The performance of the waste stabilization pond system at Boujaad, 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 two main objectives of this plant are the prevention of pollution of water resources and the environment by means of wastewater discharges as well as the saving of fresh water by means of reuse of treated wastewater for irrigation purposes. Within the period of March 1997 to March 1998 a comprehensive analysis campaign of both the raw and the treated wastewater at a number of different sampling points has been carried out in order to evaluate the treatment efficiency of this wastewater treatment plant. The results of these investigations showed an average raw wastewater flow of 1600 m³/d, which is well below the design flow of 2500 m³/d.

With respect to the physico-chemical treated wastewater quality and in comparison with the French treated wastewater standards (1980) these results indicated that 90 % of the wastewater samples showed BOD₅-figures below the quoted French standard, whereas 83 % of the samples showed COD-figures above the corresponding French treated wastewater standard.

With average treated wastewater suspended solids contents of 56 mg/l the suspended solids removal rate has been determined as being in the range of 65 %.

If compared to the anticipated Moroccan wastewater standards for direct wastewater discharge into receiving water bodies as stipulated in the Moroccan Standards Project the obtained wastewater analysis results showed COD- and BOD₅-values below these foreseen Moroccan wastewater discharge standards. The analysis results of SS, TKN and total phosphorus (P tot) showed figures slightly above these Moroccan standards. In view of the microbiological wastewater characteristics the treated effluents of the Boujaâd WSP respond to the WHO directive with respect to wastewater to be used for restricted irrigation (category B).

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 the SS-removal, the removal of organic matter (expressed by BOD₅ and COD) as well as the removal of nutrients (expressed by TKN and P tot). This relatively low efficiency might basically 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. Besides the evaluation of the overall treatment efficiency, detailed investigations of the performance of individual ponds have been carried out as well.

Keywords Stabilisation ponds, wastewater treatment efficiency, microbiological parameters, seasonal variations

Introduction
In Morocco wastewater stabilisation ponds (WSPs) have been applied for more than 15 years, but are still not yet fully developed. However, the experiences gathered within this period indicate that this technique can be considered as being most appropriate in most of the cases under Moroccan weather conditions.
Within the framework of data collection on the process of natural wastewater lagoon systems and their performance under these climatic conditions, a study has been carried out on the waste stabilisation pond system of the city of Boujaâd.

The work of this study has been guided along the pond performance control in order to allow for more profound knowledge with respect to the treatment efficiency of this pond system, which is considered as being the pilot-scale largest pond system in Morocco. Therefore one of the main objectives of this study is to obtain more detailed on-site experiences in the field of natural lagooning systems in Morocco.

Within this paper the results of the detailed investigations on the wastewater characteristics of the waste stabilisation pond system of the town of Boujaâd are presented. Furthermore the local and temporal development of microbiological parameters are shown, added by the identification and quantitative determination of helminth eggs for each step of the treatment line. Besides the evaluation of actual plant performance special attention has been drawn to the treated wastewater quality with reference to potential treated wastewater reuse options depending on the corresponding established wastewater quality standards.

Material and methods
Study site
The waste stabilisation ponds are located south of the city of Boujaad close to the main road connecting the cities of Casablanca and Beni Mellal. The pond’s latitudinal location is about 32.2°N, the longitude is around 6°47 W and the pond’s altitude reaches from 650 to 700 m above sea level.

The climatic conditions of the city of Boujaad is of the semi-arid Mediterranean type, characterised by relatively low precipitation rates, long sun periods, an intensive evaporation rate and high temperature fluctuations in terms of both daily and seasonal variations.

As can be seen in Figure 1 the studied waste stabilisation pond system shows 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 number of 6 stabilisation ponds: 2 parallel anaerobic ponds (AP) with a surface of 940 m² each and a depth of 2 m, two parallel facultative ponds (FP) with a surface of 11,250 m² each and a depth of 1.5 m and 2 maturation ponds (MP) in series, each one having a pond surface of 5,750 m² and a depth of 1.5 m.

Sampling and analysis methods
Wastewater samples have been taken at the plant intake as well as at different points of the treatment line. The sampling method for the samples taken at the plant intake as well as of the outlet of the anaerobic ponds slightly differs from the method applied for the other

![Figure 1 Schematic flow diagram - waste stabilisation ponds of Boujaad](https://iwaponline.com/wst/article-pdf/42/10-11/9/428076/9.pdf)
samples. For the above mentioned sampling points the samples have been 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 hours.

For reasons of better sample handling and increased representing sample character the samples at the outlet of the facultative and the maturation ponds have been taken by means of a glass column of 2 m length. Each sample of 2 l taken at a water depth of 1 m is directly transferred to a 30 l sample container. A composite sample of 48 hours has been taken and sub-samples from this container have been taken and fixed for physico-chemical analysis.

For bacteriological wastewater analysis, immediate samples have been taken around noon-time (highest 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 BOD₅, in the Moroccan Standards Project (GLVPM, 1996) for NH₄, the TKN and P₉, and in the AFNOR Standards (modified method) for the SS, Faecal Coliforms (FC) and Faecal Streptococcis (FS). The determination of helminth eggs has been done according to the Janeckso – Urbany method.

Statistical analyses have been applied in order to evaluate seasonal effects on the pond efficiency.

The comparison of average microbiological wastewater analysis results during summer and during winter using the Student test allows to accept or to reject zero hypothesis at a confidence level of 1 – α = 95%.

Results and discussion
Characteristics of raw wastewater
The average annual raw wastewater flow entering the wastewater treatment plant is in the range of 1600 m³/d, which is well below the design raw wastewater flow of 2500 m³/d. The measured average BOD₅ concentration of the raw wastewater with figures around 45 mgO₂/l is also well below the expected design concentration of 150 mgO₂/l.

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

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

With the exception of the figures determined for SS and TKN – being in the average raw wastewater characteristics range if compared to the three quoted references – the

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Raw wastewater of Boujaad WSP</th>
<th>Average raw wastewater composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD (mg O₂/l)</td>
<td>200</td>
<td>300–1000 250–1000 500–1500</td>
</tr>
<tr>
<td>BOD₅ (mg O₂/l)</td>
<td>45</td>
<td>100–400 110–400 150–650</td>
</tr>
<tr>
<td>SS (mg/l)</td>
<td>160</td>
<td>150–500 100–350 250–700</td>
</tr>
<tr>
<td>TKN (mg/l)</td>
<td>29</td>
<td>30–100 20–85 50–150</td>
</tr>
<tr>
<td>P₉ (mg/l)</td>
<td>4.5</td>
<td>10–25 4–15 5–30</td>
</tr>
</tbody>
</table>

Table 1 Mean wastewater concentrations of general pollution parameters of raw wastewater of Boujaad WSP compared with average national and international raw wastewater concentrations
concentrations of COD, BOD$_5$ as well as P$_{tot}$ are clearly below these expected average concentration ranges.

These results indicate that the incoming raw wastewater is already highly diluted, which leads to the assumption of a significant amount of groundwater infiltrating into the sewage network. This hypothesis is confirmed by analysis of dissolved oxygen, which show concentrations in the raw wastewater in the range of 2 mgO$_2$/l, considered as being relatively high for raw wastewater and thus confirming the assumption of infiltration of relatively non-polluted water into the sewerage network.

The analysis results related to the determination of organic pollution parameters (such as COD and BOD$_5$) indicate a relatively high COD/BOD$_5$ ratio of around 4.5, definitely being higher than the usually found ratio for domestic wastewater (COD/BOD$_5$ ratio in the range of 2). This high ratio could be caused by the dilution of organic matter and suspended solids by means of 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) stays more or less constant, which as a result increases the COD/BOD$_5$ ratio of the incoming raw wastewater.

Microbiological profile

The analysis of the indicators of faecal wastewater pollution, such as FC and FS, shows a relatively constant raw wastewater characteristics in this respect. Mean values vary around 7.8$\times$10$^6$ germs per 100 ml for the FC and 3$\times$10$^6$ germs per 100 ml for the FS.

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

As could be expected and can be seen in this figure no relevant reduction of faecal pollution indicators can be observed in the primary treatment (AP). However, a significant reduction for each of the two species 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 the above mentioned indicators.

The comparison of seasonal variations of the microbiological wastewater characteristics as given in figures 3 and 4 clearly shows, that the microbiological pollution load at the plant inlet is increased during summer period (SP) ranging from May to September if compared to the colder winter period (WP) from October to April.

For the FC the relevant concentrations at the treatment plant inlet point have been registered. During summer period they have been determined to be in the range of 1.6$\times$10$^6$7 germs per 100 ml (7.20 logU) and around 2.0$\times$10$^6$ germs per 100 ml (6.3 logU) in the winter

![Figure 2](https://iwaponline.com/wst/article-pdf/42/10-11/9/428076/9.pdf)

**Figure 2** Evolution of FC and FS concentrations along the Treatment line
season. Similar results have been obtained for the FS with concentrations at the plant inlet being in the range of $4 \times 10^6$ germs per 100 ml (6.6 logU) in summer and $1.6 \times 10^6$ germs per 100 ml (6.2 logU) in winter season.

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

These cumulative reduction rates are in the range of 4.7 logU and 4.14 logU during the summer for the FC and FS respectively, whereas being in the range of 3.60 logU and 3.4 logU only during the winter period. These results coincide with those found by Baloux and Trousslier (1983) concerning the performance in FC removal for the waste stabilisation ponds of Metz as well as with the observations notified by Boussaid (1987), Imzlin (1990), Hassani (1993) and Lafdal (1994) for the wastewater stabilisation ponds of Marrakech.

Analysis of pond performance parameters:

For the anaerobic ponds the volumetric loading has been determined to be 18.3 g BOD$_5$/m$^3$/d. However, considering the fact, that currently the volume of sludge within the anaerobic ponds represent around 60% (measured by trace monitoring), this volumetric

![Figure 3](https://iwaponline.com/wst/article-pdf/42/10-11/9/428076/9.pdf)

**Figure 3** Variation of FC-Concentration in summer (SP) and Winter Period (WP)

![Figure 4](https://iwaponline.com/wst/article-pdf/42/10-11/9/428076/9.pdf)

**Figure 4** Variation of FS-Concentration in summer (SP) and Winter Period (WP)
loading rate is increased to around 45 g BOD$_5$/m$^3$/d. If compared to CERMHER references, stipulating common volumetric loading rates ranging from around 50 to 300g BOD$_5$/m$^3$/d the above mentioned current loading rates found for the anaerobic ponds of Boujaad WSP are considered to still be very low.

General recommendations formulated by Mara and Pearson (1987), which are widely applied such as by the Israeli practice (Zahar, 1986) indicate optimum volumetric loads in the range of 100 to 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 criterion commonly used in order to ensure optimum anaerobic pond performance. The corresponding results obtained for the Boujaad WSP showed that the surface load never exceeds 400 kg BOD$_5$/ha/d, a figure again being very low if compared to the minimum surface load of 1,000 kg BOD$_5$/ha/day, as specified by CERMHER (1992). Surface loading rates below this recommended value would facilitate aerobic conditions to be found throughout the whole pond volume 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 days, 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 23ºC. The BOD$_5$-removal rates vary between 38% during winter period and 55% during summer period, with corresponding temperatures of 18ºC and 38ºC respectively and with the theoretical retention times for those two periods being 1 day and 1.45 days respectively.

For the facultative ponds, optimum performance highly depend on the admissible surface load. This surface load of the facultative ponds of the Boujaad WSP system is estimated to 16 kg BOD$_5$/ha/d, a figure again being clearly below the commonly recommended interval ranging from 150 to 200 kg BOD$_5$/ha/d, as for example indicated by CERMHER (1992).

Average surface loads applied in waste stabilisation ponds in France and Germany show figures in the range of 100 kg BOD$_5$/ha/d (Mara and Pearson 1987). Again it can be stated, that also the facultative ponds of the Boujaad WSP are operated well below their design loads as well as below commonly found operation loads.

With respect to potential nutrient removal the facultative ponds allow a nitrogen reduction of around 20% (in terms of TKN), 13.5% removal of ammonium (NH$_4^+$) and only 8.5% for phosphorous removal.

However, the above, described extremely low hydraulic and organic pond loadings do not disturb the pond efficiency in terms of faecal pollution reduction. These reduction rates, for the facultative ponds determined as being in the magnitude of 2 logU for the FC and 1.78 logU for the FS are significant.

The maturation ponds, receiving the effluents of the facultative ponds with an average content of around 3.8x10$^4$ FC/100 ml leave the first maturation pond (MP1) with a concentration of around 3.4x10$^3$ FC/100 ml. The second maturation pond (MP2) again reduces this number of faecal coliforms down to around 4.2x10$^2$ FC/100 ml. These figures represent a faecal coliform reduction rate of 0.47 logU for the first and 0.9 logU for the second maturation pond. The overall reduction rate thus amounts to 1.37 logU for the two maturation ponds.

Based on the initial design, considering a faecal coliform reduction of 2.84 logU the above mentioned removal rate is again relatively low. Considering a theoretical retention time of 14 days a degradation constant k of 1.5 is recommended by CERMHER (1992) for
the climatic conditions of Morocco. The determined degradation constant \( k \) of 0.65 only for the Boujaad WSP proves the limited pond efficiency of the maturation ponds.

The maturation pond performance can also be evaluated on the basis of the surface load. Taking into consideration the organic load at the outlet of the facultative ponds, this organic surface load of the maturation ponds is determined to only 30 kg BOD\(_5\)/ha/d, a figure again being extremely low if compared to the corresponding recommended figure by CERMHER being in the range of 100 to 140 kg BOD\(_5\)/ha/d.

**Overall wastewater treatment efficiency of the waste stabilisation ponds**

Table 2 summarises the overall wastewater treatment efficiency of the waste stabilisation ponds of the city of Boujaad. As already indicated above, the removal rate of SS is rather low being in the range of only 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 if compared to those removal rates stipulated in the CEC directive related to domestic wastewater discharges into sensitive receiving water bodies.

From the microbiological point of view the WSP Boujaad allows for a significant treatment efficiency in terms of faecal pollution reduction. These reductions rates are 4.27 logU and 3.57 logU for FC and FS respectively. As an example for parasitic parameters it could be observed that the WSP Boujaad is able to eliminate all helminth eggs found in the influent of the plant, thus proving a performance rate in this respect of 100%.

The microbiological quality of the WSP effluent shows values below 1,000 colonies per 100 ml of sample volume for both Faecal Coliforms (FC) as well as Faecal Streptococci (FS).

These effluents do not contain any helminth eggs. This fact allows for consideration of the possibility 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 French Superior Board for Public Hygiene (1992) related to the reuse of treated wastewater.

**Conclusions**

The raw wastewater at the inlet of the Boujaad WSP system shows the general characteristics of domestic wastewater being highly diluted by infiltrated groundwater, which results in the fact that the organic wastewater load is reduced by around 70% if compared to the originally considered raw wastewater load.

Throughout the whole study period of one year the WSP system of Boujaad was operated well below its design capacity both in terms of its hydraulic as well as its organic wastewater load, with this extremely low load negatively affecting the overall wastewater treatment efficiency.

**Table 2  Overall wastewater treatment efficiency of the WSP of Boujaad**

<table>
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<th>Parameters</th>
<th>Influent</th>
<th>Effluent</th>
<th>Efficiency (%)</th>
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<tbody>
<tr>
<td>COD (mg O(_2)/l)</td>
<td>200</td>
<td>120</td>
<td>40</td>
</tr>
<tr>
<td>BOD(_5) (mg O(_2)/l)</td>
<td>45</td>
<td>25</td>
<td>45</td>
</tr>
<tr>
<td>SS (mg/l)</td>
<td>160</td>
<td>56</td>
<td>65</td>
</tr>
<tr>
<td>TKN (mg N/l)</td>
<td>29</td>
<td>16</td>
<td>45</td>
</tr>
<tr>
<td>NH(_4)+ (mg N/l)</td>
<td>19.5</td>
<td>6.6</td>
<td>65</td>
</tr>
<tr>
<td>P(_{tot}) (mg P/l)</td>
<td>4.5</td>
<td>2.2</td>
<td>50</td>
</tr>
<tr>
<td>FC (germsFC/100ml)</td>
<td>(7.8 \times 10^4)</td>
<td>(4.2 \times 10^2)</td>
<td>4.27 logU</td>
</tr>
<tr>
<td>FS (FS/100ml)</td>
<td>(2.9 \times 10^6)</td>
<td>(7.8 \times 10^2)</td>
<td>3.57 logU</td>
</tr>
<tr>
<td>HE (eggs/l)</td>
<td>2</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>
Taking into consideration the application of statistical analyses the bacteriological analyses results did show that significant seasonal variations of around 95% in terms of the pond performance could be observed for the facultative as well as for the maturation ponds, whereas the seasonal variations in the performance of the anaerobic ponds have been found 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).

In terms of suspended solids as well as organic matter the treated wastewater meets the level of the French standards (4th November, 1980). In terms of nitrogen components and phosphorous the treated effluents meet the level NK$_2$ and Pt$_1$.

With respect to the bacteriological wastewater quality, expressed by the content of faecal coliforms and to the parasitic wastewater quality, expressed by the content of helminth eggs, the treated effluents of the Boujaad WSP meet the standards set out in the WHO Directive (1989) as well as those stipulated in the recommendations of the French Superior Board for Public Hygiene (1992) related to the reuse of treated effluents for crop irrigation, for sport grounds as well as for public recreation zones.

References


