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ORIGINAL RESEARCH ARTICLE

Socioeconomic, environmental, and health impacts of reusing treated wastewater in agriculture in some Arab countries, including occupied Palestine, in view of climate change

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ABSTRACT

The increase in water stress and shortage, facing many countries around the world, is one of the main difficulties confronting practical progress and sustainable development and management. Accordingly, managing the water assets of many countries around the world is nowadays a big challenge due to immense difficulties and vulnerabilities, including rapid industrialization and urbanization processes, population growth, geopolitical instability, and the effects of environmental changes, namely global warming and climate change. Because of global fresh waters scarcity and shortage, the demand for using non-conventional water resources, such as reusing treated wastewater for irrigation and industrial purposes, has become a nessitiy. However, the reuse of effluents for agricultural irrigation can have negative impacts on crop quality and soil conditions, as well as on public health and the environment. Moreover, improper management of agricultural irrigation with treated wastewater can also cause problems for plant production and soils' physical and chemical propeties. This paper investigates the status of freshwater and wastewater in view of climate change, and socioeconomic, environmental, and health impacts of reusing treated wastewater for irrigation in the Arab region, with the focus on the Occupied Palestinian Territories (OPT), as an example. The paper concludes that: 1) Approximately 13.2 billion cubic meters (BCM) of wastewater is yearly produced in the Arab countries, of which 5.7 BCM (43.2%) is treated and 7.5 MCM (56.8%) is untreated and dumped in open environments; 2) Regarding the OPT, where more than 87% of its fresh water resources are controlled and forcefully taken by the Israeli occupation authorities, Palestinians discharge large amounts of untreated wastewater into open lands (as in the case of the occupied West Bank) and in the Mediterranean Sea (as in the case of occupied and besieged Gaza Strip); and 3) The reused portion of treated wastewater in the OPT is close to zero.

Keywords: water shortage and scarcity; wastewater treatment and reuse; agriculture and irrigation; climate change impacts; Arab region, including the Occupied Palestinian Territories (OPT)

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1. Introduction

1.1. Global water crisis

As the world population continues to grow and climate change continues to create more water crises, people throughout the world have to think practically and environmentally, in order to save freshwater resources and also to find enough water to meet their needs for domestic, agricultural, and industrial purposes. One of the mechanisms to save freshwater is to reuse treated wastewater. No surprise that currently people in some countries are using treated wastewater for drinking, cocking, and other household utilizations, though using recycled water for these house usages is less common. This is, in large part, due to the fact that many people are repulsed by the idea that the water in their toilets goes to their taps. But a few countries, like Singapore, Australia, and Namibia, and some American states, such as California, Virginia, and New Mexico, are already drinking recycled water, showing that pure sewage can be safe and clean, and help alleviate water shortage[1–6].

1.2. Arab region and water-energy-food (WEF) Nexus

Regarding the Arab region, although it has the highest oil and gas reserves in the world, it is also one of the world's poorest regions, with respect to water and food resources[7,8]. The uneven distribution of wealth amongst people in most Arab countries, particulalrly the rich-producing oil states; the lack of security in many Arab countries (in terms of national, water, and food security); and the scarcity and high demand on natural resources, particulalrly water and food, have made the interconnected nature of these three resources (water, energy, and food) a necissity, and have created remarkable challenges and opportunities for policy-makers, strategists, and planners across the Arab region. This approach has become known, worldwide, as water-energy-food (WEF) Nexus[8]. Because the importance of each of these three components (water, energy, and food) of the WEF Nexus' compound or approach is closely related at multiple levels, the consumption of one of them affects the demand for the other two[8]. Ineffective governance institutions, weak public participation, lack of responsibility, and limited interaction and coordination amongst the three sectors (WEF), as well as political and geopolitical instabilities in the Arab region have all put Arab governments in a critical situation. This means that Arab governments should take responsibility in providing adequate planning, management, and protection of their peoples and natural resources. This is with regard to national, water, food, and energy (in)securities, especially in the presence of many problems and challenges related to political (internal) and geopolitical (external) instabilities, water shortage and scarcity, and food and energy insecurity. A worrying example of water insecurity in some Arab countries is the water conflict between Ethiopia, Egypt, and Sudan over the Grand Ethiopian Renaissance Dam (GERD) on the Blue Nile River[8–14].

1.3. Wastewater in the Arab region

Wastewater treatment can play an important role in climate change mitigation and adaptation strategies, while integrated approaches through the water-energy-food-environment (climate change) Nexus can maximize benefits[7,8,15–18]. This is particulalry important in the Middle East and North Africa (MENA) region, which represents one of the most water-stressed regions worldwide. Therefore, wastewater treatment and reuse (WWTR) can be of great importance to the water budget in the Arab countries. However, the related infrastructure financing gap is large and, thus, there is an urgent need for alternative investment options, such as the inclusion of the private sector in the freshwater and wastewater infrastructure projects. This, in turn, will enable policy-makers in water-stressed countries and their relevant financial institutions to assess water strategies and apply best practices, with the aim of exploring how good governance can attract private investment, identify regulatory and institutional gaps, and enhance the potential of public-private partnerships[8]. Lack of data and public awareness, and limited stakeholders participation and funding are just some of the obstacles that face the wastewater treatment programs in the Arab region. Currently only half of the amount of the wastewater produced in the Arab region is collected, and of that collected portion approximately 57% returns untreated to open environments, and thus considered a "missed potential." In a region where 85% of freshwater use is for agriculture[19], reusing treated wastewater for agricultural and industrial purposes could allow freshwater to be reallocated to the domestic sector, based on the fact that many countries in the Arab region are below the water poverty line, which is less than 1000 m^3/person/year (m^3/pe/yr). In addition, the reuse of treated wastewater can relieve pressure on unsustainable water resources, especially for many Arab countries in the MENA region, where "fossil" groundwater from non-renewable aquifer systems accounts for more than 70% of the total water withdrawals[8,20–32]. Due to the acute water shortage and scarcity in semi-arid and arid regions, such as the Arab region, in particular, the reuse of treated wastewater for agricultural production has become a widespread practice, although Arab countries still lag behind many other countries using this technique, worldwide. The reuse of treated wastewater for agricultural irrigation is an important tool for supplementing water resources, in order to save freshwater, which also goes hand-in-hand with the United Nations Sustainable Development Goals (UN's SDGs).

1.4. Wastewater management with respect to UN's SDGs

Wastewater management is an exceptional example of a paradigm shift towards sustainable development, providing multiple social, economic, environmental, and healthly benefits. This is with the consideration of human rights to water, sanitation and reduced health risks, and efficient resource reuse and decontamination efforts. Such an approach can go hand-in-hand and build strong links with the United Nations Sustainable Development Goals (UN's SGDs), particularly the Sixth Goal: Clean Water and Sanitation[33]. This is with the focus on Target 6-3: improve water quality, wastewater treatment, and safe reuse; Target 6-4: increase water-use efficiency and ensure freshwater supplies; and Target 6-5: implement integrated water resources' management. It also goes well with Indicator 6-A: expand water and sanitation support to developing countries, and with Indicator 6-B: support local engagement in water and sanitation's management.

1.5. Paper's novelty

This research paper is novel because of the following reasons:

1) It presents original research that lacks plagiarism and is supported by many relevant and up-to-date references.

2) It identifies a very important issue that affects the Arab population of approximately 474 million living in 22 Arab countries, with the focus on the Occupied Palestinian Territories–OPT). The issue is wastewater treatment and reuse (WWTR), in view of fresh water scarcity and shortage, water and food (in)security, population growth, industrialization, and urbanization, as well as climate change impacts.

3) It investigates socioeconomic, environmental, and health impacts of WWTR on agriculture, in view of climate change.

4) It provides new approaches, and opens new horizons to understand and solve the WWTR's problems in the Arab region.

5) It is of great benefits to a wide audience, including postgraduate students, researchers, scholars, academicians, educators, politicians, policy-makers, strategists, industrialists, environmentalists, agriculturists, farmers, land owners, water and climate specialists, and so forth.

2. Methodolgy

The research undertaken and presented in this paper was systematically designed to ensure valid and reliable results that address the research aims and objectives, and also to answer important questions related to the wastewater treatment and reuse issues investigated. This paper investigates the issue of WWTR in view of climate-adaptive approaches to risk monitoring and sustainable water resources' management in the Arab world, with the focus on the Occupied Palestinian Territories. To achieve the purpose of the paper, some of the data used were cllected and some other data were generated, analyzed, and interpreted. The data used to serve the goals of this paper were obtained from other works that are already published in well-refereed and highly authentcated references. To serve the purpose of this paper, two different approaches were used in the investigation: qualitative research that focuses on the collection and analysis of the data obtained, and quantitative research that focuses on using numerical data, whereas the relationships amongst many variables related to WWTR were analyzed. The obtained results were discussed and conclusions and recommendations presented. To serve the purpose of the work, several recent references have been cited to support the data used and the results obtained. It should be noted that, in general, no major problems occurred during the preparation of the work presented in this paper, as they were minimized to a degree that does not negatively affect the data collected and the results obtained, as well as the interpretation, discussion, conclusions, and recommendations reached.

3. Results and discussion

3.1. Population and area of Arab countries

The Arab countries collectively comprise a total area of over 13 million km^2 (more than 5 million mi^2) and boast a 2022-population of over 474 million[34] (**Figure 1**, **Table 1**).

Figure 1. Map of the Arab world[35].

By most definitions, Arab countries are 22 countries, whose primary language for their citizens is Arabic. Every Arabic-speaking country is located in one of two general global regions (**Figure 1**; **Table 1**): in Africa (10 countries), including 6 countries in northern Africa (Egypt, Libya, Tunisia, Algeria, Morocco, and Muritania) and 4 countries in Eastern Africa (Sudan, Somalia, Comoros, and Djibouti); in Asia (12 countries), including 4 countries in the Levant (Syria, Lebanon, Jordan, and Palestine), in addition to Iraq (known, historically, as “Mesopotamia”) and 7 countries in the Arabian Peninsula (AP: Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates (UAE), and Yemen), where the first 6 countries in the AP form the Gulf Cooperation Council (GCC), while Yemen, in southern AP, is not a GCC member.

These 22 countries are collectively referred to as the Arab World, Arab Region, or Arab States. Each Arab country is also a member of the League of Arab States (LAS), which is an intergovernmental alliance created to unite Arab states politically, representing the Arab nation’s security, social, economic, and other interests, though LAS could not achieve any of these interests. Since it was established in March 1945, LAS has declined as an organization–from one that represents and drives meaningful and effective collective and collaborative Arab action to a mere facade of ineffective institutions that reflect the prevailing society and discord in the Arab world. LAS, in its early years, represented an attempt by the newly independent Arab states to form a coalition in the aftermath of World War II (WWII), that would speak on behalf of the Arab masses emerging from decades of oppression resulted from foreign powers’ colonization of the Arab world. Nevertheless, LAS soon fell victim to the ideologies of the various Arab states’ elites that sought to achieve their interests and sowed the seeds of discord. This division has limited the League’s ability to represent, regionally and internationally, the interests of approximately 474 million Arabs, as of June 2023 (**Table 1**)[34]. It also deprived them of effective participation in decisions on global issues that affect them and their future[36].

According to **Table 1**, Egypt is the most populous Arab country, with a 2023-population of approximately 113 million, while Comoros is the smallest, with an approximate population of only 852,000. In terms of area, Algeria is the largest Arab country with an area of approximately 2.4 million km^2, while Bahrain is the smallest Arab country with an area of 765 km^2. In terms of population, the largest city in all Arab countries is the

Egyptian capital–Cairo, with a population of over 16 million, while Baghdad (Iraq's capital) and Riyadh (Saudi Arabia's capital) are in the top three places, after Cairo.

Table 1. 2022-population and area (in km^2 and mi^2) of each of the 22 Arab countries[34].

Country	Projected population (in June 2023)	Area (km^2)	Area (mi^2)
Algeria	45,606,480	2,381,741	919,352
Bahrain	1,485,509	765	295
Comoros	852,075	1862	719
Djibouti	1,136,455	23,200	8955
Egypt	112,716,598	1,002,450	386,946
Iraq	45,504,560	438,317	169,190
Jordan	11,337,052	89,342	34,486
Kuwait	4,310,108	17,818	6878
Lebanon	5,353,930	10,452	4034
Libya	6,888,388	1,759,540	679,182
Mouritania	4,862,989	1,030,700	397,850
Morroco	37,840,044	446,550	172,368
Oman	4,644,384	309,500	119,467
Occupied Palestinian Territories (OPT)*	5,371,230	6220	2402
Qatar	2,716,391	11,586	4472
Saudi Arabia	36,947,025	2,149,690	829,780
Somalia	18,143,378	637,657	246,136
Sudan	48,109,006	1,886,068	728,022
Syria	23,227,014	185,180	71,479
Tunisa	12,458,223	163,610	63,153
United Arab Emirates (UAE)	9,516,871	83,600	32,270
Yemen	34,449,825	527,968	203,796

*Regading the Occupied Palestinian Territories (OPT), it is part of Historic Palestine, with a total area of 27,002 km^2 (10,426 mi^2), and a total population of approximately 15 million, including 7.6 million Arab Palestinians (5.5 million in the OPT and 2.1 in Israel), and approximately 7.2 million Jews (see below for further details)[37,38].

3.2. Historic Palestine (Israel and the Occupied Palestinian Territories–OPT)

Historic Palestine, as being the focus of this study, constitutes of Israel and the Occupied Palestinian Territories (OPT). Israel was established in 1948 over 78% of the lands of Historic Palestine, and the rest (22%) was occupied by Israel in June 1967, which since then has become known as the "Occupied Palestinian Territories" (OPT)[39]. The OPT is composed of the West Bank (including East Jerusalem) and the Gaza Strip. As of April 2023, Israel's population has reached approximately 10 million, including 7.2 million Jews (73.5%), about 2.1 million Arab Palestinians (21%), and about 534,000 identified as "others" (5.5%)[37]. By adding approximately 5.5 Arab Palestinians in the OPT, it would total 15–16 million inhabitants in Historic Palestine. However, the OPT's population does not include the Jewish settlers, who live illegally in Jewish-only settlements in the OPT[39]. As of 2022, there are 140 Israeli illegal settlements (for-Jews-only) in the occupied West Bank, including 12 in occupied East Jerusalem[40], with a settlers' total population estimated at 600,000–

750,000[41] (**Figure 2**). Some estimates put the number of illigal Jewish settlements in the occupied West Bank (including East Jerusalem) at 250 settlements, representing a "War Crime"[41,42].

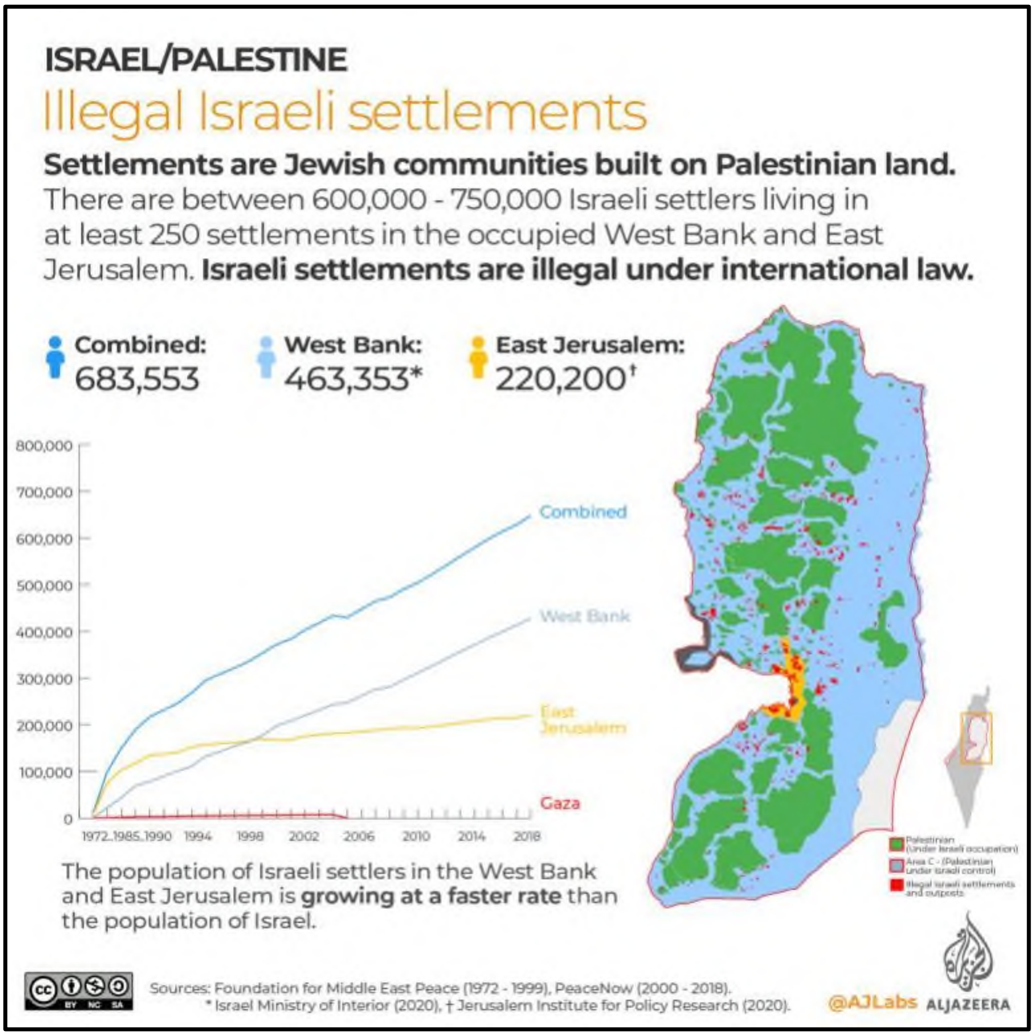

Figure 2. Increasing trends of the Jewish settlers in the occupied West Bank, including East Jerusalem, during the period of 1972–2018. This figure also shows a map of the occupied West Bank that looks like Swiss chease, demonstrating the Palestinian communities living in claves spreading all over the West Bank (in green); Area C, which is entirely under the control of the Israeli occupation authorities, security-wise and administration-wise (in blue); and the 250 for-Jews-only settlements, scattering throughout the occupied West Bank (in red)[41].

However, some Israeli observers expeculated that the number of Jewish settlers in the OPT will reach one million in a few years. *"One Israeli politician predicted that the number of Jewish settlers in the West Bank and East Jerusalem would reach one million within four years. At that point the revolution will have been completed, Yaakov Katz told the newspaper"*[43]. Since Israel's founding in 1948, *"Israel has pursued a policy of establishing and maintaining a Jewish demographic majority"*[41,44,45]. Israel also exercises complete control over land and natural resources for the benefit of the Jewish Israelis, including those in "Israel" as well as those living in the illegal Jewish settlements in the occupied West Bank, including occupied East Jerusalem.

Based on population's estimates prepared by the Palestinian Central Bureau of Statistics (PCBS), as of mid-2022, there are about 14.3 million Palestinians in the world, of whom about 5.35 million in the OPT (the West Bank, including East Jerusalem, and the Gaza Strip), including 2.72 million males and 2.63 million females[46]. The population of the West Bank is estimated at 3.2 million (1.62 million males and 1.57 million females), while the population of the Gaza Strip is estimated at 2.2 million (1.1 million males and 1.1 million females).

3.3. Freshwater status in the Arab world

The Arab countries have approximately 6% of the world's population and only 1% of freshwater resources[47]. Most of the countries in the Arab region are characterized as having semi-arid to arid climate. The Arab countries generally depend on seasonal rainfall and a few rivers; some of which carry runoff from other countries, while some other Arab countries depend on fragile, sometimes non-renewable, underground aquifer systems. The rich oil-producing Arab countries in the Gulf region (represented in the GCC) depend mostly on seawater desalination that is financially costly, and environmentally represents unfriendly processes. Thus, the GCC economies are more sensitive to the way water is extracted, transported, and consumed than the economies of the other Arab countries. Despite this big reality, the Arab countries have lost approximately 144 BCM of its groundwater reserves in aquifer systems during the period of 2003–2009 only[48], which (water amount) is supposed to be annually replenished. This rate of freshwater loss in the Arab region is amongst the largest losses of freshwater on the planet Earth during the same period of time. The analyses indicate that groundwater depletion is the single largest contributor to this observed negative trend, accounting for about 60% of the total volume of the water lost, most of which occurred after the 2007 droughts[48], which can be possibly attributed to the climate change impacts and global warming, including lower rates of annual precipitation and higher rates of evaporation.

On the other hand, surface water depletion, such as the transfer of water from the Jordan River and Lake Tiberias (Galilee Lake) by Israel to coastal cities on the Mediterranean Sea and other cities in the southern parts of the country, has lowered the water level in the Dead Sea to alarming rates. The water level of the Dead Sea has decreased by more than 50 m (164 ft) in the past 50 years, falling at an average rate of one meter per year (m/yr), which has resulted in dissolving the salt layers in the Dead Sea and the surrounding geological environments, and thus led to the occurrence of thousands of sinkholes on both sides of the Dead Sea Basin[20–22,49,50]. Therefore, besides the devastating effects of climate change on water resources in the Arab region, there are also destructive anthropogenic (man-made) effects on them.

The Arab region has run out of renewable freshwater resources for decades, meaning that Arab countries will be unable to meet their nutritional needs from the freshwater resources available within their borders, and to that matter, they will be unable to achieve the UN's SDGs by 2030, as the UN has already planned[8]. Continuous over-pumping of groundwater has lowered the groundwater table in underground aquifer systems and deteriorated groundwater quality, and thus it has encouraged seawater to intrude aquifer systems, increase groundwater salinity levels, and cause environmental degradation to the underground aquifer systems. Thus, non-conventional water resources, such as seawater desalination, rainwater harvesting, and wastewater treatment and reuse, are urgently needed to meet the water's increasing demand in the Arab world.

According to estimates and projections of the countries' population and annual renewable water resources, by the year 2025 most of the Arab countries will have renewable water resources of less than 1000 m^3/person/year (m^3/pe/yr). Currently, only Iraq and Lebanon in the Arab region have annual renewable water resources that exceed 1000 m^3/pe/yr. On the other hand, many Arab countries, such as Kuwait, Libya, Qatar, Saudi Arabia, UAE, and Yemen, have annual renewable water resources of less than 100 m^3/pe/yr. Higher temperatures have led to increased evaporation rates from surface water resources (such as rivers, lakes, wetlands, etc.), loss of soil's moisture, higher rates of evaporation in vegetated areas, lower rates of runoff and groundwater recharge, and thus increasing water requirements needed for the agricultural crops. To this connection, 14 out of the 22 Arab countries were classified as water-deficit in 2010[51].

Based on climate-change models for the Arab region made by the Intergovernmental Panel on Climate Change[52], a decreased precipitation rate of 10–25%, a decreased runoff rate of 10–40%, and an increased evaporation rate of 5–20% were projected. As indicated above, Arab countries represent approximately 6% of the world's population, but they have less than 1% of the world's water resources. Considering this fact in addition to the climate change impacts, the Arab region is facing an even greater water shortage and scarcity[53–55]. Water supplies in Arab countries are under severe pressures, or what is known as "water stress"[56]. Demographic growth (which was in 2021 at a rate ranging from −0.8% in Lebanon to 2.9% in Somalia, and an overall average rate for the Arab countries of 1.9%[57], economic growth, urbanization, industrialization, and expansion of irrigated agricultural land have contributed to significant and unsustainable increases in water consumption over the past decades.

Frequent droughts, along with the overuse of groundwater and major groundwater aquifer systems, have significantly reduced the availability of both renewable and non-renewable water resources in the Arab region, including Palestine[58]. Consequently, most Arab countries are moving towards severe water scarcity, resulting in more droughts, deforestation, and desertification. A closer look at the current state of the water supply in the Arab region shows that it continues to deteriorate. By 2025, the per-capita water supply in Arab countries will be around 500 m^3/pe/yr, representing only 15% of what it was in 1960, when it was at 3300 m^3/pe/yr[53].

Recently, Arab countries are running out of water, meaning that major water shortages in the Arab region could lead to dire social, economic, political, and environmental consequences for the region in the near future[59–62]. Such consequences surely reflect on the economies of Arab countries. The World Bank found that the Arab region has the largest expected economic losses from climate-related water scarcity, estimated at 6–14% of the gross domestic product (GDP) by 2050[56].

Figure 3 shows that 10 out of the 22 Arab countries are facing severe water stress (75%–7512%). These are Kuwait, UAE, Qatar, Saudi Arabia, Libya, Jordan, Egypt, Bahrain, Yemen, and Oman. Meanwhile, the other 12 Arab countries are facing moderate water stress (25%–60%) to serious water stress (60%–75%).

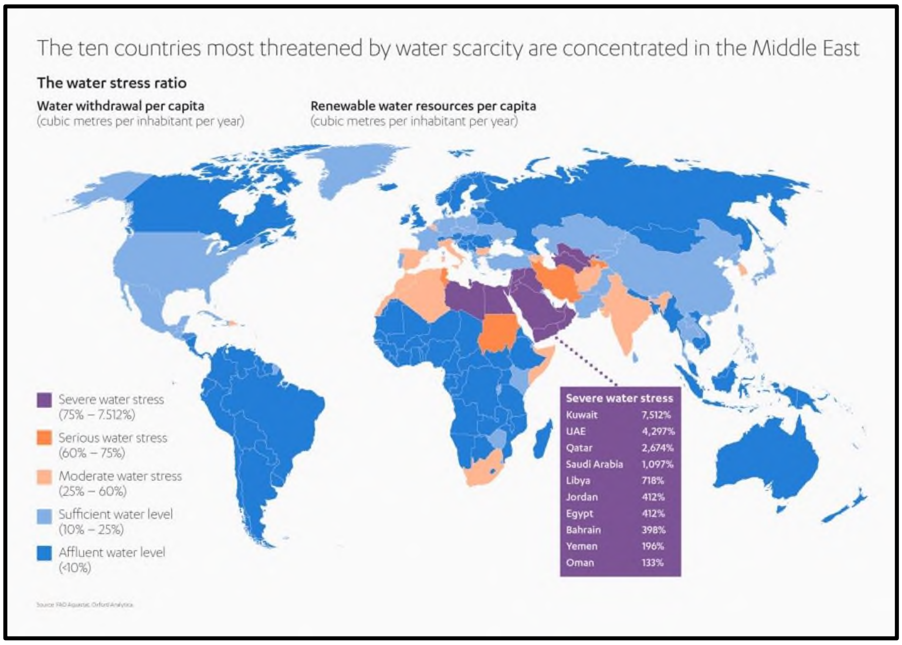

Figure 3. A map showing water stress in the Arab region[60].

Agriculture is the main consumer of freshwater in all of the Arab countries. On average, 86% of the water withdrawn for various water user sectors is used in crop production. Meanwhile, only 8% of fresh water is used for domestic purposes, and only 6% of it is used in industrial activities[63].

3.4. Wastewater treatment mechanisms, its usages, and its status in the Arab world

The term "wastewater" refers to any water that is no longer required. It is the used/consumed water that is discharged by households (from usages such as showering, dishes and clothes' washing, toilet's flushing, etc.), as well as by agricultural and industrial activities. About 99% of the household's wastewater is fluid (dirty water) and only 1% is solid waste.

Wastewater treatment is the process of removing contaminants from wastewater through engineered physical, chemical, and biological processes to produce wastewater that can be safely reused or discharged into the environment (**Figure 4**). There are four main stages[64–68] of wastewater treatment (**Figure 4**), which are:

1) Preliminary treatment that includes sieving and degranulation units to remove large, coarse particles present in raw wastewater (sanitary ware, plastic, rags, hair, rocks, gravel, etc.) that may clog or damage mechanical equipment.

2) Primary treatment that separates suspended solids from wastewater by emptying the wastewater into sedimentation tanks to allow the solids to settle down, whereas the settled solids, called sludge, is scraped from the bottom of the tanks by large skimmers and pumped away for further processing.

3) Secondary treatment removes degradable organic matter, suspended solids, and nutrients by pumping wastewater into aeration systems and biological treatment systems.

4) Tertiary treatment that removes specific components that cannot be removed by previous steps, such as refractory organic matter, heavy metals, and dissolved solids.

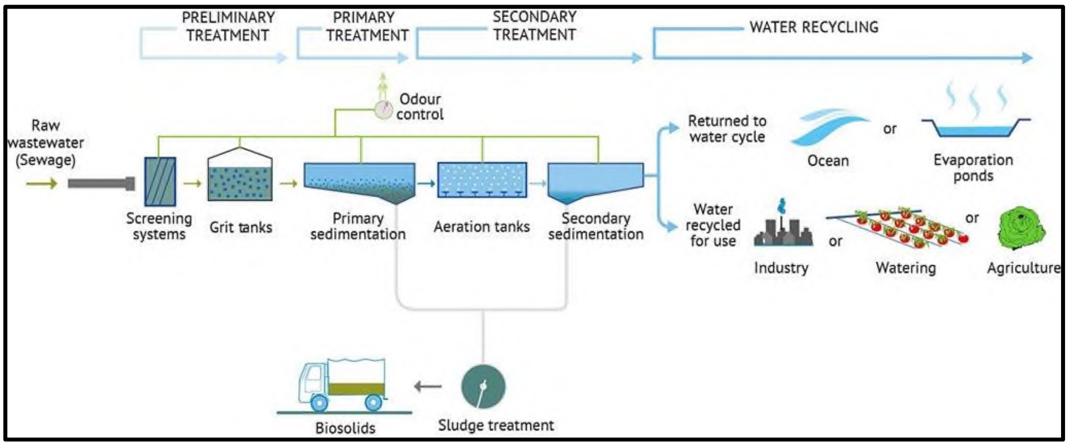

Figure 4. Wastewater treatment processes[25].

Reused or recycled wastewater can be defined as the use of wastewater or water reclaimed from one application for another application. The intentional usages of treated wastewater must be consistent with the rules in place for a beneficial purpose, and treated wastewater can be reused in the following areas:

1) Agricultural reuse: irrigation of non-food crops, such as fodder, fiber, commercial nurseries, and pasture lands[23,69,70].

2) Urban reuse: recreational sidewalks and irrigation of parks, ponds, lakes, playgrounds, plazas, highway medians, and residential landscapes[71,72].

3) Industrial reuse[73–79].

4) Flushing latrines and fire protection in commercial and industrial buildings[80,81].

5) Environmental uses: constructed wetlands is an environmentally friendly technique used for removing pollutants from wastewater, municipal wastewater, wastewater generated from petroleum refinery and borehole drilling, agriculture drainage, and acid mine drainage[82–85].

6) Aesthetic uses[86,87].

7) Groundwater recharge: by direct injection into groundwater aquifers[88–90].

For food crops production and groundwater recharge, treated wastewater of high-quality must be used **(Figure 4)**.

In view if these many treated wastewater's usages, wastewater has a great potential to alleviate the shortages of freshwater in semi-arid and arid regions, like the Arab countries. Based on the fact that the Arab countries are facing severe stress and shortages of freshwater resources, WWTR has been gaining some increasing interest and importance for certain utilizations in Arab countries, mainly in agricultural irrigation[91–97]. This is with the consideration that agriculture is the main user of freshwater in the Arab region. Moreover, the volume of discharged wastewater from various sources has increased and is expected to continue to increase in the future due to population growth, urbanization, improved living conditions, and economic development, especially in the GCC States.

Due to the high consumption of freshwater for agricultural and domestic purposes in the Arab countries as being water-stressed countries, the estimated amount of wastewater produced is between 30–90 m^3/pe/yr[98]. The volume of wastewater generated annually by the domestic and industrial sectors in the Arab region is 13.2 billion cubic meters (BCM), of which 5.7 BCM (43.2%) is treated, meaning that the annual volume of untreated wastewater discharged in open environments is 7.5 MCM (56.8%) of the total wastewater produced in the region)[99] (**Figure 5**).

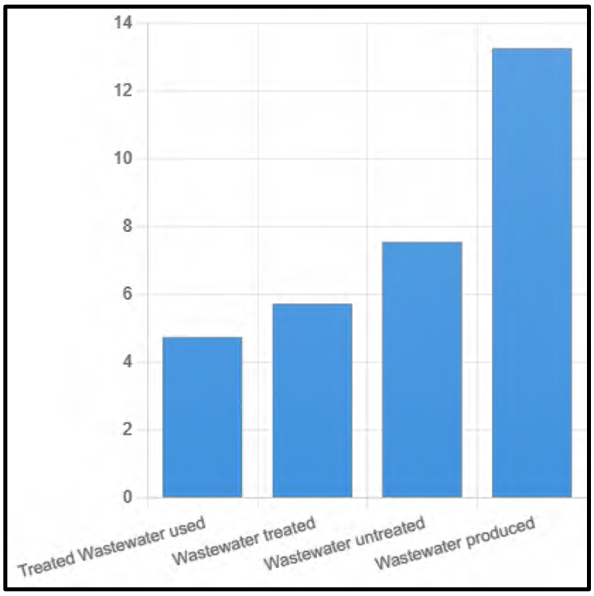

Figure 5. Volumes of wastewater produced, disposed (untreated), treated, and reused in agricultural irrigation in the Arab region[25,100].

Approximately 83% of the treated wastewater in the Arab region is used for agriculture, while most of the partially treated, diluted, or untreated wastewater is used by urban and peri-urban farmers to grow crops. Some Arab countries use treated municipal wastewater more to meet the growing demand in urban areas. The GCC countries use about 40% of their treated wastewater for fodder, landscaping, and irrigation of non-edible crops[101].

Table 2 shows the rate of sanitation and level of treatment in urban and rural areas in several Arab countries, in addition to Israel and Iran as non-Arab countries in the region. These countries use different wastewater treatment options. For example, all wastewater collected in Bahrain is treated by activated sludge and tertiary treatment processes, while less than 10% of wastewater collected in Iran, Lebanon, Morocco, and Libya undergoes treatment. In other words, more than 90% of wastewater produced in these countries is discharged untreated in open environments. This, consequently, results in damages to the green cover, air, water, and soil, causing pollution to them and the ecological systems in general.

Table 2. Sewage coverage in urban and rural areas and wastewater reuse in Arab countries, in addition to Iran and Israel as non-Arab countries[23,25,51].

Country	Percentage of households connected to sewage system (urban) (%)	Percentage of households connected to sewage system (rural) (%)	Percentage of households connected to sewage system (overall) (%)	Percentage of collected wastewater by volume (%)	Percentage of treated wastewater by volume (%)	Percentage of reuse efficiency of treated wastewater by volume (%)
Algeria	92	50	77	46	40	N/A
Bahrain	N/A	A/A	77	73	49	18
Egypt	74	18	42	57	52	24
Iraq	39	3.3	28	30	17	N/A
Jordan	67	4	56	98	53	76
Kuwait	N/A	N/A	>99	N/A	78	63
Lebanon	N/A	A/A	66	81	23	50
Libya	54	54	54	24	13	100
Morocco	86	2.8	53	20	18	6
Oman	53	17	44	34	27	66
Palestine (OPT)	67	12	54	N/A	N/A	N/A
Qatar	N/A	N/A	78	100	78	50
Saudi Arabia	44	7	37	93	69	40
Syria	96	45	72	N/A	40	78
Tunisia	79	8.9	54	77	68	20
UAE	93	63	87	N/A	87	25
Yemen	42	0.4	12	66	8	40
Iran*	39	5.3	30	78	21	N/A
Israel*	99.5	95	98	N/A	90	99

*Iran and Israel are two non-Arab countries in the MENA region, which were investigated to compare them with Arab countries.

In the Arab region it is only about 48% of municipal wastewater are treated annually, and the remaining amount (52%) is discharged without treatment[102]. **Table 2** (3rd column) shows that the overall percentage of households connected to sewage system ranges from 12% in Yemen to >99% in Kuwait. Considering the last column as the most important column in the Table, showing the percentage of treated wastewater reuse efficiency by volume in each of the provided countries, it (the last column) indicates that Libya is the best (100%) followed by Jordan (76%), while Morocco is the worst (6%) followed by Bahrain (18%). Meanwhile, Israel (as a non-Arab country in the region) is leading the processes of wastewater treatment and reuse, using advanced technologies, as it collects 98% of all wastewater generated from urban and rural areas, and treats 90% of that collected wastewater, which both result in a reuse efficiency of treated wastewater by 99% (**Table 2**). Until 2016 Israel used to treat up to 85% of its wastewater annually[103]. Meanwhile, Iran (as a non-Arab country dealing with the WWTR issue in the MENA region) can be generally described as being similar to all Arab countries (**Table 2**) with low efficiency of wastewater treatment and reuse.

3.5. Status of freshwater and wastewater in the Occupied Palestinian Territories (OPT)

The Palestinians, who have been living under Israeli military occupation since June 1967 and many of whom are refugees enforced to leave their homes in Palestine (what is currently knows as "Israel"), are supposed to have sufficient and safe water for their domestic, agricultural, and industrial consumption, on the basis of international law and human rights' treaties[50]. The United Nations' Human Rights Council (UNHRC) issued a report in March 2017, which investigated the human rights' situation in the Occupied Palestinian Territories (including East Jerusalem), with the focus on the recurrence and persistence of human rights' violations by the Israeli occupation authorities, and the key policies that lead to such inhumane patterns. The 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"*[104]. More on the Israeli restrictions that prevent Palestinian farmers from reaching their agricultural lands is given in the study of Salem[105].

Israel, since its establishment in 1948 on 78% of the land of Historic Palestine and since it occupied in 1967 the remaining parts (22%) of Historic Palestine, has controlled, almost completely, the Palestinian water resources. Accordingly, Israel has enforced its full control on the Palestinian land and its natural resources, considering water resources in Historic Palestine as a strategic asset[50]. Israel's full control over legitimate Palestinian water resources has taken place in various forms, including "water control," "water domination," "water deprivation," "water policies," "water strategies," "water politics (hydropolitics)," "water militarization," etc.[23,50,106]. As a result, Palestinians in the Occupied Palestinian Territories have controlled only a small portion of their legitimate water resources; not exceeding 13% of the amounts of water resources available in Historic Palestine (**Figure 6**).

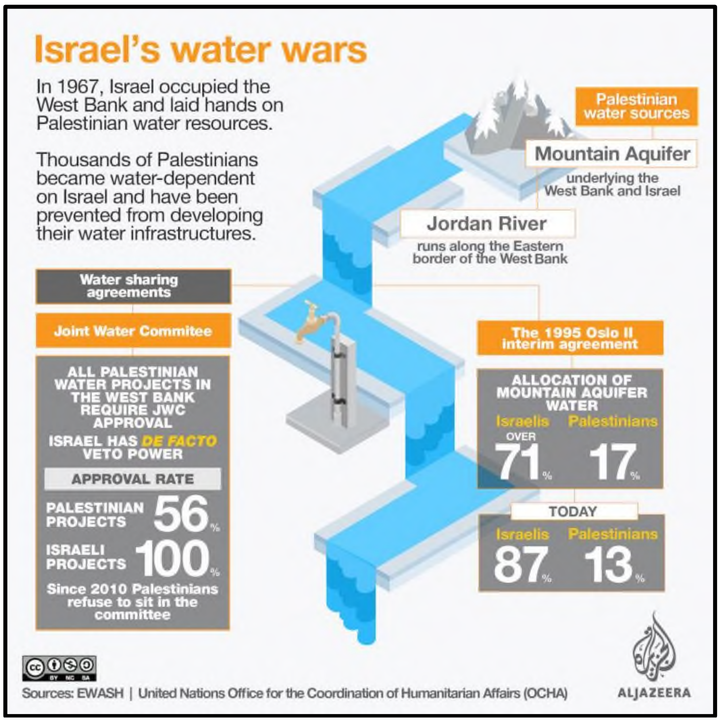

Figure 6. Water status in the occupied West Bank[23,50,107,108].

Regarding wastewater in the OPT, about 15 million cubic meter of wastewater is collected per year (MCM/yr), and approximately 10 MCM/yr of that collected wastewater is treated by large centralized wastewater plants, as well as by small on-site wastewater treatment plants. Despite the fact that approximately 67% (10/15) of the collected wastewater is treated in the OPT (as also indicated in **Table 2**), the volume of treated wastewater that is reused in agriculture or industrial processes remains close to zero[23]. In addition, despite the fact that the reuse of treated wastewater is a very important issue in the Gaza Strip, because nearly half of the current use of freshwater is for the agricultural sector, there is no wastewater available for reuse in the agricultural sector. This is due to the fact that all wastewater is discharged into the Mediterranean Sea, because Israel (the occupying power) has destroyed the wastewater treatment plants in the Gaza Strip[23,55,109–111].

The reuse of a near-zero amount of treated wastewater in the OPT may be attributed to several reasons, including, amongst others:

1) Some centralized wastewater treatment facilities do not treat wastewater with appropriate standards for treated wastewater reuse.

2) Lack of funding.

3) The inadmissibility of reusing treated wastewater for various reasons, including social, cultural (mainly religious), health, lack of public awareness, and others.

4) The Israeli restrictions that do not allow Palestinians to use their own land in Area C, which constitutes more than 60% of the occupied West Bank[39,105].

However, despite these limitations and challenges, Palestinian farmers must be convinced that reusing treated wastewater for irrigation cannot only enable them to save money but also provide them with better agricultural crops in terms of quality and quantity[23]. Ironically, the wastewater dumped by the West Bank's Palestinians is collected, treated, and reused by Israel for agricultural irrigation for its own benefits entirely. On the other hand, Israel charges the Palestinian government 0.97–2.12 NIS (NIS is Israeli New Shekel; the currency used in the Occupied Palestinian Territories; this is equivalent to 0.30–0.65 USD) to treat each cubic meter of wastewater produced in the OPT and that flows into Israeli proper without being reused by the Palestinians[23].

On the other hand, in the occupied West Bank, the Palestinians are surrounded by more than 250 Israeli (for-Jews-only) settlements and outposts, built in contravention of international law, many of which discharge their sewage into Palestinian farmlands (**Figure 7**).

Figure 7. Discharge of untreated sewage into Palestinian agricultural lands in the village of Deir Ballut by neighboring Jewish settlements in the occupied West Bank[112].

It is estimated that at least 50 settlements discharge approximately 35 MCM of wastewater into the occupied West Bank annually[113]. This volume of wastewater is equivalent to 14,000 Olympic-size swimming pools, and it increases every year as old settlements continue to expand and new ones are built at skyrocketing and speedy rates in the occupied West Bank. These expansion activities, creating "facts on the ground," contribute to the de facto annexation of the West Bank's territory. The human impact of sewage discharged by Jewish settlements into the occupied West Bank is significant. Palestinian lands are severely polluted, which has prevented landowners from using the affected areas of their lands for agriculture or other subsistence purposes, and limited economic opportunities (**Figure 7**). In addition, prolonged exposure to sewage has serious health effects on the local population (**Figure 7**).

"He [a Palestinian farmer] *says his land was once a paradise. Today, it has become a wastewater swamp, due to the sewage that runs from the illegal settlement of Leshem nearby. We can no longer reach our land, nor can we harvest the olives. The settlement sewage water has drowned the land completely"*[113] (**Figure 7**). Not to mention the settlers' assault on the olive groves of the indigenous Palestinian population and the cutting down of millions of olive and other kinds of trees since Israel occupied the West Bank in June 1967[114–116], which can be described as "environmental genocide." Recent works have suggested that settler colonial genocide has often been enacted through "ecocide"[117,118].

3.6. Impacts of wastewater treatment and reuse (WWTR) in the Arab world

Wastewater treatment and reuse has several impacts, including socioeconomic, environmental, and health-related benefits. WWTR offers economic value by saving significant additional volumes of freshwater, and contributing to the conservation of freshwater resources. Other socioeconomic benefits of WWTR include employment of professionals, training and capacity building in WWTR-related areas, and producing more crops for internal (local) and external (export) consumption. Additionally, WWTR provides nutrient-rich water for irrigation, and reduces the need for chemical fertilizers. Environmental benefits of WWTR include reducing pollution of water resources and sensitive receiving bodies, and controlling saltwater intrusion through groundwater recharge. Since mineral and organic trace substances and pathogens in wastewater represent a public health risk, wastewater treatment eliminates this risk by appropriately treating wastewater for intended reuses.

However, WWTR comes with many challenges, limitations, problems, and restrictions, which include:

1) The rate of treated and reused wastewater is still very low to low in all of the Arab countries (**Table 2**).

2) Many wastewater treatment's plants are poorly maintained and are operating beyond their design and load capacity.

3) Insufficient information on the status of reuse and disposal of different forms of wastewater and their associated socioeconomic, environmental, and health-related impacts. Even when the information on WWTR is available, there are large variations in the evaluation of the wastewater's status, which are due to the different criteria used and applied.

4) There are costs associated with specific WWTR systems; however, analyses are usually limited to financial viability.

5) Perceived high cost of developing wastewater collection networks and wastewater treatment plants and facilities varies from site to site, and depends on the infrastructure needed, the quality of wastewater collected, and the expected quality of wastewater treated.

6) Other factors include centralized and decentralized treatment options, degree of treatment, and intended end reuse options and transportation options for treated effluents.

7) Lack of mechanisms to treat and reuse wastewater for cost recovery, including a commitment to support wastewater treatment programs. Besides, the availability of untreated wastewater makes it difficult to convince farmers to pay anything for treated wastewater that is not of high quality.

8) The failure of Arab governments to advocate and support comprehensive wastewater treatment programs, which has resulted in a lack of public understanding of the perceived environmental benefits of wastewater treatment and reuse of reclaimed water.

9) End users are skeptical about the quality of the reclaimed water and, therefore, people still prefer the use of freshwater over wastewater, regardless the level of treatment.

10) Water pricing must take into account the value of water scarcity. This aspect is of a particular importance in the agricultural sector, as well as for the domestic use due to the fact that large amounts of freshwater are lost yearly. The price of freshwater delivered to farmers does not even reflect the cost of the water supply. Therefore, there is incompatibility between water pricing and water scarcity.

11) Because wastewater is collected far from urban areas, households do not realize the benefits of WWTR amid severe water scarcity.

12) Governments find it easier to collect connection and sewage service fees than ultimately treating wastewater.

13) Inefficient irrigation and water management systems undermine the potential for reusing treated wastewater. Management schemes often do not consider the potential of reclaimed water as a resource that can be used for irrigation, environmental conservation, and other purposes, such as groundwater recharge and municipal, recreational, and industrial utilizations.

Further details on WWTR advantages, disadvantages, challenges, constrains, restrictions, and limitations can be found in, just to mention a few references[23,51,98,100,119–124].

4. Conclusions and recommendations

Competition for freshwater resources will escalate more than ever. The world, as a whole, during the past few decades until now has been going through a very difficult and critical situation, regarding freshwater stress, scarcity, and shortage. This is due to various factors, including, amongst others, climate change impacts (such as higher temperatures, higher rates of evaporation, lower rates of precipitation, floods, droughts, etc.); population growth (the current world's population has reached more than 8 billion, and is expected to reach 8.6 billion by 2030 and 9.8 billion by 2050); economic growth; industrialization; and urbanization, as well as due-resulting impacts, such as air, water, and soil pollution; and geopolitical instabilities, worldwide. These dynamics have already led to an increase in the consumption of water, energy, and food resources, which have led scientists, policy-makers and strategists to focus on the relationship between water (W), energy (E), and food (F), in terms of WEF Nexus, as a saving tool, regarding the three components or subsystems, and conservation of natural resources.

Due to freshwater stress, scarcity, and shortage, as a result of the reasons mentioned above, the Arab countries should seriously consider the issue of wastewater treatment and reuse as a strategic option, in order to be used in various sectors and applications, including agriculture, industry, and others to save freshwater resources. This is with consideration of the following factors:

1) Approximately 13.2 billion cubic meters (BCM) of wastewater is yearly produced in the Arab countries, of which 5.7 BCM (43.2%) is treated and 7.5 MCM (56.8%) is untreated, and thus dumped into land and sea open environments.

2) As it is roughly estimated, only about 47% of treated wastewater is reused in the Arab countries.

3) Regarding the Occupied Palestinian Territories (OPT), where more than 87% of its fresh water resources are controlled and forcefully taken by the Israeli occupation authorities, Palestinians discharge large amounts of untreated wastewater into open lands (as in the case of the occupied West Bank) and into the Mediterranean Sea (as in the case of the occupied and besieged Gaza Strip).

4) The reused portion of treated wastewater in the OPT is close to zero.

5) Palestinian farmers are encouraged to reuse more treated wastewater for agricultural irrigation; meanwhile Palestinians must enhance and strengthen their claim for their full water rights with regard to all water resources in the Occupied Palestinian Territories.

6) Those responsible for treating and reusing wastewater in the Occupied Palestinian Territories and other Arab countries must follow international standards and guidelines, especially those issued by the World Health Organization (WHO) of the United Nations[125,126].

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Declarations

Ethical approval: This paper was not published before and is not considered for publication anywhere else. Human/animal rights' statement: The research presented herein does not involve human participants and/or animals. Consent to participate: No individual participants or material were involved in the research presented in this paper and, thus, there is no need to obtain informed consent. Consent to publish: All material presented herein does not need consent to publish. Funding: The research presented in this paper did not receive any funding from any individuals or organizations. Availability of data and material: All the data and material used for the purpose of this work are provided in the paper.

Conflict of interest

The author declares no conflict of interest.

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