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Treated wastewater for meeting challenges of climate change in arid regions

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ABSTRACT: *This paper focuses on treated wastewater in addressing the impacts of climate change on water sources, especially in arid and semi-arid regions that suffer anyway from water scarcity. Jordan with its severe water situation is expected to be defenseless to climate change effects taking into account the unbalance between available water resources and urgent demands. The paper helps in assessing treated wastewater as an effective adaptation measure to cope with water scarcity in Jordan and to consider it as an integral part of the national water budget. Wastewater is a promising alternative to cover the shortage in water supply in regions where severe drought is an anticipated effect of climate change, also to provide water of good quality to secure drinking water for the population, at the same time to increase the efficiency of the uses of the available water sources. Jordan has 36 wastewater treatment plants in operation scattered throughout the country and producing about 430,000 CM/day of reclaimed wastewater. According to the reports Ministry of Water and Irrigation, more than 85 percent of this water is of in full compliance to the quality required for irrigation of field crops and forest trees according to JS 893/2006.*

KEY WORDS: climate change challenges, water resources, treated wastewater, arid and semi-arid regions.

INTRODUCTION

Climate change is no longer a science imagination to predict dangers that may threaten the environment and all forms of life on Earth. Rather, it is a realistic fact that the earth is heading towards a climate and environmental disaster. The negative effects of climate change has been reported by several research studies since modern technological tools enabled researchers to monitor the transformation of greenhouse gases (GHG) in the atmosphere and followed the changes of global temperature [Isobe 2013; Moss et al. 2010; Parry et al. 2007; Seinfeld and Pandis 2006]. In addition, Intergovernmental Panel on Climate Change reconfirmed the phenomenon by long-term observation through relevant indicators such as temperature, greenhouse gases (GHGs) concentrations, unusual meteorological events, sea level changes, sand storms and hydrological cycle variations. Despite the presence of natural and other anthropogenic causes of climate change, the role of human activities is clear in the emergence and exacerbation of this environmental problem [IPCC 2013].

The climate change is recently considered one of the most important global phenomena because of its significant impact on natural and water resources, especially in dry and semi-arid regions of the globe that suffer anyway from chronic scarcity of water resources. The countries of the Middle East and North Africa (MENA) are asked to intensify efforts to enhance partnership with various local and international sectors to confront the effects of climate change that present challenges on the world in general and the water reality in these regions in particular. The shortage of fresh water in the MENA countries represents a real threat to economic growth, social unity, security and political instability. Predictions expect that the changes in global climate are likely to affect the natural hydrological cycle, impact surface-water levels and slow groundwater recharge to aquifers and raise global temperatures causing several related impacts on natural socio-ecosystems.

The expected climate changes will have an inevitable results such as changes in precipitation (temporal and spatial) and evapotranspiration rates that are particularly important because they directly affect groundwater recharge and indirectly affect groundwater withdrawals or discharge. Even small changes in precipitation may lead to large changes in recharge rates in some semi-arid and arid regions [Woldeamlak et al.2007; Rajsekhar and Gorelick 2017]. A study, showed that a 15% reduction in precipitation, even with no change in temperature, could lead in a 40–50% reduction in groundwater recharge rates [Sandstrom,1995]. Today, climate change may account for approximately 20% of expected increases in water scarcity on earth [Sophocleous 2004]. These reductions in water resources will lead to social and economic consequences that are difficult to address and overcome. Because water is vital for food processing, energy production, manufacturing, navigation, land use, and recycling. it is therefore, difficult to maintain a balance between all human needs, as there is a constant shortage of water sources. For example, it is expected that if the temperature increases, there will be an increase in the water requirement of crops by 5 to 8% by the year 2070, which must be compensated by the use of water in the energy sector, and thus threatens the possibility of energy production. In addition, the shortage of water sources contributes to the increase in water prices, through monthly water bills or water delivery services. The predicted temperature rise will, furthermore, increase evaporation and evapotranspiration, and decrease groundwater recharge and surface runoff [Bates et al.2008; Vargas-Amelin and Pindado 2014; Gosling and Arnell 2016].

Jordan’s area is 89.3 thousand km^2, three-fourths of which is desert receiving less than 200 mm of rain. The population of Jordan increased from 5.7 to 10.07 million people within 14 years from 2005 to 2019, including forced migration fluxes that brought 2.5 million people from neighboring countries. Projections indicate that the expected number of people living in the country will reach 10.61 million in 2025 and is expected to reach 12 million by 2035. Regional development and migration have increased pressure on Jordan's water resources.

Despite the small size of Jordan, it includes several eco- climate systems within its territory including: desert Ecosystem: covers approximately 75% of Jordan’s area. Scarp and Highlands Ecosystem, Sub-tropical ecosystem, Dead Sea Basin Ecosystem and Jordan River Basin Ecosystem, and the Gulf of Aqaba Ecosystem. Mediterranean climate prevails in the heights region of Jordan, where summer is moderate and dry and winter cold and rainy. The region affected by

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the Mediterranean climate has the highest rainfall, ranging from 600 to 1500 mm, rarely 2000 mm. The desert climate dominates in the Badia, where the summer is hot and the winter is cold and dry. The Jordan Valley area has a semi-tropical climate with a hot summer and warm winter [MWI 2016]. Precipitation is extremely variable among the different eco-systems and is confined largely to the winter and early spring seasons and ranges from over 500 mm in the highlands to less than 50mm in the Badia. The long-term average annual precipitation is ≈ 8224.6MCM [MWI 2016]. The high temperatures and low humidity in Jordan result in an extremely high evaporation rate with a long-term average of about 80 % -90 % of precipitation over the entire area of Jordan. Potential evaporation ranges from 1600 mm/y in the northern Highlands to more than 4000 mm/y in the southern and eastern desert.

The greatest environmental and socio- economical challenge that Jordan faces today is the scarcity of water. Jordan is a poor water country with a per capita water share of 130 m^3 / person / year as estimated by MWI in 2015 [MWI, 2016], which is expected to fall to 90 m^3 per year by the year 2025 far below the level of the globally accepted limit for water poverty. Water scarcity, according to the UNDP [Ross-Larson et al. 2006], occurs at 1000 m^3 /p/year and absolute scarcity at only 500 m^3 /p/year. According to the United National Development Program (UNDP), the "national threshold for meeting water requirements for agriculture, industry, energy and the environment" should be in the range of 1,700 m^3 / person / year [Ross-Larson et al. 2006].

The gap between supply and demand for water is widening and getting more difficult by potential impacts of climate change on the water cycle. Climate change raises the potential for low precipitation and high temperatures. Frequent droughts and high evaporation lead to poor recharge of water resources, reduce surface water reserves and may cause soil degradation and accelerate desertification. Climate change is expected to reduce annual rainfall by 4% to 27% of current levels, in conjunction with other factors such as rainfall intensity, frequency of rainfall and humidity. Increases in evapotranspiration due to higher temperatures will increase water required for irrigated agriculture and landscaping while changes in precipitation patterns may diminish the ability of existing water infrastructure to capture water.

Reuse of reclaimed wastewater is one of the most promising options in regions suffering from scarcity of freshwater resources. Properly and purposely treating wastewater has been considered as significant part of sustainable water management scheme [Marlow et al 2013]. In the past three decades, it has been observed a steady increase in the reuse of treated wastewater in various parts of the world [NWC 2011]. The investigations were very diverse, ranging from Wastewater reuse applications and advantages [Guest et al. 2009], treatment technologies and operational issues [de Koning et al. 20087; Venkatesan et al. 2011]; economics of water reuse [Daniels and Porter 2012] to its impacts on the environment, as well as impacts on public health and safety [Peterson et al.2011; Rose 2007].

Despite the large number of studies dealing with the reuse of treated wastewater for various purposes, just few papers observed the role wastewater in meeting climate change effects. By questioning the capability and trust worthiness of Jordanian wastewater production for reuse as an adaptive measure to climate change, this paper identifies a research topic designed to help Jordan progress in making the most appropriate use of the resource and was able to demonstrate that effluents of wastewater can be set as integral part of renewable water resources and the national water budget.

DISCUSSION

Water resources and future perspectives

In terms of water availability, Jordan ranks amongst the fourth lowest countries worldwide for water availability. The country suffers greater water scarcity than any other country on global basis, due to the interaction between low annual average precipitation and successive years of drought, and the country's complex hydro- and geopolitical context. Water is therefore the single most important natural constraint on social and economic growth in Jordan, and the optimal control of its allocation between regions, the timing of the allocation, as well as the quality and quantity of water have been critical development factors for many years. Water supply in Jordan relies mainly on resources, which are located at a considerable distance to consumers. Consequently, the water sector is considered as the largest in consuming energy by the operation of large water pumps, boosting, and treatment and distribution facilities.

The total available water per capita is 88 % and lies far below the international water poverty line of 1,000 m^3 per year. All available water resources are exploited and so far utilized. Many groundwater resources are over-abstracted, while demand for water is continuously and constantly growing. The sources of water in Jordan include traditional sources such as rain, surface water and groundwater, including non-conventional sources such as sewage treatment and desalination [JS 893/2006]. Moreover, climate change is expected to affect the country negatively as temperature increases while precipitation most likely becomes erratic [Abdulla et al.2009]. Decision makers are becoming increasingly aware of the opportunities that a sustainable use of groundwater resources may offer in the face of the uncertain consequences related to climate change. Therefore, a glimmer of hope strategy for the Jordanian government is to meet most of the water demand for the agricultural sector by producing more treated wastewater [Al-Omari et al. 2009].

Conventional water resources of Jordan

Surface water

Surface water comes from rivers, running springs and valleys, as well as flood waters in winter season, with an estimated quantity of 713 million m^3 distributed over 15 surface water basins [MWI, 2016]. Surface water of Jordan depends mainly on two main sources: rainfall on the territory of the country, and water originating in other countries that enters Jordan via cross-border Rivers. 28% of the country's total water supply relies on surface water resources. The country's three main rivers, the Jordan River, the Yarmouk River, and the Zarqa River, are a major part of the country's surface water system. However, the water supplies available in each of them became largely unreliable due to upstream diversion and over-pumping in Syria. In addition, Jordan is recognized as a semi-arid region and has a climate ranging from Mediterranean to arid, with approximately 80 % of the country territories receiving less than 200 mm of precipitation annually. Less than 4 % of the country receives over 300 mm, which is considered to be the minimum limit to grow wheat in the region. Jordanian agriculture is therefore heavily dependent on irrigation. According to MWI reports [MWI, 2015] the volume of annual rainfall for the period 2007–2020 is estimated to about 7480.3 million m^3, 93.26 % of it evaporated, while 4.36 % was infiltrated to the ground, and a small part 2. 36% appeared in the form of surface run-off. Surface runoff flows in Jordan was estimated in the range of 886 MCM divided into 386 as base flow and 500 MCM flood flow. A further development of surface water resources is not foreseen in near future.

Ground water resources

The Jordanian groundwater resources are distributed among 12 water basins, all of which are renewable, except for the Al-Jafr and Disi basins, which are considered non-renewable. Groundwater is considered the key source of water supply to the country and with priority given to supply population with drinking water. Regarding the quality, the Jordanian groundwater is of good quality. However, there are many potential sources of contamination groundwater including industrial and municipal wastes, excessive use of pesticides and chemical fertilizers in agriculture, and over-pumping far beyond the safe yield that may lead to the intrusion of saline water and the content of septic tanks in certain aquifers. Current exploitation of these groundwater resources is at maximum capacity, and for most aquifers exploitation is well above what is defined as a safe yield. At national level, it is estimated that the extraction of groundwater resources exceeds the safe extraction rate by over 50 percent (table 4). The long-term annual safe yield for has been estimated at around 326.5 MCM which equals to 4 % of the long term average of rainfall, while over-abstraction stands at around 223.1 million m^3 making a deficit of around 103 MCM/year. Well planned actions are immediately needed to reduce abstractions to self-sustaining levels. This can be done by a phased reduction in irrigation abstractions and the substitution of groundwater with treated wastewater as far as possible; sustained improvements in water use efficiency in irrigation; and the construction of alternative water sources to alleviate pressure on groundwater resources.

Groundwater of Jordan is of two types, renewable makes 95 % and fossil makes 5%. The main source of non-renewable groundwater is the Disi deep aquifer in the south of the country close to Saudi boundary. Annual abstraction is estimated to about 125 million m^3, enabling the aquifer to sustain this yield for 50 years. Water from the Disi aquifer is conveyed for use in the north of Jordan via the Disi-Amman conveyance system which supplies Amman district with potable water, a portion goes to Aqaba (14 MCM/year) for municipal and industrial uses and 51 MCM/year used for irrigation purposes.

Jordan relies mainly on groundwater to secure water supplies and with the reduction of groundwater resources, Jordan will be forced to use more expensive water sources, such as the (National Water Conveyor) project, the wider reuse of treated wastewater, desalination of salt water, and the use of surface water to fill the deficit. The lack of improved mechanisms in how Jordan uses its water, the steady increase in population and economic growth will increase water demand significantly, which is likely to be as high as 1,550 million cubic meters per year by 2025.

Challenges of groundwater resources

According to the reports data of MWI [MWI 2016], the depletion of groundwater basins. Six of the twelve are over-extracted, four are operating at capacity, and only two small basins are still underexploited. In order to cover the shortage between available water and demand, the water institutions the increases pumping even from drained and non-renewable wells. From Disi aquifer, about 100 million cubic meters of water are withdrawn annually for drinking water purposes. The Jafer basin is the other non-renewable groundwater resource in Jordan. It is anticipated that this aquifer can release 18 MCM/year over the next 40 years. This is another evidence of the urgent need to compensate for the shortfall in water extraction from these drained basins, especially since most of them are used to irrigate crops.

As reported by MWI, [MWI. 2016] from the total number of springs in Jordan, 361 are perennial, 23 are intermittent, and 195 are dry. These discouraging statistics about the state of the groundwater basins, which leads to their decline year after year, as the annual decline reached 5 meters annually, while some water basins recorded a sharp decline that reached 60 meters during the past 15 years. This caused the drying up of the main water layers in the northern regions and their salinization in other regions. On the basis of collected data for 117 wells, groundwater levels in the six basins were declining, on average about -1 meter per year (m/yr), in 2010. The highest average rate of decline, -1.9 m/yr, occurred in the Jordan Side Valleys basins. The highest rate of decline for an individual well was -9 m/yr. From 30 to 40 percent of the saturated thickness, on average, was forecast to be depleted by 2030. Five percent of the wells evaluated were forecast to have zero saturated thickness by 2030.

Table 1: Jordan water use (MCM/a) by sector according to the Ministry of Water and Irrigation reports. [MWI 2016]. Jordan water use (MCM/a) by sector according to the Ministry of Water and Irrigation reports.

Year	Domestic	Industrial	Agriculture	Total
2015	463 ≈ 36.2 %	112 ≈ 8.75 %	704 ≈ 55.04 %	1279
2020	517 ≈ 39.4 %	130 ≈ 10%	665 ≈ 50.7 %	1312
2025	652 ≈ 42 %	182 ≈ 11.7 %	716 ≈ 46.1 %	1,550

Table 1 gives a summary of the main sources of water for each key consumer category in Jordan. The biggest water consumer is the agricultural irrigation sector. Irrigation using surface water and treated wastewater is predominant in the Jordan Valley, while groundwater-based irrigation is characteristic of the highlands and eastern Badia. Groundwater contributes about 61% to the total water supply and forms 55% of total water used for agriculture, while surface water provide 105 MCM/year making 23% of the agricultural use. According to (MWI, 2016), 53.7% of total water use is directed for irrigation purposes, a major sources for irrigation water for the year 2014 is covered by treated wastewater reuse with a share of 25 % of agricultural water use.

Recent observations have reported a rapid increase in the water consumption for municipal use. The data indicates that municipal water consumption increased by an average of 8% per year while it ranged 6.6% and 3% within the industrial and agricultural sectors respectively. This fact has resulted from the increasing population in the urban areas and the greater water requirements due to raised standards of living, migration and regional development. Increases are expected to continue in future as urban populations getting higher and consequently claim more water to meet their needs. The observed average consumption per capita in the municipal sector reaches 138 l/day compared to 147 and 145 l/day/capita in 2010 and 2011 respectively. As reported by Ministry of Water and Irrigation [MWI 2014], municipal water use reached 313.4, 330.0 and 330.1 MCM in 2009, 2010 and 2011 respectively, which equals a share of 144,147 l/capita/day and 150 l/capita/day in these years respectively.

Non-conventional water resources

Non-conventional water resources are considered as potential water supply options, these include treated wastewater, desalination of sea and brackish water and to miner importance water harvesting or importation of water across boundaries.

Desalination of salt water

Salt water desalination is one of the options offered to solve the intractable water problem in Jordan. However, it is associated with the high energy cost, which constitutes a major obstacle to the expansion and development of this option. There are currently 27 private desalination plants under operation located in the Jordan Valley with a production capacity of 1,000 m^3/h used for irrigation purposes. Six desalination plants have been operated for drinking water purposes in separate areas (Abu Zhigan, Al-Rishah, Al-Ruwaished, Gaza camp and in Zarqa) managed and operated by the Ministry of Water and Irrigation. The total production capacity of these plants is estimated at about 5,500 m^3 / hour, mostly used for drinking water (Ministry of Water and Irrigation, 2021). More than 50 brackish water desalination plants have been installed by farmers in the Jordan Valley and Dead Sea area for irrigation purposes. In all plants, reverse-osmosis technology is applied. The plants' capacities are 360 to 2400 m3/d. The total water abstracted is about 11.7 MCM, whereas the total desalinated amount reaches 7.7 MCM and the brine discharge is about 4.1 MCM. Brackish water, having salinity between 1300 and 7000 ppm with an average of 3150 ppm. Desalinated waters have a salinity between 50 and 800 ppm, averaging 195 ppm. The only energy source used to run these plants is the electric power grid. The average investment cost per cubic meter for the installed capacity of the desalination plants ranges between $124/ ($m^3$/h) for small plants and $63.5/ ($m^3$/h) for large plants; with an average of $89/ (m3/h). The average desalination cost is ranging from ($0.33/m3) per cubic meter for large plants and $0.48/m3 for small plants. This figure does not include any water pre-treatments, storage costs or brine disposal costs as they vary from one source to another, and the required energy has been estimated at 1.9-3.2 kWh/m^3 of water produced depending on the quality of the raw water flow and the TDS required from outflow [Qtaishat et al., 2017].

Rainwater harvesting (RWH)

RWH continues to receive increased attention worldwide, as a non-conventional resource gained with simple and cost-effective technologies, to enhance water supply in water-scarce regions. The main drawbacks of RWH systems being associated with high initial cost, maintenance requirement, and the unpredictable rainfall. Also, with regard to infrastructure for practicing RWH, it is not prepared at the national level, so the feasibility may be reasoned at the individual level, but it has little impact on the national level. A public questionnaire revealed that 46% of people do not have rooftop rainwater harvesting largely because of the high costs of storage tanks [Abu-Zreig et al. 2019].

Treated Wastewater reuse

Being the most important alternative to enhance the water supply potential, treated wastewater will be the focus of this research.The phenomenon of water scarcity in Jordan forced concerned institutions to conserve water by providing non-conventional water supplies to cover the demands of agriculture. However, several challenges have still to be defeated in terms of wastewater treatment and reuse such as quality aspects, public acceptance, hygienic issues, institutional and legal aspects. Given the constant shortage of water resources, Jordan has seriously practiced the use of treated wastewater for irrigation purposes. In 2014, over 128 million m^3 of treated wastewater effluents were used for irrigation, representing about a quarter of all water used for irrigation in Jordan. Despite the overall success of this non-conventional water source, many questions have therefore emerged about the quality of the wastewater being released for irrigation purposes. Some of the wastewater treatment plants are overloaded organically as well as hydraulically, with rates reaching two or three times the design capacity, which suggests that the plants cannot achieve the desired treatment standards, and/or that the excess sewage is being diverted into by-pass channels without being treated, especially in winter seasons. However, mixing it with freshwater may help to dilute pollutants and improve the quality of the water and to overcome quality preservations arisen.

Table 2: A summary of the main sources of water for each key consumer category for year 2014 [MWI, 2016].

Source	Consumer sector				
	Domestic	Agriculture	Industry	Total	% of share
Surface water	103.8	150	4.8	259	26.6
Ground water	325	231.3	32.2	589	60.6
Treated WW	0	123.3	1.7	125	12.8
Total used	429	505	39	973	100
Sector share	44.1 %	51.9 %	4 %		

In the case of domestic (urban) use, over three-quarters of all water supply is groundwater based, about 50 % of which originates from non-renewable deep fossil sources. Industrial water use is about 4.4 percent of overall water consumption, mainly came from groundwater sources.

Table 3: A summary of expected available sources of water and total demand required in years 2015 – 2025 given in MCM [MWI,2016].

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Σ avail.resources	992	992	1027	1034	1054	1082	1165	1237	1251	1253	1459
Σ sust.resources	832	836	875	886	920	942	1030	1106	1125	1131	1341
Σ demand	1401	1403	1412	1442	1448	1455	1485	1493	1503	1536	1548
Σ Deficit*	409	411	385	408	384	373	320	256	252	283	88

* with over extraction

As per table 3, the projected water amount which will be needed in 2025 is around 1548 MCM/a, while the maximum available and sustainable amount will be in the range of 1341 MCM making a deficit equals 207 MCM/a. Estimates predict that this number may reach 250 due to the effects of climate change [Sophocleous 2004; IPCC 2013]. It is to stress that, if current domestic, agricultural, and industrial water consumption practices are not improved, the water supply in Jordan will deteriorate in quantity and quality with time, so that maintaining a balance between demand and supply will become a serious challenge very soon and will probably become even more difficult in the future.

The water demand in Jordan is growing very rapidly. The portion of the quantity of the potable water is increasing on the account of irrigation water, while water resources budget is constant giving signs that the country will face water deficiency in near future. A reliable way to secure the required water for irrigation is by collecting and reclaiming each drop of water used. Highest priority should be given to guarantee hygienic standards without having adverse effects on the environment. Wastewater treatment in Jordan should aim to produce wastewater that is suitable for reuse for irrigation in accordance with WHO and FAO guidelines as a minimum. Irrigated crops must be chosen carefully, taking into account the quality and characteristics of the water, the soil, its physical and chemical properties, and the potential cost. In addition, climate change will result in reduced rainfall and increased temperatures, which means a further reducing of availability of water for drinking, household uses, and for agriculture. In respect to recent report studies, a rise in mean temperature between 3.1°C to 5.1°C by the end of year 2100, a likely decrease in precipitation from 15 to 21% in the majority of the country will be expected [MoEnv.2014].

Jordan operates more than 36 wastewater treatment plants (capacities ranging from 200 – 300,000 m3/d) scattered throughout the country and producing about 430,000 m3/d of reclaimed water. In regards to quality, 85 percent of effluents are of a quality satisfied quality requirements for irrigation of field crops and forest trees according to the Jordanian Standard No. 893/2006 [JS 893/2006, Ibrahim 2019]. As for the remaining 15% of the wastewater effluents, which showed excesses in constituents exceeding the limit allowed by the JS 893/2006, each case should be taken individually and the excesses should be treated, if effluents have to become a part of the reuse scheme. Processed wastewater is currently being used according to local Jordanian standards (JS 893/2006), which is mainly dependent on WHO, Food and Agriculture Guidelines FAO.

Two factors combined enhance the importance of treated wastewater is that the current amount of effluents is likely to increase as sewage collection systems extend to all areas, particularly communities under 5,000 inhabitants. It is to pinpoint that 48 % of the generated wastewater from domestic use does not reach wastewater treatment plants due to the fact that only 62 % of residential areas in Jordan are connected to the sewer network systems, while the remaining still use cesspools as an alternative. Future governmental approaches to increase the number of residences and dwellings connected to the sewage system in some areas, while in others, particularly in hilly or rural areas, a better option is to adopt decentralized wastewater treatment plant. The decentralized approach to wastewater collection and treatment offers new means of addressing wastewater management.

Treated wastewater will play a promising and vital role in addressing climate change and countering its negative impact on water resources in Jordan.Wastewater treatment plants are scattered all over Jordan, giving this water a unique advantage in reducing the effects of rainfall interruptions, as it is easy to meet the needs of crops, especially those located near wastewater treatment plants and valleys that receive treated wastewater discharges.

The significance of treated wastewater in addressing the adverse effects of climate change is compounded by the fact that if wastewater is to be considered as part of national water budget with high efficiency, it is necessary to take necessary measures taking into account the conditions that cause climate change and know how to mitigate them. Agricultural production is closely dependent on climate, making agriculture one of the most climate-sensitive of all economic sectors. According to [Al-Bakri et al. 2010], a 2°C increase in temperature and 20% decrease in precipitation will decrease wheat yield by 21%, 35% for barley, and 10% for tuber and root crops [NRC 2011].

According to the National Water Strategy of Jordan, [NWS, 2016–2025] , the annual quantities of water entering and leaving wastewater treatment plants for the year 2019 range between 168.4 and 156.5 MCM/a. The collected data demonstrated that from the 36 WWTP under operation, there are 11 WWTP in the Northern Governorates, 12 in the Middle Governorates, and 13 WWTPs in southern governorates. Almost 90% of the wastewater is generated within the middle governorate, where most of Jordanians are living and around 85% of irrigation practices occur.

The National Water Strategy [NWS, 2016–2025] recommends that wastewater should be considered an important and integral part of the water system as a reliable source of water. Treatment of wastewater shall be directed towards producing effluents of a quality for reuse in irrigation that meets requirements the Jordanian standards for reclaimed domestic wastewater (JS 893/2006), which is based mainly on the guidelines of the World Health Organization (WHO) and Food and Agricultural Organization (FAO). Regarding the irrigation of crops the JS 893/2006, identifies four categories: A, B, C and D. Category A related to the irrigation of vegetables that are normally cooked, parking areas, sides of roads inside cities, and playgrounds. Category B included the irrigation of fruit trees, green areas, and sides of roads outside the cities. Category C specified the irrigation of industrial crops, field crops, and forest trees, while Category D related

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to the irrigation of cut flowers [JS 893/2006]. In order to efficiently manage the issue of wastewater reuse, appropriate treatment technologies must be selected, taking into account operating and maintenance costs and energy savings, in addition to their efficiency in achieving and maintaining quality standards. Priority is given to agricultural reuse of treated wastewater for unrestricted irrigation. To achieve this, treated wastewater should be mixed with fresh water to improve quality wherever possible. The crops to be irrigated with treated water or mixed with fresh water sources are selected in proportion to the irrigation water, soil type, chemistry and economics of reuse. Another factor which enhances the importance of treated wastewater for increasing water resources is that, in Jordan, Wastewater collection and drainage networks are relatively new, about 63 of population are served and the rates of connection to sewage collection networks ranged from 55 – 72 %, treatment plants are spread throughout, sometimes in the middle of agricultural lands and close to valley paths, so that it is easy to transport water wherever it is needed.

CONCLUSIONS

Increased pressure on water resources due to population growth, urbanization, water resources pollution and recently climate change impacts is raising interest for wastewater reuse, in arid or semi-arid areas.

In Jordan, it is predicted that climate change will result in reduced rainfall, increased temperatures, more frequent droughts and more extreme weather events. These changes will negatively affect all social and economic sectors, especially the existing fragile water systems (e.g. less recharge and replenishment of surface water and groundwater reserves, groundwater depletion and salinization, desertification) and the agricultural sector. Climate change is expected to reduce annual rainfall by 15% to 21% of current rates, rainfall intensity, and frequency of rainfall and humidity, which means a further reduction of naturally available and renewable water resources. The current deficit of 207 MCM/a of water resources is expected to reach 250 MCM/a.

Generally, rainfall amounts and climatic conditions of the country do not support good rain fed agriculture, except for few areas in the northern and western highlands. In addition, climate change, through higher temperatures, land and water scarcity, flooding, drought and displacement, all negatively impacts agricultural production and cause breakdown in food systems. In Jordan, treated wastewater is therefore crucial to sustainable development through provision of low-cost, drought-reliable and with accepted quality water supplies for non-drinking purposes.

The reuse of reclaimed wastewater has the potential to significantly increase the total water resources available in the country, covering more than a quarter of the needs of agriculture. Treated wastewater is a widely distributed resource responding at basin scale; therefore, it could offer significant untapped water supplies, particularly in areas facing water shortages. But this resource is affected by local users and polluters (municipalities, industrial enterprises and farmers) whose behaviors are greatly influenced by national policies determining land and water use.

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