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Wastewater treatment and reuse in Jordan, 10 years of development

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ABSTRACT

Water reuse is considered as one of the available options to overcome the problem of water scarcity in Jordan. The overall objective of this study is to evaluate the performance of wastewater treatment plants in Jordan and assess the suitability of reclaimed water for different purposes and the development in wastewater treatment for the period between 2008 and 2018. Data were collected for 32 treatment plants. Results revealed that out of 32 treatment plants, 31 are operated below the hydraulic load, therefore, there is an opportunity for treatment of additional 180,000 m^3/d of wastewater. Locally wastewater was classified as a very strong waste, it contains valuable nutrients reached 123, 22.5, and 10.69 ton/d of total organic carbon, total nitrogen (TN), and total phosphorus; respectively. The performance of the plants can be ranked according to the number of indicators that violated standards ranged from the lowest Wadi Musa to the highest Tall Al-Mantah. About 80%, 77.79%, and 76.9% of the treated wastewater comply with the performance standards limits of total suspended solids (TSS), biochemical oxygen demand (BOD) and chemical oxygen demand (COD); respectively. Only four plants showed positive values of summation of water quality index, and based on summation of weighted water quality index (ΣWWQI), the most suitable reuse category is irrigation type C followed by, discharge to Wadis, irrigation type B, irrigation type A, groundwater recharge, while cut flower purpose has the lowest ΣWWQI. Total dissolved solids and NO_3 are the lowest violated indicators followed by NH_4, while *Escherichia coli* is the highest violated indicator followed by COD, BOD, TSS, TN, and PO_4. Construction of new treatment plants, extension and development of the existing ones, in addition to reallocation of the treated wastewater for the most suitable purposes such as constrained agriculture and artificial groundwater recharge are recommended.

Keywords: Wastewater; Reuse; Treatment; Irrigation; Reclaimed water

1. Introduction

Water scarcity is driven foremost by the arid to semiarid climatic regime in Jordan. In the last decade almost 92% of the country area received an average precipitation of less than 200 mm/y. Climatic records indicate that precipitation has decreased around 20% over the last eight decades [1]. On the other hand, water consumption in Jordan is briskly incrementing comparatively with water supply and production. This is attributed to an ever-increasing population growth from 0.58 million in 1950 to 9.53 million in 2015 [2], the unprecedented influx of Syrian refugees, improvements in living standards, and growth in economic activity. In addition, erratic rainfall patterns and more intense and longer droughts have been observed over wider areas since the 1970s [3,4]. The entirely aforementioned causes aggravate the risk of water deficit. Subsequently, an unremitting imbalance between the

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total sectoral water demands and the available freshwater supply is currently prevailing. The National Water Strategy developed in 2016 stated that the total water demand in the country in 2016 was 992 MCM vs. 1,401 MCM total water demand per annum. This increase in water demand combined with the limitation of water resources lead to amplify the importance of developing new water resources [5].

The growing rate of water consumption by different uses consequently increases the generated amount of wastewater. Reclamation of wastewater needs processing for treatment and reuse according to certain standards and specifications. The reclaimed water is an important resource as unconventional water contributes to improving environment and protecting public health [6]. The urban and rural areas in Jordan have sanitation coverage approaches 93% out of which 63% are connected to sewer system till the year 2014, and this is anticipated to increase to 80% by the year 2030. The rest use septic tanks as on-site sanitation alternative [7].

The Water Authority of Jordan associated key objectives through Jordan's Water Strategy (2016–2025) to prioritize the water use by ranking municipal water needs on top of the list, followed by the economic activities, and the irrigated agriculture as the lowest priority without affecting Jordan valley allocation needs. The water used for irrigation was reduced from 80% in 1970's to 60% in recent years owing to the diversion of most water resources to municipal usage. However, the National Water Strategy (2016–2025) paid attention to irrigated agriculture by considering blended treated wastewater effluent with fresh water as a substitute water resource and was added as contributor in water budget for reuse in agriculture [1].

The existing wastewater treatment plants in Jordan generated treated wastewater as an important water source for substitution and reuse. Owing to the fact that urban expansion extends above the Jordan Valley cliff, the majority of treated wastewater effluent discharged into Wadis to flow into the Jordan Valley for irrigation. Namely, the Ministry of Water and Irrigation (2016) reported that in 2014 the 32 central wastewater treatment plants discharged around 125 MCM of treated wastewater that were used after being blended with freshwater or in some specific areas directly. The aforementioned volume is expected to reach 240 MCM by the year 2025 [7].

The quality of treated wastewater effluents permitted to be discharged into Wadis or directly reused for irrigation purposes is defined by the Jordanian standards and regulations. Thus, a secondary level of wastewater treatment is a must, and specifications of reclaimed water quality as mentioned in the Jordanian Standards should comply with WHO and FAO guidelines for the safe reuse of treated effluent.

The suitable wastewater treatment and water substitution and reuse approach is indispensable for conservation of the natural environment, human health, and sustainable water resources, which seriously impact social and economic well-being. According to the water sector capital investment plan 2016–2025, the drainage from these sources in the catchment area and infiltration into groundwater recharge zone are assumed to be 70% (Around 50 MCM/y) [8] which confirms the importance of complying with relevant standards and specifications [1]. Therefore, the risk of pollution of water substituted should be seriously identified.

The overall objective of this study is to evaluate the performance of wastewater treatment plants in Jordan and determine the suitability of reclaimed water for different reuse purposes. Water quality index will be determined for each plant and each reuse purpose. Also, this study aims to assess the development in wastewater treatment sector during the last 10 y in terms of treatment performance, amount of reused water, and its quality.

2. Methodology

2.1. Data

Data of wastewater treatment plants, description, method of treatment and flow discharge were obtained from the Ministry of Water and Irrigation (MWI) report of 2019. Monthly data of the characteristics of wastewater effluent from each plant is available in the form of monthly reports of MWI 2019. The data include the concentrations of: pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS), NH_4, NO_3, PO_4 and *Escherichia coli*.

2.2. Regulations

According to the design criteria, most of wastewater treatment plants should achieve a limit of 25 mg/L for both indicators BOD and TSS and 60 mg/L for COD. Performance of the treatment plants was evaluated based on these limits. For water reuse, water quality was assessed according to many guidelines which control the quality of treated wastewater based on reuse purposes. Namely they are Jordanian standards for reclaimed domestic wastewater (JS 893-2006) that include the following:

- Guidelines for water discharge to Wadis and water courses.
- Guidelines for water reuse for groundwater artificial recharge.
- Guidelines for water reuse for irrigation: cooked vegetables, parks, stadiums and roads sides within cities (irrigation type A).
- Guidelines for water reuse for irrigation of fruit trees, road sides outside the cities, and green areas (irrigation type B).
- Guidelines for water reuse for irrigation of cereal crops and forest trees (irrigation type C).
- Guidelines for water reuse for irrigation of cut flowers.

2.3. Development in wastewater treatment

Development in the performance of treatment plants and water quality were discussed based on a comparison with previous published data in 2008 [9]. Thus, development was evaluated using the following indicators:

- Compliance with performance standards and guidelines.
- Amount of treated wastewater.
- Suitability of water for reuse.

2.4. Calculations

Many aspects were calculated in order to inspect the performance and development of wastewater treatment plants for the period between 2008 and 2018. These aspects were as the following:

Removal efficiency (*E*) was calculated using the following formula:

$$E = \frac{\left(C_i - C_e\right)}{C_i} \times 100\% \quad (1)$$

Water quality index (WQI), and weighted water quality index (WWQI) of each plant was calculated according to Eqs. (2) and (3); respectively.

$$\text{WQI} = \frac{\left(C_r - C_e\right)}{C_r} \quad (2)$$

$$\text{WWQI} = \frac{\left(C_r - C_e\right)}{C_r} \times \frac{Q_i}{Q_t} \quad (3)$$

where C_i and C_e refer to the influent and effluent concentration of a certain quality indicator; respectively, C_r is the reference concentration or the standard limit of a certain indicator for a specific reuse category, Q_e and Q_t are the effluent from a certain plant and the total treated wastewater from all plants; respectively, as Q_e/Q_t represents hydraulic weight.

Performance of the plant was calculated and expressed as the summation of WQI (ΣWQI) and summation of WWQI (ΣWWQI) of all indicators. Similarly, the suitability of water of all plants for a specific reuse category was expressed as ΣWQI and ΣWWQI.

3. Results and discussions

3.1. Description of treatment plants

Presently, there are 32 treatment plants, most of them are using conventional activated sludge (AS) treatment method or modified AS such as extended aeration (EA), oxidation ditch (OD) and most of the waste stabilization ponds (WSP) plants were shifted to AS and only five plant are still using WSP. Table 1 shows in-operation plants in Jordan in 2018, applied technologies, design capacity and location.

The plants cover all governorates in Jordan distributed as 11, 12 and 10 in the northern, central, and southern region of Jordan; respectively. In terms of the plant size, Al-Samra (located in Hashemite area-Zarqa city) is the largest one which receives around 69% of the total raw sewage generated by 2.8 million inhabitants in Amman, Jordan's capital, and Zarqa city. It has been constructed in 1985 as WSP, shifted to AS in 2008 with new capacity of 267,000 m^3/d, and then extended to 364,000 m^3/d in 2012. The effluent from the plant is discharged to the main surface water course in Jordan (Zara River) thus causing significant deterioration in its water quality during the period 1985–2008 [11]. Recent reports indicated an improvement in the river water quality was noticed due to the improvement of the performance of Al-Samra treatment plant [12]. Most of the plants have been subjected to extension or modification during the last 10 y. MWI has a monitoring program of water quality for all plants.

3.2. Hydraulic load

The influents design capacity of all plants is about 673,000 m^3/d while the total current influents is about 493,000 m^3/d which indicates an opportunity for the treatment of additional 180,000 m^3/d of wastewater. The current hydraulic load percentage to the design load is shown in Fig. 1.

The hydraulic load for all plants with the exception of Salt are operated below the design capacity, of which 13 plants receive <50% and 21 plants receive <75% of their capacity. The 13 and 21 plants treat 7.9%, and 16.4%; respectively, of total wastewater in Jordan. Only 5 plants receive >90% of their capacity and treat about 9.7% of the treated wastewater. It is worth mentioning that the influent to the plants increased sharply in 2011 because of the Syrian refugees, and subsequently decreased gradually in 2017 when some of them returned home.

According to the Jordan water strategy 2016–2025, sanitary system is provided for about 63% of the population and it is expected to cover more than 80% in 2025 [7]. Currently, the treatment plants produce about 163.4 MCM/d used as follow: 26.1; irrigation inside the plant, 0.2; forestry, 1.9; landscaping, 131.4; discharge to Wadis and 3.8 MCM; industrial purposes [13]. Treated wastewater share about 12.8% of the total water resources, and will reach 240 MCM by 2025 representing 16% of water resources [7]. These figures show and buttress the importance of water reuse in Jordan water budget and the beneficial of providing an adequate treatment level and acceptable reclaimed water quality.

3.3. Wastewater strength

Wastewater is mainly composed of water together with relatively small concentrations of suspended and dissolved organic and inorganic solids. According to the concentrations of some indicators, wastewater strength as per the international classification is shown in Table 2 [14].

In comparison with the mentioned classification, it is clear that all wastewater generated in Jordan is classified as a strong waste in terms of BOD, total solids, TSS, TDS, total nitrogen (TN), total phosphorus (TP), and Cl^-. High strength of waste is attributed to the low water consumption per capita in the majority of regions in Jordan which is below 130 l/c.d [7]. High strength wastewater poses heavy operational load on the treatment plants and may cause shock to the biological system, subsequently the performance of the plants become deteriorated. In contrast, high content of organic, P and N may be considered as significant sources of nutrients in wastewater as will be discussed later.

3.4. Nutrients value in wastewater and biosolids

The calculated amount of nutrients in wastewater in Jordan either in the effluent treated wastewater or in the accumulated biosolid (sludge) are illustrated in Table 3.

Table 1
Main information of wastewater treatment plants in Jordan [10]

Name of the treatment plant	Year of construction/modification	Design capacity, m^3/y	Applied technology	Region
Al-Samra	1984/2008/2012	364,000	AS	C
South Amman	2016	52,000	AS	C
Wadi Esseir	1997	48,000	AL	C
Wadi Arab	1999	21,000	AS/EA	N
Al Baqa	1987/2000	14,900	TF	C
Shalalah	2012	13,700	AS	N
Aqaba New	2005	13,000	AS	S
Irbid	1987/2018	11,023	AS/OD + TF	N
Kufranjah	1989/2017	9,000	TF + EA/AS	N
Jerash	1983/under extension	9,000	AS	N
Al-Miradh	2011	9,000	AS/EA	N
Aqaba Old	1987	9,000	WSP	S
Azraq camp	2011	8,200	MBBR	C
Salt	1981/1994	7,700	AS/EA	C
Madaba	1988/2005	7,600	AS	C
At-Tafilah	1988	7,500	TF	S
Ramtha	1987/2004	7,400	AS	N
Mazzar	2014	7,060	AS	S
Mafraq	1988/2015	6,050	WSP/AL	N
Maan New	2009	5,772	AS	S
Tall Al-Mantah	2005	5,000	AS + TF	C
Jiza	2008	4,500	AS	C
Al Fuhais	1997	4,100	AS	C
Al Ekeder	2005	4,000	WSP	N
Abu Nusayr	1986	4,000	AS, RBC	C
Zaatari Camp	2011	3,500	MBR, TF	C
Wadi Musa	2000	3,400	EA	S
Al-Lajjoun	2005	1,900	WSP	S
Karak	1988	1,900	TF	S
Wadi Hassan	2001	1,600	OD	N
North Shouna	2017	1,100	WSP	N
Shoubk	2010	280	WSP	S

AS: Activated sludge; OD: Oxidation ditch; EA: Extended aeration; WSP: Waste stabilization ponds; AL: Aerated lagoon; TF: Trickling filter; MBR: Membrane biological reactor; MBBR: Moving bed bioreactor; RBC: Rotating biological reactor; C: Central region; N: Northern region; S: Southern region

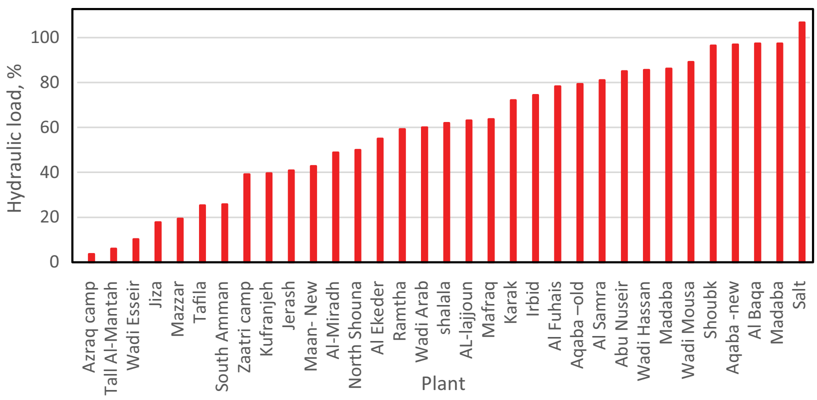

Fig. 1. Current hydraulic load percentage to the design load.

Table 2
Classification of wastewater strength according to the concentrations of some indicators [14]

Wastewater indicators	High	Medium	Low	Average data, 2018
BOD_5	300	200	100	758.5
Total solids	1,200	700	350	1,705
Total suspended solids	350	200	100	724.7
Total dissolved solids	850	500	250	1,050
Total Nitrogen-Nitrogen	85	40	20	97.5
Total Phosphorus-Phosphorus	20	10	6	25.6
Chloride	100	50	30	197

All units in mg/L.

Table 3
Calculated amount of nutrients in wastewater of Jordan in 2018

Indicator	Quantity in the effluent treated discharge, ton/d	Quantity in the sludge, ton/d
TOC*	9.6	113.32
N	7.7	14.88
P	3.2	7.70
Ca	17	6.54
Na	65	0.119
K	10.7	0.676
Mg	17.7	0.938
Zn	0.14	0.13
Total dissolved solids	313.7	NA

*Assumed TOC = 3 × BOD.

It is worth to mentioning that these results are based on theoretical calculations, and the actual amount may be less than these figures due to evaporation of some volatile organic compounds and other constituents. The amount of nutrients in the effluent water was calculated based on the concentration of each indicator and discharge data of 2018. For nutrients in the sludge, it is assumed that about 97% of wastewater in Jordan is treated by activated sludge technologies either conventional or modified ones. Sludge production rate for activated sludge ranged from 35–45 gSS/c.d for primary sludge, 25–35 gSS/c.d for secondary sludge and 60–80 gSS/c.d for mixed sludge [15]. About 63% of population in Jordan have a sanitary system indicated a total sludge production of 374 tons/d of which 156 of primary sludge and 218 ton/d of secondary sludge. It was assumed that the sludge nutrient contents of the dried matter for total organic carbon (TOC), N, P, Ca, Na, K, and Mg were 303, 39.8, 20.6, 17.5, 0.32, 1.81, 2.51 g/kg; respectively [16]. Regarding the calculation of the slurry sludge, a study displayed that the moisture content of the mixed sludge is about 96%–94%, while the dry solid is about 4%–6%. Based on assumption of 5% solid content, the rate of sludge production is about 7,484 m^3/d [17]. Another study showed that the sludge production in Jordan was 5,050 m^3/d in 2017 [18]. Table 3 shows that the treated wastewater and the generated sludge have huge amount of nutrients and can be considered a valuable source of organics, N, P and minerals. The presence of these nutrients in the treated wastewater should be considered in nutrient-water-soil budget. The high salinity (average TDS = 1,000 ppm) may affect the plant yield and the soil fertility.

3.5. Performance of the treatment plants

In most countries, performance standards of wastewater treatment plants are limited at least by two indicators: BOD and TSS. High BOD in the effluent water may causes oxygen depletion in receiving water and eutrophication phenomenon in lakes and rivers. Environmental hypoxia causes offensive odor, environment toxic for aquatic organisms and disturbing the ecological process. There is a strong relationship between the concentration of TSS and the presence of harmful bacteria and viruses which adhere to solid particles and transport through water. Also, the presence of TSS can adversely affect the performance of the disinfection process. In drip irrigation technique, TSS may close the drips, reduce in-pipe water pressure and affect water distribution. Many standards state that the treatment plants should achieve BOD, COD, TSS, TN, and TP limits of: 30, 120, 30, 15 and 1 mg/L; respectively, while stricter limits were determined for sensitive environment with limits of 20, 60, 20, 15, and 1 mg/L for the mentioned indicators; respectively [19]. Canadian performance standards for BOD, TSS, and the residual chlorine are: 25, 25, and 0.02 mg/L; respectively [20].

Figs. 2 and 3 below show the performance of 23 treatment plants in terms of BOD, TSS and COD in comparison with selected guidelines of 25, 25, and 60 mg/L for the related indicators, respectively.

The considered plants receive about 97% of the total wastewater generated in the country. It is clear that out of the 23 plants 7, 6 and 5 plants achieved BOD, TSS and COD performance standards.

Table 4 shows the percentage of water that meet the performance standards of TSS, BOD and COD.

It is clear that 80%, 77.79%, and 76.9% of the treated wastewater met the performance standards limits of TSS, BOD and COD; respectively. Also, it can be claimed that 11.2%, 19.6%, and 14.4% of treated wastewater have slight violations in terms of the aforementioned indicators, indicating total percentages of 91.2%, 97.4% and 91.3% of water are treated to the acceptable limits.

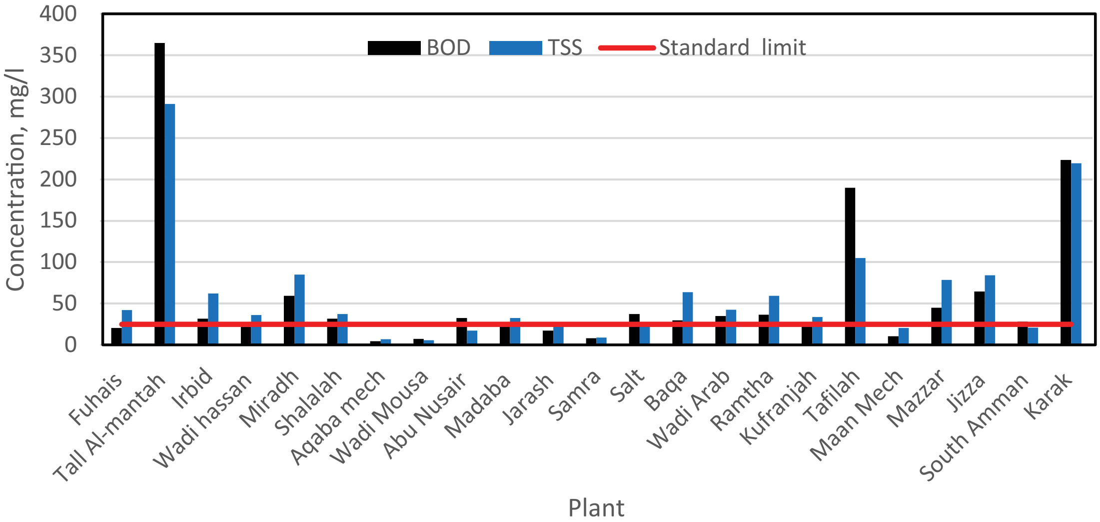

Fig. 2. Performance of the treatment plants for biochemical oxygen demand and total suspended solids in the year 2018.

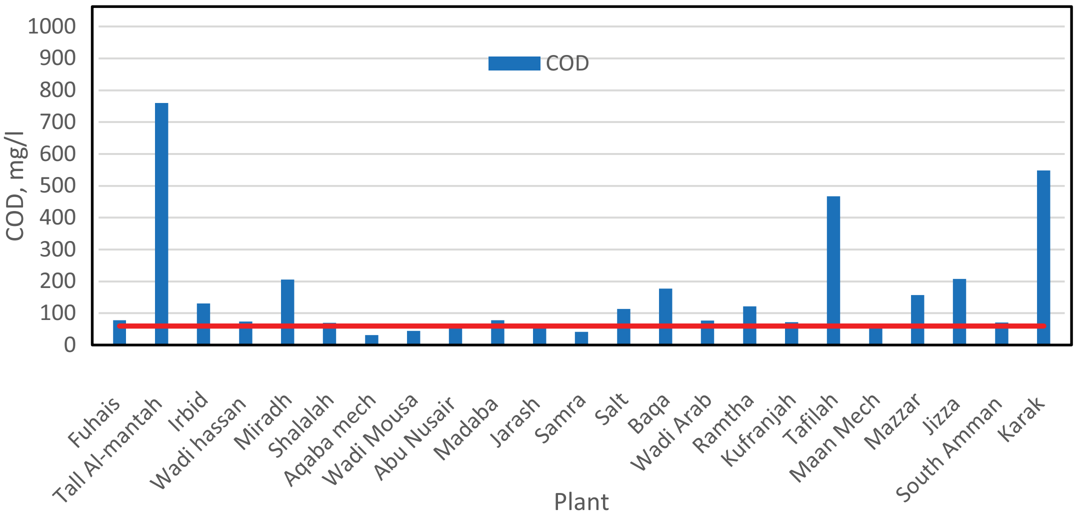

Fig. 3. Performance of the treatment plants for chemical oxygen demand in the year 2018.

3.6. Quality of the effluent discharge

Descriptive statistics of quality indicators of the treated wastewater are summarized in Table 5.

The effluent water quality varies significantly among the different plants with high standard deviation for most of the considered indicators. This difference is attributed to three indicators: the applied technologies, the availability of the treatment unit for a specific indicator and the operational conditions such as hydraulic and organic loads. The difference in treatment units include but not limited to the existence of infiltration unit, disinfection unit, digester, primary sedimentation, coagulation, maturation ponds, oil trap, and tertiary treatment units. For instance, some of the plants have no technologies for nitrogen removal which explains the high nitrogen concentrations in effluent water from Madaba and At-Tafilah plants. Also, technologies in use have significant effect on solid-liquid separation, where moving bed bioreactor has a high performance in comparison with other technologies. Disregarding the operational conditions, OD showed high efficiency in removal of most pollutants including *E. coli* bacteria. Although AS showed good removal efficiency of organic matter in terms of (BOD, COD), but low efficiency for TSS and *E. coli*. Trickling filter showed low effectiveness in BOD, and COD in addition to NH_4 and TSS removal.

3.7. Suitability of treated wastewater for reuse

3.7.1. Water quality index

While Jordan has rather limited options to compensate water scarcity, reuse of wastewater is considered an attractive valuable option. Table 6 shows water quality index for treated wastewater in selected 23 treatment plants.

Most of the plants have a high level of *E. coli* which affect the suitability of water for reuse. Plants showed positive values of ΣWQI are Wadi Musa, Aqaba New, and

Abu Nusayr, whereas four plants showed slightly negative ΣWQI namely (Al-Samra, South Amman, Maan New, and Jerash). In contrast, At-Tafilah plant had the lowest ΣWQI followed by Al Baqa, Karak and Shalalah.

According to the ΣWQI, the plants can be ranked as: Wadi Musa > Aqaba New > Abu Nusayr > Al-Samra > South Amman > Maan New > Jerash > Wadi Hassan > Mazzar > Jiz a > Miradh > Irbid > Madaba > Al Fuhais > Ramth > Salt > Ku franjah > Tall Al-Mantah > Wadi Arab > Shalalah > Karak > Al Baqa > At-Tafilah. WWQI represents the multiplication of WQI by the hydraulic weight (Qe/Qt), therefore the importance of water quality and its impact on water budget depends mainly on the plant's flow. Subsequently, the treated wastewater of the plants of high amount of flow have higher importance than that of less flow. ΣWWQI of some plants was close to zero, this is due to the low flow of the plant and/or low reclaimed water quality. The plants can be ranked according to ΣWWQI as: Aqaba New > Wadi Musa > Abu Nusayr > Maan New > South Amm an > Jerash > Al-Samra > Wadi Hassan > Jiza > Mazzar > Al Fuhais > Miradh > Madaba > Tall Al-Mantah > Irbid > Ram th > Kufranjah > Karak > Salt > At-Tafilah > Shalalah > Wadi Arab > Al Baqa. This result indicated that ΣWWQI could be used as an indicator of determining the significance of each treatment plant in contributing to water budget.

While ΣWWQI considers the hydraulic flow, ΣWQI depends only on water quality regardless of the plant's flow which explains the difference in the plants ranking for ΣWQI and ΣWWQI. In terms of irrigation types, water quality has positive WQI for irrigation type C only, while the other reuse categories have negative WQI. Based on ΣWWQI, the most suitable reuse category is the irrigation type C followed by the irrigation type B, discharge to Wadis, irrigation type A, groundwater recharge, while cut flower purpose has the lowest ΣWWQI.

Table 4
Percentage of treated water meet total suspended solids, biochemical oxygen demand and chemical oxygen demand performance indicators

Parameters	Concentration, mg/L	Percent of water meet the determined concentration, %
Total suspended solids	<25	80
	25–50	11.2
	50–100	8
	>100	0.8
Five-day biochemical oxygen demand	<25	77.8
	25–50	19.6
	50–100	1.68
	>100	0.93
Chemical oxygen demand	<60	76.9
	60–120	14.4
	120–250	7.94
	>250	0.76

3.7.2. Critical quality indicators

There are 23 treatment plants and six reuse categories which were supposed to indicate 138 factorials. The most critical indicator was determined based on a number of violations out of 138 factorials, where the higher value, is the higher critical indicator. Table 7 shows the matrix of the treatment plant, reuse categories and quality indicators.

Based on values in Table 7, it can be concluded that TDS and NO_3 are the lowest violated indicators followed by NH_4, while *E. coli* is the most violated indicator followed by COD, BOD, TSS, TN, and PO_4. In term of water quality, *E. coli* makes most of water is unfit for one reuse categories or more, while NO_3, and TDS are fit for all reuse categories for all plants. According to their violations, quality indicators can be ranked as (from the lowest violations): TDS, NO_3 > NH_4 > PO_4 > TN > TSS > BOD > COD > *E. coli* with 0, 1, 28, 43, 48, 57, 61 and 90 violations; respectively. It is worth mentioning that NH_4 is only limited for water reused in groundwater recharge, while there is no limit of *E. coli* for this purpose.

3.7.3. Critical treatment plants performance

The critical performance was evaluated based on two indicators: number of violations of quality indicators of

Table 5
Statistics of effluent water quality of treated wastewater in 2018

Indicator	Min.	Max.	Average	SD
E. coli	1.31	9,898,166	1,541,017	2,623,857
PO_4	0.8	43.6	15.11	9.90
T-N	5.85	231.10	51.43	50.35
NO_3	1.25	28.67	7.99	7.62
NH_4	0.57	169.85	45.37	43.04
Total dissolved solids	708.10	1,442.67	1,000.17	191.38
Total suspended solids	5.71	291.29	61.16	67.81
Chemical oxygen demand	31.96	759.71	161.20	183.36
Biochemical oxygen demand	4.34	364.71	58.77	85.47
pH	6.67	7.92	7.66	0.26

All units in mg/L, except *E. coli* in MPN/100 mL.

Table 6
Water quality index and WWQI for the treatment plants with various categories of reused water

Plant	Discharge to Wadi	GW recharge	Irrigation			Cut flower	ΣWQI (1,000)	ΣWWQI (1,000)
			A	B	C			
Al Fuhais	–116.8	–55,377	–1,214.0	–115.5	5.6	–110,756	–167.57	–1.097
Tall Al-Mantah	–2,369.1	–1,070,611	–2,3576	–2,357.1	–0.8	–2,141,104	–3,240.02	–2.340
Irbid	–103.8	–48,791	–1,070.6	–101.6	5.0	–97,582	–147.64	–2.890
Wadi Hassan	3.6	–260	–2.3	5.0	4.9	–522	–0.77	–0.003
Al-Miradh	–53.9	–25,053	–551.5	–50.6	4.0	–50,092	–75.80	–1.137
Shalalah	–4,315.4	–1,963,126	–43,186	–4,313.7	4.6	–3,926,223	–5,941.16	–121.484
Aqaba New	4.0	0.4	4.9	5.6	4.8	–3	0.02	0.001
Wadi Musa	5.9	3.1	5.4	6.4	5.6	–0.001	0.03	0.000
Abu Nusayr	4.8	–6.9	3.9	6.0	5.3	1.6	0.01	0.000
Madaba	–117.2	–55,269	–1,212.7	–116.1	5.0	–110,510	–167.22	–1.289
Jerash	3.4	–22	3.1	5.1	4.4	–47	–0.05	–0.001
Al-Samra	5.6	–1	4.6	6.0	5.4	–23	0.0024	–0.002
Salt	–1,087.9	–496,458	–10,919	–1,086	5.2	–992,902	–1,502.45	–26.765
Al Baqa	–6,130.1	–2,787,865	–61,331	–612	4.7	–5,575,699	–8,431.63	–240.770
Wadi Arab	–3,101.3	–1,411,288	–31,045	–3,099	4.8	–2,822,561	–4,271.09	–133.664
Ramtha	–327.3	–150,010	–3,298.4	–325	4.4	–299,996	–453.95	–5.191
Kufranjah	–2,311.0	–1,052,193	–23,145	–2,309	4.8	–2104375	–3,184.33	–21.157
At-Tafilah	–9,901.4	–4,499,201	–98,990	–9,895	2.9	–8,998,347	–13,616.33	–47.529
Maan New	6.2	–9.0	5.3	6.8	6.0	–24	–0.009	0.000
Mazzar	–5.0	–3,405	–74.3	–2.8	4.3	–6,765	–10.25	–0.030
Jiza	–8.5	–4,476	–99.0	–5.3	4.1	–8,921	–13.51	–0.023
South Amman	5.4	–9.8	4.3	6.4	5.7	–20	–0.008	0.000
Karak	–5,478.0	–2,487,461	–54,736	–5,469.9	2.5	–4,974,869	–7,528.01	–25.516
ΣWQI (1,000)	–35.39	–16,110.89	–354.42	–29.81	0.08	–32,221.34		

water reuse categories for one or more indicators, and percentage of water that violate one standard or more. Table 8 shows the suitability of treated wastewater for reuse.

Out of 138 factorials, Tall Al-Mantah plant violated 30 indicators, while Al-Samra, and Mann plant violated five indicators, and Wadi Musa plant has the lowest number of violations with two violated indicators only. The performance of the plant can be ranked according to the number of the violated indicators ascendingly as: Wadi Musa > Al-Samra > Maan New > Aqaba New > South Amman > Abu Nusayr > Wadi Hassan > Al Fuhais > Kuf ranjah > Jerash > Wadi Arab > Salt > Madaba > Irbid > Al Baqa > Ramtha > Al- Miradh > Shalalah > Mazzar > Jiza > Karak > At-Tafilah > Tall Al-Mantah. As shown in Table 8, all plants violated one reuse standard or more which indicates that none of the plant has water quality suitable for all purposes. In terms of reuse categories, Tall Al-Mantah, At-Tafilah, Karak and Aqaba New violated one or more standards and their water is not suitable for any of the regulated reuse purposes. In contrast, effluents form Maan New, Wadi Musa, Al-Samra and South Amman plants comply with four standards and suitable for three types of irrigations (irrigation types A, B, and C).

Regarding to Al-Samra and Maan New Treatment plants, the main problem that makes their water unsuitable for reuse is the high concentration of *E. coli*, so if this problem is solved this amount of water can be considered in the water budget.

3.7.4. Critical reuse purpose

In most cases, there is no chance to select the irrigated vegetable, trees, and crops due to the geographic limitations, climate, marketing considerations, legal restriction, and social acceptability. For this reason, suitability of water for a certain purpose does not mean it will be reused for this purpose which may be wasted. The most critical reuse categories were determined from the number of the violated quality indicators and the percentage of water that is suitable for a certain reuse category. The available data indicated that none of the treatment plants have water quality complies with all reuse standards. Out of 23 treatment plants, only 6, 4, 6, and 18 plants have effluent suitable for discharge to Wadis, Irrigation type A, Irrigation type B, and irrigation type C; respectively, while none of the plant has an effluent suitable for groundwater recharge and cut flower (Tables 7 and 8). In terms of water amount, 76.6%, 75.5%, 76.6%, and 95% of treated wastewater are suitable for the mentioned purposes; respectively (Fig. 4).

It can be concluded that, more than 76% of treated wastewater is suitable for all non-potable purposes except of cut flower and groundwater recharge. Based on the

Table 7
Violated indicators for each plant with various categories of reuse

Plant	Discharge to Wadi	GW recharge	Irrigation			Cut flower
			A	B	C	
	Violated indicators					
Al Fuhais	*E. coli**	*E. coli**, NH_4^{x}, COD^{++}, BOD^{++}	*E. coli**	*E. coli**	–	*E. coli**, TSS^{x}, COD^{++}, BOD^{+}
Tall Al-Mantah	*E. coli**, PO_4^{++}, TN^{x}, TSS^{x}, COD^{x}, BOD^{x}	*E. coli**, PO_4^{++}, TN^{x}, TSS^{x}, COD^{x}, BOD^{x}	*E. coli**, TN^{x}, TSS^{x}, COD^{x}, BOD^{*}	*E. coli**, TN^{x}, TSS^{++}, COD^{++}, BOD^{++}	TN^{x}, COD^{++}, BOD^{++}	*E. coli**, TN^{x}, TSS^{*}, COD^{*}, BOD^{x}
Irbid	*E. coli**, PO_4^{++}, TSS^{+}	*E. coli**, PO_4^{++}, TSS^{++}, COD^{++}, BOD^{x}	*E. coli**, TSS^{++}, COD^{++}, BOD^{+}	*E. coli**	–	*E. coli**, TSS^{x}, COD^{x}, BOD^{++}
Wadi Hassan	PO_4^{++}	*E. coli**, PO_4^{++}, COD^{++}, BOD^{++}	*E. coli*^{x}	–	–	*E. coli**, TSS^{x}, COD^{++}, BOD^{+}
Al-Miradh	*E. coli**, PO_4^{++}, TSS^{++}, COD^{++}	*E. coli**, PO_4^{++}, TSS^{++}, COD^{++}, BOD^{x}	*E. coli**, TSS^{++}, COD^{++}, BOD^{++}	*E. coli**	–	*E. coli**, TSS^{x}, COD^{x}, BOD^{++}
Shalalah	*E. coli**, PO_4^{++}, TN^{+}	*E. coli**, PO_4^{++}, TN^{++}, COD^{++}, BOD^{++}	*E. coli**, TN^{++}, BOD^{+}	*E. coli**, TN^{+}	–	*E. coli**, TN^{+}, TSS^{x}, COD^{++}, BOD^{++}
Aqaba New	PO_4^{x}	*E. coli**, PO_4^{x}	PO_4^{++}	PO_4^{++}	PO_4^{++}	*E. coli*^{x}, PO_4^{++}
Wadi Musa	–	*E. coli**	–	–	–	*E. coli*^{x}
Abu Nusayr	–	TN^{++}, COD^{++}, BOD^{++}	TN^{++}, BOD^{+}	–	–	*E. coli*++, TSS^{++}, COD^{++}, BOD^{++}
Madaba	*E. coli**, TN^{++}	*E. coli**, TN^{++}, COD^{++}, BOD^{++}	*E. coli**, TN^{++}	*E. coli**, TN^{++}	–	*E. coli**, TN^{++}, TSS^{x}, COD^{++}, BOD^{++}
Jerash	–	*E. coli**, BOD^{++}, COD^{++}	PO_4^{+}, TN^{++}	PO_4^{+}	PO_4^{+}	*E. coli**, PO_4^{+}, TSS^{++}, COD^{++}, BOD^{+}
Al-Samra	–	*E. coli**	–	–	–	*E. coli**
Salt	*E. coli**	*E. coli**, TN^{+}, COD^{++}, BOD^{x}	*E. coli**, TN^{+}, COD^{++}, BOD^{++}	*E. coli**	–	*E. coli*, TSS^{++}, COD^{x}, BOD^{++}
Al Baqa	*E. coli**, TSS^{+}, COD^{++}	*E. coli**, TN^{++}, TSS^{++}, COD^{++}, BOD^{x}	*E. coli**, TN^{++}, TSS^{++}, COD^{++}	*E. coli**	–	*E. coli*, TSS^{x}, COD^{x}, BOD^{++}
Wadi Arab	*E. coli**, PO_4^{++}	*E. coli**, PO_4^{++}, COD^{++}, BOD^{++}	*E. coli**, BOD^{++}	*E. coli**	–	*E. coli**, TSS^{x}, COD^{++}, BOD^{++}
Ramtha	*E. coli**, PO_4^{++}	*E. coli**, PO_4^{++}, TN^{++}, TSS^{++}, COD^{++}, BOD^{x}	*E. coli**, TN^{++}, TSS^{++}, COD^{++}, BOD^{++}	*E. coli**	---	*E. coli**, TSS^{x}, COD^{x}, BOD^{++}
Kufranjah	*E. coli**, PO_4^{++}	*E. coli**, PO_4^{++}, COD^{++}, BOD^{++}	*E. coli**	*E. coli**	–	*E. coli**, TSS^{x}, COD^{++}, BOD^{++}
At-Tafilah	*E. coli**, PO_4^{++}, TN^{++}, TSS^{++}, COD^{+}, BOD^{++}	*E. coli**, PO_4^{++}, TN^{x}, TSS^{x}, COD^{x}, BOD^{*}	*E. coli**, TN^{x}, TSS^{x}, COD^{x}, BOD^{x}	*E. coli**, TN^{++}	TN^{+}	*E. coli**, TN^{++}, TSS^{x}, COD^{x}, BOD^{x}
Maan New	–	*E. coli**, COD^{++}	–	–	–	*E. coli**, TSS^{+}, COD^{++}
Mazzar	*E. coli*^{x}, TN^{++}, TSS^{x}, COD^{x}	*E. coli**, TN^{x}, TSS^{++}, COD^{x}, BOD^{x}	*E. coli**, TN^{x}, TSS^{++}, COD^{++}, BOD^{++}	*E. coli*^{x}, TN^{++}	–	*E. coli**, TN^{++}, TSS^{x}, COD^{x}, BOD^{++}
Jiza	*E. coli*^{x}, TN^{++}, TSS^{++}, COD^{++}, BOD^{+}	*E. coli**, TN^{++}, TSS^{++}, COD^{x}, BOD^{x}	*E. coli**, TN^{++}, TSS^{++}, COD^{++}, BOD^{x}	*E. coli*^{x}, TN^{++}	–	*E. coli**, TN^{++}, TSS^{x}, COD^{x}, BOD^{++}
South Amman	–	*E. coli**, COD^{++}, BOD^{++}	–	–	–	*E. coli**, TSS^{++}, COD^{++}, BOD^{++}
Karak	*E. coli**, TSS^{x}, COD^{x}, BOD^{x}	*E. coli**, TN^{++}, TSS^{x}, COD^{x}, BOD^{*}	*E. coli**, TN^{++}, TSS^{x}, COD^{x}, BOD^{x}	*E. coli**, TSS^{+}, COD^{+}, BOD^{+}	COD^{+}	*E. coli**, TSS^{x}, COD^{x}, BOD^{x}

$^{+}$Violation <10%; $^{++}$Violation = 10%–100%; ^{x}Violation = 100%–1,000%; *Violation >1,000%, ---: no violation for any indicator.

Table 8
Treated wastewater suitability for reuse

	No. of the violated standards	Suitability
Al Fuhais	11	Irrigation Type C
Tall Al-Mantah	30	None
Irbid	17	Irrigation Type C
Wadi Hassan	10	Irrigation Type B and C
Al-Miradh	18	Irrigation Type C
Shalalah	18	Irrigation Type C
Aqaba New	8	None
Wadi Musa	2	Discharge to Wadis, Irrigation Type A, B and C
Abu Nusayr	9	Discharge to Wadis, Irrigation Type B and C
Madaba	15	Irrigation Type C
Jerash	12	Discharge to Wadis
Al-Samra	2	Discharge to Wadi, Irrigation Type A, B and C
Salt	14	Irrigation Type C
Al Baqa	17	Irrigation Type C
Wadi Arab	13	Irrigation Type C
Ramtha	18	Irrigation Type C
Kufranjah	12	Irrigation Type C
At-Tafilah	25	None
Maan New	5	Discharge to Wadis, Irrigation Type A, B and C
Mazzar	21	Irrigation Type C
Jiza	22	Irrigation Type C
South Amman	8	Discharge to Wadis, Irrigation Type A, B and C
Karak	23	None

Ir.: Irrigation

quantity of the suitable water, reuse categories can be ranked as: irrigation type C > irrigation type B > discharge to Wadis > irrigation type A > groundwater recharge > cut flower. This result is in line with calculated WQI values in Table 6. Similarly, a previous study mentioned that out of 22 treatment plants in Jordan, 7, 16, and 17 plants have suitable water for irrigation type A, B and C, respectively [21].

For cut flower standards, *E. coli*, TSS, COD and BOD are the main violated indicators, while *E. coli* and nitrogen are the main violated indicators for groundwater recharge. All effluent water is not suitable for cut flowers and groundwater recharge, this is may be attributed to the restricted standards especially the *E. coli* which is limited by <1.1 and 2.2 MPN/100 mL; respectively. There is no limit for *E. coli* in water reused for irrigation type C which explains the high suitability of water for this purpose (95%). Since there are different standards for each reuse categories, the government should allocate the treated wastewater to the best suitable purpose which enhance agricultural yield and avoid negative health issues.

3.8. Development in wastewater treatment

3.8.1. Extension and development

During the last 10 y, many plants had been developed in terms of increasing the hydraulic load capacity, development in treatment technologies, involvement of new treatment units, construction of new plants and building capacity. Eight treatment plants have been constructed after 2008, of which two in Syrian camps, whereas most of the existing plants have been modified partially or substantially. In 2010, USAID's financed a five-year investment program involves the delivery of improvements in Amman, Tafileh, Zarqa, Jerash, Maan, and Irbid water/wastewater facilities. These projects aimed to provide water/ sanitary system to new communities, improvement of the treatment plants and development of reused management. Al-Samra wastewater treatment plant, the largest one in Jordan, its capacity has been increased from 68,000 m^3/d in 2007 to 267,000 m^3/d in 2008, to 367,000 m^3/d in 2015. This extension accompanied with an improvement in the plant performance and the quality of the effluent from the plant, which increase volume of treated wastewater, volume of water suitable for reuse, expansion in the irrigated areas, and farmers' income. The treatment process shifted from WSP to AS, and new treatment units were added including: Nitrification–denitrification, sulphide removal, clarification units, disinfection, sludge treatment and biogas unit. Also, Irbid treatment plant was subjected to substantial modification including development in treatment process (OD), new units (sand filtration and UV disinfection unit), and increasing in the hydraulic capacity.

The hydraulic load of Karak and Kufranjah treatment plants reached more than 175% and 227% of the design capacity; respectively. For this reason, a project started in 2014 aimed to increase their capacity to 5621 and 8,995 m^3/d;

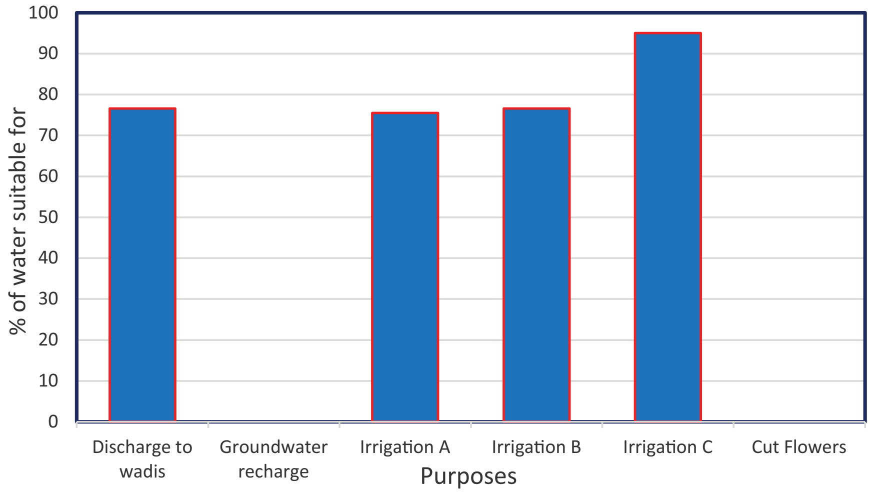

Fig. 4. Percentage of reclaimed water suitable for different purposes.

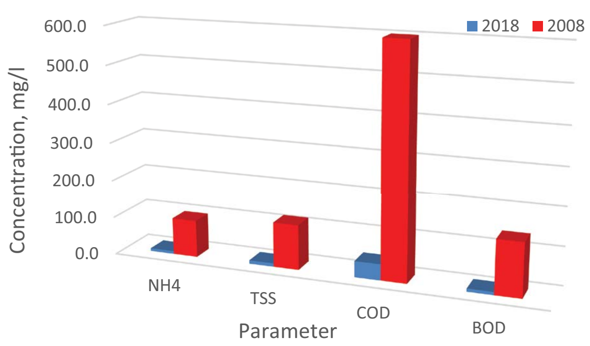

Fig. 5. Average concentrations of NH_4, TSS, chemical oxygen demand, and biochemical oxygen demand in the effluent water of the Al-Samra treatment plant.

respectively to bring these plants in compliance with increased hydraulic load until 2030. Currently, there are two projects for extension and development of Mafraq and Jerash plants.

Jordan water strategy 2016–2025 projected to implement 16 projects in wastewater sector with cost of about 604 million JD, including expansion of 14 treatment plants, and establishment of two new ones.

3.8.2. Development in plants' performance

Since Al-Samra is the major treatment plant in Jordan and treats more than 67% of total treated wastewater in Jordan, its development is the major factor affected the amount and quality of the treated wastewater in Jordan. Fig. 5 shows the performance of the plant in 2008 and 2018 in terms of NH_4, TSS, COD and BOD [9].

As demonstrated in Fig. 5, it is clear that Al-Samra treatment plant performance was enhanced significantly and the concentration of pollutants in 2018 decreased to 7.4%, 7.5%, 6.9% and 5.8% of that in 2008 for the mentioned indicators; respectively. This improvement is attributed to the increase in the hydraulic capacity; it received 330% of its design capacity in 2008 while in 2018 it received 81% of its design capacity. Also, diversion of the plant from WSP operation to AS contributed to the development of the plant performance.

The new constructed plants (South Amman, Aqaba New and Maan New) showed good performance in terms of BOD, COD and TSS, with good ΣWQI, this could be attributed to the advanced technologies used in these plants and adequate capacity for flow. Also, the plants which were subjected to extension or development (Irbid and Kufranjah) showed an improvement in their performance due to the increase in their hydraulic capacity and the new treatment units. In 2008, all of the treatment plants received about 165% of the total design capacity [9], whereas in 2018 the plants were below the design capacity with overall ratio of 68%.

For treatment plants of small amount of influent and high wastewater strength, it is recommended to use combined treatment processes in order to improve its treatment performance through better removal of colloidal and nonbiodegradable particles [22]. As examples of the proved combined system are: biological with electrocoagulation processes and biological with membrane filtration technology (membrane bioreactor system) [23–25]. However, extra research is needed to prove this concept for large-scale application as well.

3.8.3. Development in the amount of the treated water

Water reuse is the key factor of water budget in Jordan and it may be one of the limited available options to squeeze the gap between supply and demand. Due to the construction of new plants and extension of the existing ones, additional communities were covered with sanitary system, and additional wastewater are collected, treated then discharged. In 2008, about 56% of population have central sanitary system, in comparison to 63% in 2018. In terms of the influent water, the amount increased from 109 in 2008 to 117 in 2010, 125 in 2014 and 162 MCM in 2018 [10,26].

3.8.4. Development in the suitability of water for reuse

A previous study in 2008 showed that 74% of the treated water failed to comply with BOD, COD and NH_4 standards for discharge to Wadis and groundwater recharge, and COD standards of irrigation type A, Irrigation type B and irrigation type C [9]. In 2018, only 23.4, 24.5, 23.4, and 5% of water violated the standards of discharge to Wadis, irrigation type A, irrigation type B, and irrigation type C; respectively. This result indicated that the development in wastewater treatment sector achieved its goal in increasing the available water for reuse with suitable quality. Table (8) revealed that out of 23 treatment plants, the effluent from 19 plants is suitable for one or more irrigation purpose, and 75.6% of the treated water is suitable for all irrigation types except for cut flowers.

4. Conclusion

Jordan experience in quality aspects of reclaimed water standards represents a good exemplar of how to take full advantage of reclaimed water as a valuable resource depending on numerical standards for intensive monitoring of wastewater treatment plant performance assessment within the standard limits of reclaimed water JS893/2006. This standard varies with the type of application, hence different water quality requirements and criteria for each use. Most of the studied plants (18 out of 23) has effluent suitable for irrigation type C, while none of the plant has an effluent suitable for groundwater recharge and cut flower. In other words, more than 76% of treated water is suitable for all non-potable purposes except of cut flower and groundwater recharge. During the period between 2008 and 2018, construction works of new treatment plants, extension and development of the existing ones resulted in an enhancement in the plants performance and the quality of the effluent, increased amount of reusable water, expansion in the irrigated areas, and the farmers' income. Moreover, classifying treated water according to its quality facilitated its reuse for the best suitable option. While significant development in the plants performance occurred during the aforementioned period, the need for continuous development is an absolute necessity. Furthermore, Increasing of water supply can reduce the strength of wastewater and enhance the treatment performance and water quality. Overall, to build a roadmap for optimum utilization of reclaimed water as reliable, socially acceptable, safe, commercially viable, and environmentally sustainable and valuable source in water budget, diagnostic study is necessary to determine the drawbacks in wastewater treatment system.

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