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Assessment of the irrigation quality of the admixture of reverse osmosis permeate and tertiary effluent

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ABSTRACT

Conventional reverse osmosis (RO) treatment deprives reclaimed wastewater of nutrients and other essential elements for plant growth. One way to make the RO reclaimed wastewater suitable for agricultural irrigation purposes is to blend it with a tertiary effluent. This paper assesses the suitability of the quality of RO permeate and tertiary effluent admixture for agricultural irrigation, using the WHO guidelines for irrigation waters. Obtained results indicated that the admixture is suitable for agricultural irrigation, but with some restrictions. Unsuccessful attempt to predict the quality of the admixture, using only ideal mixing principles, confirmed that effluent storage reservoirs (ESRs) constitute a complex ecosystem.

Keywords: Wastewater; Reclamation; Reuse; Tertiary Effluent; RO Permeate; Irrigation water

1. Introduction

Water scarcity and the increasing demand for food and fibers are the main reasons for the increasing reuse of wastewater in agriculture worldwide. At the present time, wastewater reuse has become the most attractive option to alleviate pressure on freshwater resources, especially in arid and semiarid regions where these resources are very limited. Generally, reuse of wastewater has proven to be economical and environmentally beneficial [1]. Specific advantages of wastewater reuse include reduction of the amount of freshwater extracted from the environment, provision of a reliable supply of large amounts of water, enhancement of crop productivity and reduction of environmental degradation [1–3]. In spite of these advantages, wastewater reuse has some limitations which include risks from pathogenic microorganisms, increased soil salinity due to high total dissolved solids (TDS) concentrations, clogging of soils and/or irrigation systems with suspended solids, and introduction of toxic compounds, for example, endocrine disrupters and pharmaceuticals. With adequate treatment of the wastewater, however, most of these risks can be reduced to tolerable levels.

The use of wastewater as irrigation water increases crop productivity, mainly due to the presence of organics, nutrients and trace elements [2,3]. However, large amounts of organic and nutrients can lead to soil clogging, and consequently to reduction in the amount of water available for crops [4]. Also, high TDS concentrations in reused wastewater can increase soil salinity. Further, some crops are sensitive to certain trace elements

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(e.g., Na, B and Se) that are present in wastewater [5]. Thus, it is essential that treated wastewater reused as agricultural irrigation water has low TDS levels and adequate amounts of nutrients and trace elements. The Food and Agriculture Organization (FAO) has proposed the quality requirements of the treated wastewater that will be used as agricultural irrigation water. These requirements can be found in publications of the FAO [6], as well as the publications of the World Health Organization (WHO) [5].

Wastewater is conventionally treated to a secondary level (i.e., biological treatment plus chlorination) or to a tertiary level (i.e., biological treatment plus, for example, sand filtration and chlorination). However, secondary and tertiary treatments usually result in limited removal of dissolved salts and toxic compounds, and therefore, they are usually not considered to meet the irrigation quality requirements. This explains why advanced membrane filtration of wastewater, especially using reverse osmosis (RO) systems, has lately received great attention [7].

Wastewater constituents of main concerns for agricultural irrigations are salts, trace elements (heavy metals and toxic organic compounds) and nutrients [8]. Also certain metals (e.g., Cd, Cu, Mo, Ni, and Zn) pose health risks to crop consumers. Further, a variety of organic compounds present in wastewater (e.g., pesticides, endocrine disrupters, and pharmaceuticals) can cause serious public health and environmental problems. Although they are fundamental plant macronutrients, presence of N and P in large amounts can cause negative environmental (e.g., eutrophication) and public health impacts [5]. The conventional use of RO systems in wastewater reclamation usually leads to almost complete removal of these pollutants, and thus, production of effluents of almost potable water quality. Complete removal of N, P, K, B, S, and plant essential trace metals (Cd, Cu, Mo, Ni and Zn) obviously makes the RO permeate unfit for agricultural irrigation.

Two methods have been tried so far for making the conventionally RO-treated wastewater suitable for agricultural applications. In the first method, external fertilizers were added in amounts that make nutrients concentrations of the RO permeate equal to that of secondary effluent. This method was studied by Oron and co-workers [7,9,10]. In the second method, a nanofiltration (NF) was adopted prior to RO filtration. NF can selectively remove divalent ions, while letting monovalent ions (e.g., Na) pass through [11]. In the study conducted by Zou et al. [12], Poly Acrylic Acid (PAA) was added to enhance the rejection of divalent ions in the brine stream which was re-circulated and mixed with RO permeate. Thus, addition of PAA was found to make the effluents more suitable for agricultural applications.

Blending the RO permeates with tertiary effluents can also be another option for making the RO permeates more suitable for irrigation purposes [13]. However, this option has not yet received a thorough evaluation. This study was undertaken with the aim of assessing the suitability the admixture of RO permeate and tertiary effluent for agricultural irrigation purposes.

2. Municipal wastewater treatment and reuse in kuwait

Kuwait municipal wastewater is treated to tertiary or advanced levels at four main activated sludge plants located in Jahra, Riqqa, Sulaibiya and Um-Al-Haiman areas (Table 1). Only effluents of Jahra (tertiary) and Sulaibiya (RO permeate) plants are pumped to a central facility called the Data Monitoring Center (DMC), located about 30 km from Kuwait City, from where it will be stored, further chlorinated and distributed for restricted (fodder) irrigation at the main farming areas situated in Abdalli, Sulaibiya and Wafra areas. The DMC facility has six ESRs of total capacity equal to 340,000 m^3, pump houses, chlorination units, a laboratory for water analysis and a computerized data management facility for recording the daily quantity and

Table 1
Kuwait's municipal wastewater treatment plants

Plant	Secondary treatment	Tertiary treatment	Advanced treatment
Jahra (70,000 $m^3\ d^{-1}$)	6 Conventional activated-sludge systems operated in extended aeration mode	Sand filtration + chlorination	–
Riqqa (120,000 $m^3\ d^{-1}$)	12 Conventional activated-sludge systems operated in extended aeration mode	Sand filtration+ chlorination	–
Sulaibiya (420,000 $m^3\ d^{-1}$)	9 BNR activated-sludge systems	–	Disc filtration + UF + RO + chlorination
Umm-Al-Haiman (20,000 $m^3\ d^{-1}$)	4 Oxidation ditch systems	Sand filtration + UV + chlorination	–

quality of the ESRs inflows and outflows. Storage of treated wastewater effluents in properly designed and operated ESR's is reported to improve the effluent quality, particularly with respect to concentrations of nutrients and trace metals [14], and thus help in producing high crop yields [15].

3. Materials and methods

DMC daily records for the year 2005 were collected, summarized and statistically analyzed. DMC records contained daily information about the quantity and quality of in- and outflows of the ESRs. During the study period, the average inflows from Sulaibiya and Jahra plants were 331,367 m^3 d^{-1} and 25,805 m^3 d^{-1}, respectively (mean residence time at the ESRs was 25.5 h). Thus, the mixing ratio (Jahra stream/Sulaibiya stream) during 2005 ranged from 0.03 to 0.14 (mean is 0.08).

All wastewater quality parameters were determined at the DMC laboratory in accordance with the American standard methods for water and wastewater examination [16], except for the EC and pH, which were determined in the field using portable measuring devices. Solids (TSS, TDS and VSS) were determined by gravimetric method. COD was determined by standard open reflux method. BOD_5 was found after five days incubation at 20°C. Hach spectrophotometers were used to measure NO_4, PO_4 and SO_4. NH_4 and org-N were determined by distillation and digestion methods. Heavy metals, Na and Ca were measured using a flame atomic adsorption spectrophotometer (ASS).

Quality parameters of the DMC admixture (outflow) were assessed for irrigation using criteria adopted from the WHO guidelines [5], which consisted of pH, EC, TDS, TSS, SAR, Cl, Na, Ca, Mg, B, HCO_3 and TN (Table 2) plus some trace elements (Table 4). The Sodium Adsorption Ratio (SAR) was calculated from the DMC records as follows:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (1)$$

where Na^+, Ca^{2+} and Mg^{2+} are in meq l^{-1}.

Furthermore, prediction of the quality of the admixture (DMC outflow) was attempted using only ideal mixing principles Eq. (2). Liquid mixing usually depends on many factors. For simplicity, however, an ideal mixing condition has been assumed. First-order kinetics is usually used to model *Escherichia coli (E. coli)* in ESRs [17,18]. But for simplicity, bio-kinetic was not taken into account since the effect of chlorination was found to be faster and more pronounced than the effect of storage.

$$C_{Jah}Q_{Jah} + C_{Sul}Q_{Sul} = C_{DMC}Q_{DMC} \quad (2)$$

Table 2
Guidelines for interpretation of water quality for irrigation (Adopted from [5])

Potential irrigation problem	Unit	Degree of restriction		
		None	Slight to moderate	Severe
EC	dS m^{-1}	<0.7	0.7–3.0	>3.0
TDS	mg l^{-1}	<450	450–2000	>2000
TSS	mg l^{-1}	<50	50–100	>100
EC at SAR = 0–3	dS m^{-1}	>0.7	0.7–0.2	<0.2
EC at SAR = 3–6	dS m^{-1}	>1.2	1.2–0.3	<0.3
EC at SAR = 6–12	dS m^{-1}	>1.9	1.9–0.5	>0.5
EC at SAR = 12–20	dS m^{-1}	>2.9	2.9–1.3	<1.3
EC at SAR = 20–40	dS m^{-1}	>5.0	5.0–2.9	<2.9
Sodium (Na^+): sprinkler irrigation	meq l^{-1}	<3	3–9	>9
Chloride (Cl^-): sprinkler irrigation	meq l^{-1}	<3	>3	
Chloride (Cl^-): surface irrigation	meq l^{-1}	<4	4–10	>10
Bicarbonate (HCO_3)	mg l^{-1}	<90	90–500	>500
Boron (B)	mg l^{-1}	<0.7	0.7–3.0	>3.0
Total Nitrogen (TN)	mg l^{-1}	<5	5–30	>30
pH	–	Normal range: 6.5–8.0		
Trace elements	mg l^{-1}	*See* Table 4 for recommended maximum concentrations		

Table 3
Calculated irrigation quality of the DMC admixture (outflow)

Quality variable	Minimum	Maximum	Mean	Standard error
pH (-)	6.6	7.7	7.1	0.3
EC (μS m^{-1})	0.08	1.09	0.48	0.36
TDS (mg l^{-1})	23	620	395.9	228.3
TSS (mg l^{-1})	0.3	5.1	1.8	1.5
SAR (meq l^{-1})$^{1/2}$	0.36	3.32	1.54	0.94
Ca^{2+} (mg l^{-1})	0.00	11.7	4.9	4.3
Mg^{2+} (mg l^{-1})	0.00	6.73	2.7287	2.7718
Na^{+} (mg l^{-1})	0.06	2.20	0.97	0.78
Cl^{-} (mg l^{-1})	23	178	94.4	60.1
B (mg l^{-1})	0.04	0.26	0.1072	0.0717
HCO_3 (mg l^{-1})	26.0	59.0	37.8	11.4
TN (mg l^{-1})	0.7	8.9	6.9	9.9

where, C_{Jah}, concentration in Jahra tertiary treated effluent; C_{Sul}, concentration of Sulaibiya advanced treated effluent; C_{DMC}, concentration of the DMC outflow; Q_{Jah}, flow rate of Jahra tertiary treated effluent; Q_{Sul}, Flow rate of Sulaibiya advanced treated effluent; and Q_{DMC}, flow rate of the DMC outflow.

4. Results and discussion

Calculated irrigation quality for the DMC admixture (outflow) is given in Tables 3 and 4. The following sections discuss the obtained results and the attempt to predict the quality of the DMC admixture.

4.1. pH

The calculated value of pH varied from 6.6 to 7.7 (mean = 7.1). According to WHO, a pH range of 6.5–8.0 is desirable for irrigation purposes (Table 2). Therefore, pH of the admixture satisfies the WHO recommended range. Irrigation water with low pH (<6.5) promotes leaching of heavy metals, while high pH (>11) destroys bacteria and can also temporarily inhibits movement of heavy metals. In general, pH outside the recommended range can cause a nutritional imbalance or may contain a toxic ion, and thus, negatively affect plant growth [6,19]. Therefore, water with a pH outside the range 6.5–8.0 must be carefully evaluated for other chemical constituents.

4.2. Salinity hazards

Increases of soil salinity due to irrigation with wastewater can decrease crop productivity in the long-term [5]. EC and TDS are good indicators of salinity hazards to crops. The EC of the DMC admixture was found to be

Table 4
Concentrations (mg l^{-1}) of heavy metals in DMC outflow during 2005

Element	Minimum	Maximum	Mean	Standard error	Maximum recommended concentration [5]
Al	0.0000	0.4173	0.0901	0.1451	5.0
Cd	0.0000	0.0108	0.0068	0.0042	0.01
Cr	0.0000	0.1065	0.0263	0.0392	0.10
Co	0.0000	0.0527	0.0082	0.0185	0.05
Cu	0.0000	0.0085	0.0026	0.0030	0.20
Fe	0.0000	0.0011	0.0008	0.0003	1.0
Pb	0.0193	0.1029	0.0568	0.0275	5.0
Mn	0.0000	0.0137	0.0039	0.0044	0.20
Ni	0.0000	0.0577	0.0074	0.0203	0.20
Zn	0.0000	0.0217	0.0104	0.0073	2.0

in the range of 0.08–1.09 µS m^{-1} (mean = 0.48) and 23–630 mg l^{-1} (mean = 395.9), respectively. WHO recommends application of slight to moderate degrees of restriction when irrigating with such water (Table 2). Main restrictions that should be applied in such a case are selection of salt tolerant crops and application of appropriate salinity control measures. Although EC in the range of 0.75–2.25 µS m^{-1} is widely used [20], irrigation with water that has EC closer to 2.0 µS m^{-1} can be a long-term health hazard to animals and humans due to accumulation of trace elements in soil and plant [21].

4.3. Total suspended solids

Suspended solids present in irrigation water can be organic matters (e.g., plants, algae, bacteria), and/or inorganic matters (clay, sand and silt). High suspended solids concentration may cause mechanical problems to irrigation systems, seal a soil surface, fill in air spaces between sand particles, reduce infiltration and drainage and increase soil compaction. According to the WHO standards, total suspended solid (TSS) concentration <50 mg l^{-1} is safe for a drip irrigation system, while above 100 mg l^{-1} can cause plugging. TSS of the DMC admixture ranged from 0.3 to 5.1 mg l^{-1} (mean = 1.8), indicating that TSS is not a cause for concern.

4.4. Sodium, calcium and magnesium hazards (SAR)

Sodium content is an important criterion for evaluating irrigation water quality. Excessive amount of sodium can lead to development of alkaline soil and consequently to reduction of soil permeability. Sodium can also cause injury to leaves [22]. Sodium concentration of the DMC admixture was found to vary between 0.4 and 1.5 meq l^{-1} (mean = 1.54). For slight to moderate degree of restriction, WHO recommended Na concentration to be between 3 and 9. Accordingly, no degree of restriction is required when irrigating with the DMC admixture.

Although they are essential plant nutrients, high concentration of Ca and Mg can increase soil pH and thus reduce phosphorus availability. Concentrations of Ca and Mg in DMC admixture were found to range from 0 to 11.7 (mean = 4.9) and 0 to 6.7 (mean = 2.7), respectively. The combined effect of sodium, calcium and magnesium hazard is usually measured in the term of SAR, which expresses better the exchangeable sodium percentages in the soil than simpler sodium percentage [23]. SAR of the DMC admixture was found to be in the range of 0.4–3.0 (mean = 1.0). That is, SAR of the DMC admixture satisfies the WHO guidelines (Table 2) and thus no degree of restriction is required. However, a slight to moderate degree of restriction is required since EC is in the range of 0.08–1.09 µS m^{-1}.

4.5. Chloride

High chloride concentrations can cause leaf burn or dying of leaf tissues because it is usually not absorbed by soil and thus it moves in the transpiration stream and accumulates in the leaves. The chloride concentration of the DMC admixture was found in the range of 0.65–5.01 meq l^{-1}, with 2.66 meq l^{-1} as a mean. According to the criteria given in Table 2, a slight to moderate degree of restriction is required when the DMC admixture is used as irrigation water. Note that chloride uptake by plants is not only dependant on the water quality but also on chloride concentration of the soil. Further, crop tolerance to chloride is not so well documented [6].

4.6. Boron

Boron is an essential micronutrient for plant growth. Although it is reported to affect sensitive crops (e.g., ornamental plants), it is not reported to affect soil [5]. Boron concentration of the DMC admixture was found to be in the range of 0.04–0.26 mg l^{-1} (mean = 0.11). According to the criteria given in Table 2, no degree of restriction is required when irrigating with the DMC admixture.

4.7. Total nitrogen

Nitrogen is a very essential macronutrient for plants. It is usually found in wastewater in the forms of ammonia, nitrite, nitrate and organic forms of nitrogen. Total nitrogen (TN) is the sum of these forms of nitrogen. TN concentration of the DMC admixture was found to be in the range of 0.7–8.9 mg l^{-1} (mean = 6.9). According to the WHO guidelines (Table 2), this indicates that a slight to moderate degree of restriction is required when irrigating with the DMC admixture. Crops are usually not affected by nitrogen concentration <30 mg l^{-1}, except sensitive crops (e.g., sugar beets) which can be affected by nitrogen concentration above 5 mg l^{-1} [6]. Usually very high nitrogen concentration (>50 mg l^{-1}) can pose negative environmental and human health effects.

4.8. Heavy metals

Irrigation with water that contains high heavy metals concentrations could lead to metal accumulation in soils and crops and can consequently cause health problems to crop consumers [5]. As shown in Table 4, concentrations of heavy metals in DMC admixture are all far below the recommended maximum levels. That is, there is no health risk from accumulation of heavy metals on crops due to irrigation with the DMC admixture. Heavy metals are usually not absorbed by plants unless they reach the threshold concentrations [5]. Further, the

Table 5
Comparison of the measured and estimated physico-chemical quality of DMC outflow (bolds are values estimated within ±25% of the measured values)

Parameter	Measured	Estimated
pH	7.07	–
EC (dS m^{-1})	0.53	0.29
TSS (mg l^{-1})	2.06	2.45
VSS (mg l^{-1})	2.30	1.91
COD (mg l^{-1})	6.04	4.70
BOD (mg l^{-1})	4.41	4.62
NH_4–N (mg l^{-1})	1.04	0.82
Org-N (mg l^{-1})	1.53	1.13
NO_3 –N (mg l^{-1})l	0.07	0.03
TN (mg l^{-1})	7.81	2.21
Cl (meq l^{-1})	2.95	1.59
PO_4 (mg l^{-1})	3.73	2.19
Turbidity NTU	8.80	6.43
SO_4 (mg l^{-1})	83.57	69.94
TDS (mg l^{-1})	334.86	159.35
Na (mg l^{-1})	11.1	0.55
Ca (mg l^{-1})	5.5686	2.7722
Al (mg l^{-1})	0.0917	0.1079
B (mg l^{-1})	0.1129	0.0687
Cd (mg l^{-1})	0.0077	0.0690
Cr (mg l^{-1})	0.0288	0.0110
Co (mg l^{-1})	0.0019	0.0054
Cu (mg l^{-1})	0.0030	0.0052
Fe (mg l^{-1})	0.0008	0.0008
Pb (mg l^{-1})	0.0621	0.0519
Mg (mg l^{-1})	3.1157	12.2395
Mn (mg l^{-1})	0.0025	0.0030
Ni (mg l^{-1})	0.0002	0.0013
Zn (mg l^{-1})	0.0118	0.0161
Total coliform (colonies/100 ml)	145	14011
Fecal coliform (colonies/100 ml)	15	6470
Salmonella (colonies/100 ml)	0	123
Fungi (colonies/100 ml)	15	14

greater part of heavy metal concentrations are removed by common wastewater treatment processes [24].

4.9. Prediction of DMC admixture quality

Results of the attempt to predict the quality of the DMC admixture are presented in Table 5. As shown in this table, very few parameters (TSS, VSS, COD, BOD_5, Al, Fe and Mn) were predicted within ± 25% of the measured values, while most of the estimated parameters deviate greatly from the measured values. Failure to predict the quality of DMC admixture using only principles of ideal mixing confirms that ESRs constitute a complex ecosystem, where complicated physicochemical and biological processes (e.g., sedimentation, chemical oxidation, biological oxidation, etc.) take place. Performance of ESRs systems are usually determined by many other factors such as wastewater characteristics, climatic conditions, ecosystem characteristics, ESRs design features and operational modes [21]. Note that measured values of the physio-chemical parameters, except TSS, are generally higher than the estimated ones. That can be attributed to generation of more substances due to un-modeled biochemical processes (such as cell lysis/decay) that may have taken place in the ESRs. Also, low measured values of TSS can be due to solids settling (sedimentation) that may have taken place in the ESRs. However, the low measured values of the bacteriological parameters, except fungi, are clearly due the effects of the second chlorination conducted at DMC, which was not taken into account while estimating the bacteriological quality of the admixture.

4.10. Process feasibility

Technically, the process of mixing RO permeate with tertiary effluent is very simple and straightforward. This explains why it looks to be a very attractive method for improving the irrigation quality of RO treated wastewater. However, the economic and environmental feasibilities of this method are still unknown. Economic and environmental feasibilities usually require detailed studies about the socio-economic and environmental impacts, which are beyond the scope of this paper.

5. Conclusions

Based on the results of this study, the following conclusions could be made:

- The admixture of RO permeate with tertiary effluent is suitable for irrigation, but with slight to moderate restriction with respect to salinity, water infiltration, TN content and chloride content.
- Concentrations of the various constituents of the admixture cannot be predicted using only ideal mixing principles. Many physicochemical and biological processes should be taken into account, such as sedimentation biochemical oxidation processes.

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References

[1] A. Layson and L. Sorgini, Low-pressure membranes help solve water scarcity, Water, 34 (2007) 34–36.
[2] B. Sheikh R.S. Jaques and R.P. Cort, Reuse of municipal wastewater effluent for irrigation of raw-eaten food crops: a five year field study, Desalination, 67 (1987) 245–254.
[3] C. Chakrabarti, Residual effect of long-term land application of domestic wastewater, Environ. Int., 21 (1995) 333–339.
[4] S. Toze, Reuse of effluent water: benefits and risks, Agric. Water Manage., 80 (2006) 146–159.
[5] WHO, Guidelines for the safe use of wastewater, excreta and grey water, vol. 2, Wastewater use in agriculture, World Health Organization, France, (2006).
[6] R.S. Ayers and D.W. Westcot, Water quality for agriculture, FAO irrigation and drainage, Paper No. 29, Food and Agriculture Organization, Rome, Italy, (1985).
[7] G. Oron, L. Gillerman, A. Bick, N. Buriakovsky, Y. Manor, E. Ben-Yatshak, L. L. Katz and J. Hagin, A two stage membrane treatment of secondary effluent for unrestricted reuse and sustainable agricultural production, Desalination, 187 (2006) 335–345.
[8] US-EPA, Environmental Protection Agency, Guidelines for water reuse, EPA/625/R-04/108, (September 2004).
[9] G. Oron, L. Gillerman, A. Bick, Y. Manor, N. Buriakovsky and J. Hagin, Advanced low quality waters: treatment for unrestricted use purposes, imminent challenges, Desalination, 213 (2007) 189–198.
[10] G. Oron, L. Gillerman, N. Buriakovsky, A. Bick, M. Gargir, Y. Dolan, Y. Manor, L. Katz and J. Hagin, Membrane technology for advanced wastewater reclamation for sustainable agriculture production, Desalination, 218 (2008) 170–180.
[11] I.S. Chang, E.W. Lee, S. Oh and Y. Kim, Comparison of SAR (sodium adsorption ratio) between RO and NF processes for the reclamation of secondary effluent, Water Sci. Technol., 51 (2005) 313–318.
[12] L. Zou, P. Sanciolo and G. Leslie, Using MF-NF-RO train to produce low salt and high nutrient value recycled water for agricultural irrigation, Water Sci. Technol., 58 (2008) 1837–1840.
[13] K.K. Tanji and N.C. Kielen, Agricultural water management in arid and semi-arid areas, FAO irrigation and drainage, Paper No. 61, Food and Agriculture Organization, Rome, Italy, (2002).
[14] G. Mancini, C. Barone, P. Roccaro and F.G.A. Vagliasindi, The beneficial effects of storage on the quality of wastewater for irrigation: a case study in Sicily, Water Sci. Technol., 55 (2007) 417–424.
[15] S. Barbagallo, G.L. Cirelli, S. Consoli and F. Somma, Wastewater quality improvement through storage: a case study in Sicily, Water Sci. Technol., 47 (2003) 169–176.
[16] APHA, Standard methods for examination of water and wastewater, 20th ed., American Public Health Association, Washington, DC, 1998.
[17] G.L. Cirelli, S. Consoli and V.D. Grande, Long-term storage of reclaimed water: the case studies in Sicily (Italy), Desalination, 218 (2008) 62–73.
[18] G.L. Cirelli, S. Consoli and M. Juanico, Modeling Escherichia coli concentration in a wastewater reservoir using an operational parameter MRT/RE and first order kinetics, J. Environ. Manage., 90 (2009) 604–614.
[19] M.B. Pescod, Wastewater treatment and use in agriculture, Irrigation and drainage, Paper No. 47, FAO, Rome, Italy (1985).
[20] A.H.M.J. Alobaidy, M.A. AL-Sameraiy, A.J. Kadhem and A. Abdul-Majeed, Evaluation of treated municipal wastewater quality for irrigation, J. Environ. Prot., 1 (2010) 216–225.
[21] H.D. Forth, Fundamentals of soils science, 7th ed., Wiley, New York, 1984.
[22] H.D. Begum and M.G. Rasul, Reuse of stormwater for watering gardens and plants using green gully—a new stormwater quality improvement device (SQID), Water Air Soil Pollut. Focus, 9 (2009) 371–380.
[23] T.N. Tiwari and A. Manzoor, Pollution of Subarnarekha river near Jamshedpur and the suitability of its water for irrigation, Indian J. Environ. Prot., 8 (1988) 494–497.
[24] B. Shiekh, R.S. Jaques and R.P. Cort, Reuse of tertiary municipal wastewater effluent for irrigation of raw eaten food crops: a 5 y study, Desalination, 67(1–3) (1987) 245–254.
[25] M. Juanico, Wastewater reserviors, in: A. Shilton (ed.), Pond treatment technology, IWA Publishres, London, (2005) pp. 357–380.