WASTEWATER RECLAMATION AND REUSE FOR AGRICULTURAL IRRIGATION IN ARID REGIONS: THE EXPERIENCE OF THE CITY OF ARAD, ISRAEL

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ABSTRACT

A full-scale advanced integrated pond and reservoir system was constructed in 1999 to treat the wastewater of the City of Arad, in the Negev Desert of Israel, in order to upgrade the classical stabilization pond systems to increase their effluent quality. The innovative disposition of the treatment components and their multiplicity turns this integrated system into an in front treatment facility allowing to conduct continuous field research. The performance the different components of this system was evaluated for one year, regarding bacterial and viral indicators (fecal coliforms, somatic coliphages and F-specific bacteriophages)behaviour, and physico-chemical parameters. The overall removal of organic matter and microorganisms was excellent. The polishing treatment by the stabilization reservoirs played an important role in the elevated effluent quality. The rock filter pond had a good performance in terms of removing TSS, BOD5, fecal coliforms and bacteriophages. The final effluent is, actually, reused for irrigation of a variety of crops in an adjacent commercial farm, under onsurface and subsurface drip irrigation systems, during the entire year without any additional disinfection treatment stage.

KEYWORDS: Fecal coliforms; F-specific bacteriophages; reservoirs; rock filter; somatic coliphages; stabilization ponds.

INTRODUCTION

The most severe water scarcity in the world is in the Middle East. The management of water resources has the basic scope of balancing water availability (quantitatively and qualitatively) and water demand in space and time, at a reasonable cost and with acceptable environmental impacts. The mismatch of water availability and water need has a strong impact in all aspects of water use in the region. Such impacts are: a) The necessity to build reservoirs to store water in the wet season; (b) the need for diverting water from one basin to another; (c) the over exploitation of groundwater and increasing risk of sea water intrusion in coastal areas; and (d) finally, very strong effects on water quality and on water treatment requirements.

Wastewater is widely recognized as a significant, growing and reliable water source. Wastewater production is the only potential water source which will increase as the population grows and the demand on fresh water increases. Therefore, intensive and safe wastewater treatment and reuse schemes should be practice on a large scale in the Mediterranean region and specially in the Middle East. Use of treated wastewater in landscaping and agriculture is common in many countries such as Israel, Tunisia, Egypt, Jordan, and Syria. Water resources management strategies in these countries consider wastewater as part of the water budget (World Bank, 1996).

During the last two decades, the reuse of treated wastewater for agricultural irrigation has expanded, especially in arid and semi-arid regions, helping to relieve water scarcity and improving the means for local food production (Blumenthal et al., 2000). Wastewater treatment technology needs to be appropriate and sustainable. It also needs to be less costly, easy to operate and maintain, and very efficient in removing both organic matter and the wide range of excreted pathogens present in wastewaters. In developing countries and many small and isolated communities and rural areas of the developed countries; non-conventional treatment systems, also called natural treatment systems, are more suitable. Natural treatment systems are considered one of the best treatment options, particularly in warm climates, such as the Middle East region countries, because site characteristics and environmental conditions are more critical factors for natural treatment processes as compared to conventional mechanical technology (Angelakis, 2001).

There is an increasing interest in extensive technologies, specially Waste Stabilization Pond Systems (WSPS) as the Best Available Technology (BAT) for wastewater reuse in arid and semi-arid regions. Due to the health risks associated to wastewater reuse, WSPS design and operation have evolved to comply with higher effluent quality demands. The combination of different pond types with other treatment components (integrated WSPS) is becoming the most suitable option for many areas of the world. However, the potential transmission of infectious diseases by pathogenic agents (bacteria, viruses and parasites) is one of the highest concerns associated with human health, when crops are irrigated with treated wastewater (Shuval et al., 1984; Tanaka et al., 1998). Adequate monitoring of the applied effluent for the presence of pathogens can assist in preventing the outbreak of diseases.

The effluent quality, in particular the microbiological quality, and the stability of performances are important issues which have to be taken into account in the design and operational procedures of these systems. Empirical and theoretical models are being developed in order to predict waste stabilization pond efficiency and hydraulic patterns to assist engineers in an efficient design of ponds (Saqqar & Pescod, 1992; Ellis & Rodrigues 1995; Nameche & Vasel, 1998; Torres et al., 1999). Despite their operational simplicity, the organic matter, nutrients and pathogen removal mechanisms in WSP involve a series of complex physical, chemical and biological interactions, and although a considerable amount of research, the results are conflicting (Mara, 1998; Maynard et al., 1999). Moreover, a great proportion of the research done in stabilization ponds has been carried out to a laboratory and pilot-scale level. Nevertheless, these results will not be always reliable for real-scale systems. Therefore, the studies should, wherever possible, to be carried out on samples taken from ponds to ensure that they reflect actual conditions in waste stabilization ponds. These data would give engineers a deeper understanding of how ponds operate and provide a rational basis for deciding which design of pond is best suited for a given location.

A full-scale advanced integrated pond and reservoir system was constructed in 1999 to treat the wastewater of the City of Arad, in the Negev Desert of Israel, in order to upgrade the classical stabilization pond systems to increase their effluent quality. The innovative disposition of the treatment components and their multiplicity turns this integrated WSPS into an in front treatment facility allowing to conduct continuous field research. The system consists of: (i) three anaerobic ponds operating in parallel; (ii) a facultative and a maturation pond in series with internal circulation; (iii) a two-stage rock filter pond, performing like an horizontal trickling filter; (iv) three stabilization reservoirs operating in parallel however, separately, and; (v) a seasonal large storage reservoir. Directions of research include: (i) enhancement of better system performance and capability adjusted to local conditions; (ii) evaluation of the efficiency of the different components performance, regarding bacterial and viral indicators (fecal coliforms, somatic coliphages and F-specific bacteriophages), physico-chemical, and hydraulic parameters. The performance of this treatment system was first evaluated for almost one year, focusing the monitoring program on microorganisms (fecal coliforms, somatic coliphages and F-specific bacteriophages) and organic matter removal.

MATERIAL AND METHODS

Experimental site description

The study was performed in a full-scale integrated pond and reservoir system located near the City of Arad, in Israel, at 525 m. above the sea level. The climatic conditions reflect an arid or semi-arid area. The mean annual precipitation during the rainy season (October-April) is around 150 mm. The solar radiation is high along the entire year, being the maximum monthly mean of approximately 1,000 W/m2.

The full-scale integrated pond and reservoir system is in operation since 1999, and treats the wastewater of the city, that has a stable population of around 22,000 inhabitants. The wastewater is mainly domestic and the daily flow rate mean is about 5,000 m^3/d. The treatment system of Arad includes different treatment components (Table 1, Figure 1): (i) three anaerobic ponds operating in parallel (one of the anaerobic ponds is covered with a standard floating plastic sheet, and another one with a submerged plastic made tent, both for biogas collection as an alternative energy source); (ii) a facultative and a maturation pond in series (with an internal re-circulation); (iii) a two-stage rock filter pond with two dikes of 8-12 cm of gravel, performing like an horizontal trickling filter; (iv) three stabilization reservoirs operating in parallel under a "fill-rest-withdraw" mode, and; (v) a seasonal large storage reservoir. The final effluent is reused for irrigation of a variety of crops in an adjacent farm, such as almond trees, wheat, barley, sunflowers, and alfalfa; under onsurface and subsurface drip irrigation systems.

Analytical methods

Wastewater samples were collected three to four times per month from June 2000 until March 2001. Sample collection dates were randomly chosen and all collections were done between 09:00 and 11:00 a.m. Sampling locations were at the main inlet (raw wastewater) and pond outlets (Figure 1). Raw wastewater samples were 24-hour composite samples and pond effluent samples were grab samples. The physico-chemical (Biological Oxygen Demand (BOD5), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS)) and fecal coliform analysis were performed according to the standard proceedings recommended by APHA (1998). The bacteriophages monitored were somatic coliphages (ISO/DIS 10705-2/1999) and F-specific bacteriophages (ISO/CD 10705-1/1996). Water temperature was measured "in situ" at 25 cm from the surface of the ponds with a portable device model Schott, Handylab 1. All data from the microbial analysis were converted into log10 scale. Therefore, values below the detection limit were assumed as 0 value. The detection limit for the fecal coliform assay was 10 CFU/100mL and for the bacteriophage assay was 10 PFU/100 mL.

Table 1. Design characteristics of the integrated WSPS components.

Components of the system	Volume (m^3 x 10^3)	Surface area (m^2 x 10^3)	Depth* (m)	Hydraulic retention time** (days)
Anaerobic ponds	5	2.3	5	2
Facultative pond	42.5	29	2.5	8.5
Maturation pond	37.5	25.5	1.5	7.5
Rock filter	13	7.7	2	2.6
Stabilization reservoirs	100	26.3	5	40
Seasonal storage reservoir	650	50	13	150

* Maximal depth of the water in the related pond/reservoir.

** Theoretical hydraulic retention time.

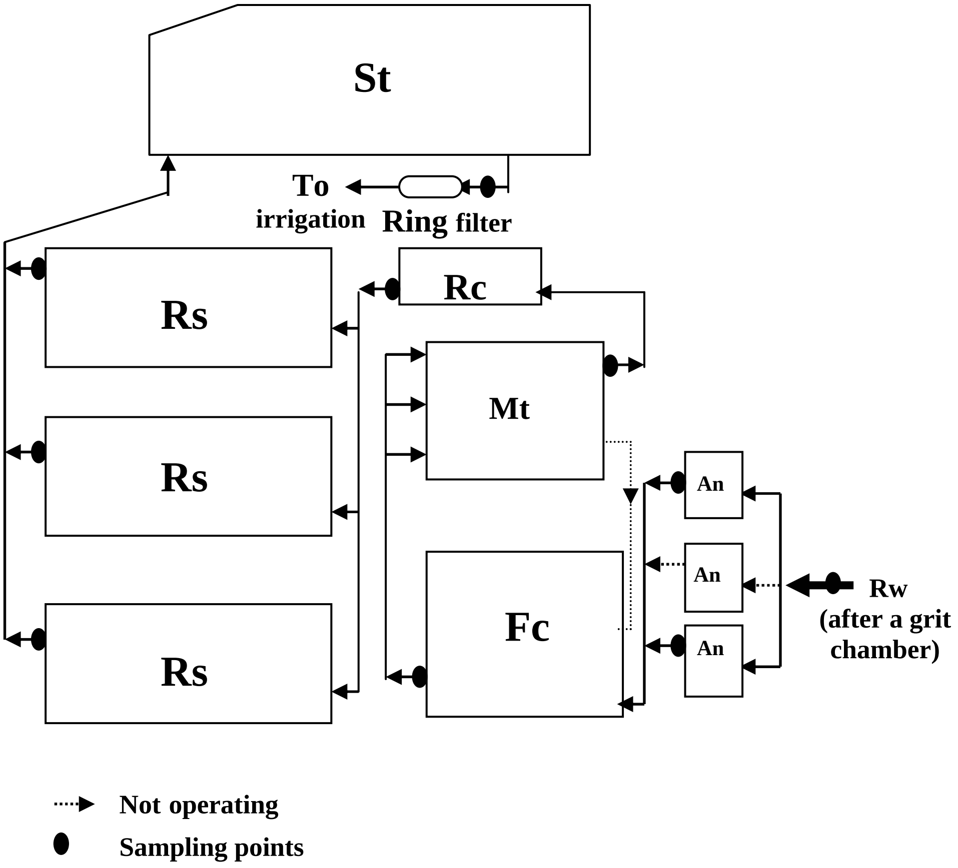


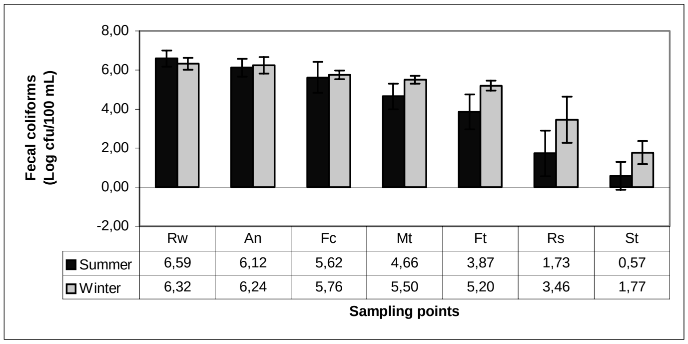
Figure 1. Flow diagram of the treatment system and sampling points. Rw=raw wastewater, An=anaerobic pond, Fc=facultative pond, Mt=maturation pond, Rc= rock filter, Rs=stabilization reservoir, St=seasonal storage reservoir.

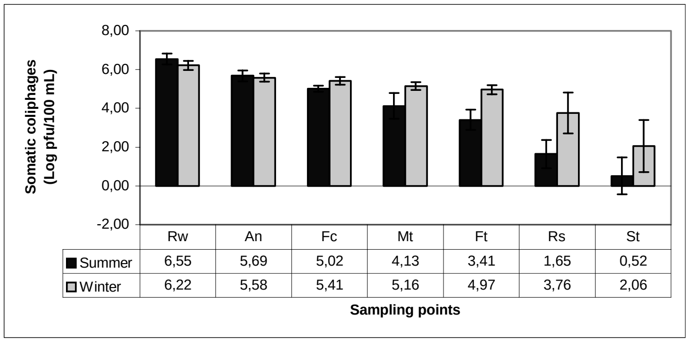
RESULTS AND DISCUSSION

It has to be noticed that results are presented separetely for the summer period (June 2000-October 2000) and the winter period (November 2000-March 2001).

Microorganism removal through the treatment system

The fecal coliform (FC), somatic coliphage and F-specific bacteriophage content in the raw wastewater and the effluent of each system's component are presented in Figure 2. The numbers of the three pathogen indicators in the raw wastewater are quite similar for the two seasons with a slightly increase during summer. The average content of FC in the final effluent of the treatment system never exceeded from 3.00 log units/100 mL along the period of study. Therefore, the final effluent of this treatment system complies with the WHO guidelines regarding the FC content (≤1000 CFU/100 mL or 3 log units/100 mL), and can be used for unrestricted irrigation of several crops during the entire year without any additional disinfection treatment.





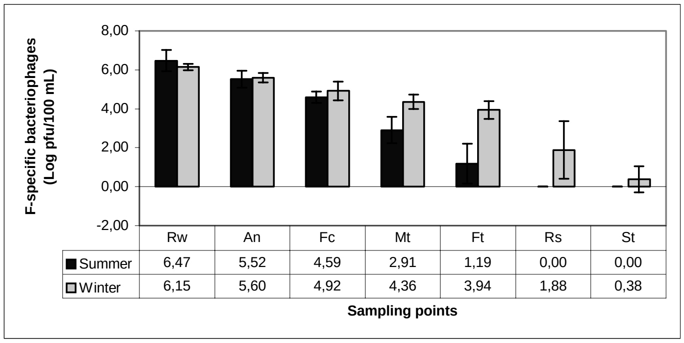


Figure 2. Mean and standard deviation of fecal coliform, somatic coliphage and F-specific bacteriophage content in the raw wastewater and the effluent of each component of the treatment system for summer and winter periods. Rw=raw wastewater, An=anaerobic pond, Fc=facultative pond, Mt=maturation pond, Rc= rock filter, Rs=stabilization reservoir, St=seasonal storage reservoir.

During this study, the highest value for the average content of somatic coliphages and F-specific bacteriophages in the final effluent was 3.67 log units/100 mL and 1.37 log units/100 mL, respectively, and most of the values were below the detection limit. Although there are no guidelines from the WHO or other institutions regarding maximal content of these phages in reclaimed wastewater for irrigation, due to the low numbers found in this study, it can be concluded that the concentration of pathogenic viruses will be also low.

Figure 3 presents the average removal of FC, somatic coliphages and F-specific bacteriophages for summer and winter in each component of the treatment system. All the components have an average removal of the three indicators monitored higher during summer than during the winter, except the seasonal storage reservoir and, in the case of the F-specific bacteriophages, also the stabilization reservoirs. These exceptions are probably due to the low numbers of the three-pathogen indicators found in these two last components of the system, being difficult to determine significant improvement in the removal efficiencies. The major environmental factors effects can explain the higher removal rates during summer for the three indicators monitored. These include the high ambient temperature, solar radiation and pH, which cause microorganisms content reduction (Davies-Colley et al., 1999).

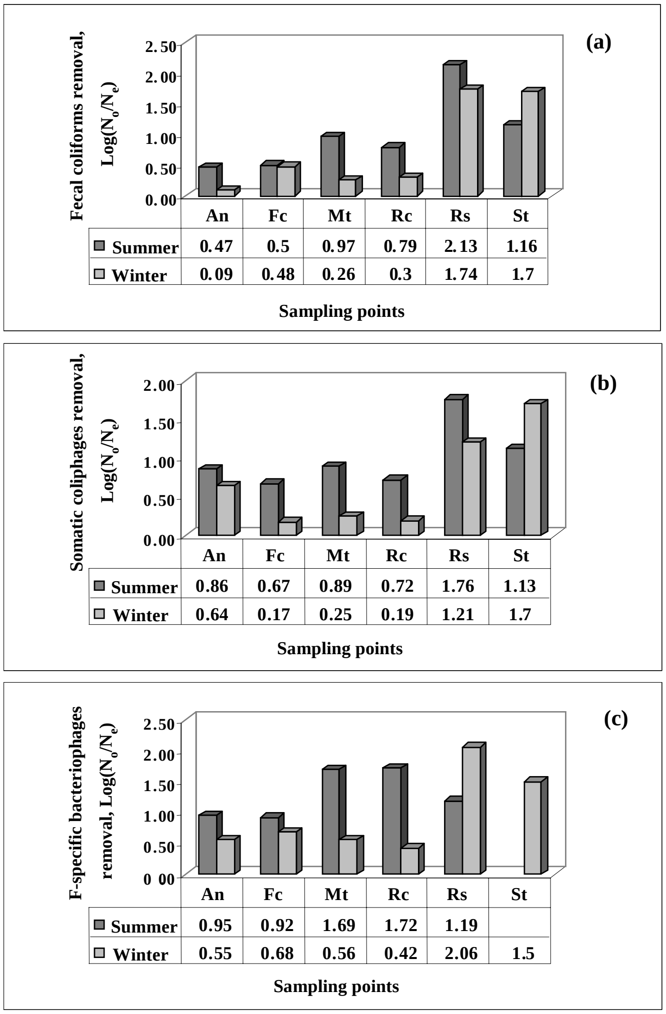


Figure 3. Average removal of fecal coliform (a), somatic coliphages (b) and F-specific bacteriophages (c) in each component of the treatment system for summer and winter. No=microorganisms concentration in the affluent of each component, Ne=microorganisms concentration in the effluent of each component. Rw=raw wastewater, An=anaerobic pond, Fc=facultative pond, Mt=maturation pond, Rc= rock filter, Rs=stabilization reservoir, St=seasonal storage reservoir.

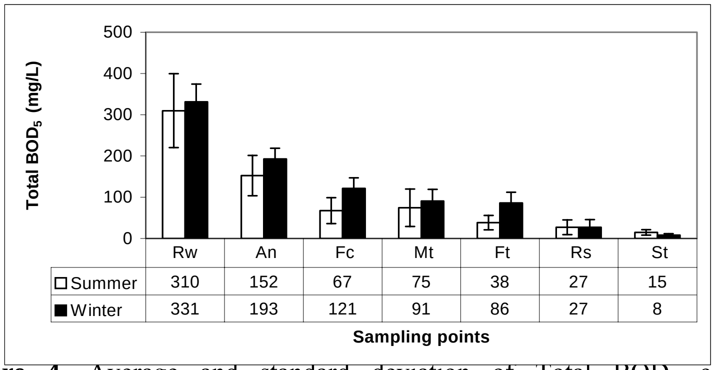
The stabilization reservoirs and the seasonal storage reservoir were the components of the treatment system with the highest reduction rates of FC and somatic coliphages, for summer and winter. These results emphasize the major importance of the hydraulic retention time in pond disinfection. The stabilization reservoirs have a theoretical hydraulic retention time of 40 days and in the seasonal storage reservoir the retention time is about 150 days (Table 1). The extended retention time in ponds allows other factors in the lagoon environment, such as pH, temperature, solar radiation, etc., to affect microorganisms die-off.

During the summer period, the maturation pond and the rock filter had the highest reduction rate for F-specific bacteriophage removal (Figure 3). This behaviour differs from the one observed for FC and somatic coliphages. F-specific bacteriophages were removed in a higher rate than FC and somatic coliphages in all the components of the treatment system (Figures 3). Turner and Lewis (1995), in their evaluation of a stabilization pond treatment system in New Zealand, also found that F-specific bacteriophages were reduced at a higher rate than FC. These results indicate that F-specific bacteriophages may not be adequate as viral indicators for this treatment system, due to their rapid elimination. However, more work is needed to confirm this tendency. The removal of somatic coliphages and F-specific bacteriophages in the anaerobic ponds is higher than for FC (Figure 3). The main mechanism for microorganisms removal in anaerobic ponds is the adsorption onto settling solids (Bitton, 1975). The rock filter presents a good reduction of the three pathogen indicators content monitored. The less land requirements for the rock filters would minimize this disadvantage of the classical stabilization pond systems, being an upgrading phase for WSPS.

Physico-chemical constituents removal through the treatment system

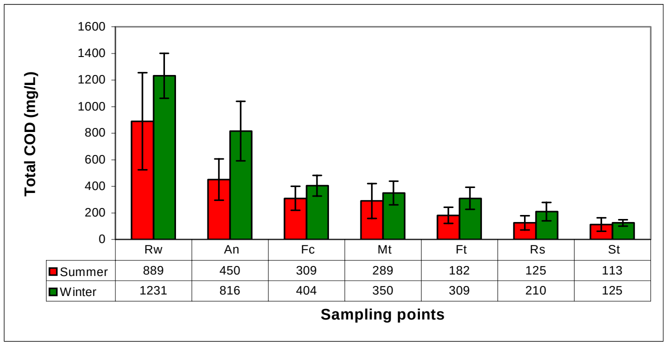
The performance of the system regarding water temperature and BOD5, COD, and TSS removal is presented in Figures 4, 5, 6, and 7.

The capability of the system for BOD5 removal was around 95% during summer and 98% during winter, and for COD removal was 87% during summer and 90% during winter. The TSS removal was approximately 92% during summer and 94% during winter. The anaerobic ponds and the facultative pond show the most important reduction of BOD5, COD and TSS, confirming the great importance of these components in the treatment system for organic matter and suspended solids removal. The difference between the summer and winter periods are less important and hardly explain the capability of the treatment system for a higher microbial removal rates during summer. Water temperature is the parameter that better explains the higher removal rates during summer. This result is in agreement with other studies (Maynard et al., 1999) and emphasizes the importance of the temperature in pond disinfection.



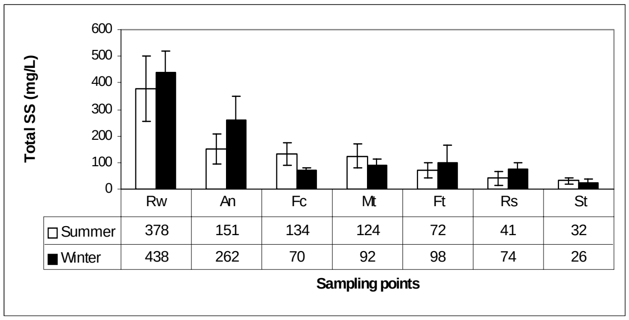
	Rw	An	Fc	Mt	Ft	Rs	St
□ Summer	310	152	67	75	38	27	15
■ Winter	331	193	121	91	86	27	8

Figure 4. Average and standard deviation of Total BOD_5 concentration.



	Rw	An	Fc	Mt	Ft	Rs	St
🟥 Summer	889	450	309	289	182	125	113
🟩 Winter	1231	816	404	350	309	210	125

Figure 5. Average and standard deviation of Total COD concentration.



	Rw	An	Fc	Mt	Ft	Rs	St
□ Summer	378	151	134	124	72	41	32
■ Winter	438	262	70	92	98	74	26

Figure 6. Average and standard deviation of TSS concentration.

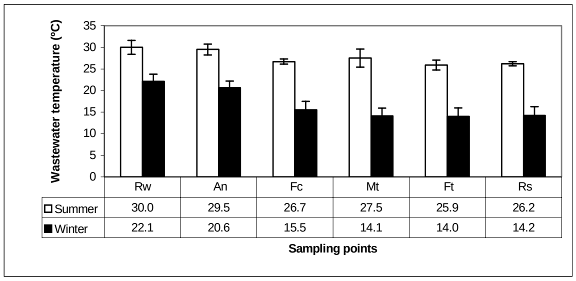


Figure 7. Average and standard deviation of the wastewater temperature.

CONCLUSIONS

On the basis of the results of the evaluation of a full-scale integrated WSPS performance in an arid zone, several conclusions can be drawn:

(a) The FC content of the final effluent complies with the WHO guidelines (1989) for unrestricted irrigation with reclaimed wastewater.

(b) The rock filter presents a good reduction of the three pathogen indicators content. The reduced land requirements for rock filter ponds would minimize this disadvantage of the classical WSPS and make the rock filters an upgrading phase.

(c) The polishing treatment by the stabilization reservoirs and the seasonal storage reservoir played an important role in the elevated effluent quality, regarding microbiological and physico-chemical parameters, confirming that the additional hydraulic retention time improves the microbial quality of the water. These two last components of the system also permit the irrigation season to last for the whole year.

(d) Anaerobic ponds seem to be more efficient for the removal of bacteriophages than for FC.

(e) F-specific bacteriophages seem not to be suitable indicators of pathogenic viruses behaviour for WSPS of long retention time due to their rapid elimination in the system. However, more work is needed to confirm this tendency.

(f) Temperature seems to be the most influential parameter in microorganisms removal in this kind of treatment systems.

(g) The performance of the integrated WSPS regarding BOD5, COD, and TSS removal is very good, yielding removal rates of around 90% or above with negligible differences between summer and winter periods.

(h) The anaerobic ponds and the facultative pond are the most efficient components of the system for organic matter and suspended solids removal, confirming the necessity of these components in integrated WSPS design.

The evaluation of this integrated WSPS will continue in the future, according with the directions of research mentioned above. The results obtained will be used for implementing mathematical models for an efficient design and operation of integrated WSPS. The data collected will also be integrated in a Knowledge-Based Decision Support System to improve the selection of the Best Available Technology.

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