


The status of freshwater and reused treated wastewater for agricultural irrigation in the Occupied Palestinian Territories

Hilmi S. Salem , Yohannes Yihdego and Hadi Hamaaziz Muhammed

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

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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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NOMENCLATURE

ANERA	American Near East Refugee Aid
ARGs	Antibiotic resistance genes
BOD	Biochemical oxygen demand
CAS	Coastal Aquifer system
COD	Chemical oxygen demand
DO	Dissolved oxygen
EB	Eastern basin of the Mountain Aquifer, West Bank
EQA	Environmental Quality Authority
EWASH	Emergency water, sanitation, and hygiene
IoFDM	Integrated on-farm drainage management
IWRM	Integrated water resources management
MAS	Mountain Aquifer system, West Bank
MENA	Middle East and North Africa
NEB	North-eastern basin (or Northern basin) of the Mountain Aquifer, West Bank
NIS	New Israeli shekel (currency used in the OPT)
OCHA	Office for the Coordination of Humanitarian Affairs, UN
OFID	OPEC's Fund for International Development
OIIA	Oslo II Agreement
OPEC	Organization of the Petroleum Exporting Countries
OPT	Occupied Palestinian Territories
pH	Alkalinity-acidity indicator
PWA	Palestinian Water Authority
SAR	Sodium adsorption ratio
STHs	Soil-transmitted helminths
SWD	Seawater desalination
TDS	Total dissolved solids
USD	United States dollar
WB	Western basin of the Mountain Aquifer, West Bank
WHO	World Health Organization, UN
WHO's MS	World Health Organization's minimum standard
WSP	Waste stabilization ponds
WSRC	Water Sector Regulatory Council
WWTR	Wastewater treatment and reuse
g/cc	Gram per cubic centimeter
km ²	Kilometer square

l/d	Liter per day
m ²	Meter square
m ³ /d	Cubic meter per day
MCM/yr	Million cubic meter per year
me/l	Milliequivalent per liter
mg/l	Milligram per liter

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 2007; Barceló & Petrovic 2011; Agrafioti & Diamadopoulos 2012; Fatta-Kassinos *et al.* 2016; Ghosh 2019). Therefore, when wastewater is reused for agricultural irrigation, management strategies (such as periodical monitoring of soils and crop properties) and suitable irrigation are vital to reduce human and environmental risks (Aiello *et al.* 2007; Yihdego 2017). 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 (Winpenney *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 & Ardakanian 2018). High sodium to calcium and magnesium concentration ratio ($\text{Na}/\text{Ca} + \text{Mg}$) may cause unstable soil structure, as discussed later in further detail. The unstable structures of soils are subject to compaction, crusting, 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

[Grobela *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-Kasinos *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 1993; 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 me/l

(milliequivalent per liter):

$$\text{Na}^+ / (\sqrt{\text{Ca}^{++} + \text{Mg}^{++}} / 2) \quad (1)$$

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 (*ἅλας*) 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

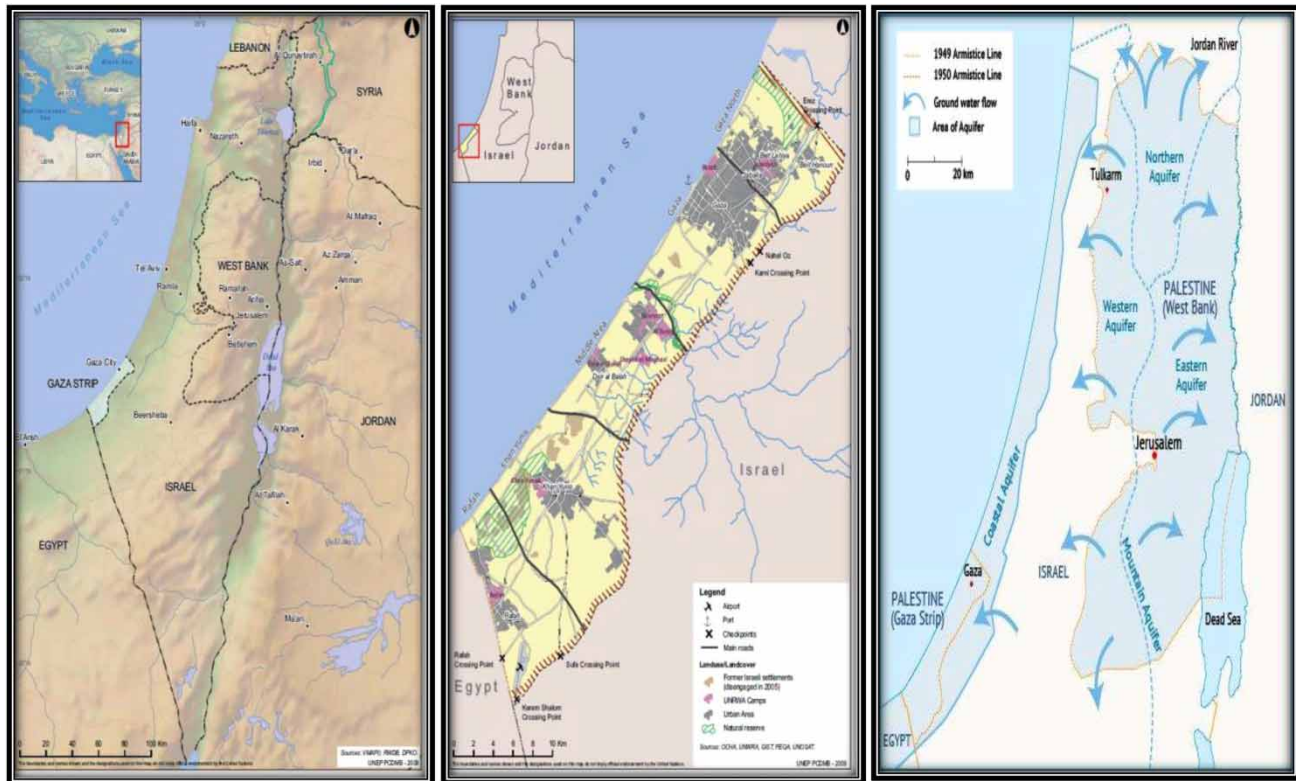


Figure 1 | (Left) map of Historic Palestine; (middle) map of the Gaza Strip; (right) map of the West Bank. The West Bank map on the right shows the Mountain Aquifer system (MAS) with its three basins: Western, Northern or North-Eastern, and Eastern), existing underneath the West Bank. It also shows the Coastal Aquifer system (CAS), existing underneath the Gaza Strip, and the groundwater movement in both of the West Bank's and Gaza Strip's aquifer systems (MAS and CAS).

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 B'Tselem (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 (OIHA – 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 OIHA in 1995. According to OIHA, 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)).

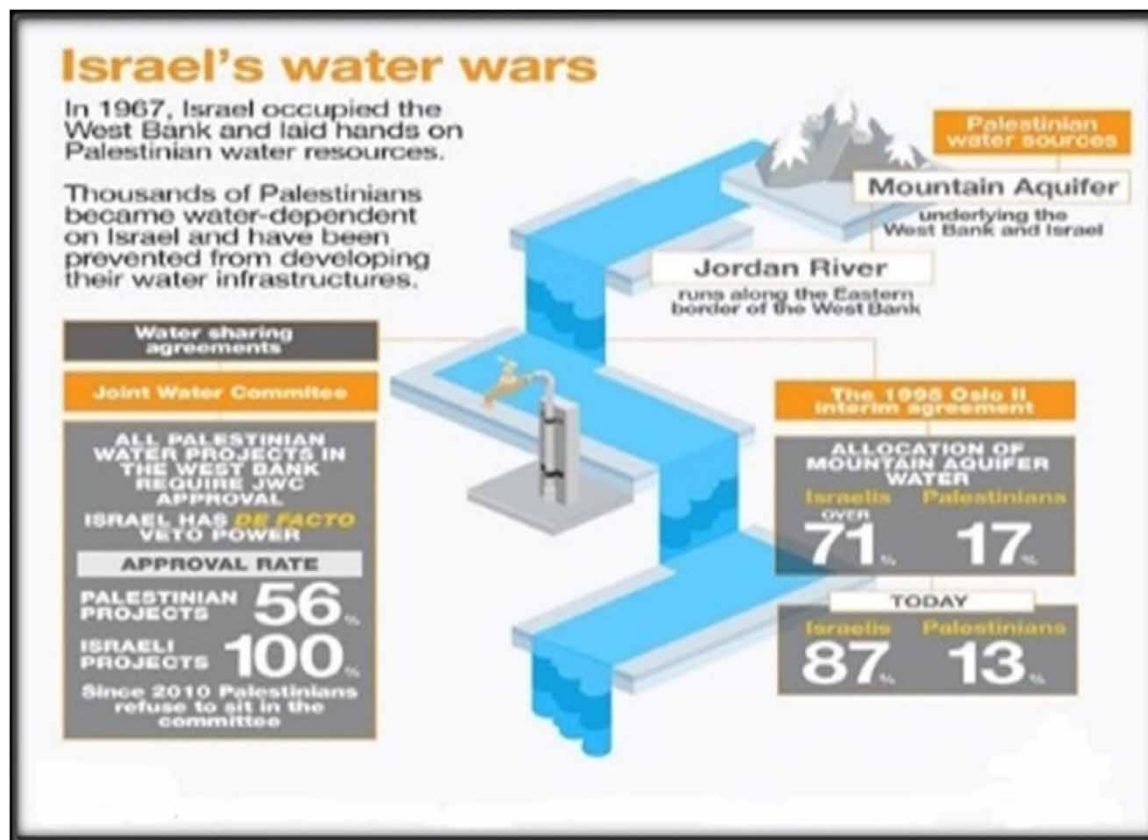


Figure 2 | Water status in the Occupied West Bank (modified after Corradin 2016; Khaled 2016, based on data taken from EWASH and OCHA).

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 2011a).

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

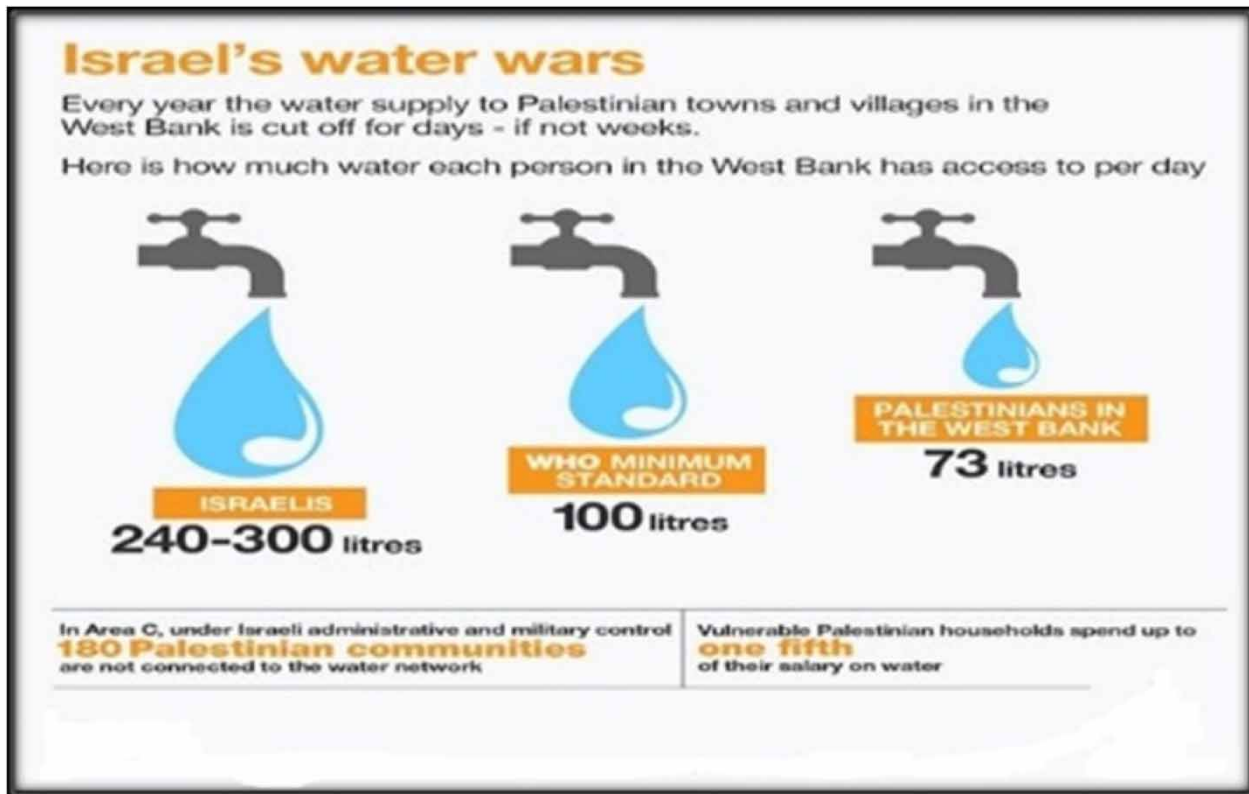


Figure 3 | Access to water in the occupied West Bank per person per day (consumed by the Israeli settlers (left) and by the Palestinian citizens (right)), compared with the World Health Organization's (WHO) minimum standard (middle) (modified after Corradin 2016; Khaled 2016, based on data taken from EWASH and OCHA).

means that the Israeli settler's share from the Palestinian rightful water is 240–300% greater than the WHO's MS, and is approximately 330–411% 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, 2019a, 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

Target	Observations/Results	Studies
Review of wastewater status	Reviewed the status of wastewater and, to some extent, freshwater	Fatta <i>et al.</i> (2004); PWA (2006); Salem <i>et al.</i> (2007); Abu Madi & Al-Sa'ed (2009); USAID (2010); Samhan <i>et al.</i> (2011); PWA (2012a); Samhan (2012); Kellis <i>et al.</i> (2013); PWA (2013a), (2015)
Wastewater management	Attempted to develop wastewater management plans and strategies	Gearheart <i>et al.</i> (1994); Nashashibi (1995); PWA (1996), (2013b); UNEP (2003a); Zimmo <i>et al.</i> (2005); Salem <i>et al.</i> (2007); ARIJ (2011, 2015); Barceló & Petrovic (2011); HWE (2012); McKee (2012); Mahmoud & Yasin (2013); Royal Haskoning DHV (2013); Adwan (2014); EEA (2014); Bushkar (2015); GWP <i>et al.</i> (2015); Jeuland (2015); Lipchin (2017); UN Water (2017); World Bank (2018a); EPME (2019)
Wastewater as a pollution source affecting groundwater aquifers, water springs, and seas	Investigated wastewater as a major source of pollution, affecting the groundwater and springs' water quality, when disposed untreated to the environment	Isaac <i>et al.</i> (1995); UNEP (2003a); PWA (2011); Salem (2011b); Alhousani <i>et al.</i> (2012); Hammad & Ghanem (2016); Tiehm <i>et al.</i> (2016); Dagghara <i>et al.</i> (2019); Reliefweb (2019)
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	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	Shreim (2012); Al-Sa'ed & Al-Hindi (2013); NGEStP (2013); Yaqob <i>et al.</i> (2014a, 2014b); Aryaeinejad <i>et al.</i> (2015); Man (2016); Yaqob (2016); EPME (2019); Reliefweb (2019); UN (2019)
Wastewater treatment plants	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	Sbeih (1996); Mubarak (2004); Sbeih (2007); Haddad <i>et al.</i> (2009); Adilah (2010); TCA (2011); DGIS-UNESCO-IHE (2016); Reliefweb (2019), (2020)
Public awareness	Carried out public awareness projects to promote best practices in water conservation, including treated wastewater	Al-Labadi (1997); Arafat (2012); Arafat (2015)
Sociocultural acceptability of using treated wastewater	Conducted sociocultural studies to evaluate the population's acceptability of wastewater reuse for agriculture	Al Khateeb (2001); Zimmo <i>et al.</i> (2005)
Wastewater characteristics and analysis of chemical and physical properties of sewage	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	Nashashibi & van Duijl (1995); Mahmoud <i>et al.</i> (2003); Houshia <i>et al.</i> (2012); Mahmoud (2012)

(continued)

Table 1 | continued

Target	Observations/Results	Studies
Wastewater reuse, planning, and evaluation, policies and practices	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	UNEP (2003b); Afifi (2006); Hansen (2012); McKee (2012); Mizyed (2012); PWA (2012b, 2013a, 2013c, 2013d); BZU (2013); Shomar (2013); Wawi (2017); El Hamarneh (2018)
Tools and guidelines development	Developed tools and guidelines for the promotion of sustainable urban wastewater treatment and reuse in agricultural production in the Mediterranean countries, including the OPT	MEDAWARE (2004)
Designing monitoring systems for wastewater	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	Mogheir <i>et al.</i> (2005); Mogheir & Lubbad (2008); Arafeh (2012); Hilles <i>et al.</i> (2014); Jaradat (2016)
Existing practices and constraints, and health impacts of reused wastewater	Investigated the existing practices and constraints, regarding wastewater treatment and reuse, and described the health impacts resulted from inappropriate practices	Al Salem & Abouzaid (2006); BWD (2008); NGESTP (2013); UN (2019)
Wastewater reuse in agricultural irrigation, home gardens, safe use, and impacts on crops' production and soils' quality	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	Abu Baker (2007); Fatta & Anayiotou (2007); Abu Nada (2009); Abumohor (2012); Barghouthi & Gerstetter (2012); Haddad (2012); McKee (2012); Attaallah (2013); Idais (2013); Abu Foul <i>et al.</i> (2014); Lebdi (2014); Abunada & Nassar (2015); Abu Sultan (2015); Alsahhar (2015); Omar (2015); Abu Seiba (2016); Al-Khatib <i>et al.</i> (2017); ANERA (2017); Barghouthi <i>et al.</i> (2017); SWIM and HORIZON 2020 (2018)
Problems facing wastewater treatment	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	Al-Sa'ed (2007)
Trade or trade-off of reclaimed wastewater	Trade or trade-off of wastewater between Israel and the Palestinian government, and among the Palestinian governorates, as well as in agriculture and industry	Bushkar (2015)

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 m³/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

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 2012b) 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 2 | The main transboundary wadis (streams or valleys) between the occupied West Bank and Israel, and their catchment areas of wastewater and discharge outlets (see Figure 4)

No.	Given names of wadis (valleys – streams) by Palestinians	Given names of wadis (valleys – streams) by Israelis	Catchment area	Discharge in
1	Al-Moqatta	Kishon	North Jenin, and Jewish settlements	Mediterranean Sea
2	Abu Nar	Hadera	West Jenin, and Jewish settlements	Mediterranean Sea
3	Zomar	Alexander	Nablus, Tulkarm, and Jewish settlements	Mediterranean Sea
4	Al-Zuhur	Yarkon	South Qalqilia, North Salfit, and Jewish settlements	Mediterranean Sea
5	Suriq	Sarar	West Jerusalem, Beit Jala, North Bethlehem, and Jewish settlements	Mediterranean Sea
6	Al-Samen	Hebron or Besor	South of Hebron, and Jewish settlements	Mediterranean Sea
7	Al-Qilt (Al-Qelt)	Nahal	Ramallah, Al-Bireh, Jericho, and Jewish settlements	Jordan River
8	An-Nar	Kidron	Inside the Green Line that separates the West Bank from Israel, East Jerusalem, Bethlehem, Beit Sahour, and Jewish settlements	Dead Sea

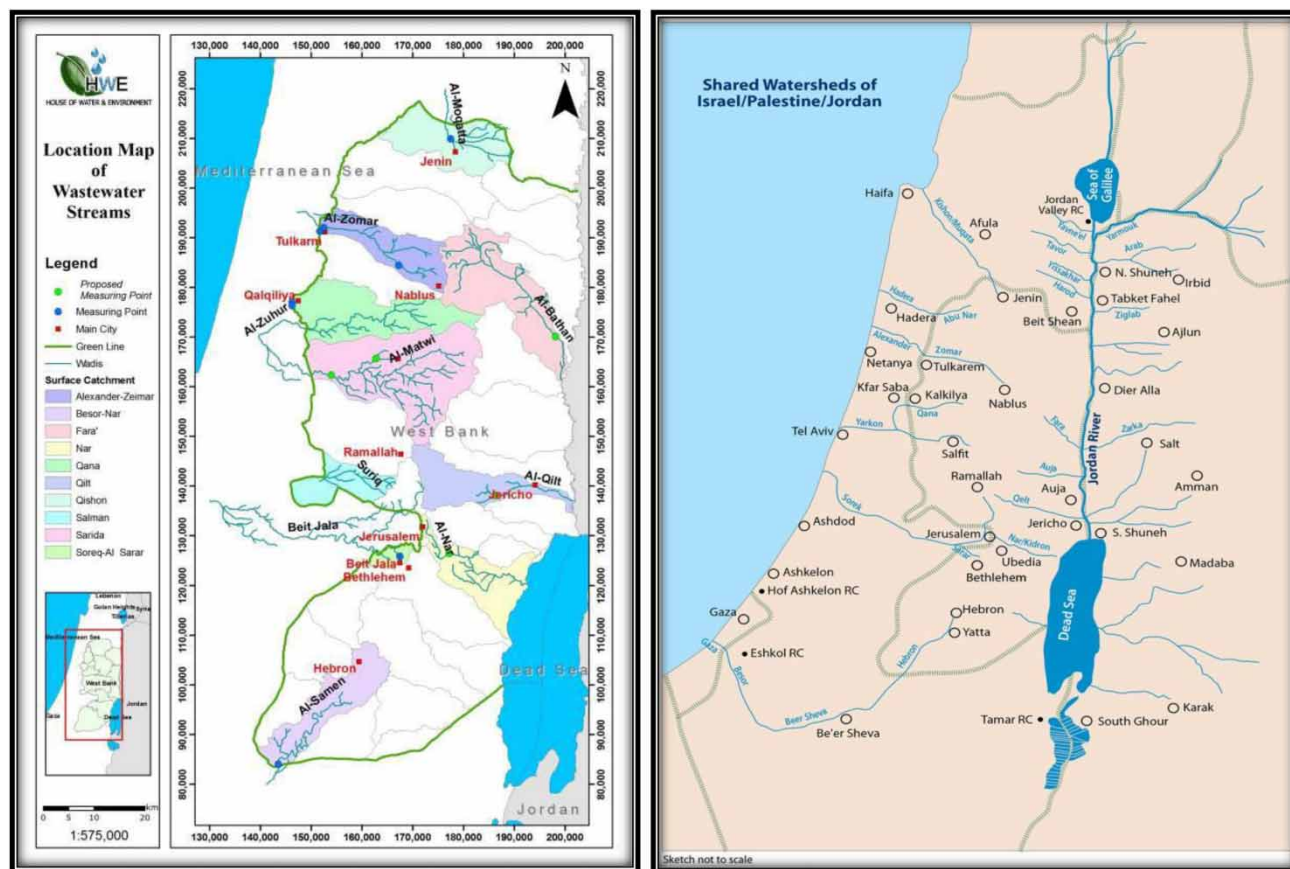


Figure 4 | Location map of the wastewater wadis (streams or valleys) and their catchment areas in the West Bank, Occupied Palestinian Territories (OPT), as well as their discharge outlets (after HWE 2012 (left) and EPME 2019 (right)).

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-Birah. This is in addition to another plant that is about to become operational in Tayaseer (Tubas governorate) and another two plants that are planned to be constructed in the regions of east Nablus (northern West Bank) and Hebron (southern 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 3 | Analyses of characteristics of raw wastewater flowing in some of the wadis in the West Bank, as well as for the partially treated wastewater in the wastewater treatment plant (WWTP) in Ramallah (data after HWE 2012)

Location: wadi of	pH	BOD mg/l	COD mg/l	BOD/COD	TSS mg/l	NH ₄ mg/l	PO ₄ mg/l	Cl mg/l	B mg/l	TDS mg/l	DO %	Temp. °C
Al-Moqatta	7.5	334	662	0.50	618	114	1.6	457	8.5	1,364	1.9	17
Zomar	7.6	282	503	0.56	3,567	82	1.5	775	6.4	1,737	1.4	20
Al-Zuhur	7.3	242	493	0.49	282	36	1.4	258	8.6	1,013	1.3	20
Suriq (Beit Jala)	7.8	469	900	0.52	626	114	2.1	423	5.6	1,438	1.9	20
Al-Samen	7.6	265	404	0.66	9,775	104	1.9	755	5.0	1,839	1.9	20
Ramallah (WWTP)	7.2	104	260	0.40	104	68	2.1	348	3.6	1,093	1.2	19
Ranges												
Range of averages for all	7.2–7.8	104–469	260–900	0.40–0.52	104–9,775	36–114	1.4–2.1	258–775	3.6–9.6	1,013–1,839	1.2–1.9	17–20
Range of minimums for all	6.8–7.3	43–248	120–800	0.31–0.36	42–7,080	23–92	0.16–0.48	250–500	<1.0–3.2	854–1,300	0.78–1.0	17–21
Range of maximums for all	7.7–8.1	286–589	480–960	0.60–0.61	166–11,710	48–168	3–6.3	300–1,325	7.4–101	1,192–2,510	2–3.7	20–22

West Bank (Table 2; Figure 4), as well as for the wastewater treated in the Ramallah Wastewater Treatment Plant (WWTP). The characteristics analyzed are alkalinity-acidity indicator (pH), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammonium (NH_4), phosphate (PO_4), 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 NH_4 values are generally higher than normal, whereas the normal value for domestic wastewater is around 40 mg/l (BMS 2013). However, the NH_4 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 PO_4 (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 2005).

The Cl ion in the wastewater (Table 3) shows higher values than normal, where normal is around 230 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 NH_4 . Meanwhile, the low TDS levels (750 mg/l and 1,500 mg/l) enabled phosphate removal with high efficiency (>99%), whereas the

efficiency of the phosphate removal dropped to 57.8% and 45.9%, respectively, for TDS levels of 3,000 and 4,500 mg/l. These results indicate that the presence of TDS in higher concentrations in wastewater makes wastewater's treatment more complicated.

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 2013; 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 (Arafteh 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 2018b; 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 reusing 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 ($\approx 14\%$ 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 = $291,000 \text{ m}^2 = 0.291 \text{ km}^2$. 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 reusing 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.

REFERENCES

- Abou-Elela, S. I., El-Sayed, M. M. H., El-Gendy, A. S. & Abou-Taleb, E. M. 2012 Comparative study of disinfection of secondary treated wastewater using chlorine, UV and ozone. *Journal of Applied Sciences Research* **10** (8), 5190–5197. Available from: https://www.researchgate.net/publication/260753626_Comparative_Study_of_Disinfection_of_Secondary_Treated_Wastewater_Using_Chlorine_UV_and_Ozone
- Abu Baker, M. S. M. 2007 *Wastewater Characteristics and the Impact of its Use in Irrigation on Soil. The Case of Faria Catchment*. Master thesis in water and environmental engineering, An-Najah National University, Nablus, Palestine. Available from: <https://repository.najah.edu/handle/20.500.11888/7580>
- Abu Foul, A. M., Alkhatib, R. Y., Abu Alqumboz, M. S. & Abunama, T. J. 2014 Effects of irrigation with treated wastewater on the physical properties and chemical composition of white corn. *IUG Journal of Natural Studies* **22** (1), 77–96. Available from: <https://journals.iugaza.edu.ps/index.php/IUGNS/article/view/308>
- Abu Madi, M. & Al-Sa'ed, R. 2009 Towards sustainable wastewater reuse in the Middle East and North Africa. *Journal of Sustainable Development* **2**, 1475–1481. Available from: <https://consiliencejournal.org/2009/02/17/towards-sustainable-wastewater-reuse-in-the-middle-east-and-north-africa/>
- Abumohor, E. 2012 Domestic wastewater treatment and its reuse for irrigating home gardens (case study). In *Conference of Water Crisis and Agricultural Development in Palestine*, May 21–22, 2012. Palestine Technical University. Kadoorie, Tulkarm, West Bank, Palestine. Available from: https://www.researchgate.net/publication/319307143_Water_Crisis_and_Agricultural_Development_in_Palestine_Conference_Proceedings_Book_PTUK_21-22_May_2012_Hilmi_S_Salem_Organizing_and_Scientific_Committees%19_Member_and_Author
- Abu Nada, Z. M. 2009 *Long Term Impact of Wastewater Irrigation on Soil and Crop Quality Parameters in Gaza Strip (Case Study: Beit Lahya Pilot Project)*. Master thesis in water resources engineering, Islamic University of Gaza, Gaza City, Gaza Strip, Palestine. Available from: <http://library.iugaza.edu.ps/thesis/87309.pdf>
- Abunada, Z. & Nassar, A. 2015 *Impacts of wastewater irrigation on soil and Alfalfa crop: case study from Gaza strip*. *Environmental Progress and Sustainable Energy* **34** (3), 648–654. Available from: <https://onlinelibrary.wiley.com/doi/abs/10.1002/ep.12034>
- Abu Seiba, I. 2016 *Agricultural Reuse of Treated Effluent and Stabilized Biosolids From Jericho Wastewater Treatment Plant*. Master thesis in water and environmental engineering, Birzeit University, Birzeit, Albireh-Ramallah, Palestine. Available from: <http://iews.birzeit.edu/sites/default/files/theses/Ibrahim%20Thesis%20%20MAM%201October2016.pdf>
- Abu Sultan, I. M. 2015 *Wastewater Reuse Tariff for Agriculture in the Gaza Strip*. Master thesis in civil engineering, Islamic University, Gaza City, Gaza Strip, Palestine. Available from: <http://library.iugaza.edu.ps/thesis/115267.pdf>
- Adegoke, A. A., Amoah, I. D., Stenström, T. A., Verbyla, M. E. & Mihelcic, J. R. 2018 *Epidemiological evidence and health risks associated with agricultural reuse of partially treated and untreated wastewater: a review*. *Frontiers in Public Health* **6**, 1–20. doi:10.3389/fpubh.2018.00337. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6292135/>
- Adilah, O. 2010 *Assessment of Wastewater Reuse Potential in Palestinian Rural Areas*. Master thesis in water and environmental engineering, Birzeit University, Birzeit, Albireh-Ramallah, Palestine. Available from: https://fada.birzeit.edu/bitstream/20.500.11889/1747/1/thesis_338.pdf
- Adwan, N. H. 2014 *Management of Water Resources for Agriculture Sector at Khanyounis Governorate Using*

- Modeling Approaches*. Master thesis in civil engineering, Islamic University of Gaza, Gaza City, Gaza Strip, Palestine. Available from: <http://library.iugaza.edu.ps/thesis/113702.pdf>
- Afifi, S. 2006 *Wastewater reuse status in the Gaza Strip, Palestine*. *International Journal of Environment and Pollution* **28** (1/2), 76–86. <https://doi.org/10.1504/IJEP.2006.010876> & available from: <https://www.inderscienceonline.com/doi/abs/10.1504/IJEP.2006.010876>
- AGI (Australian Government Initiative) 2020 *Water Quality Australia. Australian Guidelines for Water Recycling*. Available from: <https://www.waterquality.gov.au/guidelines/recycled-water> (accessed 25 October 2020).
- Agrafioti, E. & Diamadopoulos, E. 2012 *A strategic plan for reuse of treated municipal wastewater for crop irrigation on the Island of Crete*. *Agricultural Water Management* **105**, 57–64. Available from: <https://www.sciencedirect.com/science/article/pii/S0378377412000054>
- Ahsan, S., Arifur Rahman, M., Kaneco, S., Katsumata, H., Suzuki, T. & Ohta, K. 2005 *Effect of temperature on wastewater treatment with natural and waste materials*. *Clean Technologies and Environmental Policy* **7** (3), 198–202. doi:10.1007/s10098-005-0271-5. Available from: <https://www.infona.pl/resource/bwmeta1.element.springer-182f8945-def1-368b-bc22-115b3b7adf7c>
- Aiello, R., Cirelli, G. L. & Consoli, S. 2007 *Effects of reclaimed wastewater irrigation on soil and tomato fruits: a case study in Sicily (Italy)*. *Agricultural Water Management* **93** (1–2), 65–72. <https://www.sciencedirect.com/science/article/pii/S0378377407001692>
- Albasel, N. & Pratt, P. F. 1989 *Guidelines for molybdenum in irrigation waters*. *Journal of Environmental Quality* **18** (3), 259–264. Available from: <https://dl.sciencesocieties.org/publications/jeq/abstracts/18/3/JEQ0180030259?access=0&view=pdf>
- Al-Busaidi, A. & Ahmed, M. 2017 *Maximum use of treated wastewater in agriculture*. In: *Water Resources in Arid Areas: The Way Forward* (O. Abdalla, A. Kacimov, M. Chen, A. Al-Maktoumi, T. Al-Hosni & I. Clark, eds). Springer Water, Germany, pp. 371–382. https://doi.org/10.1007/978-3-319-51856-5_21 & available from: https://link.springer.com/chapter/10.1007/978-3-319-51856-5_21#citeas
- Alemu, T., Mekonnen, A. & Leta, S. 2019 *Integrated tannery wastewater treatment for effluent reuse for irrigation: encouraging water efficiency and sustainable development in developing countries*. *Journal of Water Process Engineering* **30**, 100514. <https://doi.org/10.1016/j.jwpe.2017.10.014> & available from: <https://www.sciencedirect.com/science/article/abs/pii/S2214714416303415>
- Alfarra, A. & Lubad, S. 2004 *Health Effect due to Poor Wastewater Treatments in Gaza Strip*. October 10, 2004. Available from: <https://ssrn.com/abstract=1457842> & <http://dx.doi.org/10.2139/ssrn.1457842>
- Alghobar, M. A. & Suresha, S. 2016 *Effect of wastewater irrigation on growth and yield of rice crop and uptake and accumulation of nutrient and heavy metals in soil*. *Applied Ecology and Environmental Sciences* **4** (3), 53–60. Available from: <http://pubs.sciepub.com/aees/4/3/1/>
- Alhousani, M., Alhafeth, M., Alsalmiya, M., Asaad, H. & Harb, J. 2012 *Using of phytoremediation to clean up contaminated soil in Wad Asamin Valley – Hebron District*. In *Conference of Water Crisis and Agricultural Development in Palestine*, May 21–22, 2012. Palestine Technical University. Kadoorie, Tulkarm, West Bank, Palestine. Available from: https://www.researchgate.net/publication/319307143_Water_Crisis_and_Agricultural_Development_in_Palestine_Conference_Proceedings_Book_PTUK_21-22_May_2012_Hilmi_S_Salem_Organizing_and_Scientific_Committees_Member_and_Author
- Al-Jabari, M. 2002 *Managing wastewater treatment in stone cutting industry in Palestine, basic physicochemical and engineering aspects*. In: *Role of Engineering Towards A Better Environment – RETEBE2*. Alexandria University, Alexandria, Egypt, December. Available from: https://www.researchgate.net/publication/275581859_Managing_Wastewater_Treatment_in_Stone_Cutting_Industry_in_Palestine_Basic_Physicochemical_and_Engineering_Aspects
- Al Khateeb, N. 2001 *Sociocultural acceptability of wastewater reuse in Palestine*. In: *Water Management in Islam* (N. I. Faruqi, A. K. Biswas & M. J. Bino, eds). United Nations University Press, Tokyo, New York, Paris. Available from: <https://unu.edu/publications/books/water-management-in-islam.html>
- Al-Khatib, N., Shoqair, J. A. H., Özerol, G. & Majaj, L. 2017 *Governing the reuse of treated wastewater in irrigation: the case study of Jericho, Palestine*. *International Journal of Global Environmental Issues* **16** (1–3), 135–148. <https://doi.org/10.1504/IJGENVI.2017.083424> & <https://eqa.unibo.it/article/view/6303>
- Al-Labadi, A. M. 1997 *Domestic water conservation best water practices in the Palestinian Territories (West Bank and Gaza Strip)*. Middle East Water Conservation Awareness Project: Best Practices Research. Academy for Educational Development, Regional Public Awareness and Education Program. Multinational Working Group on Water Resources. Environmental Education and Communication Project/ GreenCOM. Universal Dar for Engineering and Environment, Ramallah, Palestine.
- Almanaseer, N., Hindiyeh, M. & Al-Assaf, R. 2020 *Hydrological and environmental impact of wastewater treatment and reuse on Zarqa River Basin in Jordan*. *Environments* **7** (2), 1–14. doi:10.3390/environments7020014. Available from: <https://www.mdpi.com/2076-3298/7/2/14>
- Almas, A. A. M. & Scholz, M. 2006 *Potential for wastewater reuse in irrigation: case study from Aden (Yemen)*. *International Journal of Environmental Studies* **63** (2), 131–142. Available from: <https://www.tandfonline.com/doi/abs/10.1080/00207230500505569>
- Al-Sa'ed, R. 2007 *Sustainability of natural and mechanized aerated ponds for domestic and municipal wastewater treatment in Palestine*. *Water International* **32**, 310–324. Available from:

- <https://www.tandfonline.com/doi/abs/10.1080/02508060708692209>
- Al-Sa'ed, R. & Al-Hindi, A. M. 2013 Challenges of transboundary wastewater management for Palestinian communities along the Green Line – The Israeli-Palestinian border. In: *Shared Borders, Shared Waters: Israeli-Palestinian and Colorado River Basin Water Challenges*, 1st edn (S. B. Megdal, R. G. Varady & S. Eden, eds). CRC Press-Balkema, Taylor & Francis Group, pp. 203–220. Available from: <https://www.crcpress.com/Shared-Borders-Shared-Waters-Israeli-Palestinian-and-Colorado-River-Basin/Megdal-Varady-Eden/p/book/9780415662635>
- Alsahhar, A. M. 2015 *Impacts of Using Treated Wastewater in Irrigated Agriculture on Efficiency of Farming Resources and Activities in Almawasi, Khan Younis, Gaza Strip, Palestine*. Master thesis in science of water and environment, Al Azhar University–Gaza, Gaza City, Gaza Strip, Palestine. Available from: <http://www.alazhar.edu.ps/arabic/He/files/20102514.pdf>
- Al Salem, S. S. & Abouzaid, H. 2006 Wastewater reuse for agriculture: regional health perspective, review. *Eastern Mediterranean Health Journal* 12 (3-4), 446–458. Available from: <http://apps.who.int/iris/handle/10665/117107>; <https://www.semanticscholar.org/paper/Wastewater-reuse-for-agriculture%3A-regional-health-Salem-Abouzaid/2e74ca254d5bdb311020592894f7663abe9ddc08>
- Andrews, D. M., Robb, T., Elliott, H. & Watson, J. E. 2016 Impact of long-term wastewater irrigation on the physicochemical properties of humid region soils: 'The living filter' site case study. *Agricultural Water Management* 178, 239–247. Available from: <https://www.sciencedirect.com/science/article/pii/S0378377416303869>
- ANERA (American Near East Relief Agency) 2017 *Jenin, Palestine: Securing A Productive Future*. ANERA. Available from: <https://www.anera.org/stories/jenin-palestine-securing-productive-future/> (accessed 27 October 2020).
- Apostolidis, N., Hertle, C. & Young, R. 2011 *Water recycling in Australia*. *Water* 3, 869–881. doi:10.3390/w3030869. Available from: <https://www.mdpi.com/2073-4441/3/3/869>
- Arafat, W. 2012 *The Role of Public Awareness Towards Sustainable Use of Treated Wastewater in Agricultural Irrigation*. Master thesis in water and environmental science, Birzeit University, Berzeit, Albireh-Ramallah, West Bank, Palestine. Available from: http://www.pwa.ps/userfiles/file/%D8%A7%D9%84%D9%86%D9%85%D8%B3%D8%A7%D9%88%D9%8A/wesam_master%20thesis%20final2.pdf
- Arafat, L. Y. A. 2015 *Assessing the Potential of Wastewater Reuse in Palestine Using Business Processes Re-Engineering Coupled with Value Chain Analysis as A Tool: The Case of Nablus Governorate*. Master thesis in water and environmental engineering, An-Najah National University, Nabuls, West Bank, Palestine.
- Arafah, G. 2012 *Process Monitoring and Performance Evaluation of Existing Wastewater Treatment Plants in Palestinian Rural Areas/West Bank*. Master thesis in water and environmental science, Birzeit University, Berzeit, Albireh-Ramallah, West Bank, Palestine. Available from: <http://www.pwa.ps/userfiles/file/%D8%A7%D9%84%D9%86%D9%85%D8%B3%D8%A7%D9%88%D9%8A/Thesis%20Ghadir%20final.pdf>
- ARIJ (Applied Research Institute – Jerusalem) 2011 *Status of Environment in the Occupied Palestinian Territory. A Human Rights Based Approach*. ARIJ, Bethlehem, Palestine. Available from: http://www.arij.org/files/admin/SOER_2011_-_English_Summary.pdf
- ARIJ (Applied Research Institute – Jerusalem). 2007 *A Review of the Palestinian Agricultural Sector*. ARIJ, Bethlehem, Palestine. Available from: http://webcache.googleusercontent.com/search?q=cache:KKLqWBnh09MJ:www.arij.org/files/admin/2007_agriculture_sector_review_arabic_lr.pdf+&cd=1&hl=en&ct=clnk&gl=ps
- ARIJ (Applied Research Institute – Jerusalem) 2015 *Status of the Environment in the State of Palestine 2015*. ARIJ, Bethlehem, Palestine. Available from: https://www.arij.org/files/arijadmin/2016/SOER_2015_final.pdf
- Aryaeinejad, K., Brinkley, L., Budak, T., Chalphin, J., Hickel, S., Neusner, G., Obi, J. & Pecorella, K. 2015 *Water, Cooperation, and Peace: The Peacebuilding Significance of Joint Israeli-Palestinian Wastewater Projects*. American University School of International Service, Washington, DC, USA. Available from: <https://arava.org/wp-content/uploads/2015/05/Water-Cooperation-and-Peace-Practicum-Summer-2015.pdf>
- Asche, K. 2013 *The Effects of Chloride From Waste Water on the Environment*. Prepared by the Center for Small Towns, University of Minnesota, Morris. In collaboration with Morris Office of Sustainability. October 9, 2013. Available from: <https://morris.umn.edu/center-small-towns>
- Attaallah, K. S. 2013 *Effect of Irrigation with Reclaimed Wastewater on Soil Properties and Groundwater Quality in Zaiton Area, Gaza, Palestine*. Master thesis in water and the environment, Al-Azhar University–Gaza, Gaza City, Gaza Strip, Palestine. Available from: <http://library.iugaza.edu.ps/thesis/113702.pdf>
- Ayars, J. E. & Soppe, R. W. O. 2014 *Integrated on-farm drainage management for drainage water disposal*. *Irrigation and Drainage* 63 (1), 102–111. Available from: <https://onlinelibrary.wiley.com/doi/pdf/10.1002/ird.1771>
- Ayers, R. S. & Westcott, D. W. 1985 *Water Quality for Agriculture*. Food and Agriculture Organization (FAO) of the United Nations. FAO Irrigation and Drainage Paper, 29 Rev. 1. Available from: <http://www.fao.org/docrep/003/T0234E/T0234E00.htm>
- Barceló, D. & Petrovic, M. (eds) 2011 *Waste Water Treatment and Reuse in the Mediterranean Region. The Handbook of Environmental Chemistry*, Vol. 14, Springer, Heidelberg, Dordrecht, London, New York. Available from: <https://www.springer.com/gp/book/9783642182808>
- Barghouthi, Z. & Gerstetter, C. 2012 Climate change and opportunities to reduce its impacts on agriculture and water, and conflict risks in Palestine. In *Conference of Water Crisis*

- crop on the soil geochemical properties, fruit safety and crop productivity. *Agriculture, Ecosystems & Environment* **192**, 105–114. Available from: <https://www.sciencedirect.com/science/article/pii/S0167880914002047>
- Corradin, C. 2016 *Israel: Water as A Tool to Dominate Palestinians*. *Aljazeera*, June 23, 2016. Available from: <https://www.aljazeera.com/news/2016/06/israel-water-tool-dominate-palestinians-160619062531348.html> (accessed 1 September 2020).
- Daghara, A., Al-Khatib, I. A. & Al-Jabari, M. 2019 Quality of drinking water from springs in Palestine: West Bank as a case study. *Journal of Environmental and Public Health*. 2019, Article ID 8631732, 7 pages. <https://doi.org/10.1155/2019/8631732> & available from: <https://www.hindawi.com/journals/jep/2019/8631732/>
- Deverel, S. J., Goldberg, S. & Fujii, R. 2012 Chemistry of trace elements in soils and groundwater. In: *ASCE Manual and Reports on Engineering Practices. No. 71, Agricultural Salinity Assessment and Management*, 2nd edn (W. W. Walender & K. K. Tanji, eds). ASCE, Reston, VA, USA, pp. 89–137. Available from: https://www.ars.usda.gov/ARUserFiles/20360500/pdf_pubs/P2199.pdf
- DGIS-UNESCO-IHE 2016 *Programmatic Cooperation UNESCO-IHE Global Partnership for Water Education and Research*. Annual Report 2015. June 2016. UNESCO-IHE Institute for Water Education, Delft, The Netherlands. Available from: https://www.un-ihe.org/sites/default/files/dupc_annual_report_2015.pdf
- Dorji, U., Tenzin, U. M., Dorji, P., Wangchuk, U., Tshering, G., Dorji, C., Shon, H., Nyarko, K. B. & Phuntsho, S. 2019 Wastewater management in urban Bhutan: assessing the current practices and challenges. *Process Safety and Environmental Protection* **132**, 82–93. <https://doi.org/10.1016/j.psep.2019.09.023> & available from: <https://www.sciencedirect.com/science/article/abs/pii/S0957582019309838>
- Du, X., Wang, J., Jegatheesan, V. & Shi, G. 2018 Dissolved oxygen control in activated sludge process using a neural network-based adaptive PID algorithm. *Applied Sciences* **8**, 261. doi:10.3390/app8020261. Available from: <https://www.mdpi.com/2076-3417/8/2/261>
- EEA (European Environmental Agency) 2014 *Horizon 2020 Mediterranean Report – Annex 5: Palestine*. No 6/2014, ISSN 1725-2237. Luxembourg. Available from: <https://webcache.googleusercontent.com/search?q=cache:CvydVpNbd6oJ:https://www.eea.europa.eu/publications/horizon-2020-mediterranean-report/annex-5-palestine+&cd=3&hl=en&ct=clnk&gl=ps>
- Efron, S., Fischbach, J. R., Blum, I., Karimov, R. I. & Moore, M. 2019 The public health impacts of Gaza's water crisis. *Rand Health Quarterly* **8**, 10. PMID: PMC6557038. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6557038/>
- EJA (Environmental Justice Atlas) 2019 *Israel's Blockade and its Effect on Gaza's Water Supply and Sanitation, Palestine*. July 25, 2019. Available from: <https://ejatlas.org/conflict/gazas-water-supply-under-threat> (accessed 27 October 2020).
- Elgallal, M., Fletcher, L. & Evans, B. 2016 Assessment of potential risks associated with chemicals in wastewater used for irrigation in arid and semiarid zones: a review. *Agricultural Water Management* **177**, 419–431. Available from: <https://www.sciencedirect.com/science/article/pii/S0378377416303213>
- El Hamarneh, B. S. 2018 *The Feasibility of Reusing Treated Effluent From Rafah Wastewater Treatment Plant*. Master thesis in civil engineering, Islamic University of Gaza, Gaza City, Gaza Strip, Palestine. Available from: https://iugspace.iugaza.edu.ps/bitstream/handle/20.500.12358/19120/file_1.pdf?sequence=1&isAllowed=y
- EPA (Environmental Protection Agency, USA) 2014 *Effluent Standards*. Revisions to Articles 2 promulgated by EPA Order Huan-Shu-Shui-Tzu No. 1030005842, January 22, 2014. Available from: <http://extwprlegs1.fao.org/docs/pdf/tw164144.pdf>
- EPM (Emerson Process Management) 2009 *Dissolved Oxygen Measurement in Wastewater Treatment*. Application Data Sheet – ADS 4950-01/rev.G, January 2009, Irvine, CA, USA. Available from: <https://webcache.googleusercontent.com/search?q=cache:lXec8Q3exF4J:https://www.emerson.com/documents/automation/application-data-sheet-dissolved-oxygen-measurement-in-wastewater-treatment-rosemount-en-68468.pdf+&cd=11&hl=en&ct=clnk&gl=ps>
- EPME (EcoPeace Middle East) 2019 *Partnering Communities, Watersheds*. EPME. Available from: <http://ecopeaceme.org/projects/community-involvement/partnering-communities-watersheds/> (accessed 27 October 2019).
- EWASH (Emergency Water and Sanitation, and Hygiene) 2012 *Thirsting for Justice, Palestinian Rights to Water and Sanitation*. EWASH, March 27, 2012. Available from: <https://reliefweb.int/report/occupied-palestinian-territory/thirsting-justice-palestinian-rights-water-and-sanitation> (accessed 27 October 2020).
- EWASH (Emergency Water and Sanitation, and Hygiene) 2016 *EWASH Concerned by Water Restrictions in the West Bank Resulting From Israeli Discriminatory Policies*. EWASH, June 12, 2016. Available from: <https://reliefweb.int/report/occupied-palestinian-territory/ewash-concerned-water-restrictions-west-bank-resulting-israeli> (accessed 27 October 2020).
- Fahiminia, M., Ardanib, R., Hashemib, S. & Alizadehc, M. 2013 Wastewater treatment of stone cutting industries by coagulation process. *Archives of Hygiene Sciences* **2** (1), 16–22. Available from: <http://jhygiene.muq.ac.ir/article-1-9-en.html>
- Fatta, D. & Anayiotou, S. 2007 MEDAWARE project for wastewater reuse in the Mediterranean countries: an innovative compact biological wastewater treatment system for promoting wastewater reclamation in Cyprus. *Desalination* **211** (1–3), 34–47. Available from: <https://www.sciencedirect.com/science/article/pii/S0011916407001956>
- Fatta, D., Skoula, I., Moustakas, C., Mentzis, A., Papadopoulos, A., Loizidou, M., Salem, Z. & Hameed, K. 2004 Conference

- protection and restoration of the environment VII. In *Water Treatment and Management I*, 2004, Mykonos.
- Fatta-Kassinos, D., Kalavrouziotis, I. K., Koukoulakis, P. H. & Vasquez, M. I. 2011 The risks associated with wastewater reuse and xenobiotics in the agroecological environment. *Science of the Total Environment* **409**, 3555–3563. Available from: <https://www.sciencedirect.com/science/article/pii/S0048969710003074>
- Fatta-Kassinos, D., Dionysiou, D. D. & Kümmerer, K. (eds) 2016 *Wastewater Reuse and Current Challenges*. Springer, Germany. Available from: <https://www.springer.com/gp/book/9783319238913>
- Ganoulis, J. 2012 Risk analysis of wastewater reuse in agriculture. *International Journal of Recycling of Organic Waste in Agriculture* **1** (3), 9. <https://doi.org/10.1186/2251-7715-1-3> & available from: <https://link.springer.com/article/10.1186/2251-7715-1-3>
- Garwood, E. 2009 *Troubled Water – Palestinians Denied Fair Access to Water*. Israel–Occupied Palestinian Territories. Water as a human right. Amnesty International, London, UK. October 29, 2009. Available from: <https://blog.amnestyusa.org/middle-east/troubled-waters-palestinians-denied-fair-access-to-water/> (accessed 27 October 2020).
- Gearheart, R. M., Bahri, A. & Al-Hamaidi, M. 1994 *Wastewater Treatment and Reuse Strategy for Gaza and West Bank: Water and Wastewater Sector*. Palestinian Economic Council for Development and Reconstruction (PECDAR), Alarm, West Bank, Palestine.
- Ghosh, S. K. (Ed.). 2019 *Waste Water Recycling and Management*. 7th IconSWM ISWMAW 2017, Vol. 3. Springer, Germany. Available from: <https://www.springer.com/gp/book/9789811326189>
- GreenFacts 1998 *Scientific Facts on Boron*. Source document: IPCS (1998), Summary & Details: GreenFacts. <https://www.greenfacts.org/en/boron/> (accessed 27 October 2020).
- Grobela, A., Grosser, A., Kacprzak, M. & Kamizela, T. 2019 Sewage sludge processing and management in small and medium-sized municipal wastewater treatment plant-new technical solution. *Journal of Environmental Management* **234**, 90–96. <https://doi.org/10.1016/j.jenvman.2018.12.111> & available from: <https://www.sciencedirect.com/science/article/pii/S0301479718315391?via%3Dihub>
- GWP, GFMWS, MP, OECD, EUWI, and PWA (Global Water Partnership, Governance & Financing for the Mediterranean Water Sector, Med-Partnership Sweden, Organization for Economic Co-operation and Development, European Union Water Initiative, and Palestinian Water Authority) 2015 *Water Governance in Palestine Sector Reform to Include Private Sector Participation*. National Report 201. Available from: <https://www.gwp.org/governanceandfinancing>
- Haddad, M. 2012 Future trends in agricultural water management and institutional innovations in Palestine. In *Conference of Water Crisis and Agricultural Development in Palestine*, May 21–22, 2012. Palestine Technical University. Kadoorie, Tulkarm, West Bank, Palestine. Available from: https://www.researchgate.net/publication/319307143_Water_Crisis_and_Agricultural_Development_in_Palestine_Conference_Proceedings_Book_PTUK_21-22_May_2012_Hilmi_S_Salem_Organizing_and_Scientific_Committees_Member_and_Author
- Haddad, M., Mizyed, N. & Abdulah, A. 2009 *Performance of Hydroponic System as Decentralized Wastewater Treatment and Reuse for Rural Communities*. An-Najah National University. Available from: [https://staff-old.najah.edu/sites/default/files/performance-hydroponic-system-decentralized-wastewater-treatment-and-reuse-rural-communities\(2\).pdf](https://staff-old.najah.edu/sites/default/files/performance-hydroponic-system-decentralized-wastewater-treatment-and-reuse-rural-communities(2).pdf)
- Hammad, M. & Ghanem, M. 2016 Feasibility of protection zones for water resources in arid areas: case study; Ein sultan spring – Jericho, Palestine. *International Journal of Innovative Science, Engineering & Technology* **3**, 64–78. Available from: <http://ijiset.com/articlesv3/articlesv3s2.html> & http://ijiset.com/vol3/v3s2/IJISSET_V3_I2_10.pdf
- Hansen, P. 2012 *Encouraging the use of Treated Graywater in Palestine*. Palestine Economic Policy Research Institute (MAS), Jerusalem and Ramallah, Palestine. Available from: <http://www.mas.ps/files/server/20141911100557-1.pdf>
- Hilles, A. H., Al Hindi, A. I. & Abu Safieh, Y. A. 2014 Assessment of parasitic pollution in the coastal seawater of Gaza city. *Journal of Environmental Health Science and Engineering* **12** (1), 2–10. Available from: <https://europepmc.org/articles/PMC3924707?fromSearch=singleResult&fromQuery=Assessment+of+parasitic+pollution+in+the+coastal+seawater+of+Gaza+city>
- Hinkle, S. R. & Polette, D. J. 1999 *Arsenic in Groundwater of the Willamette Basin, Oregon*. Water-Resources Investigations Report 98–4205. US Department of the Interior, US Geological Survey. Available from: <https://pubs.er.usgs.gov/publication/wri984205>
- Holenda, B., Domokos, E., Rédey, Á. & Fazakas, J. 2008 Dissolved oxygen control of the activated sludge wastewater treatment process using model predictive control. *Computers and Chemical Engineering* **32**, 1270–1278. <https://doi.org/10.1016/j.compchemeng.2007.06.008> & available from: <https://www.sciencedirect.com/science/article/abs/pii/S009813540700155X?via%3Dihub>
- Houshia, O. J., Abueid, M., Daghlal, A., Zaid, M., Zaid, O., Al Ammor, J., Souqia, N., Alary, R. & Sholi, N. 2012 Characterization of grey water from country-side decentralized water treatment stations in northern Palestine. In *Conference of Water Crisis and Agricultural Development in Palestine*, May 21–22, 2012. Palestine Technical University. Kadoorie, Tulkarm, West Bank, Palestine. Available from: https://www.researchgate.net/publication/319307143_Water_Crisis_and_Agricultural_Development_in_Palestine_Conference_Proceedings_Book_PTUK_21-22_May_2012_Hilmi_S_Salem_Organizing_and_Scientific_Committees_Member_and_Author
- Hülsmann, S. & Ardakanian, R. (eds) 2018 *Managing Water, Soil and Waste Resources to Achieve Sustainable Development*

- Goals. *Monitoring and Implementation of Integrated Resources Management*. Springer, Germany. Available from: <https://www.springer.com/gp/book/9783319751627>
- HWE (House of Water and Environment) 2012 *Understanding and Analyzing the Current Israeli Wastewater Practices for Transboundary Wastewater Management from Palestinian – Final Report*. A project funded by the Austrian Development Cooperation through Palestinian Water Authority. Available from: http://webcache.googleusercontent.com/search?q=cache:kR3TLQk4yoEJ:procurement-notice.undp.org/view_file.cfm%3Fdoc_id%3D27195+&cd=2&hl=en&ct=clnk&gl=ps
- Idais, R. H. A. 2013 *Evaluation of Using Treated Wastewater on Soil Chemical Properties and Crop Productivity in Gaza Strip*. Master thesis in environmental management and monitoring, Islamic University of Gaza, Gaza, Palestine. Available from: <http://library.iugaza.edu.ps/thesis/109586.pdf>
- IMFA (Israel Ministry for Foreign Affairs) 1994 *Wastewater Treatment, August 1, 1994*. Available from: <https://mfa.gov.il/mfa/pressroom/1994/pages/wastewater%20treatment.aspx#:~:text=Effluent%20quality%20of%20Jerusalem's%20sewage,450%2D500%20BOD%2FSS.&text=Effluent%20regulations%2C%20promulgated%20in%201993,as%20a%20minimum%20baseline%20level> (accessed 27 October 2020).
- IMFA (Israel Ministry for Foreign Affairs) 1995 *The Israeli-Palestinian Interim Agreement-Annex III*. The Israeli-Palestinian Interim Agreement on the West Bank and the Gaza Strip Annex III – Protocol Concerning Civil Affairs. September 28, 1995. Available from: <https://mfa.gov.il/mfa/foreignpolicy/peace/guide/pages/the%20israeli-palestinian%20interim%20agreement%20-%20annex%20iii.aspx> (accessed October 27, 2020).
- IMoH (Israeli Ministry of Health) 2020 *Irrigation with Treated Wastewater – The Conditions for Utilizing Treated Wastewater in Agriculture*. Ministry of Health, Israel. Available from: https://www.health.gov.il/English/Topics/EnviroHealth/Reclaimed_Water/kolchim/Pages/watering.aspx (accessed 27 October 2020).
- Isaac, J. & Salem, H. S. 2007 Potential mechanisms for resolution of the water conflict between Palestinians and Israelis. In *International Conference on Sustainable Development and Management of Water Resources in Palestine*, August 27–29, 2007. UNESCO, Amman, Jordan. Available from: https://www.researchgate.net/publication/301548900_Potential_Mechanisms_for_Resolution_of_the_Water_Conflict_between_Palestinians_and_Israelis
- Isaac, J., Qumsieh, V. & Owewi, M. 1995 *Assessing the Pollution of the West Bank Water Resources*. Applied Research Institute – Jerusalem (ARIJ). Available from: http://www.arij.org/files/admin/1995_ASSESSING_THE_POLLUTION_OF_THE_WEST_BANK_WATER_RESOURCES.pdf
- Jaradat, D. 2016 *Reality and Challenges of Water Quality in Palestine: Focus on Regulations and Monitoring of Wastewater Treatment and Reclaimed Water Use*. Master thesis in water and environmental sciences, Birzeit University, Ramallah, Palestine. Available from: <http://webcache.googleusercontent.com/search?q=cache:DaSdKpBxeawJ:iew.birzeit.edu/sites/default/files/theses/Dalia%2520Thesis%2520final%252013%2520february%25202016.pdf+&cd=12&hl=en&ct=clnk&gl=ps>
- Jaramillo, M. F. & Restrepo, I. 2017 Wastewater reuse in agriculture: a review about its limitations and benefits. *Sustainability* 9 (1734). doi:10.3390/su9101734. Available from: <https://www.mdpi.com/2071-1050/9/10/1734/html>
- Jeuland, M. 2015 Challenges to wastewater reuse in the Middle East and North Africa. *Middle East Development Journal* 7 (1), 1–25. Available from: <https://www.tandfonline.com/doi/abs/10.1080/17938120.2015.1019293>
- Juanico, M. 1996 The performance of batch stabilization reservoirs for wastewater treatment, storage and reuse in Israel. *Water Science and Technology* 33 (10–11), 149–159. [https://doi.org/10.1016/0273-1223\(96\)00416-7](https://doi.org/10.1016/0273-1223(96)00416-7) & available from: <https://www.sciencedirect.com/science/article/abs/pii/S0273122396004167>
- JVL (Jewish Virtual Library) 2020 *Population of Jewish Settlements in the West Bank by Community (1999 – Present)*. As of 1 January 2020. Available from: <https://www.jewishvirtuallibrary.org/israeli-settlements-population-in-the-west-bank> (accessed October 27, 2020).
- Kaboosi, K. 2016 The assessment of treated wastewater quality and the effects of mid-term irrigation on soil physical and chemical properties (case study: Bandargaz-treated wastewater). *Applied Water Science* 7, 2385–2396. Available from: <https://link.springer.com/article/10.1007/s13201-016-0420-5>
- Kellis, M., Kalavrouziotis, I. K. & Gikas, P. 2013 Review of wastewater reuse in the Mediterranean countries, focusing on regulations and policies for municipal and industrial applications. *Global NEST Journal* 15 (3), 333–350. Available from: <https://journal.gnest.org/journal-paper/review-wastewater-reuse-mediterranean-countries-focusing-regulations-and-policies>
- Khaled, S. 2016 *Israel's Water Cuts: West Bank 'in Full Crisis Mode'*. Israel stands accused of using 'water as a weapon' as some West Bank homes have gone without water for a week. *Aljazeera*, June 23, 2016. Available from: <https://www.aljazeera.com/news/2016/06/israel-water-cuts-west-bank-full-crisis-mode-160620133005799.html> (accessed 27 October 2020).
- Lebdi, A. J. M. 2014 *Reuse of Treated Wastewater to Produce Legume Grains (Case Study Alfalfa and Vetch)*. Master thesis in plant production, An-Najah National University, Nablus, West Bank, Palestine. Available from: <https://scholar.najah.edu/sites/default/files/Ahmed%20Lebdi.pdf>
- Lenntech 2005 *Phosphorous Removal from Wastewater*. Available from: <https://www.lenntech.com/phosphorous-removal.htm#:~:text=Phosphorous%20in%20wastewater&text=The%20individual%20phosphorous%20contribution%20varies,biological%20metabolism%20without%20further%20breakdown> (accessed 27 October 2020).

- Lipchin, C. 2017 *Israel is First in Wastewater Reuse, but Palestinians are Last*. *The Jerusalem Post*. February 19, 2017. Available from: <https://www.jpost.com/Opinion/Israel-is-first-in-wastewater-reuse-but-Palestinians-are-last-482025> (accessed 27 October 2020).
- Maas, E. V. & Grattan, S. R. 1999 Crop yields as affected by salinity. *Agronomy* **38**, 55–110. Available from: <https://dl.sciencesocieties.org/publications/books/abstracts/agronomymonogra/agriculturaldra/55?access=0&view=pdf>
- Maaß, O. & Grundmann, P. 2016 Added-value from linking the value chains of wastewater treatment, crop production and bioenergy production: a case study on reusing wastewater and sludge in crop production in Braunschweig (Germany). *Resources, Conservation and Recycling* **107**, 195–211. Available from: <https://www.sciencedirect.com/science/article/pii/S0921344916300027>
- Mahmoud, N. 2012 Anaerobic treatment of strong domestic sewage in up flow reactors under fluctuating ambient temperature. In *Conference of Water Crisis and Agricultural Development in Palestine*, May 21–22, 2012. Palestine Technical University. Kadoorie, Tulkarm, West Bank, Palestine. Available from: https://www.researchgate.net/publication/319307143_Water_Crisis_and_Agricultural_Development_in_Palestine_Conference_Proceedings_Book_PTUK_21-22_May_2012_Hilmi_S_Salem_Organizing_and_Scientific_Committees_Member_and_Author
- Mahmoud, N. & Yasin, A. 2013 Analysis of wastewater management sector in Palestine. In: *Water in Palestine, The Birzeit Strategic Studies Forum* (R. Barakat & R. Heacock, eds). Ibrahim Abu-Lughod Institute of International Studies, Birzeit University, Birzeit, Palestine, pp. 103–115. Available from: https://www.researchgate.net/profile/Nidal_Mahmoud/publication/290816703_Analysis_of_wastewater_management_sector_in_Palestine/links/5765c07f08ae421c4489d4f4/Analysis-of-wastewater-management-sector-in-Palestine.pdf
- Mahmoud, N., Amarneh, M. N., Al-Sa'ed, R., Zeeman, G., Gijzen, H. & Lettinga, G. 2003 Sewage characterisation as a tool for the application of anaerobic treatment in Palestine. *Environmental Pollution* **126**, 115–122. Available from: <https://www.sciencedirect.com/science/article/pii/S0269749103001477>
- Malisa, R., Schwella, E. & Kidd, M. 2019 From government to governance: a quantitative transition analysis of urban wastewater management principles in Stellenbosch municipality. *Science of the Total Environment* **674**, 494–511. <https://doi.org/10.1016/j.scitotenv.2019.04.194> & available from: <https://www.sciencedirect.com/science/article/abs/pii/S0048969719317231?via%3Dihub>.
- Malki, M., Bouchaou, L., Mansir, I., Benlouali, H., Nghira, A. & Choukr-Allah, R. 2017 Wastewater treatment and reuse for irrigation as alternative resource for water safeguarding in Souss-Massa region, Morocco. *European Water* **59**, 365–371. Available from: [http://www.globaqua-project.eu/files/repository/20180619182737_Malki2017\(IAVCHA\).pdf](http://www.globaqua-project.eu/files/repository/20180619182737_Malki2017(IAVCHA).pdf)
- Man, R. d. 2016 *Transboundary Wastewater Governance – Options Based on an Uncertainty Perspective*. The Hague Institute of Global Justice, Working Paper 15, The Hague, The Netherlands, March 2016. Available from: <http://www.thehagueinstituteforglobaljustice.org/information-for-policy-makers/working-paper/transboundary-wastewater-governance-options-based-on-an-uncertainty-perspective/> (accessed 27 October 2020).
- Marin, P., Tal, S., Yeres, J. & Ringskog, K. 2017 *Water Management in Israel: Key Innovations and Lessons Learned for Water-Scarce Countries*. Water Global Practice, Technical Paper, World Bank Group, Washington, DC, USA. Available from: <https://webcache.googleusercontent.com/search?q=cache:X23F0-Hi66UJ:https://documents.worldbank.org/curated/en/657531504204943236/pdf/Water-management-in-Israel-key-innovations-and-lessons-learned-for-water-scarce-countries.pdf+&cd=13&hl=en&ct=clnk&gl=ps>
- McKee, M. 2012 Agriculture and the need for a water strategy in Palestine. In *Conference of Water Crisis and Agricultural Development in Palestine*, May 21–22, 2012. Palestine Technical University. Kadoorie, Tulkarm, West Bank, Palestine. Available from: https://www.researchgate.net/profile/Nidal_Mahmoud/publication/290816703_Analysis_of_wastewater_management_sector_in_Palestine/links/5765c07f08ae421c4489d4f4/Analysis-of-wastewater-management-sector-in-Palestine.pdf
- McNeill, L. S., Almasri, M. N. & Mizyed, N. 2009 A sustainable approach for reusing treated wastewater in agricultural irrigation in the West Bank – Palestine. *Desalination* **251** (1–3), 315–321. Available from: <https://www.sciencedirect.com/science/article/pii/S0011916409006018>
- MEDAWARE 2004 *Development of Tools and Guidelines for the Promotion of the Sustainable Urban Wastewater Treatment and Reuse in the Agricultural Production in the Mediterranean Countries*. Task 3: Analysis of Best Practices and Success Stories. March 2004. European Commission, Euro-Mediterranean Partnership. Available from: http://webcache.googleusercontent.com/search?q=cache:XMjdOb5DHUwJ:uest.ntua.gr/archive/medaware/reports/report_task3_part1.doc+&cd=1&hl=en&ct=clnk&gl=ps
- MEM (Middle East Monitor) 2018 *97% of Water in Gaza is Polluted*. March 21, 2018. Available from: <https://www.middleeastmonitor.com/20180321-97-of-water-in-gaza-is-polluted/> (accessed 27 October 2020).
- MEM (Middle East Monitor) 2020 *463,000 Jewish Settlers Live in 150 West Bank Settlements*. February 4, 2020. Available from: <https://www.middleeastmonitor.com/20200204-463000-jewish-settlers-live-in-150-west-bank-settlements/> (accessed 27 October 2020).
- Miller-Robbie, L., Ramaswami, A. & Amerasinghe, P. 2017 *Wastewater treatment and reuse in urban agriculture: exploring the food, energy, water, and health nexus in Hyderabad, India*. *Environmental Research Letters* **12**, 075005. Online Publication (July 4, 2017). Available from: <http://iopscience.iop.org/article/10.1088/1748-9326/aa6bfe>

- Mizyed, N. 2012 Evaluation of treated wastewater reuse regulations and standards in Palestine. In *Conference of Water Crisis and Agricultural Development in Palestine*, May 21–22, 2012. Palestine Technical University. Kadoorie, Tulkarm, West Bank, Palestine. Available from: https://www.researchgate.net/profile/Nidal_Mahmoud/publication/290816703_Analysis_of_wastewater_management_sector_in_Palestine/links/5765c07f08ae421c4489d4f4/Analysis-of-wastewater-management-sector-in-Palestine.pdf
- Mogheir, Y. & Lubbad, I. 2008 Development of monitoring and evaluation system for wastewater issues in Palestine. *International Journal of Environment and Pollution* **33** (1), 54–71. Available from: <https://www.inderscienceonline.com/doi/abs/10.1504/IJEP.2008.018464>
- Mogheir, Y., Abu Hujair, T., Zomlot, Z., Ahmed, A. & Fatta, D. 2005 Treated wastewater reuse in Palestine. In *International Conference: Water: Values and Rights*, May 2–4, 2005, Ramallah, Palestine. Available from: <http://www.alazhar.edu.ps/arabic/Ewi/Researches/Abstracts-conference.pdf>
- Moretti, M., Van Passel, S., Camposo, S., Pedrero, F., Dogot, T., Lebailly, P. & Vivaldi, G. A. 2019 Modelling environmental impacts of treated municipal wastewater reuse for tree crops irrigation in the Mediterranean coastal region. *Science of the Total Environment* **660**, 1513–1521. <https://doi.org/10.1016/j.scitotenv.2019.01.043> & available from: <https://www.sciencedirect.com/science/article/abs/pii/S004896971930049X>
- Mouhanni, H., Bendou, A. & Er-Raki, S. 2011 Disinfection of treated wastewater and its reuse in the irrigation of golf grass: the case of plant M'zar Agadir-Morocco. *Water* **3**, 1128–1138. Available from: [doi:10.3390/w3041128](https://doi.org/10.3390/w3041128). <https://www.mdpi.com/2073-4441/3/4/1128>
- Moussaoui, T. E., Wahbi, S., Mandi, L., Masi, S. & Ouazzani, N. 2019 Reuse study of sustainable wastewater in agroforestry domain of Marrakesh city. *Journal of the Saudi Society of Agricultural Sciences* **18**, 288–293. <https://doi.org/10.1016/j.jssas.2017.08.004> & available from: <https://www.sciencedirect.com/science/article/pii/S1658077X17301546>
- Mu'azu, N. D., Abubakar, I. R. & Blaisi, N. I. 2020 Public acceptability of treated wastewater reuse in Saudi Arabia: implications for water management policy. *Science of the Total Environment* **721**, 137659. <https://doi.org/10.1016/j.scitotenv.2020.137659> & available from: <https://www.sciencedirect.com/science/article/abs/pii/S0048969720311700>
- Mubarak, S. 2004 *On the Sustainability of Rural Wastewater Management Systems in Ramallah/Al-Bireh District*. Master thesis in water engineering, Birzeit University, Birzeit, Albireh-Ramallah, Palestine. Available from: https://fada.birzeit.edu/jspui/bitstream/20.500.11889/1722/1/thesis_26112015_115850.pdf
- Murray, A. & Ray, I. 2010 Wastewater for agriculture: a reuse-oriented planning model and its application in peri-urban China. *Water Research* **44**, 1667–1679. Available from: http://southasia.berkeley.edu/sites/default/files/shared/events/21st_Century_Indian_City/IRay_Wastewater_for_agriculture.pdf
- Muyen, Z., Moore, G. A. & Wrigley, R. J. 2011 Soil salinity and sodicity effects of wastewater irrigation in South East Australia. *Agricultural Water Management* **99** (1), 33–41. Available from: <https://trove.nla.gov.au/work/156754015?q&versionId=170891153>
- Myers, B. J., Bond, W. J., Benyon, R. G., Falkiner, R. A., Polglase, P. J., Smith, C. J., Snow, V. O. & Theiveyanathan, S. 1999 *Sustainable Effluent-Irrigated Plantations: An Australian Guideline* (1999). An Australian Guideline CSIRO Forestry and Forest Products, Melbourne, Australia. Available from: https://books.google.ps/books/about/Sustainable_Effluent_irrigated_Plantatio.html?id=iarEPQAACAAJ&redir_esc=y
- Nashashibi, M. 1995 *Wastewater Treatment Strategies in Palestine*. Master Thesis, IHE Delft, the Netherlands.
- Nashashibi, M. & van Duijl, L. A. 1995 Wastewater characteristics in Palestine. *Water Science and Technology* **32** (11), 65–75. Available from: <https://www.sciencedirect.com/science/article/abs/pii/0273122396001199>
- NGESTP (North Gaza Emergency Sewage Treatment Project) 2013 *Effluent Recovery and Reuse System and Remediation Works*. Supplementary Environmental and Social Impact Assessment (SESIA). Final Report. April 2013. Available from: <http://www.pwa.ps/userfiles/file/%D8%AA%D9%82%D8%A7%D8%B1%D9%8A%D8%B1/Final%20SESIA%20NGESTP%2015042013.pdf>
- Nour, N. 2020 Transforming agriculture through investment and innovation. *This Week In Palestine*, Issue 267, July 2020, 60–65. Available from: <https://webcache.googleusercontent.com/search?q=cache:BdYnqHEfn6J:https://www.thisweekinpalestine.com/author/nassim-nour/+&cd=2&hl=en&ct=clnk&gl=ps>
- OCHA (Office for the Coordination of Humanitarian Affairs, UN) 2018 *Study Warns Water Sanitation Crisis in Gaza may Cause Disease Outbreak and Possible Epidemic*. November 16, 2018. Available from: <https://www.ochaopt.org/content/study-warns-water-sanitation-crisis-gaza-may-cause-disease-outbreak-and-possible-epidemic> (accessed 27 October 2020).
- Omar, R. 2015 *Sludge and Wastewater Reuse for Crop Production and the Impact on Plant Morphology (Case Study: Sheikh Ejleen Treatment Plant)*. Master thesis in water and environment, Al-Azhar University–Gaza, Gaza City, Gaza Strip, Palestine. Available from: www.alazhar.edu.ps/Library/aattachedFile.asp?id_no=0048595
- Omer, M. 2015 *Israeli Jets Destroying Gaza Water and Sewerage Systems: Officials*. Health crisis looming as Israeli attacks accused of targeting already fragile water and sewage infrastructure. *Middle East Eye (MEE)*, February 12, 2015. Available from: <https://www.middleeasteye.net/news/israeli-jets-destroying-gaza-water-and-sewerage-systems-officials> (accessed 27 October 2020).
- Oort, F. V., Thiry, M., Foy, E., Fujisaki, K., Delarue, G., Dairon, R. & Jongmans, T. 2017 *Impacts of one century of wastewater*

- discharge on soil transformation through ferrololysis and related metal pollutant distributions. *Science of the Total Environment* **590–591**, 1–13. Available from: <https://www.sciencedirect.com/science/article/pii/S0048969717305594>
- Park, M. & Snyder, S. A. 2020 Attenuation of contaminants of emerging concerns by nanofiltration membrane: Rejection mechanism and application in water reuse. In: *Contaminants of Emerging Concern in Water and Wastewater. Advanced Treatment Process* (A. J. Hernández-Maldonado & L. Blaney, eds). Elsevier, Amsterdam, The Netherlands, pp. 177–206. <https://doi.org/10.1016/B978-0-12-813561-7.00006-7> & available from: <https://www.sciencedirect.com/science/article/pii/B9780128135617000067?via%3Dihub> and <https://www.sciencedirect.com/book/9780128135617/contaminants-of-emerging-concern-in-water-and-wastewater>.
- PCHR (Palestinian Centre for Human Rights) 2019 *PCHR Organizes Workshop Titled as 'Environmental and Health Risks of Wastewater Crisis in Northern Gaza Strip'*. Ref: 14/2019. Available from: <https://www.pchrgaza.org/en/?p=12217> (accessed October 27, 2020).
- Pescod, M. B. 1992 Wastewater treatment and use in agriculture, FAO Irrigation and Drainage Paper 47. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. Available from: <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.470.8910&rep=rep1&type=pdf>
- PNN (Palestine News Network) 2018 *World Bank: North Gaza Wastewater Treatment Plant Finally Complete*. March 14, 2018. Available from: <http://english.pnn.ps/2018/03/14/world-bank-north-gaza-wastewater-treatment-plant-finally-complete/> (accessed 27 October 2020).
- Purwono, R. A., Hibbaan, M. & Budihardjo, M. A. 2017 Ammonia-nitrogen (NH₃-N) and ammonium-nitrogen (NH₄⁺-N) equilibrium on the process of removing nitrogen by using tubular plastic media. *Journal of Materials and Environmental Sciences* **8** (S), 4915–4922. Available from: https://webcache.googleusercontent.com/search?q=cache:A03IXakedk4J:https://www.jmaterenvironsci.com/Document/vol8/vol8_NS/522-JMES-2876-Purwono.pdf+&cd=1&hl=en&ct=clnk&gl=ps
- PWA (Palestinian Water Authority) 1996 *Wastewater Reuse in Agriculture in Gaza Governorates, Gaza*. PWA, Ramallah, Palestine.
- PWA (Palestinian Water Authority) 2006 *Water Sector Review: West Bank and Gaza. Report*. PWA, Gaza Office, Ramallah Office, Palestine. October 2006. Available from: http://www.lacs.ps/documentsShow.aspx?ATT_ID=733
- PWA (Palestinian Water Authority) 2011 *The Gaza Emergency Technical Assistance Programme (GETAP) on Water Supply to the Gaza Strip*. Component 1 – The Comparative Study of Options for an Additional Supply of Water for the Gaza Strip (CSO-G). The Updated Final Report [Report 7 of the CSO-G], PWA, Ramallah, Palestine. July 31, 2011. Available from: <https://www.humanitarianresponse.info/sites/www.humanitarianresponse.info/files/documents/files/PWA%20-%20CSO-G%20updated%20Final.pdf>
- PWA (Palestinian Water Authority) 2012a *Palestinian Water Sector: Status Summary Report September 2012*. In preparation for the Meeting of the Ad Hoc Liaison Committee (AHLIC), September 23, 2012, New York, NY, USA. PWA, Ramallah, Palestine. Available from: <https://reliefweb.int/sites/reliefweb.int/files/resources/Water%20Summary%20for%20AHLIC%20report%20FINAL.pdf>
- PWA (Palestinian Water Authority) 2012b *National Water and Wastewater Strategy for Palestine*. Toward Building A Palestinian State from Water Perspective. Full Report and Annexes – Version 2, December (2012), PWA, Ramallah, Palestine. Available from: http://procurement-notices.undp.org/view_file.cfm?doc_id=27192
- PWA (Palestinian Water Authority) 2013a *Status Report of Water Resources in the Occupied State of Palestine-2012*. Year of Flood Water Harvesting. PWA, Ramallah, Palestine. October (2013). Available from: <http://www.pwa.ps/userfiles/file/%D8%AA%D9%82%D8%A7%D8%B1%D9%8A%D8%B1/%D8%AA%D8%B5%D9%86%D9%8A%D9%81%201/WR%20STATUS%20Report-final%20draft%202014-04-01.pdf>
- PWA (Palestinian Water Authority) 2013b *National Water and Wastewater Strategy for Palestine*. Toward Building A Palestinian State from Water Perspective. Full Report and Annexes – Version 12, July (2013). PWA, Ramallah, Palestine. Available from: <http://www.pwa.ps/userfiles/server/%D8%A7%D8%B3%D8%AA%D8%B1%D8%A7%D8%AA%D8%AC%D9%8A%D8%A7%D8%AA/Eng/Water%20Strategy%20English%20Final.pdf>
- PWA (Palestinian Water Authority) 2013c *Water Sector Reform Plan 2014–2016 (Final)*. GZ-Emergency Capacity Building Project to the Palestinian Water Authority: Technical, Planning and Advisory Team in the Water and Sanitation Sector (TPAT). PWA, Ramallah, Palestine. December (2013). Available from: <http://www.pwa.ps/userfiles/file/%D8%AA%D9%82%D8%A7%D8%B1%D9%8A%D8%B1/%D8%AA%D8%B5%D9%86%D9%8A%D9%81%201/FinalReformPlan2014-16PWA.pdf>
- PWA (Palestinian Water Authority) 2013d *Effluent Recovery and Reuse System and Remediation Works. Supplementary Environmental and Social Impact Assessment (SESIA)*. North Gaza Emergency Sewage Treatment Project – NGESTP. Final Report. PWA, Ramallah, Palestine. April 2013. Available from: <http://www.pwa.ps/userfiles/file/%D8%AA%D9%82%D8%A7%D8%B1%D9%8A%D8%B1/Final%20SESIA%20NGESTP%2015042013.pdf>
- PWA (Palestinian Water Authority) 2015 *2014 Water Resources Status Summary Report /Gaza Strip Water Resources Directorate (2015)*. PWA, Ramallah, Palestine. Available from: <http://www.pwa.ps/userfiles/file/%D8%AA%D9%82%D8%A7%D8%B1%D9%8A%D8%B1/Status%20WR%20Report%202014.pdf>
- Qadir, M., Schubert, S., Ghafoor, A. & Murtaza, G. 2001 *Amelioration strategies for sodic soils: a review*. *Land Degradation and Development* **12**, 357–386. <https://doi.org/10.1002/ldr.458> & available from: <https://onlinelibrary.wiley.com/doi/abs/10.1002/ldr.458>.

- Ramahi, S. 2013 *The Health Risks Posed by Water Pollution in the Gaza Strip*. Middle East Monitor (MEM), January 2023. Available from: <https://webcache.googleusercontent.com/search?q=cache:CxdrhHZatxsJ:https://palestina-komitee.nl/wp-content/uploads/2017/11/The-Health-Risks-posed-by-Water-Pollution-in-the-Gaza-Strip-MEMO-January-2013.pdf+&cd=9&hl=en&ct=clnk&gl=ps>
- Reliefweb 2019 *Wastewater Management Project Mitigates Health and Environmental Threats in the West Bank and Gaza*. October 9, 2019. Available from: <https://reliefweb.int/report/occupied-palestinian-territory/wastewater-management-project-mitigates-health> (accessed 27 October 2020).
- Reliefweb 2020 *A US\$ 10 Million Grant From the World Bank to Sustain Palestinian Wastewater Treatment Services*. June 13, 2020. Available from: <https://reliefweb.int/report/occupied-palestinian-territory/us-10-million-grant-world-bank-sustain-palestinian-wastewater> (accessed 27 October 2020).
- Reuters 2016 *Water Shortage Threatens Date Palm Sector in Palestine*. Reuters, Republished in *Palestine Economy Portal*, September 1, 2019. Available from: <https://www.palestineconomy.ps/en/Article/374/Water-Shortage-Threatens-Date-Palm-Sector-in-Palestine> (accessed 27 October 2020).
- Richard, C. 2016 State of fresh water resources. In: *The United Nations World Water Development Report 2016: Water and Jobs*. The Global Perspective on Water. UNESCO, Paris, France, 15–29. Available from: <https://www.unescap.org/sites/default/files/United-Nations-World-Water-Development-Report-2016.pdf>
- Rinat, Z. 2015 Israeli wastewater policy continues to pay off. *Haaretz*, March 23, 2015. Available from: <https://www.haaretz.com/life/.premium-israeli-wastewater-policy-continues-to-pay-off-1.5341228> (accessed 27 October 2020).
- Rouyer, A. R. 1999 The water accords of Oslo II: averting a looming disaster. *Middle East Policy Council* VII (1). Available from: <https://mepc.org/journal/water-accords-oslo-ii-averting-looming-disaster> (accessed October 27, 2020).
- Royal Haskoning DHV 2013 *Integrated Trans-Boundary Regional NGO Master Plan for the Lower Jordan River Basin*. Inception Report. FoEME (Friends of the Earth Middle East), SIWI (Stockholm International Water Institute), GNF (Global Nature Fund), and EU – SIWMP, January (2013). Available from: http://ecopeace.org/uploads/13904848300%5E%5E~RHDHV_Inception_Report_January_2013.pdf
- Ruiz-Rosa, I., García-Rodríguez, F. J. & Antonova, N. 2020 Developing a methodology to recover the cost of wastewater reuse: a proposal based on the polluter pays principle. *Utilities Policy* 65, 101067. <https://doi.org/10.1016/j.jup.2020.101067> & available from: <https://www.sciencedirect.com/science/article/abs/pii/S095717872030062X>.
- Rusan, M. J. M., Hinnawi, S. & Rousan, L. 2007 Long term effect of wastewater irrigation of forage crops on soil and plant quality parameters. *Desalination* 215 (1–3), 143–152. Available from: <https://www.sciencedirect.com/science/article/pii/S0011916407004055>
- Salem, H. S. 2011a Social, environmental and security impacts of climate change on the Eastern Mediterranean. In: *Coping with Global Environmental Change, Disasters and Security – Threats, Challenges, Vulnerabilities and Risks*. Hexagon Series on Human and Environmental Security and Peace (H. G. Brauch, ÚO Spring, C. Mesjasz, J. Grin, P. Kameri-Mbote, B. Chourou, P. Dunay & J. Birkmann, eds). Springer, Berlin, Heidelberg, New York, pp. 421–445. Available from: https://link.springer.com/chapter/10.1007/978-3-642-17776-7_23 and https://www.researchgate.net/publication/321307405_Social_Environmental_and_Security_Impacts_of_Climate_Change_on_the_Eastern_Mediterranean
- Salem, H. S. 2011b Pollution of coastal areas on the Mediterranean Sea: The Gaza Strip as a case study – A real environmental threat and a big challenge. *The Working Meeting of the MIRA Project Expert Group on Decontamination of the Mediterranean (WP7) – Mediterranean Innovation and Research Cooperation Action (MIRA)*, Casablanca, Morocco, November 27–30, 2011. Available from: https://www.researchgate.net/publication/319391700_Pollution_of_Coastal_Areas_on_the_Mediterranean_Sea_The_Gaza_Strip_As_a_Case_Study_-_A_Real_Environmental_Threat_and_a_Big_Challenge
- Salem, H. S. 2019a Agriculture status and women's role in agriculture production and rural transformation in the Occupied Palestinian Territories. *Journal of Agriculture and Crops* 5, 132–150. [https://doi.org/10.32861/jac.5\(8\)132.150](https://doi.org/10.32861/jac.5(8)132.150) & available from: <https://arpgweb.com/journal/journal/14> and https://www.researchgate.net/publication/334770801_Agriculture_Status_and_Women's_Role_in_Agriculture_Production_and_Rural_Transformation_in_the_Occupied_Palestinian_Territories_Journal_of_Agriculture_and_Crops_2019_58_132-150.
- Salem, H. S. 2019b No sustainable development in the lack of environmental justice. *Environmental Justice* 12 (3), 140–157. doi:10.1089/env.2018.0040. Available from: <https://www.liebertpub.com/doi/10.1089/env.2018.0040> and https://www.researchgate.net/publication/330847246_No_Sustainable_Development_in_the_Lack_of_Environmental_Justice.
- Salem, H. S. 2020 Geopolitical challenges, complexities, and future uncertainties in the Occupied Palestinian Territories: Land and population's perspectives. *New Middle Eastern Studies* 10 (1), 45–82. Available from: <https://journals.le.ac.uk/ojs1/index.php/nmes/article/view/3639> & https://www.researchgate.net/publication/344474119_Geopolitical_Challenges_Complexities_and_Future_Uncertainties_in_the_Occupied_Palestinian_Territories_Land_and_Population's_Perspectives
- Salem, H. S. (Ed. & co-author) & ARIJ's Research Team 2007 *Status of the Environment in the Occupied Palestinian Territories*. Applied Research Institute – Jerusalem (ARIJ), Bethlehem, Palestine. Available from: https://www.researchgate.net/publication/301608421_Status_of_the_Environment_in_the_Occupied_Palestinian_Territory

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- Salem, H. S. & Isaac, J. 2007 Water agreements between Israel and Palestine and the region's water argumentations between policies, anxieties and sustainable development. In *The International Conference on Green Wars: Environment Between Conflict and Cooperation in the Middle East and North Africa (MENA)*, November 2–3, 2007, Beirut, Lebanon. Available from: https://www.researchgate.net/publication/242313866_Water_Agreements_between_Israel_and_Palestine_and_the_Region's_Water_Argumentations_between_Policies_Anxiety_and_Unsustainable_Development
- Samhan, S. 2012 Wastewater sector status in Palestine and reuse opportunities. In *Conference of Water Crisis and Agricultural Development in Palestine*, May 21–22, 2012. Palestine Technical University. Kadoorie, Tulkarm, West Bank, Palestine. Available from: https://www.researchgate.net/publication/319307143_Water_Crisis_and_Agricultural_Development_in_Palestine_Conference_Proceedings_Book_PTUK_21-22_May_2012_Hilmi_S_Salem_Organizing_and_Scientific_Committees_Member_and_Author
- Samhan, S., Al-Sa'ed, R., Assaf, K., Friese, K., Afferden, M., Muller, R., Tumpling, W., Ghanem, M., Ali, W. & Zimmo, O. 2011 Wastewater management overview in the Occupied Palestinian Territory. In: *Waste Water Treatment and Reuse in the Mediterranean Region, 14 (Handbook of Environmental Chemistry)* (D. Barceló & M. Petrovic, eds). Springer, Berlin, Heidelberg, pp. 229–248. Available from: <https://www.springerprofessional.de/en/waste-water-treatment-and-reuse-in-the-mediterranean-region/1417104>
- Samudro, G. & Mangkoedihardjo, S. 2010 Review on BOD, COD and BOD/COD ratio: a triangle zone for toxic, biodegradable and stable levels. *International Journal of Academic Research* 2 (4), 235–239. Available from: <http://connection.ebscohost.com/c/articles/52917635/review-bod-cod-bod-cod-ratio-triangle-zone-toxic-biodegradable-stable-levels>
- Sawalha, H., Alsharabaty, R., Sarsour, S. & Al-Jabari, M. 2019 Wastewater from leather tanning and processing in Palestine: characterization and management aspects. *Journal of Environmental Management* 251, 109596. <https://doi.org/10.1016/j.jenvman.2019.109596> & available from: <https://www.sciencedirect.com/science/article/pii/S0301479719313143?via%3Dihub>
- Sawyer, C. N., McCarty, P. L. & Parkin, G. F. 2003 *Chemistry for Environmental Engineering and Science*, 5th edn. McGraw-Hill, New York, USA. Available from: <https://archive.org/details/SawyerC.AndMcCartyP.AndParkinG.2003ChemistryForEnvironmentalEngineeringAndScience>
- Sbeih, M. Y. 1996 Recycling of treated water in Palestine: urgency, obstacles and experience to date. *Desalination* 106 (1–3), 165–178. Available from: <https://www.sciencedirect.com/science/article/pii/S0011916496001063>
- Sbeih, M. Y. 2007 The role of small scale wastewater treatment in the development of water resources in West Bank of Palestine. In: *Water Saving in Mediterranean Agriculture and Future Research Needs*, Vol. 2 (N. Lamaddalena, C. Bogliotti, M. Todorovic & A. Scardigno, eds). CIHEAM, Options Méditerranéennes: Série, B. Etudes et Recherches, Bari, pp. 149–161. Available from: <http://om.ciheam.org/article.php?IDPDF=800184>
- Schellenberg, T., Subramanian, V., Ganeshan, G., Tompkins, D. & Pradeep, R. 2020 Wastewater discharge standards in the evolving context of urban sustainability–The case of India. *Frontiers in Environmental Sciences*. doi:10.3389/fenvs.2020.00030. Available from: https://www.frontiersin.org/articles/10.3389/fenvs.2020.00030/full?&utm_source=Email_to_authors_&utm_medium=Email&utm_content=T1_11.5e1_author&utm_campaign=Email_publication&field=&journalName=Frontiers_in_Environmental_Science&id=483657
- Seder, N. & Abdel-Jabbar, S. 2011 *Safe use of Treated Wastewater in Agriculture: Jordan Case Study*. Arab Countries Water Utilities Association (ACWUA). December 2011. Available from: http://www.ais.unwater.org/ais/pluginfile.php/356/mod_page/content/128/Jordan_-_Case_Study%28new%29.pdf
- Shakir, E., Zahraw, Z. & Al-Obaidy, A. H. M. J. 2017 Environmental and health risks associated with reuse of wastewater for irrigation. *Egyptian Journal of Petroleum* 26, 95–102. <https://doi.org/10.1016/j.ejpe.2016.01.003> & available from: <https://www.sciencedirect.com/science/article/pii/S111006211530115X>
- Sharma, D. P. & Tyagi, N. K. 2004 On-farm management of saline drainage water in arid and semi-arid regions. *Irrigation and Drainage* 53 (1), 87–103. Available from: <https://onlinelibrary.wiley.com/doi/abs/10.1002/ird.115>
- Shay, G. 1990 *Saline Agriculture: Salt-Tolerant Plants for Developing Countries*. The National Academies Press, Washington, DC, USA. <https://doi.org/10.17226/1489> & available from: <https://www.nap.edu/catalog/1489/saline-agriculture-salt-tolerant-plants-for-developing-countries>
- Shomar, B. 2013 Water resources, water quality and human health in regions of extreme stress: Middle East. *Journal of Earth Science & Climate Change* 4 (5), 1–12. Available from: <https://www.omicsonline.org/water-resources-water-quality-and-human-health-in-regions-of-extreme-stress-middle-east-2157-7617.1000153.php?aid=18816>
- Shreim, D. A. 2012 *Environmental Assessment and Economic Valuation of Wastewater Generated from Israeli Settlements in the West Bank*. Master Thesis in Water and Environmental Engineering, An-Najah National University, Nablus, West Bank, Palestine. Available from: https://scholar.najah.edu/sites/default/files/Durgham%20Shreim_0.pdf
- Suarez, D. L., Wood, J. D. & Lesch, S. M. 2006 Effect of SAR on water infiltration under a sequential rain-irrigation management system. *Agricultural Water Management* 86, 150–164. Available from: <https://www.sciencedirect.com/science/article/pii/S0378377406002095>
- Sumner, M. E. 1993 Gypsum and acid soils: the world scene. *Advances in Agronomy Journal* 51, 1–32. Available from:

- <https://www.sciencedirect.com/science/article/pii/S0065211308605891>
- SWIM and HORIZON 2020 2018 *Reuse of Treated Wastewater for Agriculture Irrigation in Southern Part of Gaza Strip*. Implemented by OXFAM in Rafah and Khan Younis Governorates, Gaza Strip/ Palestine. October 24, 2018. Available from: <https://www.swim-h2020.eu/reuse-of-treated-wastewater-for-agriculture-irrigation-in-southern-part-of-gaza-strip-coordinator-oxfam-gaza-strip/> (accessed 8 August 2020).
- TCA (The Civil Administration) 2011 *Progress Report on the Waste Water Treatment Sector*. The Civil Administration – International Organizations Branch, Projects Department. From the Desk of LTC Avi Shalev, Head of the International Organizations Branch. March 2011. Available from: <https://www.scribd.com/document/51150217/Progress-Report-on-the-Waste-Water-Treatment-Sector>
- Tiehm, A., Schmidt, N., Lipp, P., Zawadsky, C., Marei, A., Seder, N., Ghanem, M., Paris, S., Zemmann, M. & Wolf, L. 2016 Consideration of emerging pollutants in groundwater-based reuse concepts. In: *Integrated Water Resources Management in A Changing World. Lessons Learnt and Innovative Perspectives* (D. Borchardt & R. Ibsch ed.). IWA Publishing, London, UK, pp. 67–73. Available from: <https://www.iwapublishing.com/books/9781780405261/integrated-water-resources-management-changing-world>
- Tortajada, C. & Van Rensburg, P. 2020 *Drink more recycled wastewater*. *Nature* 577, 26–28. doi: 10.1038/d41586-019-03913-6. <https://www.nature.com/articles/d41586-019-03913-6>.
- TToS (The Times of Israel) 2019 *Israel to Process Gaza Sewage with new Pipeline – Report*. 19 June 2019. Available from: <https://www.timesofisrael.com/israel-to-process-gaza-sewage-with-new-pipeline-report/> (accessed 27 October 2020).
- TWWB (The Wastewater Blog) 2016 *Wastewater Treatment Topics*. Wastewater temperature in bioreactor. September 26, 2016. Available from: <https://www.thewastewaterblog.com/single-post/2016/09/25/Wastewater-Temperature> (accessed 27 October 2020).
- UNDP (United Nations Development Programme) 2020 *Construction of Khan Younis Waste Water Treatment Plant (KYWWTP)*. Programme of Assistance for the Palestinian People. Available from: <https://www.ps.undp.org/content/papp/en/home/projects/construction-of-khan-younis-waste-water-treatment-plant-kywwtp.html> (accessed 27 October 2020).
- UNEP (United Nations Environment Programme) 2003a *Desk Study on the Environment in the Occupied Palestinian Territories*. UNEP, Nairobi, Kenya. Available from: <https://postconflict.unep.ch/publications/INF-31-WebOPT.pdf>
- UNEP (United Nations Environment Programme) 2003b *Assessment of Wastewater Reuse Practices in the Mediterranean Region*. Mediterranean Action Plan Meeting of the MED POL National Coordinators, Sangemini, Italy, May 27–30, 2003. UNEP (DEC)/MED WG.231/Inf.5, Nairobi, Kenya. Available from: <https://wedocs.unep.org/rest/bitstreams/6454/retrieve>
- UNEP (United Nations Environment Programme) 2020 *State of Environment and Outlook Report for the Occupied Palestinian Territory 2020*. UNEP, May 13, 2020. Available from: <https://webcache.googleusercontent.com/search?q=cache:PqzNMtrcO3QJ:https://www.unenvironment.org/resources/report/state-environment-and-outlook-report-occupied-palestinian-territory-2020+&cd=1&hl=en&ct=clnk&gl=ps>
- UNHRC (United Nations Human Rights Council) 2009 *Report of the United Nations Fact-Finding Mission on the Gaza Conflict*. Human Rights in Palestine and Other Occupied Arab Territories. Human Rights Council, 12th Session, Agenda Item 7. A/HRC/12/48, September 25, 2009. Available from: <https://www2.ohchr.org/english/bodies/hrcouncil/docs/12session/A-HRC-12-48.pdf>
- UNHRC (United Nations Human Rights Council) 2017 *Human Rights Situation in Palestine and Other Occupied Arab Territories*. Human rights situation in the Occupied Palestinian Territory, including East Jerusalem. Annual Report of the United Nations High Commissioner for Human Rights and Reports of the Office of the High Commissioner and the Secretary-General. Report of the Secretary-General. 34th Session, 27 February–24 March 2017, Agenda Items 2 and 7. Advance Unedited Version, Distr.: General, March 16, 2017. A/HRC/34/38. Available from: https://www.ohchr.org/en/hrbodies/hrc/regularsessions/.../a_hrc_34_38_auv.docx
- UNRWA (United Nations Relief and Works Agency for Palestine Refugees in the Near East) 2012 *Gaza in 2020. A Livable Place?* UNRWA, August 28, 2012. Available from: <https://www.unrwa.org/newsroom/press-releases/gaza-2020-liveable-place> (accessed 27 October 2020).
- UN (United Nations) 1980 *The Question of Palestine: Israel's Policy on the West Bank Water Resources, Prepared for, and under the Guidance of the Committee on the Exercise of the Inalienable Rights of the Palestinian People*. Document Symbol: 80-16332, January 1, 1980. Available from: <https://www.un.org/unispal/document/auto-insert-206852/> (accessed 27 October 2020).
- UN (United Nations) 2019 *The Question of Palestine: Wastewater Management Project Mitigates Health and Environmental Threats in Gaza – Work Bank Result Brief*. Result Briefs, October 9, 2019. Available from: <https://www.un.org/unispal/document/wastewater-management-project-mitigates-health-and-environmental-threats-in-gaza-work-bank-result-brief/> (accessed 27 October 2020).
- UN Water 2006 *Water A Shared Responsibility. The United Nations World Water Development Report 2 (WWDR 2006)*. UNESCO, Paris, France. Available from: <http://unesdoc.unesco.org/images/0014/001444/144409E.pdf>
- UN Water 2017 *2017 UN World Water Development Report: Wastewater the Untapped Resource*. WWDR 2017, United

- Nations, UNESCO, Paris, France. Available from: <http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/2017-wastewater-the-untapped-resource/>
- USAID (United States Agency for International Development) 2010 *Middle East and North Africa Water Center Network (MENA WCN): Assessment and Design: Annexes*. United States Agency for International Development (USAID), September 2010. Available from: <http://mena-nwc.net.s79942.gridserver.com/wp-content/uploads/2011/02/MENA-WCN-Final-Doha3.pdf>
- Vela, N., Fenoll, J., Garrido, I., Pérez-Lucas, G., Flores, P., Hellín, P. & Navarro, S. 2019 *Reclamation of agro-wastewater polluted with pesticide residues using sunlight activated persulfate for agricultural reuse*. *Science of the Total Environment* **660**, 923–930. <https://doi.org/10.1016/j.scitotenv.2019.01.060> & available from: <https://www.sciencedirect.com/science/article/abs/pii/S004896971930066X>.
- Wang, L. K., Shammas, N. K. & Hung, Y.-T. 2009 *Handbook of Environmental Engineering. Advanced Biological Treatment Processes*, Vol. 9. Humana Press, Springer Science, New York, USA. Available from: https://books.google.ps/books/about/Advanced_Biological_Treatment_Processes.html?id=UrWJXF2aLcC&printsec=frontcover&source=kp_read_button&redir_esc=y#v=onepage&q&f=false
- Wawi, A. 2017 *Governance Assessment of the Wastewater Reuse Policies and Practices in Palestine: The Case of Jenin and Nablus*. MSc thesis in environmental and energy management, University of Twente, Leeuwarden, the Netherlands. Available from: <https://essay.utwente.nl/77513/> and <http://purl.utwente.nl/essays/77513>
- WCC (World Council of Churches) 2016 *Palestinians Fight for Water Justice as Israelis Dominate Resources, Says Khoury*. April 19, 2016. Available from: <https://www.oikoumene.org/en/press-centre/news/palestinians-fight-for-water-justice-as-israelis-dominate-resources-says-khoury> (accessed 27 October 2020).
- WHO (World Health Organization) 1998 *Environmental Health Criteria 204 Boron*. International Programme on Chemical Safety. WHO, Geneva, Switzerland. Available from: <https://webcache.googleusercontent.com/search?q=cache:RqCTLurprNQJ:https://apps.who.int/iris/handle/10665/42046+&cd=2&hl=en&ct=clnk&gl=ps>
- WHO (World Health Organization) 2006 *WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater*. In: *Wastewater Use in Agriculture*, Vol. II. World Health Organization, Geneva, Switzerland. Available from: https://www.who.int/water_sanitation_health/publications/gsuweg2/en/
- Wikipedia 2020 *Halophyte*. Last updated: October 7, 2020. Available from: <https://en.wikipedia.org/wiki/Halophyte> (accessed 27 October 2020).
- Winpenny, J., Heinz, I., Koo-Oshima, S., Salgot, M., Collado, J., Hernandez, F. & Torricelli, R. 2010 *The Wealth of Waste: The Economics of Wastewater use in Agriculture*. FAO Water Reports, 35. Food and Agriculture Organization of the United Nations, Rome, Italy. Available from: <http://www.fao.org/docrep/012/i1629e/i1629e.pdf>
- World Bank 2009 *Assessment of Restrictions on Palestinian Water Sector Development*. West Bank and Gaza. Washington, DC, USA. Report No. 47657-GZ. April 2009. Available from: <http://documents.worldbank.org/curated/en/775491468139782240/pdf/476570SR0P11511nsReport18Apr2009111.pdf>
- World Bank 2018a *Securing Water for Development in West Bank and Gaza*. *Water Global Practice of the World Bank Group*. Washington, DC, USA. Available from: <http://documents.worldbank.org/curated/en/736571530044615402/WP-P157979-Securing-Water-for-Development-in-West-Bank-and-Gaza-PUBLIC.pdf>
- World Bank 2018b *North Gaza Communities Will Finally Benefit from Sewage Treatment Services*. March 12, 2018. Available from: <https://www.worldbank.org/en/news/feature/2018/03/12/north-gaza-communities-will-finally-benefit-from-sewage-treatment-services#:~:text=The%20long%2Dawaited%20construction%20of,disaster%20due%20to%20sewage%20pollution> (accessed 27 October 2020).
- Worldometer 2020 *State of Palestine Population (Live)*: 5,141,285. Available from: <https://www.worldometers.info/world-population/state-of-palestine-population/#:~:text=The%20current%20population%20of%20the,year%20according%20to%20UN%20data> (accessed 27 October 2020).
- Wu, S. & Maskaly, J. 2018 *Study on the effect of total dissolved solids (TDS) on the performance of an SBR for COD and nutrients removal*. *Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering* **53** (2), 146–153. <https://doi.org/10.1080/10934529.2017.1383130> & available from: <https://www.tandfonline.com/doi/full/10.1080/10934529.2017.1383130?scroll=top&needAccess=true>.
- Yaqob, E. Y. 2016 *Prospects for A Shared Management of Transboundary Wastewater: Israel-Palestine Case*. PhD dissertation, Department of Biomedical, Chemical, and Environmental Engineering (BCEE), College of Engineering and Applied Science, University of Cincinnati, Cincinnati, Ohio, USA. Available from: https://webcache.googleusercontent.com/search?q=cache:sfms-XkoZP0J:https://etd.ohiolink.edu/!etd.send_file%3Faccession%3Ducin1459243132%26disposition%3Dinline+&cd=17&hl=en&ct=clnk&gl=ps
- Yaqob, E. Y., Al-Sa'ed, R., Sorial, G. & Sudian, M. 2014a *Situation analysis and perspectives of transboundary wastewater management along Israel/Palestine borders*. *Asian Journal of Applied Science and Engineering* **3** (2), 82–95. Available from: <https://journals.abc.us.org/index.php/ajase/article/download/137-150/368>
- Yaqob, E. Y., Sorial, G. & Sudian, M. 2014b *Technical and financial challenges on Tran's boundary wastewater management from Palestinian territories (West Bank) to Israel*. *International Journal of Engineering and Innovative*

- Technology* 3, 151–158. Available from: <https://www.aaup.edu/publication/eyad.yaqob/article/technical-and-financial-challenges-tran%E2%80%98s-boundary-wastewater-management-palestinian-territories-west-bank-israel>
- Yihdego, Y. 2017 Simulation of groundwater mounding due to irrigation practice: case of wastewater reuse engineering design. *Journal of Hydrology* 4 (2), 19. 10p. doi:10.3390/hydrology4020019. <https://www.mdpi.com/2306-5338/4/2/19>.
- Yihdego, Y., Salem, H. S. & Muhammed, H. H. 2019 Agricultural pest management policies during drought: case studies in Australia and the state of Palestine. *Natural Hazards Review* 20 (1). [https://doi.org/10.1061/\(ASCE\)NH.1527-6996.0000312](https://doi.org/10.1061/(ASCE)NH.1527-6996.0000312) & available from: <https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29NH.1527-6996.0000312?af=R&> and https://www.researchgate.net/publication/327905409_Agricultural_Pest_Management_Policies_during_Drought_Case_Studies_in_Australia_and_the_State_of_Palestine_Natural_Hazards_Review_-_American_Society_of_Civil_Engineers_ASCE
- Zaidi, M. K. (Ed.) 2007 *Wastewater Reuse – Risk Assessment, Decision-Making and Environmental Security*. Springer, Germany. Available from: <https://www.springer.com/gp/book/9781402060250>
- Zeitoun, M. 2011 *Power and Water in the Middle East: The Hidden Politics of the Palestinian-Israeli Water Conflict*. Library of Modern Middle East Studies, I.B. Tauri, London, UK. Available from: <https://www.amazon.com/Power-Water-Middle-East-Palestinian-Israeli/dp/184885997X>
- Zeitoun, M., Eid-Sabbagh, K., Talhami, M. & Dajani, M. 2013 Hydro-hegemony in the Upper Jordan waterscape: control and use of the flows. *Water Alternatives* 6 (1), 86–106. Available from: <https://ueaeprints.uea.ac.uk/id/eprint/44129/>
- Zimmo, O., Petta, G., Mahmoud, N., Al-Saed, R., Mimi, Z. & Abu Madi, M. 2005 *Prospects of Efficient Wastewater Management and Water Reuse in Palestine*. A country study prepared within the Framework of the EM-Water-Project Efficient Management of Wastewater, its Treatment and Reuse in the Mediterranean Countries, May 2005. Available from: <https://fada.birzeit.edu/bitstream/20.500.11889/4792/1/Zimmo%20%20O.%20Al-Sa%60ed%2C%20R.%20et%20al.%202005%20Prospects%20efficient%20WWM%20water%20reuse%20Palestine.pdf>

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