Study on the performance of the wastewater stabilisation pond of Boujaâd, Morocco

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ABSTRACT

The wastewater stabilisation ponds system of the city of Boujaâd was constructed and put into operation in 1992. The main objectives of this plant are to prevent pollution of water resources and the environment by wastewater discharges, and to save fresh water by reusing treated wastewater for irrigation purposes. Within the period March 1997–March 1998 a comprehensive analysis of both the raw and the treated wastewater at a number of different sampling points was carried out in order to evaluate the treatment efficiency of the plant. The results of these investigations showed an average raw wastewater flow of 1600 m^3/d, which is well below the design flow of 2500 m^3/d. With average treated wastewater suspended solids (SS) content of 56 mg/l the SS removal rate has been determined to be about 65%. If compared to the anticipated Moroccan wastewater standards for direct wastewater discharge into receiving water bodies as stipulated in the anticipated Moroccan Standards (AMS 1996) the wastewater analysis results showed COD and BOD_5 values below these foreseen Moroccan wastewater discharge standards. The analysis results of SS, TKN and total phosphorous (P_{tot}) were slightly above these Moroccan standards. In view of the microbiological wastewater characteristics the treated effluents of the Boujaâd wastewater stabilisation ponds (WSP) respond to the WHO directive with respect to wastewater to be used for unrestricted irrigation (category A). Taking into consideration the CEC directive for wastewater generated by wastewater treatment plants and discharged to the environment, the efficiency of the Boujaâd WSP is relatively low with respect to SS removal, the removal of organic matter (expressed by BOD_5 and COD) and the removal of nutrients (expressed by TKN and P_{tot}). This relatively low efficiency may be caused by the already highly diluted incoming raw wastewater, which again is caused by the effect of significant infiltration of groundwater into the sewerage network.

Key words | stabilisation ponds, appropriate technology, wastewater treatment efficiency, microbiological parameters, water reuse

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INTRODUCTION

Wastewater stabilisation ponds (WSPs) have been used in Morocco for over 15 years, but are still not fully developed. However, experience gathered within this period indicates, that this technique can usually be considered to be the most appropriate for Moroccan weather conditions.

This study has concentrated on pond performance control in order to obtain more detailed knowledge of treatment efficiency of this pond system, which is the largest pilot-scale pond system in Morocco. One of the main objectives of this study was to obtain more detailed on-site experience of natural lagoon systems in Morocco.

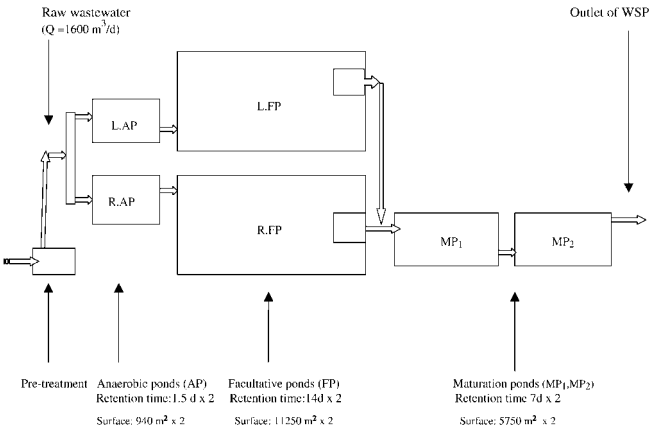

Figure 1 | Schematic flow diagram for Boujaâd WSPs.

MATERIAL AND METHODS

Study site

The waste stabilisation ponds are located south of Boujaâd close to the main road connecting the cities of Casablanca and Beni Mellal. The city contains around 36,000 inhabitants, with only 55% of them connected to the sewer network. The ponds are located at about 32.2°N latitude and 6.47°W longitude and at an altitude of 650–700 m above sea level.

The climatic conditions at Boujaâd are of under-arid Mediterranean type, characterised by relatively low precipitation rates, long periods of sunshine, an intensive evaporation rate and large temperature fluctuations in terms of both daily and seasonal variations.

As can be seen in Figure 1 the Boujaâd WSP system follows the classical pond configuration with anaerobic ponds and facultative ponds followed by final maturation ponds. The total pond system covers a surface area of around 3.6 ha.

The overall pond system comprises screen and grit removal facilities followed by a total of six stabilisation ponds: two parallel anaerobic ponds (APs) each with a surface of 940 m^2, 1.5 d retention time, and 2 m deep; two parallel facultative ponds (FPs) each with a surface of 11,250 m^2, 14 d retention time, and a depth of 1.5 m; and two maturation ponds (MPs) in series, each having a pond surface of 5,750 m^2, 14 d retention and 1.5 m deep.

Sampling and analysis methods

Wastewater samples have been taken at the plant intake as well as at different points along the treatment line. The sampling method for the samples taken at the plant intake and at the outlet of the anaerobic ponds slightly differs from the method applied to the other samples. For the above mentioned sampling points the samples were taken directly by means of a 2 l beaker glass. The samples collected at these points are composite samples taken over a period of 48 h.

To achieve better sample handling and increased representational character, the samples at the outlet of the FPs and the MPs were taken using a glass column of 2 m length. Each sample of 2 l taken at a water depth of 1 m was directly transferred to a 30 l sample container. A composite sample of 48 h was taken and sub-samples from this container were taken and fixed for physico-chemical analysis.

For bacteriological wastewater analysis, immediate samples were taken around noon (maximum sun intensity) and transported in sterile sample bottles at low temperature (4°C) to the laboratory.

The analysis methods applied are those, commonly used by ONEP and described either in the Moroccan Analysis Standards (for determination of COD and BOD_5), in the Moroccan Standards Project (for ammonium (NH_4), the total Kjeldahl nitrogen (TKN) and total phosphorus (P_{tot}), and in the AFNOR Standards (modified method) for the SS, faecal coliforms (FC) and faecal streptococs (FS). The determination of Helminth eggs was done according to the Janeckso–Urbany method.

Statistical analysis has been applied in order to evaluate seasonal effects on the efficiency of the ponds. The comparison of average microbiological wastewater analysis results during summer and winter using the Student test allows us to accept or to reject the zero hypothesis at a confidence level of $1-\alpha=95\%$.

RESULTS AND DISCUSSION

Characteristics of raw wastewater

The average annual raw wastewater flow entering the wastewater treatment plant is about 1600 m^3/d, which is

Table 1 | Mean wastewater concentrations of general pollution parameters of raw wastewater of Boujaâd WSP compared with average national and international raw wastewater concentrations

		Average raw wastewater composition		
Parameters	**Raw wastewater of Boujaâd WSP**	**France (1989)**	**USA (1979)**	**Morocco (ONEP, 1998)**
COD (mg O_2/l)	200	300–1000	250–1000	500–1500
BOD_5 (mg O_2/l)	45	100–400	110–400	150–650
SS (mg/l)	160	150–500	100–350	250–700
TKN (mg/l)	29	30–100	20–85	50–150
P_{tot} (mg/l)	4,5	10–25	4–15	5–30

well below the design raw wastewater flow of 2500 m^3/d. The measured average BOD_5 concentration of the raw wastewater (around 45 mgO_2/l is also well below the expected design concentration of 150 mgO_2/l.

Based on these results it can be stated that the Boujaâd wastewater treatment plant is well below its nominal capacity in terms of both its hydraulic (around 35% below design capacity) and its organic matter removal capacity (around 70% below design capacity).

Table 1 allows a general comparison of the measured figures with those given as average raw wastewater characteristics at national and international levels. It shows that nearly all pollution parameters measured at the inlet of the Boujaad wastewater treatment plant are well below the average expected values.

With the exception of the figures determined for SS and TKN, which are in the average raw wastewater characteristics range if compared to the three quoted references, the concentrations of COD, BOD_5 and P_{tot} are clearly below the expected average concentration ranges. These results indicate that the incoming raw wastewater is already highly diluted, which leads to the assumption that a significant amount of groundwater had infiltrated the sewerage network. This hypothesis is confirmed by analysis of dissolved oxygen, which shows concentrations in the raw wastewater of about 2 mgO_2/l, which is relatively high for raw wastewater and thus confirms the assumption of infiltration of relatively non-polluted water into the sewerage network.

The analysis results for the organic pollution parameters (such as COD and BOD_5) indicate a relatively high COD/BOD_5 ratio of around 4.5, which is higher than the usual ratio for domestic wastewater (COD/BOD_5 ratio around 2). This high ratio could be caused by the dilution of organic matter and suspended solids by groundwater infiltration, which also provides oxygen. The provision of oxygen could therefore facilitate the significant reduction of the easily degradable fraction of organic matter (represented by the BOD_5 concentration), whereas the concentration of the non-biodegradable or non-easily biodegradable portion (represented by the COD concentration) remains more or less constant, thus increasing the COD/BOD_5 ratio of the incoming raw wastewater.

Microbiological aspect

The analysis of the indicators of faecal wastewater pollution, such as FC and FS, shows a relatively constant raw wastewater characteristic. Mean values are around 7.8×10^6 germs per 100 ml for the FC and 3×10^6 germs per 100 ml for the FS.

Figure 2 illustrates the considerable reduction of indicator germs for faecal pollution along the treatment line of the different types of pond.

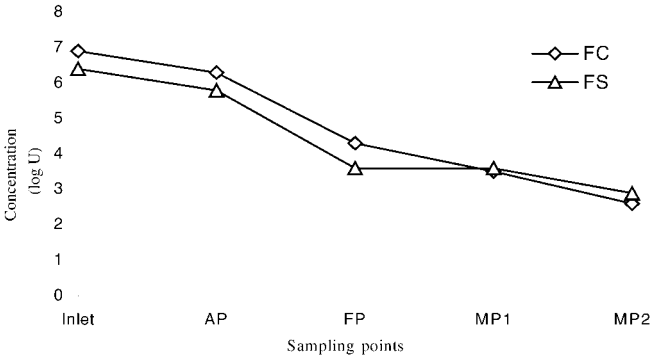

Figure 2 | Evolution of FC and FS concentrations along the treatment line.

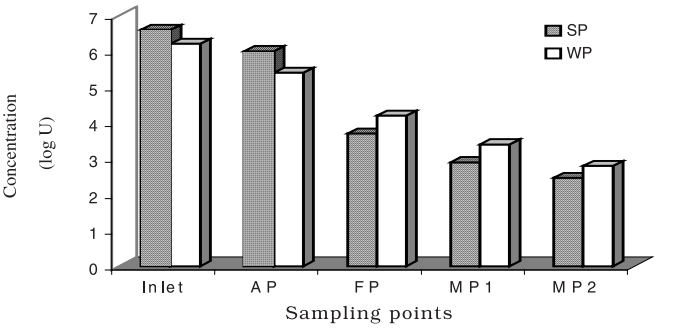

Figure 4 | Variation of FS concentrations in SP and WP.

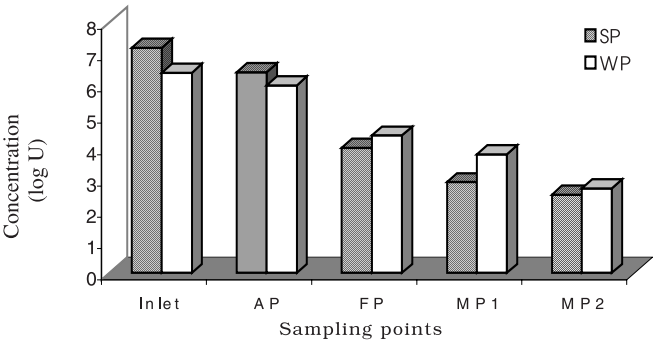

Figure 3 | Variation of FC concentrations in SP and WP.

As could be expected, and can be seen in Figure 2, no relevant reduction of faecal pollution indicators can be observed in the primary treatment (AP). However, a significant reduction for each of the two groups can be observed in the two subsequent treatment steps, namely the secondary (FP) and the tertiary (MP) treatment, with specific variations depending on the type of indicator.

The comparison of seasonal variations of the microbiological wastewater characteristics in Figures 3 and 4 clearly shows that the microbiological pollution load at the plant inlet increases during the summer period (SP), which ranges from May to September, compared to the colder winter period (WP) from October to April.

The FC concentrations at the treatment plant inlet point have been registered. During the summer period they have been determined to be in the range of 1.6×10^7 germs per 100 ml (7.20 log U) and around 2.0×10^6 germs per 100 ml (6.3 log U) in the winter season. Similar results have been obtained for the FS with concentrations at the plant inlet being in the range of 4×10^6 germs per 100 ml (6.6 log U) in summer and 1.6×10^6 germs per 100 ml (6.2 log U) in winter.

The cumulative elimination rates at different points of the waste treatment plant show that the difference observed in microbiological abatement between the cold and hot seasons does not have any statistical significance for the anaerobic ponds, whereas the difference in abatement rates registered at the outlet points of the facultative and the maturation ponds is significant, with a 95% difference between these two periods.

These cumulative reduction rates are about 4.7 log U and 4.14 log U during the summer for the FC and FS, respectively, whereas they are about 3.60 log U and 3.4 log U, respectively during the winter period. These results agree with those found by Baloux and Trousslier (1983) for FC removal for the waste stabilisation ponds at Metz, France and with the observations by Boussaid (1987), Imzlin (1990), Hassani (1993) and Lafdal (1994) for the wastewater stabilisation ponds at Marrakech.

Analysis of pond performance parameters

Anaerobic ponds

The volumetric loading has been determined to be 18.3 g $BOD_5/m^3/d$. However, considering that currently the volume of sludge within the anaerobic ponds represents around 60% (measured by trace monitoring), this volumetric loading rate increases to around 45 g $BOD_5/m^3/d$.

If compared to MHERCE references, which stipulate common volumetric loading rates at the range 50–300 g $BOD_5/m^3/d$ the current loading rates for the anaerobic ponds at Boujaad WSP are still very low.

General recommendations formulated by Mara & Pearson (1987), which are widely used (Zahar 1986) indicate optimum volumetric loads in the range 100–400 g $BOD_5/m^3/d$ in order to maintain anaerobic pond conditions and to prevent odour generation.

The surface load, expressed in kg BOD_5/ha/d, is another criteria commonly used to ensure optimum anaerobic pond performance. The results from the Boujaâd WSP showed that the surface load never exceeds 400 kg BOD_5/ha/d, a figure which is very low if compared to the minimum surface load of 1,000 kg BOD_5/ha/d specified by MHERRECE (1992). Surface loading rates below this recommended value would facilitate aerobic conditions throughout the pond, reaching down to the bottom of the ponds and thus disturbing or even inhibiting the anaerobic conditions and the corresponding anaerobic microbiological degradation processes.

Based on the average theoretical retention time of 1.23 d, the anaerobic ponds allow for a 65% removal of SS, for 40% COD removal as well as for 45% removal of BOD_5 at an average temperature of 23°C. The BOD_5-removal rates vary between 38% during the winter period and 55% during the summer period, with corresponding temperatures of 18°C and 38°C and with the theoretical retention times for those two periods being 1 d and 1.45 d, respectively.

The dissolved oxygen (DO) in the outlet of AP showed concentrations with an average of 3.55 mg O_2/l. The highest value was 8.6 mg O_2/l. These variations could disturb the efficiency of the AP, which could decease the metanisation mechanism which is the basis of the organic load degradation process.

Facultative ponds

The optimum performance of these ponds in highly dependent on the admissible surface load. The surface load of the facultative ponds of the Boujaâd WSP system is estimated at 16 kg BOD_5/ha/d, a figure which is clearly below the commonly recommended interval of 150–200 kg BOD_5/ha/d indicated by MHERRECE (1992).

Average surface loads applied in waste stabilisation ponds in France and Germany are about 100 kg BOD_5/ha/d (Mara & Pearson 1987). Again, it can be seen that the facultative ponds of the Boujaâd WSP operate well below their design loads as well as below commonly found operation loads.

With respect to potential nutrient removal, the facultative ponds allow around 20% nitrogen reduction (in terms of TKN), 13.5% removal of ammonium (NH_4^+) and only 8.5% for phosphorous removal. However, these extremely low hydraulic and organic pond loadings do not disturb the pond's efficiency in terms of faecal count reduction. These reduction rates were determined to be about 2 log U for the FC and 1.78 log U for the FS, and are significant.

Maturation ponds

These ponds receive the effluents of the facultative ponds with an average content of around 3.8×10^4 FC/100 ml and leave the first maturation pond (MP1) with a concentration of around 3.4×10^3 FC/100 ml. The second maturation pond (MP2) reduces the number of FC to around 4.2×10^2 FC/100 ml. These figures represent a FC reduction rate of 0.47 log U for the first and 0.9 log U for the second maturation pond. The overall reduction rate thus amounts to 1.37 log U for the two maturation ponds.

Based on the initial design, considering a FC reduction of 2.84 log U, the removal rate is relatively low. Considering a theoretical retention time of 14 d a degradation constant ($k = 1.5$) is recommended by MHERCE (1992) for the climatic conditions of Morocco. The determined degradation constant ($k = 0.97\ d^{-1}$) for the Boujaâd WSP proves the limited efficiency of the maturation ponds.

The performance of the maturation pond can also be evaluated on the basis of the surface load. Taking into consideration the organic load at the outlet of the facultative ponds, the organic surface load of the maturation ponds was found to be 30 kg BOD_5/ha/d. This value is extremely low if compared to the figure recommended by MHERCE which is in the range 100–140 kg BOD_5/ha/d.

Table 2 | Overall wastewater treatment efficiency of the Boujaâd WSP

Parameters	Influent	Effluent	Efficiency (%)
COD (mg O_2/l)	200	120	40
BOD_5 (mg O_2/l)	45	25	45
SS (mg/l)	160	56	65
TKN (mg N/l)	29	16	45
NH_4^+ (mg N/l)	19.5	6.6	65
P_{tot} (mg P/l)	4.5	2.2	50
FC (germsFC/100 ml)	7.8×10^6	4.2×10^2	4.27 logU
FS (FS/100 ml)	2.9×10^6	7.8×10^2	3.57 logU
HE (eggs/l)	2	0	100

Overall wastewater treatment efficiency of the waste stabilisation ponds

Table 2 summarises the overall wastewater treatment efficiency of the WSPs at Boujaâd. As already indicated, the SS removal rate is rather low being only about 65%. Even lower treatment efficiencies are observed in terms of COD and BOD_5 reduction, with removal rates of 40% and 45%, respectively. These figures are extremely low compared to the removal rates stipulated in the CEC directive on domestic wastewater discharges into sensitive receiving water bodies.

From a microbiological point of view the Boujaâd WSP allows for significant treatment efficiency in terms of faecal pollution reduction. These reductions rates are 4.27 log U and 3.57 log U for FC and FS, respectively. As an example for parasitic parameters it could be observed that the Boujaâd WSP can eliminate all Helminth eggs found in the influent of the plant, thus achieving 100% performance.

The microbiological quality of the WSP effluent shows values below 1,000 colonies per 100 ml of sample volume for FC and FS. These effluents do not contain any helminth eggs. Thus it would be possible to reuse the treated effluents for irrigation purposes, since the quality of these effluents meets both the quality criteria of the WHO Directive (1989) and those of the Conseil Supérieur d'Hygiène Public de France (CSHPF 1992) related to the reuse of treated wastewater.

CONCLUSIONS

The raw wastewater at the inlet of the Boujaâd WSP system shows the general characteristics of domestic wastewater which has been highly diluted by infiltrated groundwater, which results in a reduction of around 70% in the organic wastewater load compared to the originally considered raw wastewater load.

Throughout the year-long study the WSP system at Boujaâd operated well below its design capacity in terms of both its hydraulic and its organic wastewater load, with this extremely low load negatively affecting the overall efficiency of the wastewater treatment.

The detailed wastewater analysis results of samples taken over the period of a year clearly indicated the seasonal variations in the performance of the different stabilisation ponds. Taking into consideration the application of statistical analyses the bacteriological analysis results showed that significant seasonal variations of around 95% in terms of the pond performance could be observed for the facultative ponds and the maturation ponds, whereas the seasonal variation in the performance of the anaerobic ponds was insignificant.

The assessment on the treated wastewater quality in terms of the physico-chemical parameters (COD, BOD_5, SS, TKN and total phosphorous) clearly indicated relatively poor treated wastewater quality results if compared to the French minimum standards (version December 1994).

With respect to the bacteriological wastewater quality, expressed by the FC level and to the parasitic wastewater quality, expressed by the number of helminth eggs, the treated effluents of the Boujaâd WSP meet the standards of the WHO Directive (1989) as well as those stipulated in the recommendations of the Conseil Supérieur d'Hygiène Public de France (CSHPF 1992) related to the reuse of

treated effluents for crop irrigation, for sport grounds and for public recreation zones.

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