Evaluation of Wastewater Treatment Plants in Jordan and Suitability for Reuse.

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Research Paper

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ABSTRACT

Pressing water scarcity in Jordan increased the demands of marginal water for agriculture, of which the treated wastewater is the most prominent candidate. Meanwhile, agriculture is an important economic activity in Jordan where treated wastewater could be a valuable source for irrigation in the agricultural sector. The reuse as percentage of total treatment as index which is of limited use for policy decisions cannot reflect potentialities of wastewater use. The wastewater reuse index (WRI) reflects the actual proportion of wastewater reused from the total generated wastewater. The WRI in Jordan steadily increased from 30 in 2004 to 38% in 2007, which still has potential for development. The characteristics of wastewater in Jordan are somewhat different from other countries. The average salinity of municipal water supply is (580 ppm) of TDS and the average domestic water consumption is low. These results are in very high organic loads and higher than normal salinity in wastewater. This is particularly applicable to wastewater treated in waste stabilization ponds (85% of the total generated wastewater), where part of the water is lost through evaporation, thus, increasing salinity levels in the effluents. In addition, high organic loads impose operational problems where the plants become biologically overloaded with only a portion of their hydraulic loads. This paper describes the efforts of Jordan towards better management and control of wastewaters effluent to increase the available supply of waters of suitable quality on a sustainable basis. Effluent quality, performance evaluation, reuse extent, problems and obstacles related to wastewater sector in Jordan are discussed. Twenty-seven municipal wastewater treatment plants were evaluated over periods ranging from 2 to 15 years of operation in Jordan. Eight plants used waste stabilization pond (WSP), eight used conventional activated sludge (AS), four used trickling filter (TF), and two used mixed technology AS and TF. The AS and TF systems were found to have better performance than the WSP systems. Those wastewater treatment technologies had higher removal efficiencies for BOD_5, COD and TSS and produced good quality final effluents for final disposal in accordance with the Jordanian discharge standard. In addition, the current situation in the wastewater and reuse in Jordan taking in consideration the management system, capacity and operational of the reuse in Jordan Valley was assessed.

Key words: Treated wastewater, stabilization ponds, BOD, activated sludge, Jordan.

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INTRODUCTION

Jordan is categorized between the arid and semi-arid countries and can be considered one of the most ten water stressed countries in the world, with less than 150 m3 annual per capita of fresh water resources, while the

United Nation (UN) fact sheet realized that the world water poverty line is one thousand cubic meter.

Scarcity of water in Jordan is one of the main challenges and a limiting factor for economic development and sustainable economic growth especially for agriculture sector, while extra stress on the water resources come from population growth, particularly given the increasing population, which was nearly (6.4) million at the end of 2012 and growing yearly rate of 2.2% (Department of statistics, 2010).

The climate is generally arid, with more than 90% of Jordan's total area receiving less than 200 mm rainfall per year and more than 70% of the country receiving less than 100 mm of precipitation per year. Only 2% of the land area located in the north-western highlands has an annual precipitation exceeding 300 mm. The northern highlands may receive about 600 mm. About 5.5% of Jordan's area is considered dry land with annual rainfall ranging from 200 to 300 mm (MWI, 2010). The pattern of rainfall is characterized by an uneven distribution over the various regions and strong fluctuation from year to year in terms of quantity and timing. This shortfall is currently managed by controlling supply which is unsustainable. Water resources consist primarily of surface and ground water resources, with treated wastewater being used on an increasing scale for irrigation, mostly in the Jordan Valley. Treated waste water provides additional source of water, but there are concerns and limitations over its use (MWI 1997a).

The other major environmental benefit from reusing wastewater is a reduction in pollution of waters receiving discharge of sewage. Reducing the volume of this discharge is also a powerful driver for wastewater reuse.

The paper discusses the issues of treating and reusing wastewater in Jordan as a supplementary source of irrigation water and a means to optimize water resources management, design data, operational results and physical characteristics for the 27 wastewater treatment plants.

Wastewater treatment in Jordan

Wastewater collection was practiced in Jordan in a limited way since 1930 in the town of Salt. Some treatments were achieved by utilizing mostly primitive physical processes. However, septic tanks and cesspits were used to discharge grey water to gardens. This practice resulted in major environmental problems, especially groundwater pollution; the pollution problems were complicated by the rapid urban growth.

Modern technology used to collect and treat wastewater was introduced in the late 1960s when the first collection system and treatment plant was built at Ain Ghazal utilizing the conventional activated sludge process. The system consisted of a sewage network that runs by gravity to the lowest point in Amman, where the treatment plant was located and built. The design effluent standard was BOD_5 (20 mg/L). The treated effluent was discharged to Saill Al-Zarqa.

Since the year 1980 and during the International Drinking Water and Sanitation Decade (1980 to 1990), the Government of Jordan carried out significant and comprehensive plans with regards to the different issues of wastewater management primarily related to the improvement of sanitation. About 75% of the urban population and 52% of the total population (at that time) gained access to wastewater collection and treatment systems. This raised the sanitation level, improved public health and strengthened pollution control of surface and groundwater in the areas served by wastewater facilities.

The characteristics of wastewater in Jordan are somewhat different from other countries. The average salinity of municipal water supply is 580 ppm of TDS, and the average domestic water consumption is low. These results are in very high organic loads and higher than the normal salinity in wastewater. This is particularly applicable to wastewater treated in waste stabilization ponds (85% of the total generated wastewater), where part of the water is lost through evaporation, thereby, increasing salinity levels in the effluents. In addition, high organic loads impose operational problems where the plants become biologically overloaded with only a portion of their hydraulic loads.

Characteristics of wastewater treatment plants

There are 27 wastewater treatment plants (WWTPs) distributed in the urban centers of Jordan. Three plants used wastewater stabilization ponds (WWSP), nine activated sludge (AS), one used trickling filter (TF), and two used mixed technologies AS and TF (Department of statistics, 2010). Table 1 summarizes the characteristics of these plants, including the treatment technology used, operating date, design flow capacity, design biological loading (BOD_5).

About 61% of the population has access to wastewater collection and treatment system (Department of statistics, 2010). In 2005, about 107.3 MCM of wastewater was received by the treatment plants containing 66,000 tons of BOD_5 (Department of statistics, 2010). The quantity of treated wastewater (effluent) was about 75.4 MCM; more than 90% of this water is used in agricultural activities. The waste stabilization treatment plants discharged 80% of the produced treated effluent, while the remainder 20% was produced by the mechanical plants.

Table 1 shows seven WWTPs hydraulically overloaded and 9 of these plants biologically overloaded in 2005. The hydraulic overloading is attributed to rapid population growth in urban areas caused by continued rural to urban migration and several large influxes of refuges involved in the region conflict. Development of new wastewater treatment facilities is needed. The government is planning to construct 14 new plants by 2020. The total number of plants will be expected to treat 262 MCM/year.

Table 1. Characteristics of wastewater treatment plants and their operation conditions for year 2014.

WWTP	Treatment method	*E. coli* (MPN/100 ml)	PO4	NO3	T-N	NH4	TDS	TSS	COD	BODF	BOD5	pH unit
			(mg/L)									
Irbid	AS&TF	901551	23.74	0.71	115.79	87.26	1138.42	103.08	244.25	#DIV/0!	80	**7.91**
Fuhis	AS	229079	16.52	16.64	48.06	32.78	844.42	43.17	87.58	8.8	10	7.78
Wadi Arab	AS	78469	17.94	1.44	66.16	52.39	1031.67	23.75	75.33	-	28.3	7.86
Abu-Nusier	AS	2	11.16	12.62	19.38	10.55	759.99	12.76	55.22	-	16.7	7.18
ʾAl mu’rad		44	9.74	1.03	51.54	40.91	1366.33	45.79	100.79	13.9	19.35	7.43
Salt	AS	19973	16.85	4.49	55.85	42.87	819.42	24.63	64.5	9.68	-	7.48
Tall-Almantah	AS&TF	35889	22.67	42.32	106.56	74.85	1311.64	70.73	164.5	-	38.5	7.59
As-Samra	WSP	8	7.77	38	14.88	1.23	902.33	17.71	53.96	4	8.36	7.42
Baqa'	TF	4044029	13.16	34.71	45.04	23.12	975.08	34.04	109.58	-	21.67	7.7
Tafila	TF	5412543	33.94	2.78	107.53	79.59	900.67	86.79	302.33	-	119.64	7.76
Al-Lajjoun	WSP	295	8.91	26.13	43.25	16.84	3208.33	61.58	226.18	24.5	-	8.24
Wadi Al seer	WSP	33	23.07	2.07	92.54	75.19	789.82	37.37	129.22	17.61	-	7.73
Aqaba	WSP	94	2.69	8.67	8.81	2.66	597.5	9.49	23.23	-	4.25	7.33
Wadi Hassan	AS	49	18.75	8.76	12.33	5.42	1117.92	18.5	66	5	7.75	7.64
Kufranja	TF	12443133	42.38	1.08	161.35	113.31	1296.42	229.92	794.45	305.94	208	7.46
Ma'an Mechanical	WSP	745	1.73	11.09	11.86	7.34	936.42	15.03	61.54	7	15.6	8.05
Wadi Mousa	AS	4	11.63	34.28	11.58	3.26	846.75	6.1	31.33	3.9	6.15	7.69
Ramtha	WSP	21420	31.06	1.42	97.53	54.14	1418.25	29.29	93.13	12.7	11.8	7.59
Madaba	AS	256269	9.7	0.59	90.88	59.89	1014.17	34	98.5	13	20.88	7.81
Karak	TF	8083625	32.8	1.06	120.69	77.85	1084.83	270.17	585.33	-	289.68	7.58
الطالبيه		163725	14.36	3.17	99.1	62.03	1204	58.48	141.63	25.67	50.36	7.79
Al-Akader	WSP	605156	53.83	2.97	206.2	114.78	1837.08	294.83	933.92	200.91	-	7.92
Mafraq	WSP	4070090	37.71	17.63	136.79	96.15	1156.75	212.08	597.25	178.36	-	7.73
Aqaba Natural		6119	8.13	10.08	67.87	30.63	851.67	240	399.64	49.29	37.5	8.24
Mota Almzar		1128	26.13	118.96	36.48	9.79	1168.11	47.56	63.67	3	9.69	7.73
Shalalah		1302606	21.53	6.58	104.15	76.16	1116.33	62.88	147.75	-	38.9	7.77
Shoubak		84	12.06	41.57	15.6	6.32	2135.67	22.83	114.58	5.4	-	7.93
North Shouna		3151	12.17	3.91	47.63	35.13	1562	19.67	97.33	-	6.5	8.37

WSP: Waste stabilization ponds; TF: Trickling filter; AS: Activated sludge; *Hydraulically overloading and ** Biologically overloading.

Raw wastewater characteristics

Table 2 shows the characteristics and features of the raw wastewater (Ministry of Water and Irrigation, 2005). The characteristics of wastewater in Jordan are somewhat different from other countries. The strength of the raw wastewater is high as compared to that of the developed countries. This is due to low average per capita domestic water consumption (80 L/c/d). As mentioned earlier, the influent used to treatment plants in 2005 was about 107.3 MCM, containing 66,000 tons of BOD_5 (Ministry of Water and Irrigation, 2005). Thus, the average influent BOD_5 is estimated at 615 mg/L which is a very high organic load imposing operational problems in these plants.

Wastewater in Jordan is comparatively low in toxic pollutants such as heavy metals and toxic organic compounds. This is due to the low level of industrial discharges to sewage treatment plants. It is estimated that 10% of the biological load comes from industrial discharges.

Characteristics of treated wastewater

The Jordanian Standard JS893/2002 dealing with “Water-Reclaimed Domestic Wastewater” specifies the conditions that the reclaimed domestic

Table 2. Characteristics of main wastewater treatment plants located within the Jordan River Basin.

Wastewater treatment plant	Design hydraulic load (M³/day)	Actual hydraulic load in 2013 (M³/day)	Design BOD5 (mg/L)	Influent BOD5 (mg/L) (2013)	Mean effluent BOD5 (mg/L) (2013)	Mean effluent TDS (mg/L) (2013)	Mean effluent NO_3 (mg/L) (2013)	Mean effluent *E. coli* MPN/100 ml (2013)	Treatment technology
Kofranjeh	1900	2559	850	1100	232	1062	2.3	1.07E+06	BF & MP
Wadi Hassan	1600	1277	800	1026	5	1169	4.8	1.1E+01	ASOD
Almerad	10000	3601	800	1485	6	1315	1.1	Lt 2	ASEA
Madaba	7600	5204	950	745	18	1222	2.3	2.3E+05	AS
Wadi Seer	4000	4760	780	403	25	784	LT 1	7.11E+01	AP
Al Fuhais	2400	2305	995	552	30	876	68	4.02E+04	-
Ramtha	5400	4476	1000	931	7	1663	3.3	2.71E+01	AS
Al Samra	276000	249740	650	750	7	1406	46	6.32E+01	AS
Al Akeeder	4000	3316	1500	1500	189	1232	2.7	1.74E+05	SP
Abu Nussair	4000	2724	1100	466	6	1188	2	Lt 2	AS
Al Baqa	14900	13537	800		26	1096	21.4	2.38E+05	TF
Salt	7700	7487	1090	797	19	1136	5.6	1.29E+05	AS
Irbid	8710	8104	800	1097	39	591	1.35	2.38E+05	AS&TF

Biological Filters, MP = Maturation Ponds, ASOD = Activated Sludge Oxidation Ditches, ASEA = Activated Sludge Extended Aeration, AS = Activated Sludge, AP = Aerated Ponds, SP = Stabilization Ponds, TF = Trickling Filters, Cost of Wastewater Treatment; Pond systems from 3.9 – 100 fils/m³; Activated sludge = 90-180 fils/m³ and Combined systems 180-700 fils /m³. (Sources: National Water Quality Monitoring Project Report for the year 2013, Ministry Of Environment and Royal Scientific Society, Amman Jordan, 2014; State of The Wastewater Management in the Arab Countries, Jordan Country Report, Arab Water Council, 2011; Safe Use of Treated Wastewater in Agriculture, Jordan Case Study, Arab Countries Water Utilities Association (ACWUA), December, 2001, Amman Jordan).

wastewater effluent from wastewater treatment plants should meet in order to be discharged or used in the various fields mentioned (MWI, 2010). The qualities of most wastewater treatment plants effluent comply with the Jordanian standards for restricted irrigation and violate the standards for unrestricted irrigation. Table 3 compares the characteristics of the final effluents of the WWTPs including BOD_5, COD and TSS with the Jordanian limits for three reuse options. These options are (i) vegetable eaten cooked; (ii) fruit, forestation, industrial crops and grains; and (iii) discharge to wadis and catchments.

The BOD_5 effluent ranges between 90 to 219 mg/L for As-Samra, Aqaba, Mafraq, Ramtha, Madaba, Ma'an and Kufranja wastewater treatment plants. Five of these plants are WSP, one is AS and the other is TF. For the remaining wastewater treatment plants the BOD_5 is less than 50 mg/L. The COD effluent ranges from 500 to 629 mg/L for As-Samra (WSP), Mafraq (WSP) and Madaba (AS) wastewater treatment plants. Only two treatment plants had TSS greater than 200 mg/L, while the remaining plants had TSS less than 200 mg/L.

Almost all the WSP plants failed to meet the standard requirements for "discharge to wadis and catchments for BOD_5, COD and TSS. On the other hand, few of the AS and TF plants fail to meet this requirement especially for those plants that are hydraulically overloaded.

Performance evaluation

Most of the WWTPs are receiving influent highly contaminated and loaded with organic materials exceeding the normal influent specification for wastewater treatment plants (Department of statistics, 2010). Table 3 shows the removal efficiencies of BOD_5, COD and TSS for each WWTP. The efficiency of BOD_5 removal in WSP system is lower than 81% in 5 of the WSP plants. The highest efficiency for BOD_5 removal was found in the AS system. Six of the AS plants have BOD_5 efficiency removal greater than 96%. Only one of the AS WWTPs (Madaba) has low BOD_5 removal efficiency of about 85%. This low removal efficiency of BOD_5 of this plant may be attributed to the high organic loading (about 1000 mg/L) received. The BOD_5 removal efficiency in TF WWTPs ranges from 92.5 to 95.75%. It was noticed that the performance of the plants using WSP technology was more affected than those using AS or TF technologies or when the capacity exceeded that of its initial design.

Similar performance of the WWTPs for COD removal was observed (Table 3). The poor COD removal efficiencies (58 to 83%) were found in WSP treatment plants. The COD removal efficiencies for AS WWTPs range from 92 to 97%. The only exception is Madaba WWTP where the COD removal efficiency is about 71%. For TF WWTPs, the COD removal efficiencies range from 82 to 95%. In the case of TSS, the highest efficiencies of removal were found in AS and TF WWTPs while the lowest was found in WSP WWTPs.

Table 3. Wastewater treatment plant removal efficiency of BOD5, COD and TSS for year 2005.

WWTP	Treatment method	BOD5			COD			TSS		
		In mg/L	Out mg/L	EF%	In mg/L	Out mg/L	EF%	In mg/L	Out mg/L	EF%
As-Samra	WSP	709	135[ac]	80.96	1879	506[a,b,c]	73.07	558	130[c]	76.70
Aqaba	WSP	410	111[ac]	72.93	830	345[c]	58.43	298	576[abc]	NA
Ramtha	WSP	852	219[ac]	74.30	1435	254[c]	82.30	597	219[abc]	63.32
Mafraq	WSP	696	215[ac]	69.11	1062	527[a,b,c]	50.38	571	125[c]	78.11
Madaba	AS	1045	154[ac]	85.26	2196	629[a,b,c]	71.36	965	116[c]	87.98
Ma'an	WSP	688	161[ac]	76.60	1270	462[c]	63.62	689	176[abc]	74.46
Irbid	AS&TF	1174	22	98.13	2670	157	94.12	1136	55[c]	95.16
Jerash	AS	1219	37[a]	96.96	2109	131	93.79	1281	93[c]	92.74
Kufranja	TF	1195	90[ac]	92.47	2051	260[c]	87.32	804	92[c]	88.56
Abu-Nusier	AS	544	18	96.69	975	67	93.13	547	33	93.97
Salt	AS	764	24	96.86	1398	105	92.45	822	28	96.59
Baqa'	TF	965	41[a]	95.75	2247	110	95.11	930	46	95.05
Karak	TF	708	53[ac]	92.51	1418	238[c]	83.22	608	66[c]	89.14
	TF	671	37[a]	94.49	1323	142	89.27	606	46	92.41
Aadi Al seer	WSP	658	40[a]	93.92	964	169[c]	82.47	594	48	91.92
Fuhis	AS	679	12	98.23	1214	63	94.81	600	18	97.00
Wadi Arab	AS	836	7	99.16	1421	67	95.29	796	8	98.99
Wadi Hassan	AS	859	9	98.95	1873	64	96.58	724	23	96.82
Wadi Mousa	AS	701	9	98.72	1221	32	97.38	671	20	97.02
Tall-Almantah	AS&TF	NA	NA	NA	NA	NA	NA	NA	NA	NA
Al-Akadeer	WSP	NA	NA	NA	NA	NA	NA	NA	NA	NA
Al-Lajjoun	WSP	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jordanian Standard for effluent from wastewater treatment plants										
Vegetable eaten cooked			30			500			150	
Fruit, forestation, industrial crops and grains			300			500			150	
Discharge to wadis and catchments			60			150			60	

WSP: Waste stabilization ponds; TF: Trickling filter, AS: Activated sludge; [a]Not meet JS(893/02) for vegetable eaten cooked; [b]Not meet JS(893/02) for fruit, forestration, industrial crops and grains and [c]Not meet JS(893/02) for discharge to wadis and catchments.

In order to compare the overall performances of different plants, a general efficiency index (EI) was calculated as an average of BOD_5, COD and TSS removal efficiencies:

$$EI = 1/3\ [Eff_{BOD} + Eff_{COD} + Eff_{TSS}] \quad (1)$$

Where:
EI = the overall efficiency index of removal (%)
Eff_{BOD} = the efficiency of BOD5 removal (%)
Eff_{COD} = the efficiency COD removal (%), and
Eff_{TSS} = the efficiency of TSS removal (%).

Figure 1 illustrates the overall efficiency index for each WWTP evaluated. The highest values of EI were found in activated sludge AS WWTPs with general efficiency index values ranging from 94.5 to 97.8%. On the other hand, the plants using TF treatment technology had values of EI in a range of 88.6 to 95%. The lowest EI values were found in plants using WSP treatment technology with values ranging from 63 to 91.9%.

Despite that most of the wastewater treatment plants operate with high treatment performance and high efficiency the quality of the treated wastewater complies with the JS893-2002 for disposal and reuse of sewage wastewater. There are few treatment plants that still operate with low efficiency due to the existing treatment process and the exceeding of the inflow to the design value. These plants should be upgraded in the near future.

Reuse potential

Wastewater reuse provides a potential alternative resource for water scarce regions. Since the year 1980, Jordan carried out significant and comprehensive plans with regards to the different issues of wastewater management primarily related to the improvement of sanitation. About 50% of the urban population and 63% of the total population gained access to wastewater collection and treatment systems, thus, raising the sanitation level, improving public health, and strengthening control of surface and groundwater pollution in the areas served by wastewater facilities. In addition, Jordan made significant effort towards achieving its goal of 100% reuse of reclaimed water in order to save freshwater resources.

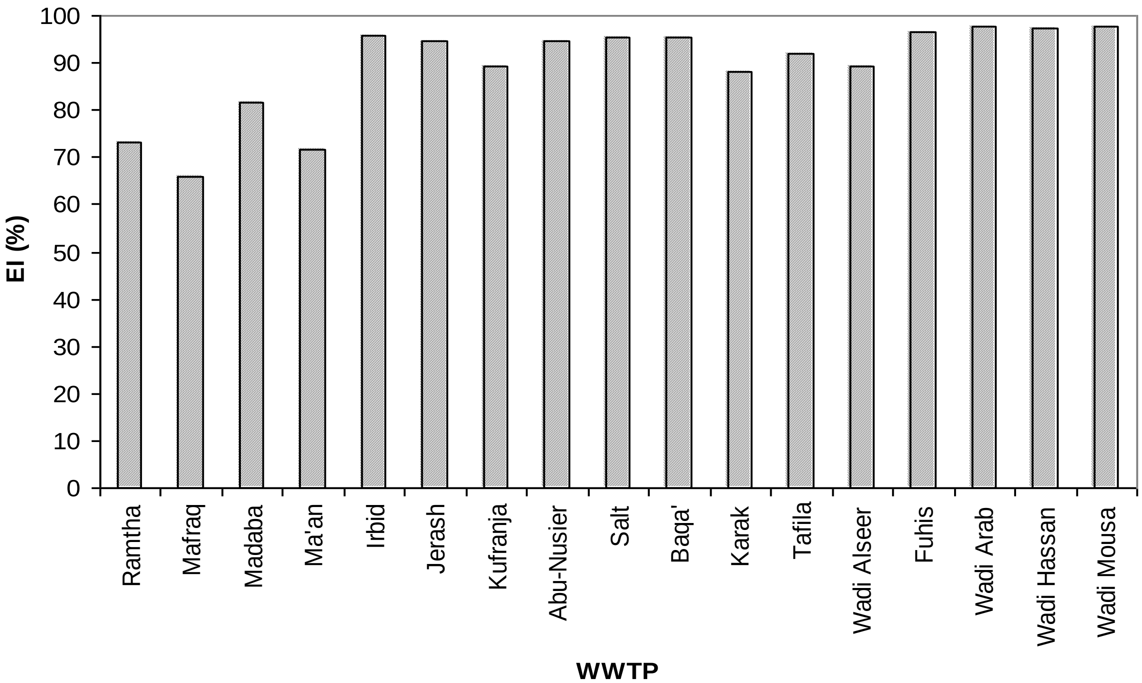

Figure 1. Overall efficiency index (EI) values of WWTPs.

Table 4. Projected wastewater reuse in Jordan valley and highlands.

Year	In the Jordan Valley (10^6 m^3)	In Highlands (10^6 m^3)	Total (10^6 m^3)
2005	65	43	108
2010	110	66	176
2015	123	84	207
2020	137	95	232

Wastewater already amounts to about 5% of the total available water resources in Jordan and will increase to a share of more than 15% within the next 30 years (Malkawi, 2003).

Irrigation with treated wastewater is a common practice in the central and southern Jordan Valley and will be more widespread in other parts of Jordan. The volume of treated wastewater produced in 2005 reached 75.4 MCM/year, of which about 90% is reused for irrigation (Department of statistics, 2010). Treated wastewater reused for agricultural irrigation purposes of 75.4 MCM/year would be 14.7% of the total irrigation water use (about 511 MCM/ year). The reuse of treated wastewater in Jordan has reached one of the highest levels in the world (MWI 1997b, 1998).

Most of Jordan’s treated wastewater is discharged from As-Samra treatment plant through Zarqa River to King Talal Reservoir (KTR) for use in irrigation in the downstream Jordan Valley after mixing with water from King Abdullah Canal (KAC). Varieties of crops are grown using irrigated wastewater including citrus, vegetables, field crops and bananas. Further amounts are likely to replace currently used freshwater in irrigation. Future plans aim at improving the quality of effluent and expanding its reuse in other areas in the upland. The share of treated wastewater reuse in the Jordan Valley is projected to increase from 65 MCM in 2005 to about 137 MCM in 2020 (World Bank, 2001). Table 4 shows the projected wastewater reuse in Jordan Valley and the Highlands.

Restricted irrigation by the treatment plant's effluent is applied in the direct neighborhood of the plants and downstream of them without any dilution with freshwater. Unrestricted irrigation takes place, in particular, in the Jordan Valley by treated effluent particularly of As Samra treatment plant after mixing with freshwater (generally one portion of wastewater to three portions of fresh water). Restricted irrigation was done for about 7,800 dunums and unrestricted irrigation for about 91,000 dunums (Department of Statistics, 1998), while restricted irrigation is limited to fodders, cereals, forests and fruit trees, comprising of additionally unrestricted irrigation various vegetables.

With regards to future reuse of treated wastewater in most of the newly planned treatment plants local reuse systems were selected in particular for the small treatment plants of low effluent quantities. However, most of the effluent quantity will be connected to irrigation systems more or less far from the treatment plants site due to the fact that the treated wastewater of the big plants close to the treatment facilities (for example, As Samra, Zarqa, Irbid) is not reused.

Conclusion

Twenty-seven municipal wastewater treatment plants were evaluated over periods ranging from 2 to 15 years of operation in Jordan. The best performance were noticed in plants that used conventional technologies such as AS and TF. Poor removal efficiencies of BOD_5, COD, and TSS were observed in plants using WSP technology. Most of the AS and TF WWTPs produced good quality of effluents for final disposal in accordance with the discharge standard. By reusing the effluent of the existing MWTPs, the reused water, particularly for irrigation of agricultural land accounts for 14.7% of the current total water use for agriculture. Thus, the freshwater that is currently used for irrigation can be saved. This percentage will be substantially increased as the number of MWTPs increase.

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