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POTENTIAL AND LIMITATIONS OF WASTEWATER REUSE IN THE HASHEMITE KINGDOM OF JORDAN

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Jordan represents a typically water constrained economy that is daily confronted with decisions on its water use. With a fast growing population and an expanding agricultural sector, the demand for alternatives of fresh water resources remains imminent. An important strategy for the Jordanian government is to meet the water demand for agricultural sector by producing more treated wastewater. In this paper characteristics of wastewater for WWTP Al-Baq'a, for example, weres introduced. Characterization of wastewater was evaluated in terms of measuring chemical oxygen demand, biological oxygen demand, total suspended solids, for the influent and effluent from the plants. The performance of the wastewater treatment plants was evaluated and the quality of the reclaimed wastewater was compared with Jordanian Standards to determine its suitability for reuse.

Keywords: water balance, wastewater reuse, agriculture, Jordan

1. CHARACTERISTIC OF WATER RESOURCES AND DEMANDS IN THE HASHEMITE KINGDOM OF JORDAN

The Hashemite Kingdom of Jordan covers a territory of about 91,880 km^2 with 99% land area. The population of Jordan was 5.7 million at the end of year 2005. The natural rate of growth of 2.8% is one of the highest growth rates in the world. About 70% of the population is urban. The capital of Jordan, Amman

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is a city of 2 million people, located in the northwest portion of the country [2, 3, 9].

Jordan's climate is mainly semi-arid to arid. Only the highlands on the east of the Jordan Rift Valley are blessed with a Mediterranean climate, where the weather is cold and wet in winter and hot and dry in summer. In the rest of the Kingdom the temperatures are usually very high during the summer season (around 46°C) and cold in winter (a few degrees below zero). Snowfall occurs generally once or twice a year over the highlands. The rainy season extends from October to April, with the peak of precipitation taking place during January and February. Only around 0.7% of Jordan's area receives an average annual more than 500 mm, 3.3% between 300 and 500 mm, 2.2% between 200 and 300 mm, 22.3% between 100 and 200 mm and the rest, 71.5%, receive less than 100 mm/year (table 1) [9]. Approximately 92.2% of the rainfall evaporates, 5.4% recharges the groundwater and the rest 2.4% flows to the surface water. Surface water resources in Jordan are limited. There are only a few small streams - the Zarqa, Yarmouk and Wadi Shuib Rivers - and essentially no natural lakes exist [9,10].

Table 1. Classification by rainfall distribution [6]

Classified zone	Annual rainfall (mm/yr)	Catchement area (km^2)	Area ratio, %
semi-humid	500-600	620	0.7
semi-arid	300-500	2,950	3.3
marginal	200-300	2,030	2.2
arid	100-200	20,050	22.3
desert	<100	64,350	71.5

Jordan does not possess rivers in the world-wide known scale, except the Jordan River which used to discharge around 1400 million m^3/year into the Dead Sea before the development of the water resources in its catchment. Jordan shares the rivers providing much of its water with Israel and Syria. Even this river is a very small source compared with international rivers like the Nile or Euphrates, because its total annual discharge amounts to only 1.5% of the former and 4.3% of the latter. Other surface water resources in Jordan are found in the Yarmouk and Zerka rivers and in Wadis like Karak, Mujib, Hasa, Yabis and El-Arab, in addition to flood flow Wadis in the different parts of the country [2,3,9].

The average annual renewable fresh water resources that can be safely exploited in Jordan amount to 780 million m^3, of which 277 million m^3 is from groundwater and the rest is from surface water resources. In additional, reused treated wastewater and nonrenewable water resources are also employed. Jordan water resources consist primarily of surface and ground water, the renewable water resources in 2010 were estimated to be about 1203 million m^3 (Fig. 1), including ground water (277 million m^3 distributed among 12 basins), usable

surface water (234 million m^3 distributed among 15 catchments basins) and treated wastewater 177 million m^3, an additional 140 million m^3/year of ground water is estimated to be available from fossil aquifers. The groundwater aquifers of Jordan are divided into three main complexes:

- Deep Sandstone Aquifer Complex.
- Upper Cretaceous Aquifer Complex.
- Shallow Aquifer Complex.

Brackish aquifers are not yet fully explored, but at least 55 million m^3/year is expected to be available for urban uses after desalination.

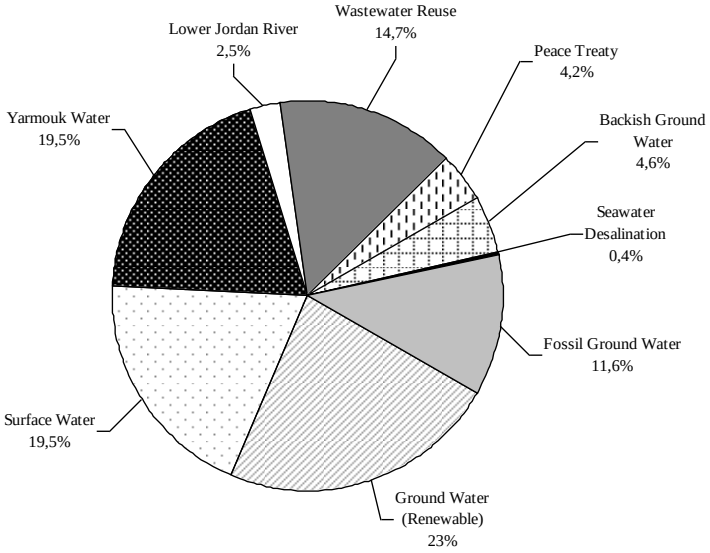


Fig. 1. Water Supply in Jordan in 2010 [2,3,9]

In year 2010, approximately 1002 million m^3 of water was used for agricultures, 435 million m^3 for municipal purposes, 102 million m^3 for industrial purposes, and 7 million m^3 for livestock purposes. Table 2 show the water demand for various sectors in 1995-2020.

Table 2. Water demand for various sectors, million m^3/year [2, 3,9]

Year	1995	2000	2005	2010	2015	2020
Agricultural	790	922	981	1002	992	963
Municipal	274	321	382	435	520	615
Industrial	37	54	80	102	134	168
Total	1101	1297	1443	1539	1646	1746

In many Jordanian cities, residents receive water only sporadically, and domestic water consumption is among the lowest in the world, less than 100 liters/capita/days [2, 3, 8]. Wastewater is about 99.85% water by weight and is

generally referred to as influent when it enters the treatment plant. Domestic wastewater primarily comes from individuals, and doesn't generally include industrial wastewater.

Wastewater will be collected, managed and used as a resource in an efficient and optimized manner. Wastewater will comply with national standards and will be treated to a level appropriate for agriculture and possibly for ground water aquifer recharge.

Table 3 shows the water supply for different demand (2006/2007) [3].

Table 3. Water supply for different demand (2006/2007), million m^3/year [9]

Demand requirements	Ground water	Surface water	Treated wastewater	Total
Domestic	214.0007	79.75	0	293.751
Rural area	0.745	7	-	7.745
Industry & remote areas	44.894	3.527	0	48.421
Agriculture	244.81	176.366	90.97	512.146
Agriculture (high land)		77.46	-	77.460
Total supply demand	504.4497	344.103	90.97	939.523

To the year 2020 Jordan will be facing considerable water deficits each year. As shown in table 4, the water deficit for all uses will grow from 260 million m^3 in year 2000 to 408 million m^3 by the year 2020.

Table 4. Projections of Water Supply and Demand (million m^3) [14]

Year	Supply	Demand	Deficit
2000	993	1.253	260
2005	1.169	1.407	238
2010	1.206	1.457	251
2015	1.225	1.550	325
2020	1.250	1.658	408

Deficit of water shows the necessity for adopting a long term water plan and future scenarios of water management that consider both demand management and non-conventional water resources, in order to decrease the gap between supply and demand. So now, wastewater is not just sewage. All water used domestically that enters drains or the sewage collection systems is wastewater, including water from baths, showers, sinks, dishwashers, washing machines, and toilets. In combined municipal sewage systems, water from storm drains is also added to the municipal wastewater sewer system.

The expected very good quality effluent of the new waste water treatment plant has made it possible to explore new water reuse methods. Among the non-conventional water resources, wastewater reuse has the lowest cost. Seawater desalination is costly, because the sea is very far from highly populated areas, making the cost of transferring. Therefore reuse of reclaimed wastewater is a necessity.

2. WASTEWATER TREATMENT PLANT AND JORDANIAN WASTEWATER QUALITY STANDARDS

Over 63 percent of the Jordanian population is connected to sewerage systems, all of which will be treated in the next few years. Generally there are two types of WWTPs in Jordan. One is the centralized WWTP recognized as a governmental institution, while the other is the decentralized WWTP such as those installed at airports, universities and private companies. There are 22 governmental (100 million m^3/year in 2006) and 23 private WWTPs (less than 3 million m^3/year in 2006) (Fig. 2) [16]. Most of the treatment plants are small, except for the plant as As-Samra, which treats more than 80% of this quantity.

Wastewater treatment plants (WWTP) treating sewage in different type of treatment systems. The systems are divided into trickling filters (Kufranja, Tafilah, Baqah, Karak), activated sludge (As-Samra, Irbid, W.Arab, Wadihasan, Salt, Madaba, Abo Nusier, Tel Mantah, Fuhais, Wadi Musa, Ramtha) and waste stabilization ponds (Maan, Mafraq, Aqaba, Wadi esseir).

Raw wastewater in Jordan can be characterized as very strong with high salinity. Given the low level of industrial discharges to wastewater treatment plant, sewages in Jordan are comparatively low in toxic pollutants such a heavy metals and toxic organic compounds. Jordanian standards for reclaimed wastewater try to regulate both water reuse and environmental discharges and allow discharging treated wastewater to valleys and streams when it meets the specific criteria for many parameters such as BOD, COD, DO, TSS, *Escherichia coli* bacteria, and helminthes eggs. In the present time, the reclaimed wastewater is used for restricted agriculture either near the plants or downstream after mixing with natural surface water [3,4].

The Water Authority of Jordan (WAJ) follows national legislation that has been issued by the Jordanian Institute of Standards and Metrology (JISM) and regulations issued by the Minister of Water and Irrigation. The most important legislated standards governing wastewater management can be summarized as follows [4]:

- JS 893/2006: this national standard addresses the properties, quality control and other requirements for reclaimed water, specifically those that domestic wastewater must meet before being discharged to any receiving body or reused for agriculture or other intended uses.
- JS 202/2004: this standard deals with industrial wastewater that is produced after being used for industrial purposes. The aim of implementing an industrial wastewater monitoring program is to protect the environment and water resources and to safeguard health and human safety.

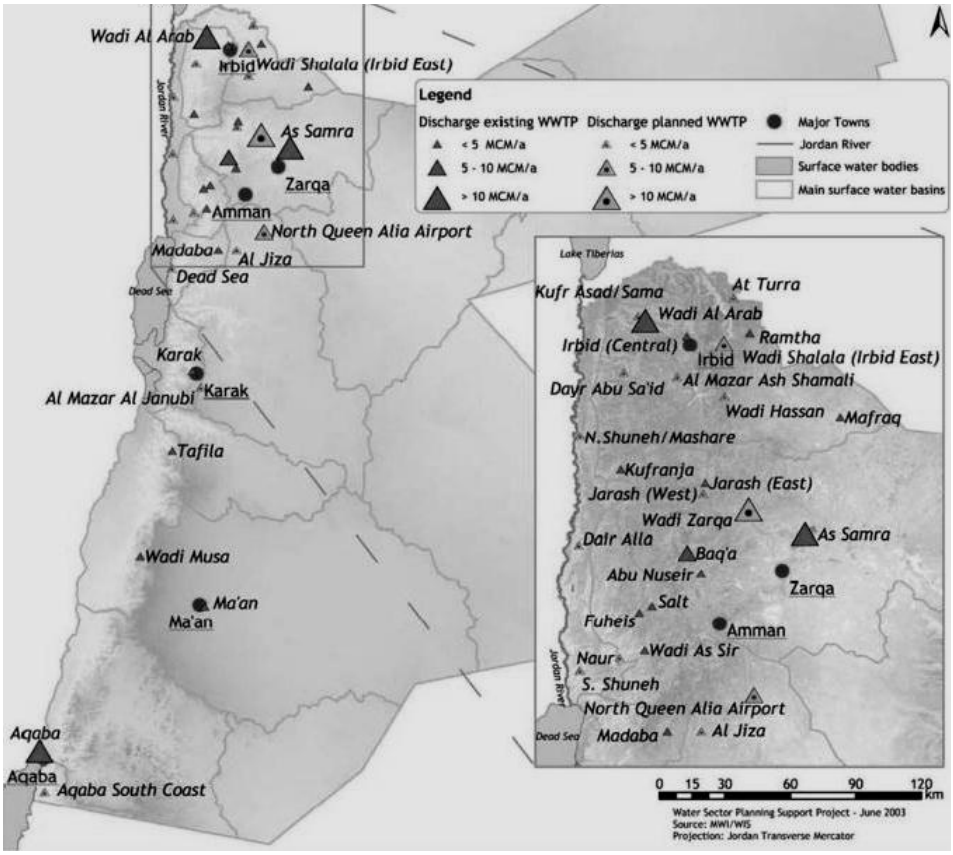


Fig. 2. Centralized and decentralized WWTP in Jordan [16]

Jordanian wastewater quality standards is shown in table 5.

Table 5. Jordanian wastewater quality standards [4]

indicator	unit	Standards for discharge of water to streams or wadis or water bodies (893/2006)	Standards for use in artificial groundwater aquifers (893/2002)	Standards for treated wastewater for irrigation purposes (893/2002)		
				Cooked vegetables, parks play areas, road sides inside cities	Fruit trees, outer road sides, green lawn	Fodder, industrial crops, forest trees
BOD_5	mg/dm^3	60	15	30	200	300
COD	mg/dm^3	150	50	100	500	500
DO	mg/dm^3	>1	>2	2<	-	-
pH	-	6-9	6-9	6-9	6-9	6-9

NO_3	mg/dm^3	45	30	30	45	45
Total N	mg/dm^3	70	45	45	70	70
Total phosphate	mg/dm^3	15	15	30	30	30
TSS	mg/dm^3	60	50	50	150	150
E.Coli	MPN/100 ml	1000	<2,2	100	1000	-
Nematode eggs.	Egg/dm^3	≤1	≤1	≤1	≤1	≤1

3. WASTEWATER REUSE OF AGRICULTURAL IN JORDAN

Agriculture is an important economic activity in Jordan. Treated waste water could be a valuable source for irrigation in the agricultural sector, as an alternative for fresh water resources that is urgently needed for the rapidly growing urban populations. Currently there is an increasing percentage of irrigated areas using treated wastewater. With a fast growing population and expansion of the irrigated areas to meet the food demand, the pressure on water resources in Jordan remains of imminent importance. In Jordan the agricultural sector consumes approximately 64% of available water per year with one-third of this amount consumed in the Jordan Valley and about 50% reclaimed water. All in all, agriculture consumes less than 35.5 % of the total amount of freshwater available in the Jordan Valley [13].

The preferred irrigation method is drip irrigation in combination with very thin plastic sheets (in Jordan called “mulch”) which cover the plant rows. The main crops that are grown in the Jordan are citrus, vegetables, bananas, grapes and certain stone fruits in open field and greenhouse cultivations (table 6).

Table 6. Jordanian experience in wastewater reuse [12]

WWTP	Area (ha)	Crops	Excess effluent flow
As-Samra	300	olive, forest, fodder	King Tatal dam
Aqaba	150	forest, olive trees	local reuse
Ramtha	50	forest, barley, Sudan grass, alfalafa	local reuse
Mafraq	25	forest, fodder crops	local reuse
Madaba	60	forest, olive, fodder, flowers	local reuse
Maan	7	forest, olive, ornamental trees	local reuse
Irbid	0,5	forest, olive, ornamental trees	Jordan River
Kfranjeh	7	forest, olive, Sudan grass, alfalfa	Wadi Kufranjech

4. AL-BAQ'A WASTEWATER TREATMENT PLANT

Al-Baq'a WWTP is located about 15 km to the north of Amman. It was constructed in 1988 and expanded in 1990 to serve about 164,000 inhabitants with 94% coverage of the total population living in the sewered zone. The method of wastewater treatment at Al-Baq'a WWTP is a combination between trickling filter and maturation pond. The total inflow into the plant is about 10,284 m^3/day (design capacity 14,900 m^3/day) with a yearly average of about $3.75 \cdot 10^6$ m^3/yr. The generated wet sludge is transported daily by tankers to Ain Ghazal pretreatment plant. From there, it is conveyed to As-Samra WWTP.

The method of wastewater treatment is quite efficient except the odour which is possibly attributed to the sludge thickness or the concentration of the influent sewage. Other problems in this plant are chlorine dosage at the end of the treatment process which produces large amounts of trihalomethanes which affect later on the water quality and assists in the hypertrophication processes [1, 2].

Figure 3 shows influent flow of raw wastewater to Al-Baq'a WWTP. Average influent flow in 2008-2009 is 10,720 m^3/d and 11,086 m^3/d, respectively [1]. Table 7 shows the influent BOD_5, COD, and TSS values for Al-Baq'a WWTP in 2008-2009 [1].

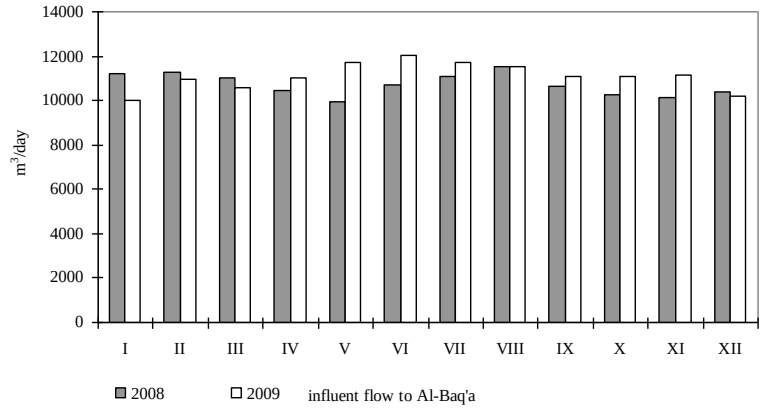


Fig.3. Influent flow of raw wastewater to Al-Baq'a WWTP in 2008/2009

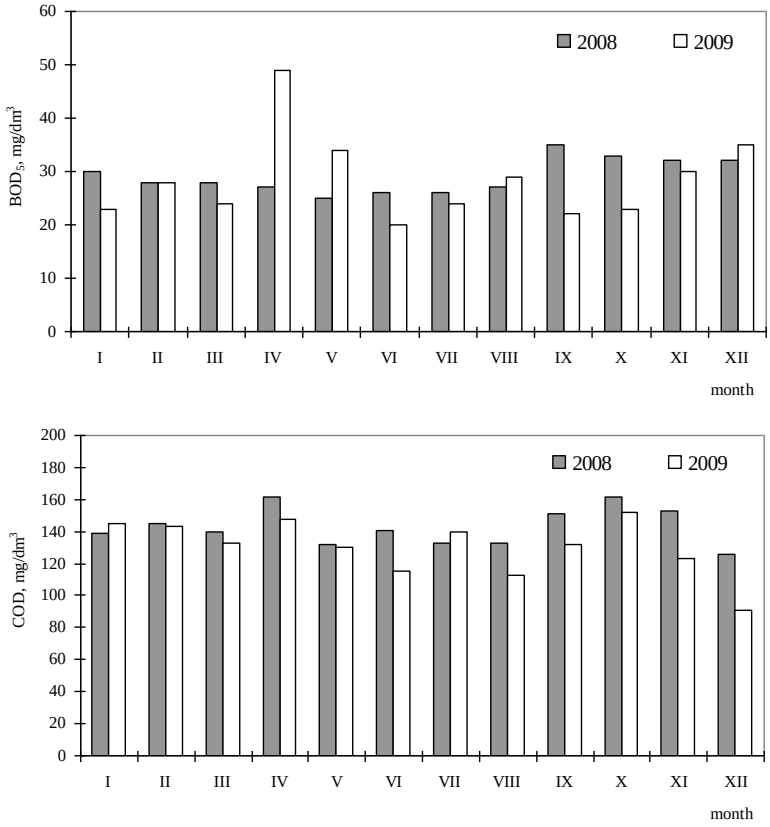
The average values in 2009 of BOD_5, COD and TSS concentrations for the influent wastewater are 709, 1676 and 620 mg/dm^3, respectively. Based on these values, wastewater in Jordan is classified as a strong wastewater, where the concentration of pollutants is much higher than the international figures.

Table 7. The influent BOD_5, COD and TSS values for Al-Baq'a WWTP in 2008-2009

parameter	month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	average
BOD_5 mg/dm^3	2008	779	744	728	798	717	779	661	730	808	676	671	765	788
	2009	710	674	680	641	706	711	756	649	972	666	606	732	709
COD mg/dm^3	2008	1742	1751	1907	1754	1776	1672	1677	1715	1928	1689	1712	1858	1765
	2009	1836	1635	1688	1619	1843	1689	1680	1497	1674	1593	1629	1733	1676
TSS mg/dm^3	2008	642	662	742	640	713	164	687	738	736	663	573	662	685
	2009	658	593	568	682	646	604	606	651	610	543	583	696	620

Characterization of treated wastewater from Al-Baq'a WWTP was evaluated in terms of measuring BOD_5, COD and TSS [1].

Figure 4 shows the effluent BOD_5, COD, and TSS values.



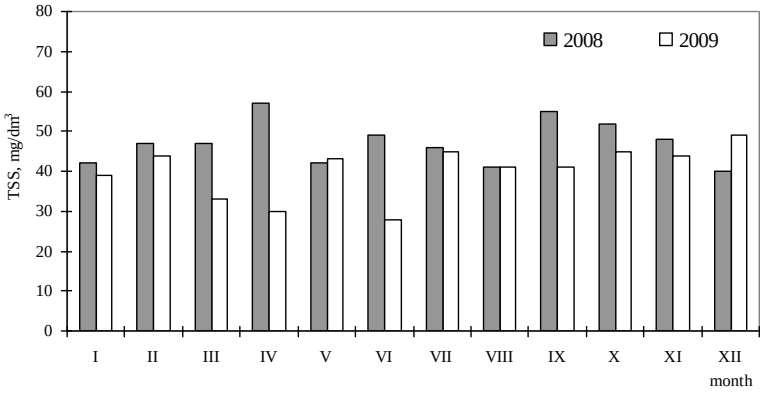


Fig. 4. The effluent BOD_5, COD, TSS values from Al-Baq'a WWTP

It can be seen, that the BOD_5 value ranges from 20 to 49 mg/dm^3. The highest COD value is 162 mg/dm^3, and the highest TSS: 57 mg/dm^3. The average values of BOD_5, COD and TSS concentrations for the effluent wastewater are 28, 130 and 40 mg/dm^3 and the values decrease are 95%, 91%, 93%, respectively.

The effluent BOD_5, COD, and TSS from Al-Baq'a WWTP complies with Jordanian standards for reclaimed wastewater discharge to fruit trees, outer road sides, green lawn, fodder, industrial crops, forest trees (data of Table 5). The Al-Baq'a WWTP is hydraulically and organically overloaded. Despite the Baq'a facility being relatively effective at lowering the values of the monitored parameters in the influent, only the BOD_5 and TDS in the effluent is within the range of the Jordanian Standards. The effluent flow can be used only for restricted irrigation cropping. The effluent from the wastewater facility is discharged into a 7-km long pipeline, which discharges into Wadi Rumman, and, in turn, to King Talal Reservoir. According to the facility manager, the effluent is not used for irrigation immediately downstream of the plant.

5. CONCLUSION

Since the quantity of renewable water resources is limited and increasingly vulnerable to pollution, the reuse of treated waste water has become an acceptable option. Water shortage is considered to be the main problem facing economic development in Jordan. The causes are limited renewable water resources, because in Jordan, average precipitation is 50-600 mm/year, rainfall on 92% of the Kingdom area less than 200 mm/year, and evaporation is 92%.

Population is concentrated 87% on 4 cities (Amman, Zarqa, Irbid, and Balqa) with growing rate 3.6-4.4 % /year. With a fast growing population and an expanding agricultural sector, the demand for alternatives of fresh water

resources remains imminent. The Ministry of Water and Irrigation of Jordan prepared in April of 1997 a draft Water Strategy for Jordan [10]. The Strategy defines long term goals that the government of Jordan seeks to achieve in the water and wastewater sector, and the main goals is Wastewater shall not be managed as "waste". It shall be collected and treated to standards that allow its reuse in unrestricted agriculture and other non-domestic purposes, including groundwater recharge. An important strategy for the Jordanian government is to meet the water demand for agricultural sector by producing more treated wastewater [11,15].

The average domestic water consumption is low. This results of very high organic loads. The average values in 2009 in Al-Baq'a WWTP of BOD_5, COD and TSS concentrations for the influent wastewater are 709, 1676 and 620 mg/dm^3. The effect of treating wastewater is high. The effluent BOD_5, COD, and TSS from Al-Baq'a WWTP complies with Jordanian standards for reclaimed wastewater discharge to fruit trees, outer road sides, green lawn, fodder, industrial crops, forest trees.

Deficit of water in Jordan shows the necessity for adopting a long term water plan and future scenarios of water management that consider both demand management and non-conventional water resources, in order to decrease the gap between supply and demand. The farmers that are growing trees near Al-Baq'a area reportedly haul in water, and are not willing to use the treated effluent. However, some farmers immediately downstream of the discharge point of the pipeline are utilizing the effluent for growing mainly olive trees. Farmers have approached the facility manager to use the effluent in the wadi for growing alfalfa [13].

In Jordan is limited space for the development of irrigated agriculture at the plant and immediately downstream. However, east of the Al-Baq'a wastewater treatment plant is a major irrigated area producing fresh vegetables. The water source for this area is groundwater. This presents a potential opportunity for exchange of recycled water, thereby freeing up fresh water for domestic use. Clearly there are many important issues with such a development, including the potential threat to the groundwater, the marketing concerns, the impact on cropping patterns and the acceptability by the present users. However, the value of the groundwater would justify investment in further treatment of the wastewater, farmer education and so forth [14,16].

LITERATURE

1. *Al-Baq'a Wastewater Treatment plant*, Monthly Report 2008-2009.
2. Alfarra A.: *Treated Wastewater for Irrigated Agriculture in the Jordan Valley*, Analysing Water allocation and Willingness to Pay for reused water.

Bauingenieur-, Geo- und Umweltwissenschaften des Karlsruher Instituts für Technologie (KIT), Dissertation 2009.
3. Al-Zboon K., Al-Ananzeh N.: *Performance of wastewater treatment plants in Jordan and suitability for reuse*, African Journal of Biotechnology, **7** (15), (2008) 2621-2629.
4. Bashaar Y. A.: *Wastewater reuse in Jordan: Present status and future plans*, Desalination **211,** (2007) 164-176.
5. Bdour A., Hadadin N.: *Potential and Limitations of wastewater reuse in rural areas in Jordan: the reuse options in the Jordan Valley*, Journal of Agronomy **4** (4), (2005) 315-322.
6. Vallentin A.: *Case study of SuSanA projects Use of treated wastewater in agriculture*, Jordan Valley, Jordan, SuSanA 2009, GTZ ecosan team.
7. Dawabsheh F.: *Case study on wastewater reuse in Jordan – Country report*, International Symposium on Environmental Pollution Control and Waste Management, 7-10 January 2002, Tunis (EPCOWM'2002), 790-803.
8. Hadadin N., Qaqish M., Akawwi E., Bdour A.: *Water shortage in Jordan - Sustainable solutions*, Desalination **250**, (2010),197-202.
9. Jordan Statistic Year Book for the year 2002-2006.
10. *Water Sector Planning & Associated Investment Program 2002-2011*, Ministry of Water and Irrigation, Amman, Jordan, February 2002.
11. Preul C. H.: *Water Pollution Control - A Guide to the Use of Water Quality Management Principles*, Ed. by Richard Helmer and Ivanildo Hespanhol Case Study XII - Kingdom of Jordan, 1997.
12. *Prospects of Efficient Wastewater Management and Water Reuse in Jordan*, "Efficient Management of Wastewater, its Treatment and Reuse in the Mediterranean Countries", February 2005.
13. Shams I. A., Awamleh M.: *Public private partnership through, build-operate transfer in Jordan wastewater sector*, Eighth International Water Technology Conference, IWTC8 2004, Alexandria, Egypt, 2004, 333-345.
14. Tutundjian S., *Water Resources in Jordan*, 2000.
15. *Use of Reclaimed Water in the Jordan Valley* (2002)., available: http://www2.gtz.de.
16. Qadir M., Wichelns D., Raschid-Sally L., McCornick P.G., Drechsel P., Bahri A., Minhas P.S.: *The challenges of wastewater irrigation in developing countries*, Agricultural Water Management **97**, (2010), 561-568.

MOŻLIWOŚCI I OGRANICZENIA WYKORZYSTANIA ŚCIEKÓW OCZYSZCZONYCH W JORDANII

S t r e s z c z e n i e

Jednym z podstawowych sektorów zarządzania gospodarką wodną Jordanii jest strategia ponownego wykorzystania ścieków oczyszczonych. Ścieki oczyszczone są ważnym składnikiem bilansu wodnego Jordanii stanowiąc ok. 15 % zasobów wodnych tego kraju. Szybko rozwijające się rolnictwo, zużywa 64 % ogólnej ilości wody i wymaga szukania jej alternatywnych źródeł. Wydajność 22 jordańskich oczyszczalni ścieków wynosi ok. 100 milionów m^3/rok. Większość obiektów jest mała, z wyjątkiem oczyszczalni As-Samra, która przyjmuje ok. 80% całkowitej ilości oczyszczanych ścieków.

W pracy przedstawiono charakterystykę ścieków surowych i oczyszczonych z oczyszczalni Al-Balqa (wydajność 11,000 m^3/d) na podstawie wartości ChZT, BZT_5 i zawiesiny ogólnej. Efektywność oczyszczalni Al-Balqa oceniono na podstawie standardów jakości ścieków oczyszczonych obowiązujących w Jordanii i możliwości ich ponownego wykorzystania. Ze względu na wysoką wartość BZT_5, ścieki oczyszczone mogą być wykorzystane tylko do nawadniania sadów, trawników, upraw roślin paszowych i lasów.