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Operate of As-Samra Wastewater Treatment Plant in Jordan and Suitability for Water Reuse

Water is a basic human need, yet millions of people around the world do not have enough access to clean water. There are many claims on the world's water supply, from agriculture and industry to drinking water, municipal uses and tourism. It is a global issue, and everyone must share what is available. However, in some places, water is exceptionally scarce and people are extracting it faster than it can be replenished. Sixty-three percent of the world's population that has no access to clean water lives in Asia, the Middle East and North Africa. By 2025 most of the Middle East countries are expected to experience water stress or scarcity. 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.

Treated wastewater generated in wastewater treatment plants (WWTP) is an important component of Jordan's water resources. In Jordan there are 23 wastewater treatment plants treating approx. 100 million m^3/year of wastewater in different type of treatment systems. The systems are divided into trickling filters, activated sludge and waste stabilization ponds. Most of the WWTP are small, except for the plant as As-Samra, which treats more than 80% of this quantity. The new As-Samra WWTP is using the activated sludge process with nutrient removal and chlorine for disinfection.

In this study, characteristics of wastewater for WWTP As-Samra were determined. Characterization of wastewater was evaluated in terms of measuring chemical oxygen demand (COD), biological oxygen demand (BOD_5), total suspended solids (TSS), 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: **Jordan, wastewater treatment plant, Jordanian standards of water reuse**

1. The Hashemite Kingdom of Jordan - country profile

The Hashemite Kingdom of Jordan covers a territory of about 91 880 km^2 with 99% land area, of which 95% receives less than 50 mm rainfall annually. It lies within the arid and semi-arid climatic zones and has a typical Mediterranean short rainy winter and a long dry summer. Annual precipitation varies with the location and topography, but in general ranges from 50 mm in the desert to 600 mm in the North West highlands. Jordan shares the rivers providing much of its water with Israel and Syria. The population of Jordan was 5,7 million at the end of year 2005, the natural rate of growth of 2,8 percent is one of the highest growth rates in the world. About 70% of the population is urban. The capital of Jordan, Amman is a city of 2 million people, located in the northwest portion of the country [1-3].

2. Jordan water resources, demand and deficit

Jordan is chronically water short. Mobilization of non-conventional water resources is an essential component for meeting the increasing water demand of the growing population. 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 (Table 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. 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, treated wastewater is being used on an increasing scale for irrigation, primarily in the Jordan River valley. In year 2010, approximately 1002 million m^3 of water was used for agricultures, 435 million m^3 was used for municipal purposes, 102 million m^3 was used for industrial purposes, and 7 million m^3 was used for livestock purposes. Table 2 and Figure 1 show the water demand for various sectors. 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 [1-3].

Table 1

Water supply 1995-2020 in million m^3 [1-3]

Year	1995	2000	2005	2010	2015	2020
Ground Water (Renewable)	277	277	277	277	277	277
Surface Water	215	220	227	234	234	234
Yarmouk Water	107	155	235	235	235	235
Lower Jordan River	0	0	30	30	30	30
Wastewater Reuse	58	87	112	177	219	246
Peace Treaty	0	30	50	50	50	50
Backish Ground Water	0	0	44	55	75	88
Seawater Desalination	0	0	5	5	10	10
Fossil Ground Water	71	61	130	140	140	140
Total	728	830	1110	1203	1270	1310

Table 2

Water demand for various sectors in million m^3/year [1-3]

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

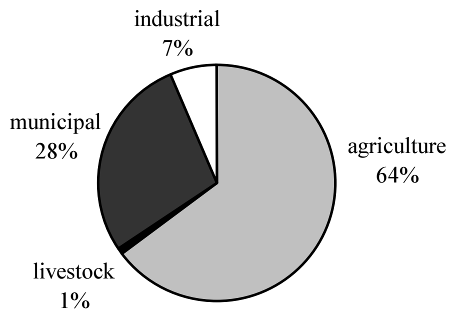

Fig. 1. The water demand for various sectors in 2010, %

To the year 2020 Jordan will be facing considerable water deficits each year. As shown in Tables 1 and 2, the water deficit for all uses will grow from 373 million m^3 in 1995 to 436 million m^3 by the year 2020.

3. Jordanian wastewater quality standards

Jordanian standards for reclaimed wastewater try to regulate both water reuse and environmental discharges. Jordanian standards 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.

Jordanian wastewater quality standards is shown in Table 3.

Table 3

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

4. Wastewater treatment plants in Jordan - As-Samra WWTP

Over 63 percent of the Jordanian population is connected to sewerage systems, all of which will be treated in the next few years. In Jordan there are 23 wastewater treatment plants (WWTP) treating approx. 100 million m^3/year of wastewater in different type of treatment systems (Fig. 2). The systems are divided into trickling filters, activated sludge and waste stabilization ponds. Most of the treatment plants are small, except for the plant as As-Samra, which treats more than 80% of this quantity.

The As-Samra WWTP is designed to treat domestic waste water emanation from the Zerqa river basin, which happens to include the country's most populated cities: Amman, Rusaifa and Zerka. In the Amman Russeifa - Zarqa basin lives 60% of the population of Jordan. The original Khirbet-es-Samra WWTP was built around 35 km northeast of Amman in 1985 with a capacity of about 67 000 m^3/d. The old treatment plant at As-Samra was consisted of stabilisation ponds, and the influent flowrate was always exceeding the plant's design capacity. It was received only 50% of its design flowrate. The plant quickly became obsolete, rendering its output water below standards and menacing water supplies, public health and agriculture in the Jordan Valley.

The As-Samra Treatment Plant was rehabilitated and upgraded in August 2008 (Fig. 3). The effluent quality has improved significantly and today it conforms to requirements of Jordanian standards for discharge into streams and rivers. It serves 2.27 million people and has a capacity to treat 276 000 m^3/d for the first stage (to 2015). It is making provision for its expansion to the second phase (to 2025) for capacity to treat 420 000 m^3/d and serves 3.3 million people.

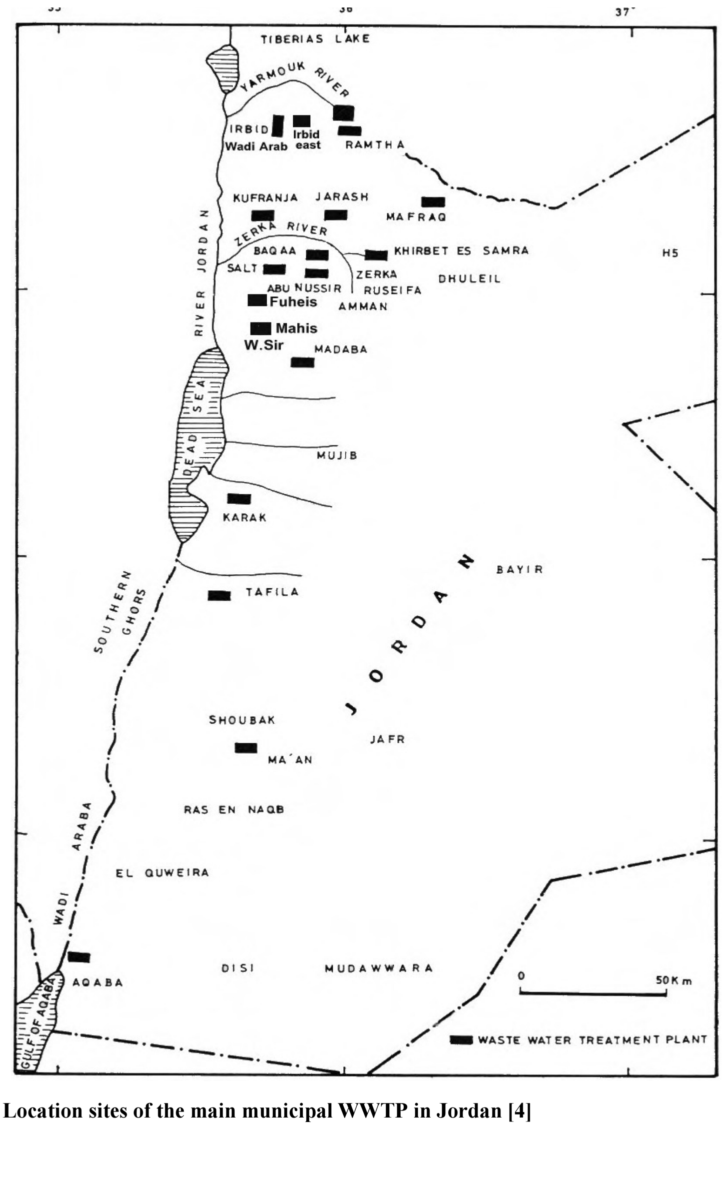

Fig. 2. Location sites of the main municipal WWTP in Jordan [4]

Raw water from Ain Ghazal pretreatment facility flows through a Ø1500 mm pipe into two Pelton turbines in the inlet structure where electrical power is generated. The net head between Ain Ghazal and As-Samara is round 78 meters. The outlet joins the incoming wastewater from Zarqa and Hashimiyya pumping stations and distributed into two grit and sulfide removal tanks each divided into chambers:

– Grit Removal Tank V = 1560 m^3,
– Sulfide Removal Tank V = 2540 m^3.

Settled water from the primary settling tanks is distributed into eight biological reactors each of a total volume of 26 200 m^3 consisting of three zones:

– anoxic zone for exogenous denitrification V = 6875 m^3,
– oxic zone where air is introduced continuously through air diffusers to remove BOD_5 and initiate nitrification V = 10 825 m^3,
– endogenous zone where air is introduced intermittently for complete nitrification V = 8500 m^3.

The effluent of the aerations tanks is then distributed into eight secondary clarifiers each of diameter 54 m, where suspended solids are separated. Part of and the settled sludge is thickened in the flotation units where the other part recycled the aeration tanks. The clarified effluent of the secondary settling tanks flows to two plug chlorine contact basins each of a volume of 3500 m^3 where it will be contact with chlorine for about 35 minutes for its final disinfection meeting the Jordanian Standards. The King Talal Reservoir, the country's largest reservoir receives effluent flows of As-Samra WWTP.

Primary sludge from the primary settling tanks is thickened in three covered circular thickeners. Biological sludge is thickened in another three covered dissolved air flotation units. The two are mixed together in a covered tank before it is pumped to four anaerobic digester each of capacity 15 000 m^3. The sludge is kept in the digester for three weeks at 35°C where it is mixed thoroughly by the Cannon®Mixers using the recycled compressed biogas. Heating of the recycled sludge is done by hot water recovered from the cooling of the engines in a shell-Tube heat exchanger. The digested sludge flows to the digested sludge storage tank where it is pumped to 25 solar evaporation basins where it is dried to about 30% dry solid. Lime will be used if necessary for sludge stabilization.

The biogas produced in the digesters is stored in two gas holders each of 5000 m^3 capacity. It undergoes H_2S removal before being used in five biogas engine generator sets for the production of electricity [5, 6].

In this study, characteristics of wastewater for WWTP As-Samra were determined. Characterization of wastewater was evaluated in terms of measuring chemical oxygen demand (COD), biological oxygen demand (BOD_5), total suspended solids (TSS), for the influent and effluent from the plants. Purpose of this study was efficiency assessment of As-Samra wastewater treatment based on effluent quality standards applicable in Jordan and the possibility of it reuse.

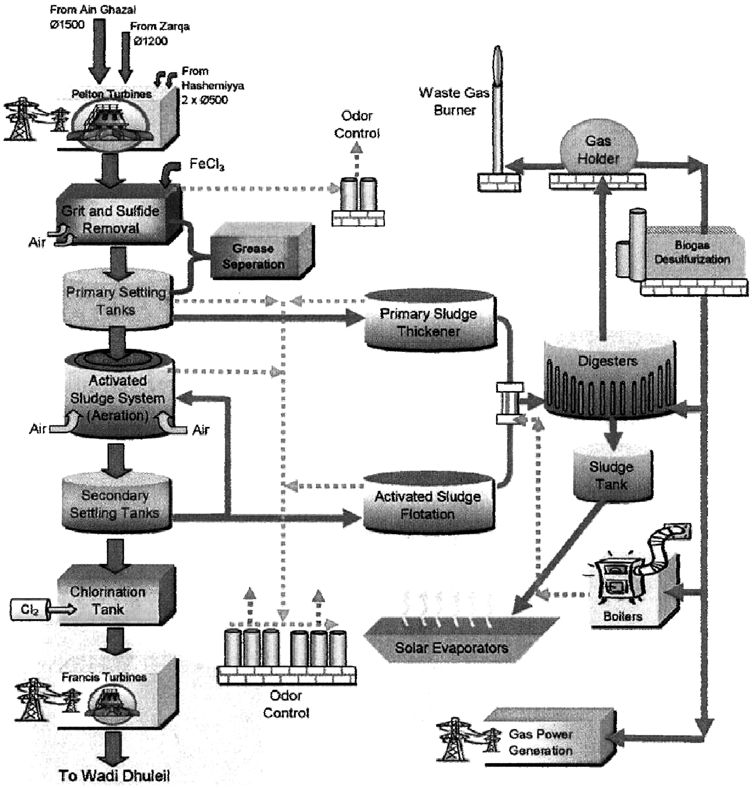

Fig. 3. Technological scheme of As-Samra WWTP [5, 6]

5. Characteristics of wastewater in As-Samra WWTP

5.1. Wastewater quantity

Figure 4 shows influent flow of raw wastewater to As-Samra WWTP and treated wastewater utilization for agricultural. Average influent flow in 2008--2009 is 229 861 and 218 027 m^3/d respectively. A part of treated wastewater is used in agricultural irrigation. Average consumption is 70 329 m^3/d in 2008, and 42 877 m^3/d in 2009 [7].

From King Talal Reservoir (KTR) the discharged effluent is led via further wadis (small streams) and canals to the middle and southern Jordan Valley. The reservoir is solely used for agriculture and has a capacity of 75 million m^3. The distance to the main canal in the Jordan valley is 14 km, and this main canal has an extension from north to south of 90 km. At the end of these canals, the reclaimed water is finally used to irrigate about 4000 farms with an area of approx. 10 000 ha. Treated effluent, which is reused for irrigation, is diluted with surface and precipitation water by the passage through the wadies etc. The water flows by gravity from the As-Samra WWTP via KTR to the agricultural fields. Pumping is not required as KTR is located 600 m above sea level and the valley 200 m below sea level. The preferred irrigation method is drip irrigation in combination with very thin plastic sheets (in Jordan called ”mulch”) which cover the plant rows [5].

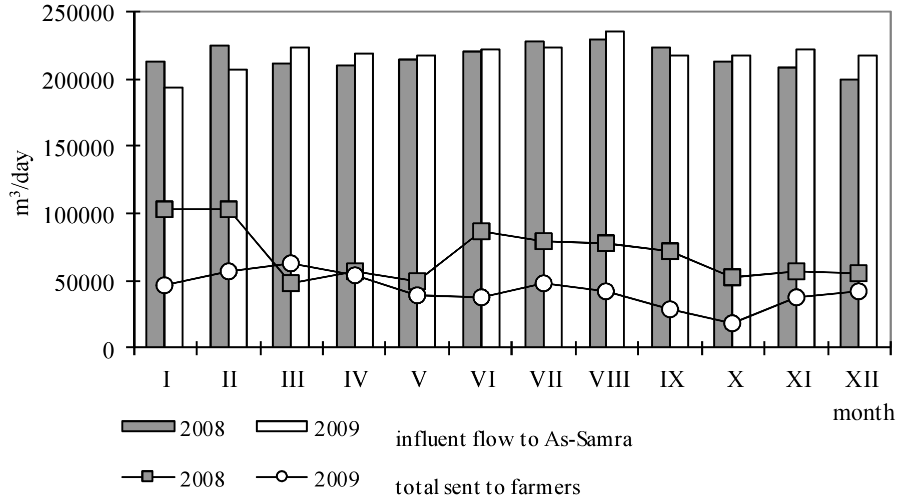

Fig. 4. Influent flow of raw wastewater to As-Samra WWTP and treated wastewater utilization for agricultural in 2008-2009

5.2. Raw wastewater

Table 4 shows the influent BOD_5, COD, and TSS values for As-Samra WWTP in 2008-2009 [7]. The average values in 2009 of BOD_5, COD and TSS concentrations for the influent wastewater are 673, 1238 and 671 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 4

The influent BOD_5, COD and TSS values for As-Samra 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	745	575	710	712	694	665	613	625	657	750	721	765	**686**
	2009	773	685	614	682	701	675	600	628	626	606	761	728	**673**
COD mg/dm^3	2008	1478	1190	1460	1468	1422	1343	1271	1245	1233	1445	1400	1250	**1350**
	2009	1430	1332	1194	1343	1393	1372	1187	1264	1252	1264	1501	1483	**1238**
TSS mg/dm^3	2008	843	655	735	761	699	655	637	641	572	848	684	746	**706**
	2009	678	671	608	622	691	697	550	697	662	681	729	775	**671**

5.3. Treated wastewater

Characterization of treated wastewater from As-Samra WWTP was evaluated in terms of measuring BOD_5, COD and TSS. The average temperature of influent flow is 24°C [7].

Figure 5 shows the effluent BOD_5, COD, and TSS values, respectively. It can be seen that the BOD_5 value ranges from 4.0 to 11.2 mg/dm^3. The highest COD value is 58.7 mg/dm^3, and the highest TSS value is 38.9 mg/dm^3. The average values of BOD_5, COD and TSS concentrations for the effluent wastewater are 7.0, 41.0 and 12.0 mg/dm^3, respectively. The values reduction for all parameters is above 99%.

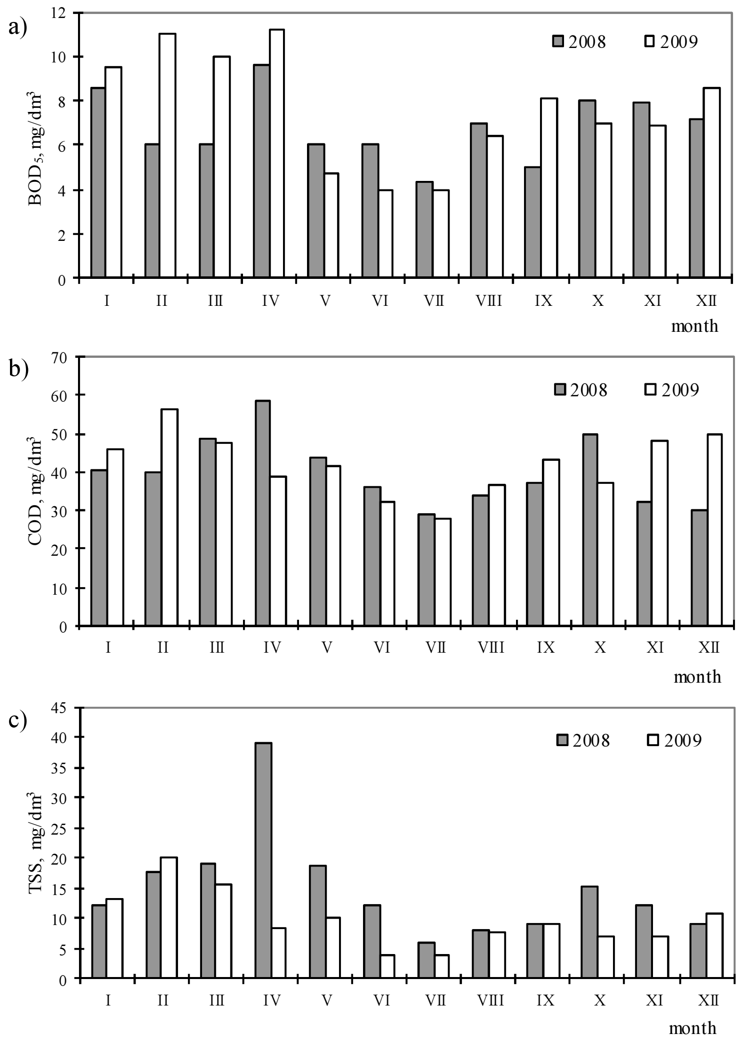

Fig. 5. The effluent: a) BOD_5, b) COD, c) TSS values from As-Samra WWTP

The effluent BOD_5, COD, and TSS from As-Samra WWTP complies with Jordanian standards for reclaimed wastewater discharge to streams, ground water recharge, irrigation parks, reuse for irrigation of cocked vegetables, fruits, and trees, and for reclaimed wastewater reuse for fodder crops (data of Table 3).

Wastewater, in addition to its beneficial nutrients, also contains contaminants and toxins. The contaminants are the excreted pathogens - disease-causing viruses, bacteria, protozoa and helminthes. The new As-Samra WWTP is using chlorine for disinfection the treated wastewater. It has to be mentioned that with respect to the quality criteria of treated wastewater according to Jordanian Standards available data on fecal coliforms and helminth eggs in wastewater from As-Samra WWTP confirmed suitability for agricultural irrigation.

Conclusion

Water is a basic human need, yet millions of people around the world do not have enough access to clean water. There are many claims on the world's water supply, from agriculture and industry to drinking water, municipal uses and tourism. It is a global issue, and everyone must share what is available. However, in some places, water is exceptionally scarce and people are extracting it faster than it can be replenished. Sixty-three percent of the world's population that has no access to clean water lives in Asia, the Middle East and North Africa.

By 2025 most of the Middle East countries are expected to experience water stress or scarcity [3]. Jordan has endured deficits in water resources since the early 1960s. The country is classified as water scarce. Its rank is number ten in the world concerning the insufficiency in water [11].

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. The Ministry of Water and Irrigation of Jordan prepared in April of 1997 a draft Water Strategy for Jordan [3]. 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 [8, 9].

The characteristics of raw wastewater in Jordan are somewhat different from other countries. Wastewater in Jordan can be characterized as very strong with high salinity and insignificant heavy metals and toxic organic compounds [10]. The average domestic water consumption is low. This results is very high organic loads. The average values in 2009 in As-Samra WWTP of BOD_5, COD and TSS concentrations for the influent wastewater are 673, 1238 and 671 mg/dm^3, respectively.

The effect of treating wastewater is very high. The values of pollutions in treated wastewater are a lot of smaller than definite in standards as permissible values and lower than the projected values. The effluent BOD_5, COD, and TSS from As-Samra WWTP complies with Jordanian standards for reclaimed wastewater discharge to streams, ground water recharge, irrigation parks, reuse for irrigation of cocked vegetables, fruits, and trees, and for reclaimed wastewater reuse for fodder crops.

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 expected very good quality effluent of the new WWTP has made it possible to explore new water reuse methods in Jordan. 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 in Jordan is necessity. Treated wastewater has, and will continue to be a major component of the national water budget, particularly in the densely populated Amman-Zarqa Basin and Jordan Valley [10].

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Efektywność oczyszczalni ścieków As-Samra w Jordanii i możliwości wykorzystania ścieków oczyszczonych

Woda jest niezbędna do życia, jednak miliony ludzi na świecie nie mają wystarczającego dostępu do jej zasobów. Codziennie należy zapewnić ciągłą dostawę czystej wody dla rolnictwa i przemysłu, do spożycia, a także do wykorzystania na cele rekreacyjne. Problem zaopatrzenia w wodę ma zasięg globalny, jednak w niektórych krajach jej zasoby są wyjątkowo małe, a zużycie jest większe niż naturalne możliwości uzupełnienia deficytu. 63% populacji ludzi na świecie, która nie ma wystarczającego dostępu do czystej wody, mieszka w Azji, na Bliskim Wschodzie i w Północnej Afryce. Przewiduje się, że około 2025 roku większość krajów Bliskiego Wschodu doświadczy znacznego niedoboru wody.

Zarządzanie wszystkimi sektorami gospodarki w Jordanii codziennie opiera się na podejmowaniu decyzji związanych z określeniem zużycia wody. Szybko rozwijające się rolnictwo (64% zużycia wody) oraz wzrost zaludnienia (28% zużycia wody) wymagają szukania alternatywnych źródeł wody. W gospodarce wodnej Jordanii duże znaczenie ma strategia ponownego wykorzystania ścieków oczyszczonych, które są ważnym składnikiem bilansu wodnego Jordanii, stanowiąc ok. 15% zasobów wodnych. W Jordanii w 23 oczyszczalniach ścieków o wydajności ok. 100 milionów m^3/rok ścieki oczyszczane są w trzech podstawowych systemach, takich jak: filtry gruntowe, osad czynny i stawy stabilizacyjne. Większość obiektów jest mała, z wyjątkiem oczyszczalni As-Samra, która przyjmuje ok. 80% całkowitej ilości oczyszczanych ścieków. Oczyszczalnia As-Samra po zakończeniu modernizacji w 2008 r. pracuje w technologii osadu czynnego z usuwaniem biogenów i dezynfekcją chlorem ścieków oczyszczonych.

W pracy przedstawiono charakterystykę ścieków surowych i oczyszczonych z oczyszczalni As-Samra na podstawie wartości ChZT, BZT_5 i zawiesiny ogólnej. Efektywność oczyszczalni As-Samra oceniono na podstawie standardów jakości ścieków oczyszczonych obowiązujących w Jordanii i możliwości ich ponownego wykorzystania.

Słowa kluczowe: Jordania, oczyszczalnia ścieków, standardy wykorzystania ścieków oczyszczonych