ELSEVIER

Desalination 152 (2002) 281–289

DESALINATION

www.elsevier.com/locate/desal

Potential of industrial wastewater reuse

Mousa S. Mohsen*, Jamal O. Jaber

Department of Mechanical Engineering, Hashemite Univeristy, 13115 Zarqa, Jordan
Tel. +962 (5) 3826600; Fax +926 (5) 3826613; email: msasmohsen@yahoo.com

Received 10 April 2002; accepted 25 April 2002

Abstract

The potential of industrial wastewater reuse in Jordan is discussed. Industrial water requirements, wastewater production, types of pollutants in industrial wastewater and the technologies for wastewater treatment have been evaluated. A total of thirty industries have been reviewed. The total effluent from the thirty industries reviewed estimated at approximately 10,200 m^3/d. Of this amount, approximately 4,400 m^3/d are discharged to public sewerage system, which is about 3% of the total flow. The amounts of metals to be controlled are: 6800 kg/y, 3000 kg/y, 45 kg/y, 65 kg/y, 20 kg/y, 2 kg/y, 25 kg/y, 60 t/y and 8 t/y of Cr, Zn, Cu, Pb, Ni, Cd, Sn, Fe and Al, respectively. Nineteen industries, which discharge mainly organic polluted process wastewater, are food industries. Approximately 5.3 t of BOD/d is discharged from these industries. Of these, approximately 2.2 t BOD/d are discharged to the public sewerage system and about 3.1 t BOD are used for irrigation. It has been shown that most of the selected industries require some treatment of their wastewater. It is recommended to carry out further studies to establish the type of wastewater pretreatment strategies and their estimated capital cost. There is a need for the introduction of a cleaner technology in the selected industries. This could include substitution of raw and auxiliary materials, water and energy saving, recirculation of water, recovery of chemicals, improved process control, waste minimization, and good housekeeping.

Keywords: Industrial wastewater; Water reuse; Pollutants in industrial wastewater; Wastewater treatment; Jordan

*Corresponding author.

Presented at the EuroMed 2002 conference on Desalination Strategies in South Mediterranean Countries: Cooperation between Mediterranean Countries of Europe and the Southern Rim of the Mediterranean.
Sponsored by the European Desalination Society and Alexandria University Desalination Studies and Technology Center, Sharm El Sheikh, Egypt, May 4–6, 2002.

PII: S0011-9164(02)01075-5

1. Introduction

The significant development over the last decades of the Jordanian economy has brought prosperity to the country. At the same time there has been a rapid growth in population. This has, however, had an adverse impact on the environment, the natural resources and possibly also on the health of the population.

The physical planning of the development has generally been inadequate and until recently there has been little concern for the environment. Today there are many signs of significant pollution and environmental degradation, in particular, in the Amman–Zarqa region, which is the largest urban center in Jordan with more than half the population of the Kingdom. It is also the largest industrial congregation, where the majority of the Jordan industry is located.

The availability of water in Jordan is very restricted compared to the demand. On an average basis, the water extraction from Jordanian wells in 1989 was so high that all water from rainfalls was used for extraction. Today more water is extracted from the wells and the level of ground water is decreasing. Since 1989, the imbalance between precipitation and consumption reaching the groundwater has been increasing from year to year. This means that the ground water basin under Jordan is being depleted, and as the wells become deeper, the average salinity of the extracted water increases. Based upon previous studies and detailed observations [1–16], the authors conclude that there is a need now to focus greater attention on the future impact of water resources planning and development. An efficient water plan should be developed now and take into consideration all related issues. It would consist of, in addition to the adverse climatic conditions, limited water resources, high population growth, desertification and urbanization, rapid industrial growth, soil salinity, environmental sustainability, imbalance between socio-economic development and water availability, and the effect of political instability on regional co-operation among water-sharing countries.

The industrial sector in Jordan used 50 MCM of water in 1998. This accounts for 5% of the total water consumption during this year, as shown in Fig. 1. A major part of this was consumed by large industries such as phosphate mining, the production of potash, cement, ceramics and soft drinks, as well as the energy sector. Almost all local industries have suffered from shortages in water supplies during the last two decades. The water shortage is also the limiting factor for the establishment of new industries as well as the expansion of certain high rate water consumption processes such as oil shale processing [9].

Industry can be considered as a source of significant amounts of reusable effluents [17–20]. Thus, industry should be encouraged to invest in better water efficiency, more recycling and management. Water use normalized indices can be developed for each industry in order to allocate only as much water as necessary to achieve their production targets.

The environmental pollution comes from many sources in society. Domestic sewage is the largest source of water pollution, followed by industrial effluents and agricultural activities. The industrial waste, in particular when it contains

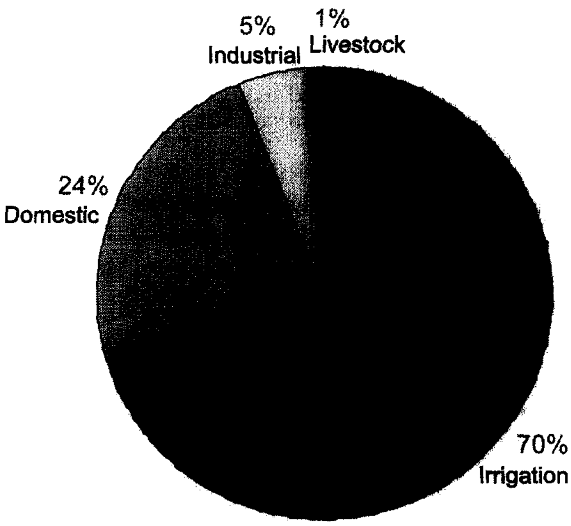

Fig. 1. Sectorial distribution of water consumption during 1998.

harmful chemicals, heavy metals and other toxic substances, can have far more serious consequences than domestic waste. These hazardous substances pollute the surface water, the soil and the groundwater, become concentrated in the food chain and therefore need a special treatment before being discharged. Many of them are slowly or not at all biodegradable. At the same time intensive pumping of ground water from the area has lowered the water table, so that the rivers today are dry most of the year. As untreated wastewater to some extent is discharged to the valleys, this has worsened the situation significantly.

The generation of hazardous waste is a serious and increasing problem. Significant quantities of toxic and hazardous waste are today deposited in uncontrolled landfills, dumped in rivers or wadis or spread in the desert. Measurements have shown relatively high contents of pesticide residues in agricultural products from the Jordan Valley and some concern has been expressed over the possible effects on the quality of the products, on the agricultural economy and on the health of the population.

The pollution mitigating measures to be implemented in industry shall be seen in this light. Every possible should be done to save water or reuse it. Reuse may take two forms: water conservation and recycling internally in the plant and disposal to a public sewer system, in which the water is treated and later reused for irrigation.

The discharge of industrial wastewater to sewage systems and to wadis is regulated through effluent standards based on maximum values for certain parameters [21]. The standards mainly deal with organic matter and with heavy metals. Regardless of category and size, many industries processing organic matter, e.g. food industries, are required to build and operate captive biological wastewater treatment plants in order to comply with the effluent standards for discharge of organic matter.

The increasing salinity of ground water is a severe problem in Jordan. This problem is becoming more acute as the consumption is increasing and wells must be drilled deeper and deeper. The problem exists for industry as well as for public water supplies. Also, there is an increase in areas, which have been irrigated by saline water so that the soil has been so loaded with salt that crop productivity has decreased, or only special saline-resistant crops like tomatoes can grow. The King Talal Reservoir (KTR) is used for irrigation of crops in an important part of the Jordan Valley.

The objective of this work is to evaluate the potential of industrial wastewater reuse in Jordan. Industrial water requirements, wastewater production, types of pollutants in industrial wastewater and the technologies for wastewater treatment have been discussed. A total of thirty industries have been reviewed in the Amman–Zarqa region.

2. Industrial wastewater production

The study area is the Amman–Zarqa region northeast of Amman and the Amman Industrial Estate at Sahab southeast of the capital. Together these two areas contain the majority of the Jordanian industry. Industrial categories represented in the area span from small food industries over textile, metal and chemical enterprises to a large oil refinery and a power plant. The majority of the enterprises are small and medium size and only few of them use heavy metals and hazardous substances in significant quantities in their production process. A total of thirty industries have been reviewed. The thirty industries reviewed have been selected from a list of enterprises in Amman–Zarqa, which are monitored regularly by the Water Authority of Jordan (WAJ), most of these industries discharge their wastewater to the municipal sewer after some pretreatment. Most of the industries in the Zarqa area are located along the Zarqa River, a small stream, which is dry most of the year. These industries have generally been located without much consideration for the environment and construction of residential houses have in many cases been allowed close to the industries, creating the basis for future problems and conflicts.

The industrial effluents discharged to the municipal sewer are carried to the As Samra Treatment Plant (STP). The effluent from STP flows through the Wadi Dhuleil and the Zarqa River to the King Talal Reservoir (KTR). Water from KTR is used for irrigation in the Jordan Valley (JV). The total effluent from the thirty industries reviewed is estimated at approximately 10,200 m^3/d. Of this amount, approximately 4,400 m^3/d are discharged to STP, which is about 3% of the total flow.

3. Pollutants in industrial wastewater

Results from analyses of sludge in STP show increased levels of chromium, zinc, cadmium and mercury while concentrations of other heavy metals seem to be within normal intervals for municipal sludge. Preliminary results from analyses of bottom sediment in KTR show, however, very low contents of heavy metals. This indicates that the load of heavy metals to KTR is low and that the retention of metals in STP is fairly high. Based on analyses of a large number of wastewater samples, the total pollution load from industries can be estimated. The total BOD load on STP from selected industries is approximately 2.1 t/d. This is about 3% of the total biological load on STP, which is approximately 70 t/d BOD. The total discharge of heavy metals (except iron) from the thirty industries reviewed is about 1.8 kg/d — approximately 1% of the total quantity discharged to STP. A number of industries discharge heavily polluted wastewater and chemical waste by tankers. Some of it may be dumped in the desert and may infiltrate down to the underlying water aquifers, other may be discharged to the sewer system without control. For the thirty industries disposal by tankers yearly accounts for 60 t iron, 8 t aluminum and 11 t of other heavy metals some of which are toxic.

Table 1 lists all twelve industries which discharge wastewater with heavy metals while Table 2

Table 1
Industries discharging wastewater with heavy metals to sewer or irrigation

Company	Discharge, m^3/y	Discharge to
Jordan Petroleum Refinery	1,400,000	Irrigation
Arabian Steel Pipes	0	Sahab
Amman Casting Electroplating	400	Sahab
Universal Electroplating	700	Sahab
Household Appliances	12,000	Irrigation
Al Hussein Power Station	440,000	STP
Jordan Imperial Knitting	2,000	STP
Lead Acid Batteries	3,000	STP
Arab Steel and Metal	19,500	Wadi
Worsted Mills	30,000	STP
Karimtex	15,000	STP
Tanning Company	45,000	STP
Total discharge	1,967,600	
Discharge to STP	535,000	
Discharge to Sahab	1,100	

Table 2
Industries disposing wastewater and chemical wastes with heavy metal contents by tankers

Company	Discharge, m^3/y	Total discharge, kg/y									
		Cr	Zn	Cu	Pb	Ni	Cd	Sn	Fe	Al	Total
Arabian Steel Pipes	1500	55	2900	20	—	20	2	—	52900	—	55897
Amman Casting Electroplating	0.5	×	×	×		×			×		72
Universal Electroplating	6000	95	25	26	2.2			27	216	8200	8591
Household Appliances	5.4	0.1	20	0.4		1.2			16		38
Lead Acid Batteries	1.2		1.9		62				105		169
Arab Steel and Metal	720								7200		7200
Tanning Company	56	6700									6700
Total disposal	8283	6815	2957	46	64	21	2	27	60437	8200	78667

includes seven industries with disposal of heavily polluted wastewater and chemical waste by tankers. Fig. 2 shows the type and percentage of heavy metals discharged by these industries. The quantities of heavy metals discharged to the STP from the industries are small compared to the total load of heavy metals on STP from all sources. The comparison is made in Table 3. It is seen that the discharge of heavy metals from the industries to STP is only a few percent of the total load.

Chromium is discharged in very large amounts to STP. Most of the chromium from the thirty industries comes from the Tanning Co. but it still accounts for less than 5% of the total load to STP. The Tanning Co. also generates much sludge with chromium. This sludge is deposited at the factory. Most of the chromium from the metal and metal finishing industry is collected and disposed of by tankers at undisclosed places.

Zinc is another prevalent metal found in high concentrations in wastewater sludge in all industrial countries. There are many sources, but the refinery and power station are responsible for most of the zinc from the thirty industries to STP. Arabian Steel Pipes also generates large quantities of zinc, but this is collected and disposed of by tankers.

Copper is rather common in city wastewater and the load on STP is not higher than normal.

Table 3
Estimation of heavy metals discharged to STP

Metal	Total quantity, kg/y	Quantity from 30 industries, kg/y
Chromium	8,200	485
Zinc	44,500	154
Copper	4,300	—
Lead	2,600	1
Nickel	650	—
Cadmium	95	—
Mercury	55	—
Iron	257,000	78
Total (excluding iron)	60,500	640

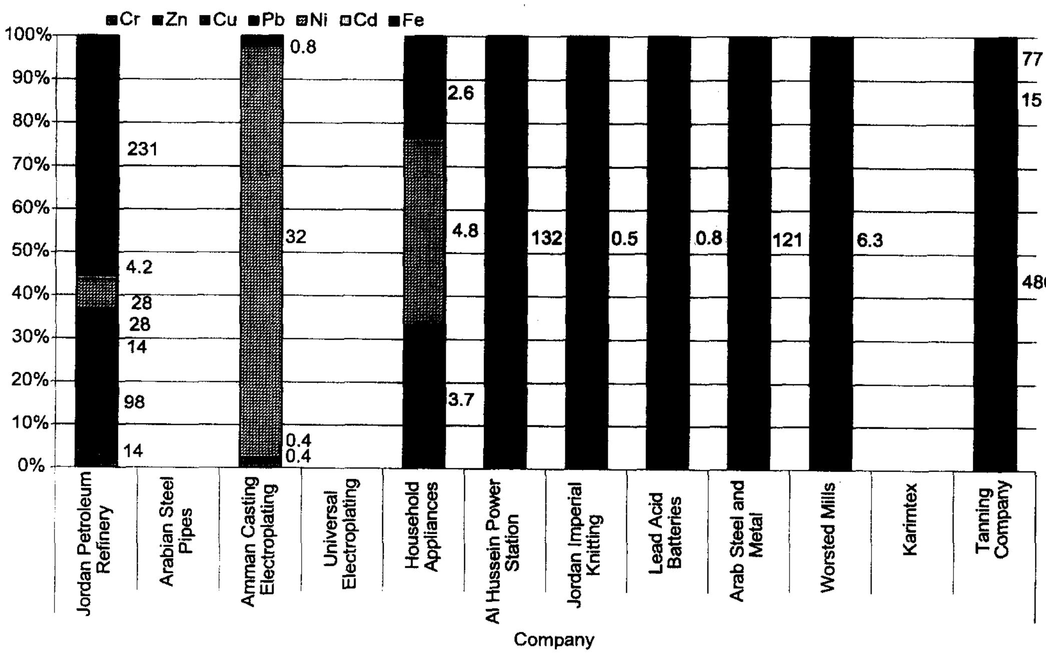

Fig. 2. Percentages of heavy metals in wastewater discharged.

Only very small amounts are discharged from the thirty industries. Lead is only discharged in small amounts to the sewer system and the load of lead on STP is relatively low. The Lead Acid Batteries Co. has recently established a new wastewater treatment plant to remove lead. Nickel is generally low in STP effluent. It generates first of all from the metal and metal finishing industry, but small amounts are also present in the wastewater from the refinery. The amounts of nickel in wastewater discharged to the sewer are very small and so are the amounts disposed of by tankers.

The cadmium load on STP is a little higher than normal compared to industrial countries, which have done much to control the cadmium pollution. No significant discharge of cadmium to the sewer system has been identified from the thirty industries. Small amounts of cadmium are disposed with wastewater in tankers from Arabian Steel Pipes Co.

Iron is present in most of the discharged water from metal and metal finishing industry. Iron is the predominant metal in the wastewater disposed by tankers where 60 t/y are disposed. Less than 100 kg/y is discharged to the sewer and this cannot account for the very high load of iron to STP.

Aluminum is not a heavy metal but it will often be found together with heavy metals. It is precipitated as metal hydroxide sludge in chemical treatment of wastewater with heavy metals. Aluminum is found in wastewater from surface treatment of aluminum and large amounts are disposed of by tankers from Universal Electroplating Co.

Table 4 shows nineteen industries which discharge mainly organic polluted process wastewater. Most are food industries. It appears from the table that approximately 5.3 t of BOD/d are discharged from these industries. Of these approximately 2.2 t

Table 4
Flow and pollutant load of organic non-toxic pollution

Industry	Average process wastewater, m^3/d	Pretreatment	Discharge	BOD, kg/d	COD, kg/d	TSS, kg/d	TDS, kg/d
Jordan Petroleum Refinery	3800	Mechanical	Irrigation	148	532	236	12122
Jordan Paper & Cardboard	600	Biological	Irrigation	124	287	110	1080
Eagle Distilleries Co.	70	Mechanical	STP	126	229	8.1	194
Ain Ghazal Slaughter House	630	No	STP	4249	20340	1014	3974
Jordan Ice and Aerated Water Co.	950	No	STP	443	837	219	2446
Arab Chemical Detergents	36	Chemical	STP	—	—	—	—
The ICA Co.	310	Biological	STP	—	—	—	—
Zeidans Refrigeration Co.	17	No	STP	99	194	43	82
Arab Brewery Co.	66	No	STP	13	26	9	107
Arabian Trade &Food Co.	33	No	STP	88	163	290	60
Jordan Brewery Co.	110	No	STP	28	52	5.5	68
United Factories Co.	6	Biological	STP	1.8	3.7	0.37	6.5
Yeast Industries Co.	530	No	Irrigation	3378	6141	597	3869
Jordan Dairy Co.	80	Biological	STP	2	6.2	35	82
Ata Ali Ice-Cream Co.	18	Mechanical	STP	—	—	—	—
Hikema Pharmaceuticals Jordan	16	No	STP	13	23	2.3	14
Danish-Jordanian Dairy Co.	90	Biological	STP	28	56	19	117
The Tanning Co.	150	Chemical	STP	15	49	28	1590
Danish Food Industries Co.	130	Mechanical	Sahab	—	—	—	—
Total	7641			8754	28938	2614	25812
Total to sewer	2711			5104	21978	1672	8741

BOD/d are discharged to the public sewerage system and STP and about 3.1 t BOD are used for irrigation. During the period 1988–1992, the average organic load on STP was measured to approximately 70 t BOD/d.

Hence the examined industries are responsible for approximately 3% of the organic load on STP. The STP is designed to treat 36 t BOD/d and consequently seriously overloaded. STP is treating wastewater from Amman, Zarqa and Ruseifa. About 1.25 million people live in these cities. Assuming a daily load of 50 g BOD/person, the load from households can be estimated to 63 t BOD/d. This figure is in accordance with measured load and confirms that the greater part of the organic load on STP comes from households. Furthermore, this indicates that a reduction of the organic pollution from industries will not significantly affect the urgent need for extension of the STP.

The proposed improvements of the industrial wastewater pretreatment will reduce the organic discharge to the STP from 2.1 to 0.9 t BOD/d. It will most likely be more cost efficient, however, to remove these relatively small amounts in a public wastewater treatment plant common for households and industries. It will be most likely that industrial pretreatment, in order to remove organic matter before discharge to the sewerage system, will focus on removal of easily degradable organic matter. The biological processes at the central treatment plant will, however, benefit from supplies of easily degradable organic matter. Removal of these organic matters can thus complicate the operation of the central treatment plant.

4. Technologies for wastewater treatment

Discharge of heavy metals to the sewer will be reduced significantly when recommended treatment projects are implemented. 460 kg/y of chromium from the Tanning Company and 30 kg/y of nickel from Amman Casting Company will be removed from the discharged wastewater through introduction of cleaner technology and a more efficient wastewater treatment in the two factories. Most of the heavy metals are today disposed of by tankers or deposited in or outside the factory areas. This practice is not environmentally sustainable and should be discontinued. The proposed solutions are based upon treatment inside the factory of wastewater with heavy metals. Heavy metals are precipitated as metal hydroxide sludge and as far as possible, iron sludge and aluminum sludge are separated from other metal sludge. As a result, most of the produced chemical waste is not toxic and can therefore be deposited safely in a normal landfill. This method will bring most of the heavy metals under control so that the metals do not end in the sewer or on the irrigated land. The amounts of metals to be controlled in this way are: 6800 kg/y, 3000 kg/y, 45 kg/y, 65 kg/y, 20 kg/y, 2 kg/y, 25 kg/y, 60 t/y and 8 t/y of Cr, Zn, Cu, Pb, Ni, Cd, Sn, Fe and Al, respectively. The sludge containing heavy toxic metals shall be handled and deposited as hazardous waste in a safe environmentally acceptable and sustainable way.

5. Discussion

In general, the consumption of water by the industries is not exceptionally high because water is expensive and there is a lack of water. However, there are many possibilities for water saving in rinsing and washing operations in many of the industrial processes reviewed. Countercurrent rinse, spray rinse, flow control and recirculation of rinse water through ion exchangers are some of the most obvious methods for water savings.

Cooling water is often made by evaporation in a cooling tower. This process consumes water and the salt concentration in the cooling water increases. This will contribute to an increase in the salt concentration in the water sources used for reclaiming fresh water. The high salt concentration in natural water sources in Jordan is a growing problem, which may need much serious attention in the future. Closed cooling systems will help somewhat. Another possibility is to replace ion exchangers with reverse osmosis for the production of deionized water. By regeneration of ion exchangers much salt is produced from sodium hydroxide and hydrochloric acid. Fewer chemicals are used by reverse osmosis. Here the water should perhaps be pretreated by a softener.

The water softening process should also be considered as a source of salt pollution. Normally, resins for water softening are regenerated with sodium chloride, which contributes to a growing sodium concentration in natural water sources. It is possible to use potassium chloride as a substitute for sodium chloride. This will improve the quality of the treated wastewater from STP, which is used for irrigation. Jordan Potash Company produces 97% pure potassium chloride. The world trend now, especially in USA, is to replace sodium chloride with potassium chloride in water softening. Doing this in Amman and Zarqa can reduce sodium salinity of STP by nearly 10% and will add nutrients to the water. It is estimated that consumption of sodium chloride in Amman–Zarqa area today is about 2500 t/y.

In Jordan it is a general principle that high organic pollution and toxic substances in wastewater shall be removed by the industry before discharging to the sewer system. Normally, it is more suitable and economic to treat organic pollution in large municipal treatment plants, such as STP or similar plants. The problem is that the existing biological treatment plants are all overloaded. Therefore, the policy is that removal of organic matter shall take place at the source to comply with the discharge limits. In the long run it is recommended that the capacity of municipal wastewater treatment be increased so industries can discharge large amounts of organic matter for further treatment. Industries with high BOD concentration should pay extra to discharge this kind of wastewater, so it is up to the industry to decide if a pretreatment should be preferred.

Toxic materials, such as heavy metals shall be removed at the source. Municipal treatment plants are not supposed to remove heavy metals. It can be done much better and much more efficiently by the industry where pretreatment or pollution abating measures can be arranged. Heavy metals are separated together with the sludge in mechanical biological wastewater treatment. The heavy metals, however, will contaminate the sludge and limit the possibilities for disposal. Sludge with high concentrations of heavy metals shall not be used for agricultural purposes but shall be incinerated or disposed of under controlled circumstances which is a much more expensive solution.

Toxic materials, such as phenol and cyanide are biologically degradable but in high concentrations they are toxic for humans and microorganisms. In this case both cyanide and phenol must be removed at the source. It could be a pretreatment where the matter is oxidized or it could be an arrangement where the chemicals are substituted with less harmful chemicals. Also a reduction of the concentration of cyanide and phenol in the wastewater should be investigated.

Industries, for which the contents of pollutants in their wastewater exceed the Jordan Regulation, shall reduce the pollution before discharge to the municipal sewer. This should be done by pretreatment in the factory. Alternatively, a number of close-lying industries, which have the same type of wastewater, may choose to build a common treatment plant. Also, industries for which the contents of pollutants in their wastewater exceed the Jordanian Standard for discharge to streams, wadis or groundwater or for irrigation should reduce the pollution as described.

6. Conclusions and recommendations

In principle all industrial wastewater should be discharged to the sewer system. Disposal through irrigation or discharge directly to the environment should be discontinued and allowed only following an environmental impact assessment. Industry should pay for the discharge of water and pollution. The authorities free of charge should collect organic waste. This system will reduce industrial discharge of organic pollutants in the wastewater.

It is recommended to conduct a study to account for all users of sodium chloride, not only industry, and to what extent it is possible to substitute this with potassium chloride. Based on the outcome of this study, WAJ may decide to limit ion discharge into sewers.

It has been shown that most of the selected industries require some treatment of their wastewater. It is recommended to carry further studies to establish the type of wastewater pretreatment strategies and their estimated capital cost. There is a need for introduction of cleaner technology in the selected industries. This could include substitution of raw and auxiliary materials, water and energy saving, recirculation of water, recovery of chemicals, improved process control, waste minimization, and good housekeeping. The water consumption in some of the industries is high and in others reasonable. Reliable monitoring data are scarce. All industries should install water meters. Dilution of wastewater should be prohibited. A water saving campaign should be conducted and the water charges should be reviewed.

Open water-based cooling systems should be closed to save water. When possible, air coolers should be used. Ion exchangers should be substituted by reverse osmosis technique. This will reduce significantly the discharge of salts. Regeneration of water softeners should be converted from sodium chloride to potassium chloride, which is more acceptable in the environmental context.

The industries should install appropriate wastewater monitoring and sampling facilities. The wastewater flow and composition should be measured by industries and checked by the appropriate authorities on a regular basis. In a forthcoming paper, evaluation of the need for upgrading the existing or building new wastewater treatment plants at the selected industries will be carried out.

References

[1] O.R. Al-Jayyousi and M.R. Shatanawi, Wat. Res. Develop., 11 (1995) 315.

[2] National Environment Strategy, Ministry of Municipal and Rural Affairs and the Environment, Amman, Jordan, 1992.

[3] National Environment Action Plan, Ministry of Planning, Amman, Jordan, 1996.

[4] A Strategy for Managing Water in the Middle East and North Africa, World Bank, Washington, DC, 1995.

[5] From Scarcity to Scarcity: Averting a Water Crisis in the Middle East and North Africa, Washington, DC, 1995.

[6] E. Salameh, Proc. Symposium on Jordan's Water Resources and their Future Potential, Amman, Jordan, 1992, pp. 113–120.

[7] M. Murakami, Managing Water for Peace in the Middle East, United Nations University Press, Tokyo, Japan, 1995, pp. 167–201.

[8] M. Ragheb, K. Toukan and R. Al-Weshah, Poc. Int. Symp. on Water Resources in the Middle East: Policy and Institutional Aspects, Urbana, IL, USA, 1993, pp. 173–180.

[9] J.O. Jaber and M.S. Mohsen, Desalination, 136 (2001) 83.

[10] B.A. Akash, O.R. Al-Jayyousi and M.S. Mohsen, Desalination, 114 (1997) 1.

[11] M.S. Mohsen and O.R. Al-Jayyousi, Desalination, 124 (1999) 163.

[12] O.R. Al-Jayyousi and M.S. Mohsen, Desalination, 139 (2001) 237.

[13] JICA final Report on Brackish Ground Water Desalination in Jordan, Amman, Jordan, 1995.

[14] Annual Reports, Water Authority, Amman, Jordan, 1996 and 1997.

[15] Annual Report, Water Authority, Amman, Jordan, 1998.

[16] R. Ta'ni, Water Resources and Usage in Jordan, Ministry of Water and Irrigation, Amman, Jordan, 1999.

[17] M.D. Afonso and R.B. Yanez, Desalination, 139 (2001) 429.

[18] B. Durham, M.M. Bourbigot and T. Pankratz, Desalination, 138 (2001) 83.

[19] A.J. Karabelas, S.G. Yiantsios, Z. Metaxiotou, N. Andritos, A. Akiskalos, G. Vlachopoulos and S. Stavroulias, Desalination, 138 (2001) 93.

[20] M.D. Afonso, A.M.B. Alves and M.S. Mohsen, Desalination, 149 (2002) 153.

[21] Jordanian Standards, 202/1991, Amman, Jordan, 1991.