conducted wastewater irrigational experiments in Jordan for two, five, and ten years, and found that crops’ irrigation with wastewater had no significant effects on soils’ heavy metals, mainly lead (Pb) and cadmium (Cd), regardless of the duration of wastewater irrigation. Barghouthi et al. (2017) conducted experimental work on olive trees in the West Bank and Gaza Strip (Occupied Palestinian Territories (OPT)), and found that organic content and cation-exchange capacity were improved in soils irrigated with treated wastewater, in comparison with soils irrigated with freshwater. Their results also showed that there were no trace elements or heavy metals’ accumulation in the soils studied.

This paper recognizes the evolution in thinking and how approaches to wastewater reuse have changed over the past four decades from an effluent disposal issue to one of recognizing wastewater as a legitimate and valuable resource. Despite recycled water being a popular choice and being broadly embraced, the concept of indirect potable reuse schemes has lacked community and political support across the planet to date. However, the benefits of treated wastewater for its reuse in IWRM and its role for water cycle management, water scarcity, climate change adaptation, and water in the cities of the future are greatly important and efficient. Treated wastewater reuse is a cost-competitive and energy-saving option to increase water availability and reliability. It is a proven water scarcity solution to mitigate climate change by increasing water availability.

This paper is meant to help close the anthropogenic water cycle and enable sustainable reuse of available water resources. When treated wastewater is integrated to water resources management, it can be considered as an integral part of pollution control and water management strategies, which also results in benefits to public health, the environment, and economic development.

The paper investigates the possibilities of WWTR for agricultural irrigation, and the environmental and agro-socio-economic-health impacts of such practices, as well as the geopolitical conditions affecting the water resources in the OPT. It contributes to the knowledge and information of those concerned with WWTR for agricultural irrigation, as it addresses several quality indicators of WWTR. The paper provides a public awareness related to the problems investigated, analyzed, and discussed, with respect to fresh water and
wastewater resources' development and management in the OPT, as well as to the health and environmental impacts. This is with the aim of improving environmental protection, based on science and technology, and on testimony and arguments provided by research scientists and organizations, locally, regionally, and internationally. The paper is very important, as it deals with WWTR in a semi-arid zone, where water shortage and scarcity are paramount, where climate change impacts are heavily affecting the Middle East and North Africa (MENA) region, and where geopolitical conflicts are prevailing.

The paper also presents perspectives aiming at developing a methodology, based on the polluter pays principle, in order to recover the cost of wastewater reuse. It is recommended that a cost-recovery model (Ruiz-Rosa et al. 2020) for a wastewater treatment and reuse process be proposed, based on the polluter pays principle that, among other things, provides appropriate incentives for efficient water use and guarantees its future availability. The proposed cost recovery model can be applied, using data provided by wastewater treatment plants. By using the tariff system for wastewater reuse, citizens would become aware of the financial investments involved in this process with the consequent impacts on saving water, which would then help maintain reserves.

The paper is of high importance to farmers, agriculturists, environmentalists, water specialists, research scientists, professional engineers, academicians, educators, policy- and strategy-makers, conflict strategists, industrialists, and graduate students, as well as to project leaders and donors, and CEOs of organizations, locally, regionally, and internationally.

**BRIEF COMPARISON WITH LITERATURE**

Many works dealing with WWTR have been carried out by researchers around the world. They have focused on the treatment and reuse of wastewater, impacts on the environment and human health, wastewater management and regulations, and removal of microorganisms and chemical components. Previous works have also dealt with other issues related to WWTR, such as wastewater treatment plants, disposal, and wastewater sludge management, as well as bio-solids in the environment. Here are some examples of past works carried out just in the last two years – 2019 and 2020, in addition to another study carried out in 2011.

**Australia’s perspective (an example)**

Australia is the driest inhabited continent on Earth, and most importantly, it experiences the most variable rainfall of all continents. The vast majority of Australians live in large cities on the coast. Since all wastewater treatment plants were located near the coast, large-scale recycling was thought to be an issue due to the infrastructure cost and pumping required in establishing the recycled water schemes. This all changed when Australia experienced a decade of record-breaking precipitation, and thus, water utilities were given strong targets for increasing the volume of recycled water. This led to the acceptance of recycled water as a legitimate source of water for non-potable purposes (including irrigation). This was in a diversified portfolio of water resources to mitigate the risks and impacts of climate change. To ensure community support for recycled water, Australia is currently leading the world in developing national guidelines for the different uses of recycled water to ensure public health and the environment are protected. Australia now offers fascinating case studies of developments in maximizing water recycling opportunities from political, regulatory, and technological perspectives (see, for example, Apostolidis et al. (2011) and AGI (2020)).

**Domestic sewage**

Dorji et al. (2019) presented a review on wastewater management practices in Bhutan along with management challenges. Bhutan is a kingdom located on the southern slopes of the eastern Himalayas. It is landlocked between the Tibet Autonomous Region in China to the north and the Indian states of Sikkim, West Bengal, Assam to the west and south, and the Indian state of Arunachal Pradesh to the east. A field survey was conducted for two major cities in Bhutan, and in addition to the survey, data were collected from local administration bodies in 35 towns. Based on the survey and the analysis of the data collected, it was found that eight towns have a public sewage system that covers about 20% of the urban population in the country. As well, the results also indicated the presence of potential flooding of the sewage system in most settlements in an urban area. This surplus flow of sewage was mostly from septic tanks, which entered the underground water aquifers, and also affected the surrounding environment.
Urban wastewater

A multidisciplinary systematic study was carried out in South Africa to assess urban wastewater management by Malisa et al. (2019). Their research activity used data reported from a Stellenbosch case study, along with quantitative data collected from participants. The results obtained helped in developing transitional frameworks and these frameworks can be used for wastewater management in urban areas. It concluded that governments in urban areas can use these frameworks and move from traditional practices to an integrated management system.

Industrial wastewater

Sawalha et al. (2019) reported the physical and chemical properties of wastewater from tanneries in the OPT. Their study monitored the characteristics of wastewater, with the focus on total solids, chemical oxygen demand, total dissolved solids, total suspended solids, chloride, and ammonia. The observed wastewater quality data were compared with data reported by tannery processing units, worldwide. In comparison, the amount of wastewater generated from tanneries in the OPT was much less compared to world data. Measurements calculated in mass balance of chromium absorption showed an efficiency of around 45%, and this factor indicates cleaner production from tanneries in the OPT.

Treatment technology

Grobelak et al. (2019) evaluated the operation of a single-line treatment technology for sludge and wastewater. Besides the process evaluation, the assessment was also made on the amount of fertilizer and biomass generated. The single-line treatment’s system process used the stabilizer device, which can produce pathogen-free organic fertilizer by-products and the raw materials used for thermal synthesis. The results showed that the technology could support in reducing the amount of nitrogen, potassium, carbon and energy loops for better management.

Agricultural reuse: positive and negative impacts

Experiments on treated municipal wastewater and surface water used to irrigate nectarine orchards were reported by Moretti et al. (2019). They focused on assessing the environmental performance, using experimental data obtained at the field level. The International Reference Cycle Data System was adopted for the analysis of toxicity, eutrophication, climate change, and acidification. Results showed better performance of nectarine orchards using treated wastewater than those irrigated with surface water, taking into account eutrophication.

The use of treated effluent from tanneries to grow vegetable crops was evaluated by Alemu et al. (2019). In their study, they used a pretreatment technique with a combination of a batch reactor and a constructed wetland. For growing field and pot vegetable crops, a random block design was used. The results showed that chromium was found in most of the cultivated vegetable crops and that its concentration was higher in field cultivated crops compared to the potted plants. Also, the estimated target risk groups related to chromium concentration present in the pot trial had no health risk.

The removal of 17 pesticides found in wastewater agriculture was examined by Vela et al. (2019). The wastewater samples were taken from agricultural waste containers, as well as from phytosanitary treatment equipment. An experimental study was conducted under natural sunlight using sodium persulfate. The results showed that the remaining pesticides acrinathrin and fluopyram were examined in agricultural wastewater. Complete degradation of the parent substance was achieved after treatment. There were no observed differences in the yield of broccoli vegetables grown, using unclaimed wastewater and reclaimed wastewater.

Wastewater quality

The quality of wastewater collected from the Marrakesh sewage treatment plant was examined by Moussaoui et al. (2019). The wastewater quality was examined taking into account the physical and chemical parameters along with the analysis of climatic data for use in agroforestry. The climate data results indicated that local climatic conditions were critical to water resources management. As well, analysis of soil samples showed that fertility loss is related to lack of organic matter. Their study concluded that, to address water scarcity in the region, treated wastewater could be a solution (Choudri et al. 2020).
Strategic plans and policies, and people’s awareness

Mu’azu et al. (2020) proposed strategic management for the reuse of treated wastewater in the Kingdom of Saudi Arabia, as it is an arid region depending almost entirely on desalinated water. This means that a significant reduction in the country’s dependence on costly desalinated water and the rapid depletion of non-renewable groundwater will certainly require the complete recycling of treated wastewater for reuse for certain purposes. In their study, Mu’azu et al. (2020) investigated socio-demographic variables that influence public perceptions of gray and mixed wastewater reuse for non-domestic uses, such as firefighting, swimming pools, and car washes.

Impacts of wastewater reuse on human health and the environment

In their study, Choudri et al. (2020) reviewed more than 50 recent studies conducted in one year (2019), related to WWTR and its impacts on human health and the environment. In addition to other factors, they evaluated the risk and potential toxicity generated by WWTR. They concluded that concerns should be directed to issues such as advanced technologies developed for treatment, governmental policies and regulations, and assistance in managing biological waste and sludge, as well as removal of chemical and microbial hazards.

APPROACHES

To achieve the approaches of this paper, the following topics are discussed: (1) concept of reusing wastewater for irrigation; (2) wastewater quality and reclamation; (3) wastewater salinity and toxicity; (4) sodium hazards caused by wastewater; (5) reclamation of salt-affected farms; (6) chemistry conditions of soils irrigated with wastewater; (7) a procedure for wastewater reuse; (8) plants’ salt tolerance and halophytes in relation to saline wastewater; (9) wastewater reuse for fuel and pasture production; and (10) integrated on-farm drainage management (IoFDM) system as a solution to wastewater.

Concept of reusing wastewater for irrigation

Urban and industrial sections often dispose of their wastewaters to ditches and streams. In many regions around the globe, urban and industrial wastewaters are either partially treated, or not treated at all. Some, who treat wastewater, reuse it for agricultural irrigation. Microbiological and chemical components of wastewater severely pollute the canals that deliver the wastewater, posing environmental problems to both humans and wildlife (Bos 1997; Fatta-Kassinos et al. 2011). Therefore, great caution must be taken when reusing treated wastewater.

Wastewater quality and reclamation

The use of untreated wastewater for agricultural irrigation can assist in the increase of chemical and biological contents in the root zones of plants to a degree that it interferes with optimal crop growth, as well as with groundwater quality in neighboring aquifer systems, especially if the water table of aquifers is shallow. Frequent use of wastewater for irrigation can impose negative effects on agriculture and soil properties and, in turn, wastewater alters chemical and physical properties of soils, leading to leaching of heavy metals from soils (Abunada & Nassar 2015). Accordingly, application of excessive wastewater during the growing season for crop-water requirements can leach the salts from the plants’ root zones and soils. Therefore, in places with limited natural drainage, leaching of untreated wastewater needs to be removed through artificial drainage.

Wastewater salinity and toxicity

In general, wastewater contains different types of salts, trace elements, and heavy metals, depending on the source and origination of wastewater. These include aluminum (Al), arsenic (As), beryllium (Be), boron (B), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), fluoride (F), iron (Fe), lead (Pb), lithium (Li), manganese (Mn), mercury (Hg), molybdenum (Mo), nickel (Ni), selenium (Se), tin (Sn), titanium (Ti), tungsten (W), vanadium (V), and zinc (Zn). The salts and trace elements, if presented in high concentrations, may become toxic (Chang 1977), depending on the
wastewater quality. The quality problem, associated with wastewater reuse, is the salts’ excessive concentration (Elgallal et al. 2016). The most common phytotoxic ions of trace elements and salts that may be present in municipal sewage and in concentrated treated effluents that cause toxicity are: boron (B), chloride (Cl), and sodium (Na). Hence, the concentration of these ions needs to be determined, in order to assess the suitability of wastewater quality for reuse in agricultural irrigation (Pescod 1992).

**Sodium hazards caused by wastewater**

Sodium hazards, for instance, caused by usage of untreated wastewater for irrigation, are related to the ability of excessive sodium or extremely low salinity concentrations to disturb the structure of soils. The sodium concentration in soils’ moisture is crucial in determining their physical behavior, because of the sodium’s effect in relation to promoting clay dispersion and/or flocculation within the soils (Sumner 1995; Basga et al. 2018). Sodium is a unique cation because of its effect on soils. When sodium is present in soils in an exchangeable form, it causes adverse physico-chemical changes in soils, particularly with respect to soils’ structure, as already mentioned. Sodium has the ability to disperse soils when it is present above a certain threshold value, relative to the concentration of the total dissolved salts in soils. Dispersion of soils is a process occurring in soils that are particularly vulnerable to erosion by water. Where soils are saturated with sodium ions, soils (known as ‘sodic soils’) can break down very easily into fine particles and wash away. Accordingly, soils’ dispersion, resulting in reduction of the infiltration rates of water and air into the soils, will lead to deterioration of soils’ quality. Dispersed soils, when becoming dry, form crusts which are hard to till and, thus, they interfere with germination and seedling emergence.

Where wastewater is reused, sodium hazards might be expected. High values of the sodium adsorption ratio (SAR) lead to decreasing soils’ hydraulic conductivity (permeability), clay dispersion, and aggregate stability (Ayers & Westcot 1985; Suarez et al. 2006). The most reliable index of the sodium hazards of wastewater irrigation is SAR, which is defined by the following formula, where the ionic concentrations are expressed in meq/l (milliequivalent per liter):

\[
\text{Na}^+/(\sqrt{\text{Ca}^{++} + \text{Mg}^{++}/2})
\]

Infiltration problems of soils can be managed by means of chemical amendments added to soils (Ayers & Westcot 1985). The aim of applying chemical amendments to soils is to improve their poor infiltration caused by either low-salinity concentration or by extra-sodium ions. Reclamation of sodic soils may require the application of the sources containing calcium which prevents sodium occupying exchange sites of soils. For example, application of gypsum (CaSO_4) to the surfaces of soils can assist in counteracting the negative impacts of high concentration of Na^+ in irrigation by wastewater (Choudhary et al. 2004; Brinck & Frost 2009).

Accordingly, irrigation with wastewater could be a source of excess sodium in soils and, hence, sodium should be evaluated for these kinds of hazard.

**Reclamation of salt-affected farms**

As indicated above, soils with a high concentration of sodium ions (Na^+) often have low hydraulic conductivity, as a result of the high sodium percentage on the soil exchange complex. The reclamation of sodic soils requires that a divalent solute (mainly calcium ions; Ca^{++}) passes through the soils’ profile, replacing exchangeable sodium and leaching the desorbed sodium ions from the root zone. Therefore, the rate at which sodic soils can be reclaimed depends on the water flow through the soils and the calcium concentration of the soils’ solution. The application of leaching water with a high electrolyte concentration promotes flocculation of the soils and, thus, improves soils’ hydraulic conductivity, which expedites the reclamation process. Amendments need to be added in order to replace sodium ions (Na^+) with calcium ions (Ca^{++}) on the soils’ exchange complex (Qadir et al. 2001).

**Chemistry conditions of soils irrigated with wastewater**

A number of the trace elements mentioned above are normally present in relatively low concentrations, usually less
than a number of mg/l, in conventional irrigation waters. These elements are, normally, not included in routine analysis of regular irrigational water, but attention should be paid to them when using wastewater and sewage effluents, particularly if contamination with industrial wastewater discharge is suspected. Heavy metals are a special group of trace elements which have been shown to create definite health hazards when taken up by plants (Jaramillo & Restrepo 2017). The heavy metals are in metallic form, with densities greater than 4 g/cc. In their experimental work, Alghobar & Suresha (2016) irrigated rice plants with untreated and treated wastewater. They found that heavy metals are concentrated in the leaves of the planted rice, with rates above the recommended levels.

High values of trace elements (including heavy metals) in soils and irrigation water (wastewater) can be observed in association with high salinity, and can be affected by the same processes of salinity (Muyen et al. 2011). However, in some areas, heavy metals may also occur independently of salinity. Deverel et al. (2012) discussed a method for assessing concentrations of trace elements in soils and shallow groundwater. There are two main processes that significantly take control of the mobility of trace elements in soils' water, namely: (1) adsorption and desorption reactions; and (2) solid-phase precipitation and dissolution processes. These processes are influenced by changes in pH, redox state and reactions, and chemical constituents (Albasel & Pratt 1989; Hinkle & Polette 1999).

A procedure for wastewater reuse

Effluent of good quality might be used directly for agricultural production. Otherwise, wastewater may be reused in conjunction with freshwater. Conjunctive reuse includes blending wastewater with freshwater resources. If not, wastewater can be used cyclically with freshwater, as being applied separately. In a cyclic way, the two water resources can be rotated within the cropping system, or can be used separately over the seasons for different crops. The option to a specific reuse may depend largely on drainage water quality, crop tolerance to salinity, and availability of freshwater resources.

The quantity and time of availability of wastewater is of major importance. The direct reuse of wastewater is applied mainly at the field level, whereby wastewater is not incorporated with freshwater. Outcomes of research carried out in some countries showed that wastewater can be reused directly for irrigation purposes without causing crop yield reduction. This can be achieved where the salinity of drainage water in good drainage systems does not exceed the salinity concentration of the plants grown (Barnes 2014). When wastewater salinity exceeds the threshold values for optimal agricultural yields, it can be mixed with freshwater to create a mixture of acceptable quality for the prevailing cropping systems. Where reuse is applied by mixing wastewater from main drains with freshwater in main irrigation canals, the most salt-sensitive crop type determines the final water quality. Where mixing is followed at the field level, the salinity of the blended water can be adjusted towards the salt tolerance of individual crops (Maas & Grattan 1999; Sharma & Tyagi 2004).

Plants’ salt tolerance and halophytes in relation to saline wastewater

Where wastewater is highly saline for irrigation of agricultural crops, irrigation of halophyte plants can be considered. The quantity and type of salts in wastewater, which salt-tolerant crops and halophyte plants can tolerate, vary among species of plants. Salt-tolerant plants have optimal growth to a limited threshold salinity, which is reduced after crop growth. Halophytes are kinds of plants that grow in waters of high salinity, coming into contact with saline water through their roots. They grow in habitats with high salinity levels, like saline semi-desert areas, mangrove swamps, marshes, sloughs, and seashores. The word ‘halophyte’ is derived from Ancient Greek (ἅλος) which means ‘salt’, and ( φυτόν), which means ‘plant’ (Wikipedia 2020).

Wastewater reuse for fuel and pasture production

There are still many small communities around the world depending on wood for cooking and heating. As agricultural land is required to feed growing populations, it is unlikely that good quality agricultural land will be used for fuel production (Shay 1990). In general, salt-tolerant plants can be grown to be used for fuel production and industrial materials, utilizing saline wastewater and marginal fields. Sustainable pasture programs across the world have used salt-tolerant plants,
grass species, and halophytes in salt-affected regions. Shrubs and trees can be considered valuable complements to grasslands, as they are less susceptible to moisture deficits and temperature changes than grasses. They can also provide valuable complementary animal feed or fuelwood.

**Integrated on-farm drainage management (IoFDM) system as a solution to wastewater**

Providing environmentally safe methods for disposal of drainage water, containing salt and nutrients, is a challenge for irrigated agriculture. A system developed for sequentially using saline drainage water for supplemental irrigation resulted in significant reduction of the drainage water volume (Ayars & Soppe 2014). This system is integrated on-farm drainage management (IoFDM), which tends to utilize drainage water as a resource to produce marketable crops and to reduce the volume of drainage water (wastewater) to be discharged. The solar evaporator encompasses a flat area lined with a plastic tool, on which the brine is disposed and the crystallized salts are gathered. The daily discharge of drain wastewater corresponds to the daily evaporation, so as to prevent water ponding that attracts water birds. This is only significant where high concentrations of toxic trace elements are available in wastewater, and where a normal evaporation basin can be used. The drainage water can be disposed of into the solar evaporator and is controlled closely to prevent ponding by adjusting sprinkler irrigation rates and timing to daily evapotranspiration rates.

**WASTEWATER TREATMENT AND REUSE (WWTR) IN THE OCCUPIED PALESTINIAN TERRITORIES**

Regarding WWTR, this paper focuses on the OPT, comprising the West Bank, including East Jerusalem, and the Gaza Strip, forming 22% of Historic Palestine. The OPT were occupied by Israel in June 1967, which was established in 1948 on 78% of Historic Palestine. Talking some politics in this scientifically approached paper is a must, in order to understand several issues related to WWTR, in particular, and to water resources and other related issues, in general. The OPT, facing a considerable number of problems, including those related to the water resources, are currently the home of more than 5.1 million Palestinians living in the West Bank (≈3.1 million) and in the Gaza Strip (≈2 million) (Worldometer 2020). This is in addition to approximately, as of 1 January 2020, half a million Jewish settlers distributed over 150 settlements built illegally in the occupied West Bank (JVL 2020; MEM 2020). Some estimates, however, indicate that the number of Jewish settlers in the OPT, including East Jerusalem’s neighborhoods, has reached 800,000 (Salem 2020). Figure 1 shows maps of Historic Palestine, the Gaza Strip, and the West Bank.

**Water status in the OPT**

Although the goal of this paper is to investigate the usages of freshwater and wastewater in the agricultural sector in the OPT, presenting some hydro-political perspectives, as related to water resources in the OPT, is a necessity to have a better understanding of the water situation in the region. Based on international law and human rights treaties, the Palestinians, living under Israeli military occupation since June 1967, are supposed to have enough and safe water for their domestic, agricultural, and industrial consumption until a satisfactory solution is reached between the Israelis and the Palestinians. A report, issued in March 2017 by the United Nations Human Rights Council (UNHRC), investigated the human rights situation in the OPT, with the focus on the recurrence and persistence of human rights violations by the Israeli occupation authorities, underlying policies leading to such inhumane patterns. The UNHRC (2017) report states, ‘Movement and other restrictions also prevent the development of the Palestinian economy. The agricultural sector has been particularly affected by the denial of access for farmers to agricultural areas, water resources, and domestic and external markets. Impediments to Palestinians’ economic, social, and cultural development also affect the exercise of the right to self-determination.’

In his work on the role of Palestinian women in agriculture in urban areas of the OPT, Salem (2019a) indicates that Palestinian women play a considerable role in making water available for domestic and agricultural usages, either by bringing water from far distances or getting water from
springs and domestic harvesting wells (cisterns). Despite the fact that the status of agriculture in the OPT is really bad and getting even worse, and despite the presence of economic, financial, and political hardships and challenges, Palestinian women have obviously contributed to the agricultural sector towards achieving sustainable development in their communities in the OPT’s rural areas (Salem 2019a).

Since it was established in 1948 over 78% of the land of Historic Palestine, and as it has occupied from 1967 the remaining parts (22%) of Historic Palestine, Israel has almost full control on the Palestinian water resources, similar to its full control on the Palestinian lands, considering water resources in Historic Palestine a strategic asset (UN 1980). The Israeli full control on the Palestinian rightful water resources has been taking place in different forms, including ‘water hegemony,’ ‘water domination,’ ‘water deprivation,’ ‘water politics’ (hydropolitics), ‘water strategies,’ ‘water pollution,’ ‘water militarization,’ etc. (UN 1980; Isaac & Salem 2007; Salem & Isaac 2007; Zeitoun 2011; Zeitoun et al. 2013; WCC 2016; EJA 2019; Salem 2019b). As a result, the Palestinians in the OPT have access to only a small fraction of their own rightful water resources (Figures 2 and 3).

According to BTselem (2017) – an Israeli civil and human rights’ organization, while the Palestinian population in the OPT has almost doubled since 1995 (i.e., since the signing of the Oslo Agreement in 1993/1995), the water allocations have remained capped at the 1995 levels stated in the Oslo II Agreement (OIIA – Article 40) (IMFA 1995; Rouyer 1999). Today, the Palestinians in the West Bank have access to less water than they were granted by the already inequitable amount stated by OIIA in 1995. According to OIIA, only 13% of the Palestinian rightful water resources is given to the Palestinians, while Israel abstracts the remaining 87% (Figure 2). As Palestinians in the West Bank do not have access to the Jordan River’s waters, the main water resource left for them is the Mountain Aquifer system (MAS) (Figure 1(right)).
The MAS’ groundwater resource is 130-km long and some 35-km wide, fed mainly by rainwater falling over the mountains of the occupied West Bank. With a total average yield of 679–734 million cubic meter per year (MCM/yr), MAS is divided into three sub-aquifer systems (or basins): (1) the Western basin (WB); (2) the North-eastern basin (or Northern) (NEB); and (3) the Eastern basin (EB) (Figure 1(right)). The MAS of the three sub-aquifer systems (or basins) contributes about 25% of Israel’s total water budget, as Israel extracts about 87% of the MAS’ potential yield (as mentioned above), and restricts the Palestinians’ share to only 13% (or even less) of the MAS’ potential. Furthermore, Israel reportedly withdraws water from MAS up to 50% beyond its sustainable yield, to provide water to its citizens in Israel and to its half a million to 800,000 Jewish settlers living illegally in the occupied West Bank, as indicated above.

The Palestinians’ share of MAS has declined over the last 10–15 years, because of: (1) the Israeli lack of respect of, and commitment to, the 1995 OIIA, although the agreement is totally unfair as it allocates to the Palestinians only 13% of their rightful water resources; (2) the Israeli over-extraction of MAS’ water; (3) the Israeli restrictions imposed on Palestinians, especially farmers, preventing them from drilling new wells and/or rehabilitating the old ones; and (4) the reduced natural recharge, due to climate change impacts (Salem 2019a).

In 1999, for example, the overall Palestinian water extraction from MAS was 138 MCM, dropped to 113 MCM in 2007, and to 87 MCM in 2011, which is less than the 118 MCM/yr that was allocated to Palestinians, according to the 1995 OIIA. As seen in Figure 3, the daily water’s average share of an Israeli settler living in the occupied West Bank is 240–300 liters per day (l/d), and the daily average share of a Palestinian citizen living in the occupied West Bank is 73 l/d. Meanwhile, the WHO’s minimum standard (WHO’s MS) is 100 l/d (EWASH 2012, 2016). This
means that the Israeli settler’s share from the Palestinian rightful water is 240–300% greater than the WHO’s MS, and is approximately 350–411% greater than the Palestinian citizen’s share of his/her rightful water. In other words, the Palestinian citizen’s share is only 73% of the WHO’s MS, and only 24–30% of what an Israeli settler obtains illegally from the Palestinian rightful water.

Figure 3, provided by international organizations, namely, the ‘Emergency Water, Sanitation, and Hygiene’ (EWASH) and the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), strongly indicates that the Palestinians in the occupied West Bank are not only living under harsh conditions as a result of the Israeli military occupation since June 1967, but also they are extremely thirsty, as they are deprived, by the Israeli occupation authorities, from using their own rightful water resources (Garwood 2009).

In the occupied, besieged Gaza Strip, the situation is even much worse than that in the occupied West Bank. The only water resource (that used to be freshwater) in the Gaza Strip is the Coastal Aquifer system (CAS), which is shared by Israel and the Gaza Strip (Figure 1 (left and middle)). Its average recharge is estimated at up to 450 MCM/yr in Israel and 55–60 MCM/yr in the Gaza Strip, totaling approximately 500 MCM/yr. However, current extraction rates in the Gaza Strip alone have reached up to 200 MCM/yr, which is nearly four times as much as CAS can sustainably recharge each year to meet the growing demands of the Gaza Strip’s population (PWA 2015), which is currently around 2 million (as indicated above), living on 365 km². The over-exploitation of the CAS’ part underlying the Gaza Strip, and the absence of adequate sewage treatment facilities in the Gaza Strip have resulted in the deterioration of water quality in the Gaza Strip. It is estimated that up to 97% of Gaza’s water is unfit for human consumption due to pollution (B’Tselem 2014; MEM 2018). Owing to this reason, and
many other reasons as well, the Gaza Strip is an unfit place to live in by 2020, according to UNRWA (2012).

In view of the above, the Palestinians under the Israeli military occupation have no other choice but to consider other options for water supply, including, for instance, WWTR to be primarily used for agricultural irrigation, and also seawater desalination (SWD) from the Mediterranean Sea. The two options (WWTR and SWD) will enable the Palestinian population in the Gaza Strip to save some of the freshwater, in order to be used for domestic purposes. This is, of course, without compromising the full rights of the Palestinians in their rightful water resources, including: (1) the surface water from the Jordan River that constitutes the eastern border of Historic Palestine with Jordan, and the Tiberias Lake; (2) the groundwater from the MAS and its three basins underneath the occupied West Bank (as discussed above); and (3) the groundwater from the CAS underneath the occupied, besieged Gaza Strip (Salem & Isaac 2007; Isaac & Salem 2007; Salem 2011a, 2013a, 2019b) (Figure 1).

Previous works on WWTR in the OPT

Many works have been undertaken in the OPT in the last 26 years (1994–2020), focusing on several issues related to WWTR (Table 1).

A review of the below-referenced works on WWTR in the OPT (Table 1) indicates the following: (1) the works done have taken place over the last 26 years or so (1994–2020), with the great majority of them between 2012 and 2016, which might be attributed to more funding during that period of time; (2) most of the works done are in the form of projects carried out, and/or funded by, international organizations (European, American, United Nations, and others); (3) the total funds of these WWTR projects have reached tens of millions and probably hundreds of millions of USD (no data available); (4) most of the works done were undertaken in partnership with Palestinian governmental institutions (such as the Palestinian Water Authority (PWA) and the Environmental Quality Authority (EQA), as well as with Palestinian academic institutions (universities and research centers); (5) a considerable number (more than 20, as being referenced in this paper) of the works done were in the form of graduate studies towards the Master degree in water and environmental science and engineering, most of which were carried out at Palestinian universities; and (6) the works done tackled or heavily investigated various issues related to WWTR, including geopolitics, technicality, finance, trade, socioeconomics, socio-culture, agriculture, health, climate change, environment, water shortage and scarcity, plans and strategies, problems and challenges, projects, and others. It is noteworthy to mention that socio-cultural (religion-wise) perspectives, in relation to the reuse of treated wastewater is a sensitive and critical issue, as investigated by researchers in some other Arab and non-Arab countries (i.e., Almas & Scholz 2006; Ganoulis 2012). Unfortunately, despite the many studies carried out on WWTR in the OPT, with the cost of millions of dollars, not much progress has been achieved, as will be discussed in the following sections of this paper.

Wastewater status in the OPT (West Bank and Gaza Strip)

Wastewater quantity

Despite the fact that wastewater is a major source for environmental pollution, it is considered a sustainable and valuable resource that should be collected, treated to acceptable standards, and reused for the sake of protecting the environment and preserving groundwater resources, as well as for the sake of conserving and augmenting the surface water and groundwater resources. Based on the per-capita wastewater’s generation in the OPT, the total volume of wastewater generated for the year 2015 was estimated at approximately 115 MCM/yr, of which ≈66 MCM/yr was generated in the occupied West Bank and 49 MCM/yr in the occupied, besieged Gaza Strip (ARIJ 2015). According to more recent data, the wastewater volume was, in 2016, around 175.5 MCM, including 95.5 MCM in the West Bank and 80 MCM in the Gaza Strip, and is estimated to reach a volume of 237 MCM in 2030, including 167 MCM in the West Bank and 106 MCM in the Gaza Strip (World Bank 2018a; UNEP 2020).

Unfortunately, as a result of the Israeli wars on the Gaza Strip, Israel destroyed the wastewater treatment plants (Omer 2015; CEO 2019). As this happened, Israel strongly
Table 1  Summary of several studies carried out on wastewater treatment and reuse (WWTR) in the Occupied Palestinian Territories (OPT: West Bank and Gaza Strip) over the period of 1994–2020

<table>
<thead>
<tr>
<th>Target</th>
<th>Observations/Results</th>
<th>Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Review of wastewater status</td>
<td>Reviewed the status of wastewater and, to some extent, freshwater</td>
<td>Fatta et al. (2004); PWA (2006); Salem et al. (2007); Abu Madi &amp; Al-Sa’ed (2009); USAID (2010); Samhan et al. (2011); PWA (2012a); Samhan (2012); Kellis et al. (2013); PWA (2013a), (2015)</td>
</tr>
<tr>
<td>Wastewater management</td>
<td>Attempted to develop wastewater management plans and strategies</td>
<td>Gearheart et al. (1994); Nashashibi (1999); PWA (1996), (2013b); UNEP (2005a); Zimmo et al. (2005); Salem et al. (2007); ARIJ (2011, 2015); Barceló &amp; Petrovic (2011); HWE (2012); McKee (2012); Mahmoud &amp; Yasin (2013); Royal Haskoning DHV (2013); Adwan (2014); EEA (2014); Bushkar (2015); GWP et al. (2015); Jeuland (2015); Lipchin (2017); UN Water (2017); World Bank (2018a); EPME (2019)</td>
</tr>
<tr>
<td>Wastewater as a pollution source affecting groundwater aquifers, water springs, and seas</td>
<td>Investigated wastewater as a major source of pollution, affecting the groundwater and springs' water quality, when disposed untreated to the environment</td>
<td>Isaac et al. (1995); UNEP (2009a); PWA (2011); Salem (2011b); Alhousani et al. (2012); Hammad &amp; Ghanem (2016); Tiehm et al. (2016); Daghara et al. (2019); Reliefweb (2019)</td>
</tr>
<tr>
<td>Evaluation of environmental, social, and economic aspects of wastewater in the West Bank and Gaza Strip, as well as of the transboundary wastewater and wastewater generated by Israeli settlements in the West Bank</td>
<td>Studied environmental, technical, financial, and economic valuation of wastewater in the West Bank and Gaza Strip, and the wastewater generated by Israeli settlements, flowing to the Palestinian communities in the West Bank, as well as of the transboundary wastewater between Israel and the occupied West Bank</td>
<td>Shreim (2012); Al-Sa’ed &amp; Al-Hindi (2013); NGESTP (2013); Yaqob et al. (2014a, 2014b); Aryaeinejad et al. (2015); Man (2016); Yaqob (2016); EPME (2019); Reliefweb (2019); UN (2019)</td>
</tr>
<tr>
<td>Wastewater treatment plants</td>
<td>Investigated the construction of small-scale and large-scale wastewater treatment plants used for agriculture, particularly in rural areas to increase the space of land used for agriculture, and to conserve the environment</td>
<td>Sbeih (1996); Mubarak (2004); Sbeih (2007); Haddad et al. (2009); Adlah (2010); TCA (2011); DGIS-UNESCO-IHE (2016); Reliefweb (2019), (2020)</td>
</tr>
<tr>
<td>Public awareness</td>
<td>Carried out public awareness projects to promote best practices in water conservation, including treated wastewater</td>
<td>Al-Labadi (1997); Arafat (2012); Arafat (2015)</td>
</tr>
<tr>
<td>Sociocultural acceptability of using treated wastewater</td>
<td>Conducted sociocultural studies to evaluate the population’s acceptability of wastewater reuse for agriculture</td>
<td>Al Khateeb (2001); Zimmo et al. (2005)</td>
</tr>
<tr>
<td>Wastewater characteristics and analysis of chemical and physical properties of sewage</td>
<td>Conducted studies to analyze sewage, which revealed that sewage has very high strength attributed to low water consumption, industrial discharge, and people’s habits, resulting in high specific COD production</td>
<td>Nashashibi &amp; van Duijl (1995); Mahmoud et al. (2005); Houshia et al. (2012); Mahmoud (2012)</td>
</tr>
</tbody>
</table>
violated several articles of the 1949–Fourth Geneva Convention (UNHRC 2009) that require, for instance, the occupying power to ensure public health and hygiene, as well as enough and safe water for the people living in occupied territories. As Israel destroyed the wastewater plants in the Gaza Strip, the Palestinians have no other choice but to discharge between 50,000 and 100,000 m$^3$/d of wastewater into the Mediterranean Sea (Salem 2011b). More recent data indicate that the amount of untreated or partially treated sewage/wastewater that flows daily from the Gaza Strip

### Table 1 | continued

<table>
<thead>
<tr>
<th>Target</th>
<th>Observations/Results</th>
<th>Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wastewater reuse, planning, and evaluation, policies and practices</td>
<td>Assessed wastewater reuse practices in the Mediterranean region, including the OPT, which covered wastewater reuse planning, and evaluation of the status of wastewater quality and quantity, as well as wastewater treatment and reuse applications</td>
<td>UNEP (2003b); Afifi (2006); Hansen (2012); McKee (2012); Mizyed (2012); PWA (2012b, 2013a, 2013c, 2013d); BZU (2013); Shomar (2013); Wawi (2017); El Hamarneh (2018)</td>
</tr>
<tr>
<td>Tools and guidelines development</td>
<td>Developed tools and guidelines for the promotion of sustainable urban wastewater treatment and reuse in agricultural production in the Mediterranean countries, including the OPT</td>
<td>MEDAWARE (2004)</td>
</tr>
<tr>
<td>Designing monitoring systems for wastewater</td>
<td>Designed systems to monitor wastewater parameters, including location of the monitored points to construct wastewater treatment plants and their impacts on public health and the environment</td>
<td>Mogheir et al. (2003); Mogheir &amp; Lubbad (2008); Arafeh (2012); Hilles et al. (2014); Jaradat (2016)</td>
</tr>
<tr>
<td>Existing practices and constraints, and health impacts of reused wastewater</td>
<td>Investigated the existing practices and constraints, regarding wastewater treatment and reuse, and described the health impacts resulted from inappropriate practices</td>
<td>Al Salem &amp; Abouzaid (2006); BWD (2008); NGESTP (2013); UN (2019)</td>
</tr>
<tr>
<td>Wastewater reuse in agricultural irrigation, home gardens, safe use, and impacts on crops’ production and soils’ quality</td>
<td>Investigated and analyzed the quality-related and safety parameters of treated wastewater reused in agricultural irrigation, as well as wastewater impacts on the quality and quantity of produced agricultural crops</td>
<td>Abu Baker (2007); Fatta &amp; Anayiotou (2007); Abu Nada (2009); Abumohor (2012); Barghouthi &amp; Gerstetter (2012); Haddad (2012); McKee (2012); Attaallah (2013); Idais (2013); Abu Foul et al. (2014); Lebd (2014); Abunada &amp; Nassar (2015); Abu Sultan (2015); Alsahhar (2015); Omar (2015); Abu Seiba (2016); Al-Khatib et al. (2017); ANERA (2017); Barghouthi et al. (2017); SWIM and HORIZON 2020 (2018)</td>
</tr>
<tr>
<td>Problems facing wastewater treatment</td>
<td>Investigated problems facing the wastewater treatment plants, and found that more than half of the current wastewater treatment facilities constructed in the OPT are waste stabilization ponds (WSP), having several problems related to their operation</td>
<td>Al-Sa’ed (2007)</td>
</tr>
<tr>
<td>Trade or trade-off of reclaimed wastewater</td>
<td>Trade or trade-off of wastewater between Israel and the Palestinian government, and among the Palestinian governorates, as well as in agriculture and industry</td>
<td>Bushkar (2015)</td>
</tr>
</tbody>
</table>
into the Mediterranean Sea increased from 90,000 m³/d in 2012 to 100,000 m³/d in 2016, and to 110,000 m³/d in 2018 (UNEP 2020). As for 2016–2018, this is equivalent, on average, to roughly 36–40 MCM/yr of wastewater dumped in the Mediterranean Sea, causing an environmental disaster to the Mediterranean’s marine life, to the groundwater CAS, and to the neighborhood. According to Hilles et al. (2014), it is estimated that around 32.5 MCM/yr of partially treated and raw sewage is discharged from the Gaza Strip into the Mediterranean Sea, of which, 25.2 MCM/yr is partially treated effluent and 7.3 MCM/yr is raw sewage. To partially reduce the impacts of wastewater, Israel is currently planning to construct a pipeline (sewage line) that will transfer wastewater from the Gaza Strip to Israel, in order to be treated within Israel and, thus, to reduce the Gaza Strip’s wastewater impacts on Israel. Israel will fund the NIS (New Israeli Shekel) 15 million (≈USD 4.4 million) bill for the new sewage line by deducting the cost from the tax revenues it transfers to the Palestinian Authority in the West Bank (TToS 2019).

In the occupied West Bank, some of the wastewater is collected through wastewater networks and, in the end, it flows through several wadis (streams or valleys) (Table 2; Figure 4).

The total annual volume of wastewater discharged in these wadis (Table 2; Figure 4) is approximately 20–25 MCM (World Bank 2009), including sewage and industrial waste (such as stone cutting slurry). The wastewater, flowing in some of the wadis, passes through Israel and ends in the Mediterranean Sea, the Dead Sea, and the Jordan River, forming what is known as ‘transboundary wastewater,’ and causing tremendous damage to the environment. Approximately 15 MCM/yr of the wastewater generated in the Occupied West Bank flows into Israel and is treated or partially treated in five Israeli treatment plants. After that, it is reused in the Israeli agricultural sector (PWA 2022b) and is not used by Palestinians in the occupied West Bank.

The cost associated with the wastewater treatment is charged to the Palestinian Water Authority (PWA), as being deducted annually by the Israeli government from the Palestinian tax revenues (ARIJ 2015), as already mentioned. According to the Water Sector Regulatory Council (WSRC), Israel (the occupation power) deducted, from the Palestinian tax revenues for the treatment of wastewater generated in the occupied West Bank, a total of no less than NIS 300 million, which is approximately USD 90 million for the years 2012, 2013, 2014, and 2015 (ARIJ 2015). For the year 2015 alone, Israel deducted over NIS 82 million (≈USD 24 million) (ARIJ 2015). In 2017, Israel billed the Palestinian Authority USD 31 million (World Bank 2018a). Currently (in 2020), the bill for dumping wastewater, including treated wastewater, into Israel costs the Palestinian budget over NIS 100 million (≈USD 30 million/yr) (Nour 2020). However, if the wastewater flowing through the wadis into Israel was treated by Palestinians, it would increase the volume of the agricultural water by 12% (HWE 2012), and it would save a great deal of money on the

<table>
<thead>
<tr>
<th>No.</th>
<th>Given names of wadis (valleys – streams) by Palestinians</th>
<th>Given names of wadis (valleys – streams) by Israelis</th>
<th>Catchment area</th>
<th>Discharge in</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Al-Moqatta</td>
<td>Kishon</td>
<td>North Jenin, and Jewish settlements</td>
<td>Mediterranean Sea</td>
</tr>
<tr>
<td>2</td>
<td>Abu Nar</td>
<td>Hadera</td>
<td>West Jenin, and Jewish settlements</td>
<td>Mediterranean Sea</td>
</tr>
<tr>
<td>3</td>
<td>Zomar</td>
<td>Alexander</td>
<td>Nablus, Tulkarm, and Jewish settlements</td>
<td>Mediterranean Sea</td>
</tr>
<tr>
<td>4</td>
<td>Al-Zuhur</td>
<td>Yarkon</td>
<td>South Qalqilia, North Salfit, and Jewish settlements</td>
<td>Mediterranean Sea</td>
</tr>
<tr>
<td>5</td>
<td>Suriq</td>
<td>Sarar</td>
<td>West Jerusalem, Beit Jala, North Bethlehem, and Jewish settlements</td>
<td>Mediterranean Sea</td>
</tr>
<tr>
<td>6</td>
<td>Al-Samen</td>
<td>Hebron or Besor</td>
<td>South of Hebron, and Jewish settlements</td>
<td>Mediterranean Sea</td>
</tr>
<tr>
<td>7</td>
<td>Al-Qilt (Al-Qelt)</td>
<td>Nahal</td>
<td>Ramallah, Al-Bireh, Jericho, and Jewish settlements</td>
<td>Jordan River</td>
</tr>
<tr>
<td>8</td>
<td>An-Nar</td>
<td>Kidron</td>
<td>Inside the Green Line that separates the West Bank from Israel, East Jerusalem, Bethlehem, Beit Sahour, and Jewish settlements</td>
<td>Dead Sea</td>
</tr>
</tbody>
</table>
Palestinian budget. Israel charges the Palestinian Authority 0.97–2.12 NIS on treatment of every cubic meter (m$^3$) of the wastewater generated in the West Bank and flows into Israel, without being reused by Palestinians (HWE 2012). This is with the consideration that irrigated agriculture in the OPT is the largest consumer of Palestinian freshwater (60–70%), forming approximately 160 MCM/yr (ARIJ 2007; World Bank 2009; Bursche 2011).

Currently, there are three treatment plants already operational in Jenin, Nablus, and Al-Bireh. This is in addition to another plant that is about to become operational in Taysaer (Tubas governorate) and another two plants that are planned to be constructed in the regions of east Nablus (northern West Bank) and Hebron (southwestern West Bank). Accordingly, the West Bank could potentially produce over 50,000 m$^3$/d of treated wastewater, which can be reused to irrigate over 20,000 dunums (20 km$^2$) to cultivate high-value crops and animal feed (Nour 2020). To date, the reuse of treated wastewater has been limited to Jenin area, and for some demonstration usages in Nablus.

It is noteworthy to mention that the environment in the OPT is greatly suffering, not only from the large amounts of wastewater and, for that matter, from other kinds of solid and fluid wastes (domestic, industrial, agricultural, chemical, medical, etc.) generated by Palestinians in the OPT (West Bank and Gaza Strip), but also from the large amounts of wastewater and other kinds of waste generated by the Jewish settlers in the occupied West Bank (Salem 2019b), as indicated in Table 2. The domestic wastewater (not to mention the industrial wastewater) generated by the Jewish settlers, living illegally in the occupied West Bank (including occupied East Jerusalem), is around 78 MCM/yr (ARIJ 2015). This is more than the annual amount of the wastewater generated by the 3.1 million...
Palestinian citizens living in the occupied West Bank, which is approximately 66 MCM/yr, as indicated above.

**Wastewater quality**

Some data for the wastewater quality in the West Bank show biochemical oxygen demand (BOD) values ranging from 400 mg/l to 1,400 mg/l, with an average value of around 600 mg/l (Isaac et al. 1995; Haddad et al. 2009; HWE 2012; Yaqob 2016). This range of BOD, according to the Australian Guidelines, is risky (Myers et al. 1999; Kaboosi 2016). The high range of BOD (400–1,400 mg/l) in the OPT, which is much higher than that (200–300 mg/l) in other countries, is due to the fact that the per-capita consumption of water in the OPT is suppressed by political restrictions applied by the Israeli occupation authorities on Palestinian water consumption and, therefore, the generated wastewater is highly concentrated (Isaac et al. 1995; World Bank 2009).

The BOD’s international standard is in the range of 30–50 mg/l (EPA 2014). Municipal sewage that is efficiently treated by the three-stage process, constituted of primary, secondary, and tertiary wastewater treatment, would have a value of <10 mg/l. In some applications, more advanced treatment is required, known as ‘quaternary wastewater treatment.’ According to old data (IMFA 1994), the BOD of untreated sewage in Israel was in the range of 60–80 mg/l for the Haifa region, and in the range of 450–500 mg/l for the Jerusalem region. According to a recent study (Schellenberg et al. 2020), the most stringent standards for BOD are observed in South Korea (<8 mg/l) and in Israel (<10 mg/l). In Jordan, which is a neighboring country to Palestine, and considered one of the most advanced countries towards approaching safety of wastewater reuse in agricultural irrigation of various kinds of plants and that incorporates strict regulations for wastewater reuse, the BOD ranges between 30 mg/l and 300 mg/l (Schellenberg et al. 2020). In Europe and the USA, the BOD in untreated wastewater generally varies between 200 mg/l and 600 mg/l (Sawyer et al. 2003; Richard 2016). The generally lower values of BOD in untreated municipal sewage in the USA, for instance, are due to the much greater water usage per capita than in the OPT and in other parts of the world. According to a Palestinian study (Jaradat 2016), the BOD standards should be limited to 150 mg/l for most forms of agricultural reuse, and a more stringent standard should be created for amenity irrigation in areas that can be accessed by the public.

**Wastewater characteristics**

Table 3 shows analyses of characteristics of the wastewater flowing in some of the wadis (valleys or streams) in the

<table>
<thead>
<tr>
<th>Location: wadi of</th>
<th>pH</th>
<th>BOD mg/l</th>
<th>COD mg/l</th>
<th>BOD/COD</th>
<th>TSS mg/l</th>
<th>NH₄ mg/l</th>
<th>PO₄ mg/l</th>
<th>Cl mg/l</th>
<th>B mg/l</th>
<th>TDS mg/l</th>
<th>DO %</th>
<th>Temp. °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Moqatta</td>
<td>7.5</td>
<td>334</td>
<td>662</td>
<td>0.50</td>
<td>618</td>
<td>114</td>
<td>1.6</td>
<td>1.0</td>
<td>1.9</td>
<td>3.6</td>
<td>2.1</td>
<td>3.6</td>
</tr>
<tr>
<td>Zomar</td>
<td>7.6</td>
<td>282</td>
<td>503</td>
<td>0.56</td>
<td>3,567</td>
<td>82</td>
<td>1.5</td>
<td>457</td>
<td>8.5</td>
<td>1,364</td>
<td>1.9</td>
<td>1.4</td>
</tr>
<tr>
<td>Al-Zuhur</td>
<td>7.3</td>
<td>242</td>
<td>493</td>
<td>0.49</td>
<td>282</td>
<td>36</td>
<td>1.4</td>
<td>258</td>
<td>8.6</td>
<td>1,013</td>
<td>1.3</td>
<td>2.0</td>
</tr>
<tr>
<td>Suriq (Beit Jala)</td>
<td>7.8</td>
<td>469</td>
<td>900</td>
<td>0.52</td>
<td>626</td>
<td>114</td>
<td>2.1</td>
<td>423</td>
<td>5.6</td>
<td>1,438</td>
<td>1.9</td>
<td>2.0</td>
</tr>
<tr>
<td>Al-Samen</td>
<td>7.6</td>
<td>265</td>
<td>404</td>
<td>0.66</td>
<td>9,775</td>
<td>104</td>
<td>1.9</td>
<td>755</td>
<td>5.0</td>
<td>1,839</td>
<td>1.9</td>
<td>2.0</td>
</tr>
<tr>
<td>Ramallah (WWTP)</td>
<td>7.2</td>
<td>104</td>
<td>260</td>
<td>0.40</td>
<td>104</td>
<td>68</td>
<td>2.1</td>
<td>348</td>
<td>3.6</td>
<td>1,093</td>
<td>1.2</td>
<td>1.9</td>
</tr>
<tr>
<td><strong>Ranges</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range of averages</td>
<td>7.2–</td>
<td>104–</td>
<td>260–</td>
<td>0.40–</td>
<td>104–</td>
<td>36–</td>
<td>1.4–2.1</td>
<td>258–</td>
<td>3.6–9.6</td>
<td>1,013–</td>
<td>1.2–</td>
<td>17–20</td>
</tr>
<tr>
<td></td>
<td>7.8</td>
<td>469</td>
<td>900</td>
<td>0.52</td>
<td>9,775</td>
<td>114</td>
<td>775</td>
<td>&lt;1.0</td>
<td>1,839</td>
<td>0.78</td>
<td>17–21</td>
<td></td>
</tr>
<tr>
<td>Range of minimums</td>
<td>6.8–</td>
<td>43–</td>
<td>120–</td>
<td>0.31–</td>
<td>42–7,080</td>
<td>23–</td>
<td>0.16–</td>
<td>250–</td>
<td>3.2</td>
<td>1,300</td>
<td>1.0</td>
<td></td>
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<tr>
<td></td>
<td>7.3</td>
<td>248</td>
<td>800</td>
<td>0.36</td>
<td>92</td>
<td>0.48</td>
<td>500</td>
<td>1.0</td>
<td></td>
<td></td>
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<tr>
<td>Range of maximums</td>
<td>7.7–</td>
<td>286–</td>
<td>480–</td>
<td>0.60–</td>
<td>166–</td>
<td>48–</td>
<td>3–6.3</td>
<td>300–</td>
<td>7.4</td>
<td>1,192–</td>
<td>2–3.7</td>
<td>20–22</td>
</tr>
<tr>
<td></td>
<td>8.1</td>
<td>258</td>
<td>960</td>
<td>0.61</td>
<td>11,710</td>
<td>168</td>
<td>1,325</td>
<td>101</td>
<td>2,510</td>
<td></td>
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</tbody>
</table>
West Bank (Table 2; Figure 4), as well as for the wastewater treated in the Ramallah Wastewater Treatment Plant (WWTTP). The characteristics analyzed are alkalinity-acidity indicator (pH), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammonium (NH₄), phosphate (PO₄), chloride (Cl), boron (B), total dissolved solids (TDS), dissolved oxygen (DO), and temperature.

The results of the wastewater analyses (Table 3) indicate the following: the pH, referring to the measurement of the hydrogen ion activity in wastewater, is generally around the neutral value (7.0) for raw wastewater. This suggests that the wastewater analyzed is balanced, meaning that it has the same amount of acid ion (H⁺) and base ion (OH⁻). The BOD and COD values can be simply evaluated in terms of their ratio (BOD/COD). This ratio reflects the biodegradability of organic matter in wastewater; it is zero if organic matter is not biodegradable and 1 if all organic matter is easily biodegradable. As seen in Table 3, this ratio ranges, in general, for the average, minimum, and maximum values, between 0.31 and 0.66. In general, the average value of the ratio for the investigated sites is around 0.5, which is typical for municipal wastewater, agreeing with the observations of Wang et al. (2009). The low values of the BOD/COD ratio suggest industrial wastewater, which generally contains low BOD concentration of less than 100 mg/l and high COD concentration of more than 800 mg/l (Samudro & Mangkoedihardjo 2010). The values of the TSS (Table 3), including organic and inorganic suspended solids, are generally high. They are, however, maximized for the Wadi Al-Samen (Table 3), which can be attributed to the solid particles generated from the stone-cutting industry in that area.

The NH₄ values are generally higher than normal, whereas the normal value for domestic wastewater is around 40 mg/l (BMS 2013). However, the NH₄ ion concentration depends on the pH and temperature of the wastewater, as it generally increases with rises in the pH and temperature. Higher pH values and higher temperatures lead to the formation of ionized ammonia that is toxic (Abou-Elela et al. 2012; Purwono et al. 2017). The presence of PO₄ (Table 3) within the ordinary range, characterizing municipal wastewater, can be attributed to several sources, including fertilizers washed out of the soils, human and animal excretions, and detergents and cleaning agents, which all are ordinary sources of phosphate found in the wastewater discharged in the West Bank’s wadis. Municipal wastewaters may contain 5–20 mg/l of total phosphorus, of which 1–5 mg/l is organic and the rest inorganic (Lenntech 2009).

The Cl ion in the wastewater (Table 3) shows higher values than normal, where normal is around 250 mg/l (Asche 2013). The high levels of Cl in the West Bank’s wastewater can be attributed to the extraordinary usage of bleach for household purposes, such as washing dishes, floors, and so forth, as well as to the high levels of salt consumption by residents. The presence of high amounts of Cl in wastewater can cause considerable damage to the fauna and flora of the ecosystems. The occurrence of boron (B) in the wastewater (Table 3) can be attributed to the wide usage of detergents at homes. Calculations by the German Government Environment Agency attributed 50% of the boron in wastewater to the usage of detergent products (Butterwick et al. 1989; WHO 1998). Boron can also be generated from other sources, including human activities mainly through agricultural materials, such as borate-containing fertilizers and herbicides; burning of domestic waste, crop residues, and wood fuel, based on the fact that boron is present in many plants being necessary for their growth; power generation using fossil fuels, such as coal and oil; waste from borate processing, including the manufacturing of glass products; leaching from treated wood or paper (GreenFacts 1998). Accordingly, the presence of considerable amounts of boron in the West Bank’s wastewater will encourage its infiltration into the ground, causing contamination to the soils and groundwater aquifer systems.

The TDS, as shown in Table 3, has the range of 854–2,510 mg/l, while it is normally in the range of 250–850 mg/l, as recently pointed out by Park & Snyder (2020). Wu & Maskaly (2018) conducted lab experiments on wastewater samples, having TDS of 750, 1,500, 3,000, 4,500, and 6,000 mg/l. They concluded that only two TDS levels (750 mg/l and 1,500 mg/l) could achieve good COD removal efficiencies (94.8% and 92.2%, respectively). They also concluded that the TDS level does not affect the removal of NH₄. Meanwhile, the low TDS levels (750 mg/l and 1,500 mg/l) enabled phosphate removal with high efficiency (>99%), whereas the
The DO is defined in biological treatment as the relative measure of oxygen dissolved in wastewater available to sustain life, including living bacteria. Whether at municipal or industrial combined wastewater treatment plants, the monitoring of DO, along with TSS, is so important. For municipal wastewater treatment plants, the amounts of TSS and DO in the wastewater determine how effective their treatment is. Dissolved oxygen is important, because the whole biological process would not exist without it. The microorganisms need a happy environment to live in, so that they can undertake their job very well, during the treatment process. In order to metabolize food and reproduce, each microorganism (or bug) must have at least 0.1 to 0.3 mg/l of DO (EPM 2009). Generally, the effluent wastewater quality is best when the DO concentration is kept in the range of 1–3 mg/l (Du et al. 2018). The DO values for the West Bank’s wastewater have a general range of 0.78%–3.7% (Table 3). However, a high DO concentration makes the denitrification less efficient, and will lead to waste of energy during treatment. On the other hand, a low DO level cannot supply enough oxygen to the microorganisms in the sludge, so the efficiency of organic matter degradation is reduced (Holenda et al. 2008; Du et al. 2018). The DO concentration in aeration tanks in an activated sludge process is an important processing control factor that has a great effect on the wastewater treatment efficiency, operational cost, and system stability. As the DO drops, the quantity of these filamentous microorganisms increases, adversely affecting the settleability of the activated sludge.

The last investigated parameter is the wastewater temperature, ranging, in general, between 17 and 22 °C (Table 3). This temperature is acceptable for the wastewater to enter the wastewater treatment plants. However, the maximum temperature of the wastewater entering a biological reactor should be 35 °C (<95 °F) (TWWB 2016). The literature seems to be consistent in setting 35 °C as the upper limit, beyond which the operation of the biological system and solids settling in the clarifiers will begin to suffer (TWWB 2016). By increasing the temperature while treating wastewater, it may partially contribute to the reduction of COD (Ahsan et al. 2005).

Suggested improvements

As discussed above, the wastewater in the OPT is generally of bad quality. Therefore, it is suggested that an efficient monitoring system is urgently needed. Such a system would help to improve the wastewater quality through awareness programs, considering the fact that most of the wastewater flow and raw sewage is dumped untreated in wadis and water streams. This, in turn, reflects in adverse consequences on surface water and groundwater resources, biodiversity, and the environment in general, as well as on the food chain and public health.

Furthermore, reused wastewater, as discussed in the following section, should be actually subjected to strict regulations, monitoring, assessment, and auditing. There is no room, in fact, for squeamishness in the face of the growing problems resulting from the wastewater and raw sewage in the OPT, and thus, three steps could vastly improve the status of wastewater and raw sewage in the OPT. These are: (1) do more effective research; (2) improve public awareness and outreach; and (3) implement projects where needed. As some developed countries in Europe have already implemented these three steps, treated wastewater is not only used for agricultural irrigation, landscape irrigation, and industrial purposes, but also for drinking and domestic purposes (Tortajada & Van Rensburg 2020).

Wastewater treatment and reuse (WWTR) in the OPT

Treatment and reuse of Palestinian wastewater benefiting Israel

In view of the above, WWTR is a necessity and is of a great importance in both regions of the OPT (West Bank, including East Jerusalem, and the Gaza Strip). The treated wastewater can be successfully used for agricultural irrigation, though with some limitations (e.g., McNeill et al. 2009; Mouhanni et al. 2011; Seder & Abdel-Jabbar 2011; Attaallah 2015; Bedbabis et al. 2015; Al-Busaidi & Ahmed 2017; Jaramillo & Restrepo 2017; Miller-Robbie et al. 2017).
as well as for some industrial purposes, such as the stone-cutting industry (Al-Jabari 2002; Fahiminia et al. 2013), as being the major industry in Palestine.

Despite the fact that the Palestinian experience in the reuse of treated wastewater (especially in the agricultural sector) is very limited, immature, and poor (Arafeh 2012), it should not prevent or discourage Palestinians, particularly farmers, from reusing it gradually on smaller scales and then on larger scales. This, in turn, would promote water conservation through replacement of freshwater reallocated for domestic uses from the Palestinian agricultural sector, and also would result in more freshwater availability to Palestinians, who are already suffering from severe shortage of freshwater, especially during the hot summers, due to the total Israeli control on the Palestinian water resources, as discussed above. This will also help in protecting the environment, considering the fact that large amounts of wastewater are discharged into open areas, ending in the Mediterranean Sea in the west, and in the Jordan River and the Dead Sea in the east, as indicated above (Table 2; Figure 4).

In spite of the collection of some 15 MCM/yr, and the treatment of approximately 10 MCM/yr of wastewater by large centralized wastewater plants, as well as by on-site small-scale wastewater treatment plants in the West Bank, the reused volume of treated effluent in agriculture or in industrial processes remains close to zero (ARIJ 2015). Despite the fact that the reuse of treated wastewater is a very important issue, considering the fact that approximately half of the current use of freshwater in the Gaza Strip is allocated to the agricultural sector, almost no treated wastewater is reused in the agricultural sector in the Gaza Strip (Abu Sultan 2015) and, thus, all of it is discharged into the Mediterranean Sea, as indicated above.

By constructing two more mega wastewater plants in the Gaza Strip, as discussed below, hopefully some of the treated wastewater will be used for agricultural irrigation. More recently, two mega wastewater plants have been constructed in the Gaza Strip: one in Beit Lahia, serving the northern part of the Gaza Strip; and the other in Khan Younis, serving the southern part of the Gaza Strip (PNN 2018; World Bank 2018; Reliefweb 2019; UNDP 2020). These two facilities will benefit around 740,000 people, forming around 37% of the total population of the Gaza Strip. The first facility (known as the North Gaza Wastewater Treatment Plant), with a total cost of USD 75 million, will benefit a population of around 400,000, with a treatment capacity of wastewater reaching 34,000 m³/d. This USD 75 million project received financial and technical support from the governments of Belgium, France, and Sweden, as well as from the European Commission and the World Bank. Meanwhile, the one in the south (known as the Khan Younis Waste Water Treatment Plant), with a total cost of USD 58 million, will benefit a population of around 340,000, with a treatment capacity of wastewater reaching 26,600 m³/d. The implementation, construction, and co-financing of the project in the south were through the UNDP with funds from the government of Japan and the Kuwait Fund for Arab Economic Development through the Islamic Development Bank.

However, there is currently not enough information about the agricultural reuse of treated wastewater produced by the two new mega projects constructed just recently in the Gaza Strip. Nevertheless, the reuse of close-to-zero amount of treated wastewater in the OPT might be attributed to several reasons, including, among others: (1) some of the centralized wastewater treatment facilities do not treat wastewater to the standards that are suitable for reuse of the treated wastewater; and (2) the lack of acceptability of the reuse of treated wastewater, due to different reasons, including sociocultural (mainly religious), health-wise, lack of public awareness, and others. Nevertheless, Palestinian farmers should be convinced that reused treated wastewater for agricultural irrigation can not only save them money, but it can also give them better agricultural yields, qualitatively and quantitatively, with the consideration of the presence of a strict monitoring system, as already mentioned.

In the West Bank, field crops irrigated with freshwater, for example, produce an average yield 11 times greater than those irrigated with rainwater (ARIJ 2015). On the other hand, irrigated agriculture with treated wastewater can promote development in other economic sectors in the OPT. However, although wastewater treatment is expensive, the reused wastewater should be treated to tertiary levels to avoid health-related problems.
Recently, it has been shown that only 30% (or 21 MCM/yr) of the 69 MCM/yr of the West Bank’s wastewater is collected, and only 9.5 MCM/yr (≈14% of total volume) is treated (World Bank 2018a). This results in discharging 25 MCM/yr of the untreated sewage into the environment, coming from 350 localities in the West Bank. Some 21.4 MCM/yr of this flows into, and is treated by Israel, resulting in charging the Palestinian Authority for the necessary treatment, as indicated above. In Gaza, out of the 80 MCM/yr of wastewater, only around 1 MCM/yr of treated wastewater is reused, 13 MCM/yr is treated and discharged into the CAS for its recovery, and 46 MCM/yr of untreated and partially treated wastewater is discharged into wadis (open areas), being infiltrated into the ground and flowing directly to the Mediterranean Sea (World Bank 2018a).

### Potential of reusing treated wastewater in fodder and palm tree irrigation

Through funding from OFID (OPEC Fund for International Development – the Member States of the Organization of the Petroleum Exporting Countries (OPEC)), ANERA (American Near East Refugee Aid), for example, established a very successful experience in treating wastewater and reusing it in the Jenin governorate, north of the West Bank, OPT. ANERA has addressed the water scarcity issue in Jenin with a first-of-its-kind project that turns wastewater into a valuable irrigation resource. The project, which was started in 2013, included installation of a water distribution network, sub-surface irrigation system, pumps, filtration system, and chlorination unit, as well as reservoir construction. Until 2017, the project helped 70 farming families to cultivate their lands, feed their livestock and, thus, generate more income (ANERA 2017). ANERA’s program also offered beneficiaries fodder crop seeds and fruit-tree saplings. This helped farmers cultivate 58 acres of fodder crops (alfalfa) and 14 acres of fruit trees. This is, in total, approximately 291 dunam = 291,000 m² = 0.291 km². The first season produced a net profit that was ten times greater than that of rain-fed crops. The project has helped farmers increase their income by 20–26%, which is expected to increase further in coming years (ANERA 2017).

The Jericho region in the occupied West Bank produced around 6,000 tons of dates during the 2016 harvest season, in comparison with 600 tons produced in 2010. This is because the area was planted by large companies, and also because small farms were doubled in size. Palestinian investment in this sector has reached up to USD 200 million, covering the costs of cultivation, packaging, and export activities, whereby around 5,000 people are working in date agriculture and industry. Jericho’s climate is suitable for producing several kinds of dates, including the internationally known Medjool dates, which forms 95% of Jericho’s production of dates (Reuters 2016). However, in the last few years, this sector has started to face some real problems, resulting mainly from the shortage of water needed for existing projects or for future expansion, as large areas of land are available for palm tree cultivation.

According to Reuters (2016), Ismail Deiq, one of the largest investors in this sector, thinks that palm tree cultivation is facing a real threat.

> ‘If the decline in available water continues over the upcoming four or five years, we do not expect to be able to produce any more dates. Date production in Palestine is equal to that of stone and marble [industry].’

Owing to water shortage in the Jericho area, similar to other areas in the OPT, where (in Jericho area) hundreds of thousands of palm trees are planted, farmers have already started reusing treated wastewater to irrigate their palm trees. Reusing treated wastewater in agriculture, especially in palm trees’ irrigation, is a more feasible option in the Jericho area, particularly as all the farms of palm trees are located near WWTPs and, therefore, no high costs are needed for infrastructure to distribute the treated wastewater among farmers (Abu Seiba 2016).

It is believed, however, that Palestinian farmers in the OPT (West Bank and Gaza Strip), with the support and assistance of Palestinian and international organizations (governmental, nongovernmental, academic, industrial, etc.), need to rethink about reusing treated wastewater for agriculture, especially in irrigation of fodder and some trees that need heavy watering and that grow in salty environments, like palm trees in the Jericho area and in the Gaza Strip. However, treated wastewater should not
be reused in vegetable irrigation, because the life cycle of vegetables is very short.

**Comparison between Palestinian experience and Israeli experience in WWTR**

The reuse of treated wastewater in the OPT is based on the following arguments: (1) the complicated geopolitical situation, as a result of the Israeli long-standing occupation (since June 1967) of the Palestinian Territories; (2) the agriculture sector, being one of the major contributors to the Palestinian economy, is the greatest water consumer (60–70%) of the available water; (3) the extremely large stresses put on the Palestinian water resources, resulting in tremendous shortages in water supply and, thus, in gross hardships in relation to the agricultural, domestic, and industrial sectors; (4) the impacts of global warming and climate change (higher temperatures, less precipitation rates, higher evaporation rates, etc.) resulting in severe droughts (Yihdego et al. 2019), and last but not least; (5) the rapid growth in the Palestinian population and development. These reasons should push Palestinian farmers towards more usage of treated wastewater.

Comparing the Palestinian experience with the Israeli experience regarding WWTR, Israel continues to be a world leader in the successful exploitation of treated wastewater. Israeli researchers have been conducting scientific research on WWTR for more than a quarter of a century (see, for instance, Juanico (1996)). Over the past decade, Israel has nearly doubled the area of the lands for which treated wastewater has been effectively reused for crop irrigation (Al-Sa’ed & Al-Hindi 2013; Rinat 2015; Lipchin 2017). Israel generates approximately 500 MCM/yr of wastewater, more than 90% of which reaches the various treatment plants, and 80% of that treated wastewater is reused in agriculture (Rinat 2015; Lipchin 2017; Marin et al. 2017). Only Singapore and Spain come close to this achievement (Lipchin 2017). Treated wastewater in Israel is regarded as a financial resource and is mostly utilized for agricultural irrigation. However, improper irrigation with treated wastewater and failure to meet the safety rules might cause widespread outbreaks of diseases. Israeli law determines that using treated wastewater for unlicensed irrigation is a criminal offense (IMoH 2020). In brief, the Israeli experience in WWTR is much more advanced than that on the Palestinian side. Hence, the Palestinians need probably decades to achieve what the Israelis have already reached and accomplished, considering, of course, the geopolitical circumstances affecting the OPT’s Palestinians.

**Health impacts of using treated wastewater**

As human settlements are the major polluters of water resources, good water and wastewater management is essential to limit pollution and minimize health risks (UN Water 2006). The many benefits of irrigation with treated wastewater do come with certain risks to both human health and environmental well-being. Irrigation with treated wastewater poses a number of potential risks to human health via consumption or exposure to pathogenic microorganisms, heavy metals, and harmful organic chemicals (Shakir et al. 2017). The standard secondary treatment process generally reduces organic material in sewage, and improves the appearance and odor intensity of wastewater, but it does not significantly reduce health hazards caused by microorganisms, such as cholera bacteria, hepatitis, polio virus, and other kinds of bacteria and viruses. To manage these risks, the WHO offered guidelines for implementing safe wastewater reuse in agriculture that include treatment and non-treatment options over the entire chain from cultivation to consumption (WHO 2006; Murray & Ray 2010).

A meta-analysis, conducted by Adegoke et al. (2018), showed that agricultural workers and family members exposed to untreated or partially treated wastewater have diarrheal disease and helminth infections. The risks were higher among children and immunocompromised individuals than in immunocompetent adults. Predominantly skin and intestinal infections were prevalent among individuals infected, mainly via occupational exposure and ingestion. Food-borne outbreaks, as a result of crops (fruits and vegetables) irrigated with partially treated or untreated wastewater, have been widely reported. Contamination of crops with enteric viruses, fecal coliforms, and bacterial pathogens, and parasites, including soil-transmitted helminths (STHs), as well as occurrence of antibiotic residues and antibiotic resistance genes (ARGs) have also been evidenced (Adegoke et al. 2018).
In view of the above, the reuse of untreated or partially treated wastewater in agricultural irrigation poses potential threats. It can also cause several problems that could result in health-related impacts. These may include crop quality deterioration, soil quality degradation, water resources pollution, habitat reduction, species extinction, and wildlife destruction. Accordingly, to make treated wastewater safe to be reused in agriculture, monitoring of treated wastewater quality parameters (Table 3) is very necessary and important. Therefore, periodical efforts are needed to determine the quantity and quality of discharged wastewater that is treated and reused for agricultural irrigation. Some studies were undertaken on the health impacts of wastewater on Gaza Strip’s citizens, as those impacts have become very serious (see, for instance, Alfarra & Lubad 2004; Ramahi 2013; OCHA 2018; Efron et al. 2019; PCHR 2019; UN 2019).

CONCLUSIONS AND RECOMMENDATIONS

In many countries around the world, domestic, industrial, and agricultural wastewater is either partially treated or untreated, and if treated, it is not fully reused or not reused at all. In the West Bank and the Gaza Strip (comprising the OPT), the four cases of wastewater (untreated, partially treated, and if treated it is not fully reused, or not reused at all) are present, which can be attributed to several reasons, including: (1) the geopolitical conditions due to the Israeli occupation and restrictions on the Palestinian people in the OPT; (2) the lack of programs on awareness and technicality of wastewater treatment and reuse; (3) the mismanagement of funding donated by international organizations for such projects; (4) the socio-cultural (mainly religious) effects; and (5) the national belief that Palestinians in the OPT have enough freshwater, especially the groundwater found in the aquifer systems underneath the OPT, which is controlled by Israel almost entirely.

Therefore, Palestinians believe in having their rightful share of their own natural water resources rather than treating wastewater and reusing it, which comes with extra costs. Nevertheless, due to the Israeli control on the Palestinian rightful water resources; the impacts of global warming, climate change, and droughts, as well as due to the population’s growth and development, the reuse of treated wastewater for irrigation and industrial purposes should be seriously considered by Palestinian farmers, as well as by the stone-cutting industry, in particular.

The Palestinians in the occupied West Bank discharge no less than 85% (around 66 MCM/yr) of their sewage into open areas, causing one of the most hazardous environmental problems. On the other hand, another 78 MCM/yr are also dumped in the occupied West Bank by the Jewish settlers, making together no less than 144 MCM/yr. To continue understanding the unbalanced equation between the Palestinians and the Israelis, large amounts of the Israeli agricultural crops that are sold in the Palestinian markets in the OPT are irrigated with treated wastewater. Hence, if this is the case, it is worth Palestinian farmers benefiting from their own wastewater by treating and reusing it.

Monitoring procedures of the wastewater treatment and reuse are highly important to avoid health and environmental problems. They are also needed to manage properly the lands used for irrigation with treated wastewater. This should be done through specific controlling and monitoring mechanisms undertaken by the Palestinian government, including the ministries and authorities of agriculture, health, environment, water, industry, planning, and economics, as well as other concerned ministries and institutions. The wastewater, which is treated up to the secondary and tertiary stages can be successfully and safely reused in irrigation of certain plants. These may include animal feed, such as alfalfa (secondary stage of treatment) and palm trees (tertiary stage of treatment), considering the fact that alfalfa and palm trees are salt-tolerant plants.

Thus, in view of the above, the following points are recommended. (1) Public awareness: acceptability by people of the reuse of treated wastewater can achieve good progress in the right direction. This means that intensive public awareness campaigns should be undertaken to change the negative perceptions on treated sewage effluent. (2) Implications for water management’s policies should be seriously considered by decision-makers. Sustainably meeting the OPT’s rising water demands requires the stringent implementation of strategic wastewater reuse policies, including bold steps towards wastewater streams’ segregation. (3) A substantial reduction in the OPT’s reliance on costly freshwater used for irrigation and some industries
is urgently needed, which should be substituted by complete recycling and reuse of treated wastewater.

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**DATA AVAILABILITY STATEMENT**

All relevant data are included in the paper or its Supplementary Information.

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