ADAPTING LOW COST WASTEWATER TREATMENT TECHNOLOGIES FOR RURAL AREAS IN THE WEST BANK

Majed Subhi Abu Sharkh

Associate Professor of Civil Engineering
College of Engineering and Technology, Palestine Polytechnic University
P.O. Box 198, Hebron-West Bank, Palestine
E-mail: msharkh@ppu.edu

ABSTRACT

The subject of sewage treatment is increasingly gaining interest in the West Bank due to the severe pollution impacts posed currently by cesspits and septic tanks used in rural areas. This study demonstrates in depth the performance of three wastewater treatment technologies applied in the rural areas of the West Bank, namely, Upflow Anaerobic Sludge Blanket (UASB)-wetland system, septic tank-biofilters system, and duckweed ponds system.

The field and laboratory works of this study include; frequent sampling, and testing of wastewater samples from different points in the treatment plants. The results of analysis for each treatment plant were compared together to recommend the most suitable small scale wastewater technology for rural areas in the West Bank.

Testing of a UASB-Wetland system at Kharas village shows COD variation from 1614 mg/l, at the head of the sewage works, to 109 mg/l as it leaves the treatment plant (93% removal). The efficiency for other pollutants removal was quite good; TSS was reduced by 90% while TS at 37%, and the effluent transparency was improved by 97%.

The Septic Tank-Biofilters system is located at Deir Samit village. The COD varies form 1315 mg/l at the inlet to less than 500 mg/l at the outlet. Such a primary treatment system was able to treat the sewage at acceptable levels and solve an environmental problem.

The removal efficiency of Duckweed Ponds system located at Al Aroub camp for COD and TSS was found in the range of 60-70%. Under adequate operational conditions, duckweed systems can match the quality characteristics of secondary effluents reused to grow a range of crops.

The results of the long-term monitoring period for these technologies' operation, and based on the results presented in this study, emphasize that these technologies are now proven under the country environmental conditions and at full-scale and could safely be applied to other rural sites.
Keywords: Wastewater, UASB, Biofilter, Duckweed, Wetland.

INTRODUCTION

Currently, no piped wastewater disposal system is available in most of the rural areas in the West Bank. Wastewater from individual residence is discharged directly into subsurface pits, allowing the wastewater to seep into the surrounding soil and percolate into the underlying aquifer causing ground water pollution. At the same time, the existing wastewater treatment plants are either non-existent, heavily overloaded or poorly operated and maintained.

Reclaimed wastewater is expected to become one of the main sources of water to be developed in Palestine. Therefore, appropriate wastewater treatment and reuse technologies have to be identified for the West Bank. Several studies and projects carried out on pilot and full scales had demonstrated that an Upflow Anaerobic Sludge Blanket (UASB) reactor represents a reliable and simple technology for the pre-treatment of domestic sewage. Therefore, this technology could be profitably applied in wastewater treatment.

The research work emphasizes here on the rural areas of the West Bank, Palestine by constructing small sewerage system together with decentralization treatment plants. This study demonstrates the performance of three wastewater treatment technologies located in Kharas village, Deir-Samit village and Al-Aroub camp of the West Bank. Low cost wastewater treatment plant at Kharas was constructed by Palestinian Hydrology Group (PHG), where wastewater treated anaerobically using UASB, and then aerobically using wetland. The system applied in Deir-Samit village is anaerobic primary treatment one. It consists of two compartment septic tanks followed four compartment biofilters and finally a storage tank. A pilot scale duckweed system was constructed at Al-Aroub secondary school by Environmental Authority. The system consists of settling tank, Duckweed lagoons (ponds) and storage reservoir.

The main objective of this study is to investigate, demonstrate and evaluate the application of three advanced wastewater treatment technologies of UASB, biofilters, and duckweed lagoons used in wastewater treatment plants in the West Bank. It is assumed that the advanced technologies are suitable for the Palestinian rural communities since they are cost effective, easy to operate and maintain.

DESCRIPTION OF THE PLANTS

Introduction

For the purpose of this study, three wastewater treatment plant located in rural areas of the West Bank were studied and evaluated. As mentioned earlier, these treatment...
plants are located in Kharas, Deir-Samit, and Al-Aroub rural communities. The name, location, population served, type of treatment, and effluent quantity of treated wastewater for each treatment plant are presented in Table (1).

Table (1): Wastewater Treatment Plants Studied in the Hebron District

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Population Served</th>
<th>Type of Treatment</th>
<th>Effluent Quantity (m$^3$/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kharas WWTP</td>
<td>2000</td>
<td>Anaerobic treatment processes (UASB) followed by aerobic treatment (wetlands)</td>
<td>120</td>
</tr>
<tr>
<td>2</td>
<td>Deir-Samit WWTP</td>
<td>400</td>
<td>Septic tanks followed by biofilters</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>Al-Aroub WWTP</td>
<td>300</td>
<td>Duck weed-based pond system</td>
<td>12-15</td>
</tr>
</tbody>
</table>

As given in Table (1), the treatment processes in Kharas village is aerobic and anaerobic (UASB followed by wetlands). Deir-Samit Wastewater Treatment Plant uses anaerobic system which is sedimentation tanks, and biofilters. Al-Aroub Wastewater Treatment Plant consists of duckweed-based pond system, settling tank, and reservoir. The description of each of the treatment plants are given below.

**Kharas Wastewater Treatment Plant**

In 2002, Palestinian Hydrology Group (PHG) designed and implemented a project on wastewater collection and treatment in Kharas village (Awadallah, 2002). The overall goals was to improve the hygienic conditions, protect water quality, reduce pollution loads and create a demonstration for sound treatment and collection of wastewater that could enhance surrounding towns to carry out such projects in their areas. The design capacity of the treatment plant is 120 m$^3$ per day which equivalent to 300 houses service. The fenced treatment plant site is 2 dounms area of which the treatment plant itself is 1063 m$^2$ area. The layout and general view of Kharas wastewater treatment plant are shown in Figure 1 and Figure 2.
Figure (1): The Layout of Kharas Wastewater Treatment Plant

Figure (2): General View of the Wastewater Treatment Plant in Kharas Village
As given in Figure 1, the treatment processes consists of six stages as follow:

**A. Bar screen:** This is designed to trap coarse material such as any type of solid waste with diameter higher than 2 cm.

**B. Sand and grit removal channel:** The channel is to remove sand and gravel and should be cleaned manually by replacing a removable plastic mesh placed inside the channel body.

**C. Anaerobic treatment stage using UASB:** This is a tank with 5 m depth and has a square surface area (4m x 4m). The schematic diagram of the UASB is illustrated in Fig. 3. The sewage inter the tank bottom through 4 vertical 4" PVC pipes, which split the flow into equal amounts. The water leaving the tank is draining through the V-notch channel at the water level meeting point. The hydraulic retention time inside this tank is 1.33 day based on the current flow rate and will be 0.67 day based on maximum flow capacity. The reactor is equipped with Gas-Liquid-Solid (GLS) separator inclined at angle of 50°; this is made of protected steel plates. Below the GLS exists the deflector, which directs the water to the GLS and it is also made of protected steel. Closed to the V-notch channel, at the top of the reactor, exists the scum baffle. After the water leaves the V-notches it passes through water locked manhole. There are four 4" PVC pipes dipped into the reactor to enable removing sludge through a submerged pump. The most interesting thing is that the reactor is equipped with a gas collection system, which allows collection and storage of all the gas produced from the reactor and this take place through a non-return pathway.

![Figure (3): Schematic Diagram of UASB at Kharas WWTP](image-url)
D. (D1, D2) - Aerobic treatment stage using wetlands: The wetland, which is selected, is subsurface flow wetlands and is covered with reed plants that absorb the nitrogen and phosphate. This stage contains lagoons lined in base and sides with high density polyethylene (HDPE) that prevents any expected leakage to the ground water. The wetlands include different sizes of gravel; the smallest are placed on the surface while the largest at the bottom, with reed plants planted at the surface. These plants make aeration in the upper half-meter of the water column through developing some 60 cm root zone. This enables the treatment to be aerobic. The basic biochemical reaction is the nitrification.

E. Effluent storage tank: This tank has 80 m$^3$ storage capacities and is equipped with a pump (2 HP) to facilitate effluent reuse options.

F. Sludge drying bed: It contains gravel with size decrease from bottom to top. It drains the water from its bottom and it daily treats 2 m$^3$ of wet sludge. The drained water that results from this sludge dewatering process receives treatment in the wetland through conveyance pipes that carry it to the wetlands. The scraped sludge is currently disposed of in the area landfill that treats the solid waste.

Deir-Samit Wastewater Treatment Plant

Deir-Samit wastewater treatment plant was constructed by the village council and PHG with a design capacity of 50 m$^3$ per day which equivalent to 50 houses service. The wastewater treatment plant at Deir-Samit village is shown in Figure 4. The system consists of 2-compartment septic tank followed by 4-compartment biofilters (see Figure 5).

Figure (4): Wastewater Treatment Plant at Deir-Samit Village
The treatment plant is composed of the following units of operation:

**A. Two compartment septic tank:** The first compartment is with a surface area of 32 m$^2$ and a depth of 4 m. The active water depth is 3.5 m with a compartment volume of 128 m$^3$ of which the water occupies 112 m$^3$. The second compartment is similar but the active water depth is 3.45 m. Based on the expected flow conditions, the retention time for the first compartment is 9.3 to 4.5 days. The second compartment enables similar retention time. This means that the total retention time inside the septic tank will be 10 to 20 days.

**B. Four compartment anaerobic biofilters:** These are designed as up flow tanks. Each tank is fed with wastewater by means of 6" UPVC pipe, which extends some 20 cm over its base. Water feeds the tank from top to bottom while it leaves each compartment from bottom to top. These are four compartments with equal size. Each is with 5 square meters surface area. The only difference among these compartments is the size of gravel and the water depth. The hydraulic gradient from one compartment to the next ensures drop in the water level by 5 cm intervals. The first compartment is with a gravel size of 5-10 cm diameter, the second compartment is with gravel size of 2-4 cm and the second and the third compartment are identical with pea size gravel.

**C. Storage tank for treated effluent:** This tank has a capacity of 105 cubic meters. It aims at making available the required volumes of treated wastewater for the target expected reuse.
Al-Aroub Wastewater Treatment Plant

Al-Aroub Wastewater Treatment Plant was constructed in 1997. A proper infrastructure were added to the plant such as sewer line, manholes and three small ponds with a dimension of $2 \times 3 \times 0.5$ m. Plastic sheet were installed at the bottom of the ponds to prevent seepage. Duckweed (Lemna gibba) fronds were brought and installed in a mixture with wastewater and tap water for cultivation and adaptation, and then it was installed in the ponds. Duckweed-based pond system at Al-Aroub treats 12-15 m$^3$ per day of wastewater from the Al-Aroub Agriculture School and College and the adjacent stable of the cows.

The general layout and view of Al Aroub treatment plant are described in Figures 6 and 7. The system consists of settling tank, two Duckweed ponds and storage reservoir. The wastewater coming from Al-Aroub Secondary School and Al-Aroub Technical College enters the treatment plant through the plastic pipeline and bar screen installed for this purpose to the settling tank. Then the wastewater goes to constructed Duckweed ponds. Duckweed (Lemna gibba) fronds were brought and installed in a mixture of wastewater and tap water for cultivation and adaptation. After that, lemma gibba fronds were installed in the ponds that slowly grew and covered the whole surface. The treated wastewater is stored in a storage tank, where then taken and used for irrigation of plants in Al-Aroub Complex Farm.

Duckweed based wastewater treatment is very efficient in removing nutrients from the wastewater. One of the major advantages of this system is that it turns the waste into valuable duckweed meal to return a net profile against both capital and operational costs. The duckweed crop is enriched with nutrients during the treatment and can be used as animal fish or chicken food. Duckweed systems are also known for their capabilities to control mosquitoes and odors.

![Figure (6): General Layout of Al-Aroub Wastewater Treatment Plant](image-url)
WASTEWATER SAMPLING AND ANALYSIS

In order to study the characteristics of wastewater before and after the treatment processes and subsequently evaluate the performance of studied treatment plant, samples from the three plants were collected, tested, and analyzed three times during the research work. The sampling procedure includes the inlets and the outlets of Deir-Samit and Al-Aroub systems, while it includes the UASB and wetlands inlets and outlets at Kharas system.

The laboratory analysis was conducted at PHG laboratory in the Hebron City. The tested parameters were measured using sens-ion meters manufactured by HACH Company. The analysis included the following tests which were performed:

- pH value (pH).
- Electric Conductivity (EC).
- Total Solid (TS).
- Total Suspended (TSS).
- Total Dissolved Solids (TDS).
- Chemical Oxygen Demand (COD).
- Dissolved Oxygen (DO).
- Salinity (S).
- Ammonium (Ammonia) (NH4+).
- Chloride (Cl-).
- Total Coliform (TC).
All the meters were calibrated according to manufacturer instruction before conducting the measurements and the parameters were measured according to the procedures reported in the "Standards Methods for the Examination of Water and Wastewater", 1998. Flow measurements were conducted by making a drop in the water level of a certain tank by mean of pumping and then calculating this level recovery over a certain period of time. Measurements were carried during the period from November, 2006 to April, 2007.

DISCUSSION OF RESULTS

Characteristics of raw sewage

Based on the three sampling sets, the average values for the raw sewage characteristics for the three rural areas (Kharas, Deir-Samit, and Al-Aroub) are shown in Table (2). The average for the averages is also given in the table as a representative for the rural area of the West Bank. These averages can reflect the wastewater characteristics for the rural areas of the West Bank.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Site of the Treatment Plant</th>
<th>Average for Rural Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>-</td>
<td>7.5 7.7 7.8 7.7</td>
<td>7.7</td>
</tr>
<tr>
<td>EC</td>
<td>µs/cm</td>
<td>2417 3680 2750 2949</td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>mg/l</td>
<td>1953 2511 1812 2092</td>
<td></td>
</tr>
<tr>
<td>TSS</td>
<td>mg/l</td>
<td>751 2300 1649 1567</td>
<td></td>
</tr>
<tr>
<td>TDS</td>
<td>mg/l</td>
<td>1225 1657 1462 1448</td>
<td></td>
</tr>
<tr>
<td>COD</td>
<td>mg/l</td>
<td>1614 1315 2376 1768</td>
<td></td>
</tr>
<tr>
<td>DO</td>
<td>mg/l</td>
<td>0.8 0.8 0.5 0.7</td>
<td></td>
</tr>
<tr>
<td>Salinity</td>
<td>mg/l</td>
<td>1.2 2.4 1.4 1.7</td>
<td></td>
</tr>
<tr>
<td>NH₄⁺</td>
<td>mg/l</td>
<td>198 157 116 157</td>
<td></td>
</tr>
<tr>
<td>Cl⁻</td>
<td>mg/l</td>
<td>238 415 377 343</td>
<td></td>
</tr>
<tr>
<td>TC</td>
<td>#/100ml</td>
<td>7x10³ 2.0x10³ 2.5x10³ 3.8x10³</td>
<td></td>
</tr>
</tbody>
</table>

Obviously, the data show a COD value of 1768 mg/l, an ammonia content of 157 mg/l, a TDS 1448 mg/l, and a TSS value of 1567 mg/l. These data and when compared with the corresponding data of the West Bank cities wastewater, indicate that sewered rural areas wastewater is with lower COD and higher TSS content. In comparison with Table (1) data, the cities wastewater of the West Bank showed COD of 2088 mg/l and TSS of 897 mg/l (Awadallah, 2002). The variation detected between the characteristics of the rural and cities wastewater is a result of incorporation of industries in the cities, while the water consumption is not affecting the characteristics here because in these three rural areas water networks having an adequate flow rates are available.
The water consumption in these rural areas is very low (about 40-70 l/c.d), and wastewater is mainly of domestic source. Because of this, the values of some parameters such as COD, NH₄⁺, and TS are comparatively higher than the typical values.

The results reveal that the values of EC, TS, TSS, TDS, and Cl⁻ for Deir Samit are the highest. This could be attributed to that the sewers available currently at Deir-Samit are only serving a cluster of houses (collecting about 12-15 m³ of wastewater).

**Efficiency of the treatment plants**

Comparing performance of the UASB-wetlands system at Kharas town with septic tanks-biofilters system at Deir Samit village, and settling tank-duckweed ponds system at Al Aroub camp (as all are primary treatment technologies) shows that for a system such as septic tanks-biofilters one, sludge removal and filter media backwashing are a key determinant factor for system operation, and the system could allow more removal of pollutants. Of course, the three systems have advantages over each others such as the available treatment surface area, and the design capacity.

Based on averaged long term data (including those of sludge accumulation) the efficiency and the three systems are compared in Table (3). The results show the following variation:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Kharas</th>
<th>Deir-Samit</th>
<th>Al-Aroub</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>RS</td>
<td>TW</td>
<td>RE (%)</td>
</tr>
<tr>
<td>pH</td>
<td>-</td>
<td>7.5</td>
<td>7.1</td>
<td>5</td>
</tr>
<tr>
<td>EC</td>
<td>µs/cm</td>
<td>2417</td>
<td>2600</td>
<td>-8</td>
</tr>
<tr>
<td>TS</td>
<td>mg/l</td>
<td>1953</td>
<td>1235</td>
<td>37</td>
</tr>
<tr>
<td>TSS</td>
<td>mg/l</td>
<td>751</td>
<td>72</td>
<td>90</td>
</tr>
<tr>
<td>TDS</td>
<td>mg/l</td>
<td>1225</td>
<td>1316</td>
<td>-7</td>
</tr>
<tr>
<td>COD</td>
<td>mg/l</td>
<td>1614</td>
<td>109</td>
<td>93</td>
</tr>
<tr>
<td>DO</td>
<td>mg/l</td>
<td>0.8</td>
<td>5.2</td>
<td>-550</td>
</tr>
<tr>
<td>Salinity</td>
<td>mg/l</td>
<td>1.2</td>
<td>1.2</td>
<td>0</td>
</tr>
<tr>
<td>NH₄⁺</td>
<td>mg/l</td>
<td>198</td>
<td>161</td>
<td>19</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>mg/l</td>
<td>238</td>
<td>284</td>
<td>-19</td>
</tr>
<tr>
<td>TC</td>
<td>#/100ml</td>
<td>7x10⁵</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Negative sign indicates the percent increase in the value compared with entering wastewater value for the parameter

RS: Raw Sewage; TW: Treated Wastewater; RE: Removal Efficiency
The whole system at Kharas achieved 93% removal in terms of COD, 90% in terms of TSS, 37% in terms of TS, and 19% in terms of ammonia. While the system of Deir-Samit achieved 62%, 70%, 20% and -20% removal for the COD, TSS, TS and NH$_4$+. The Duckweed ponds system at Al Aroub achieved removal efficiency of 60% for COD, 70% for TSS, 27% for TS, and 55% for ammonia.

It seems to be that the three systems remove the same percent of COD (60-65%) if only UASB is used in Kharas system. Otherwise, the removal efficiency of COD reaches 95% if we use UASB and wetlands at Kharas.

The three systems enabling ammonification reactions but the UASB and Duckweed are producing more ammonia rich effluent.

Negative sign indicates for some constitutes means that the percent increase in the value compared with entering wastewater value for the parameter.

The system at Kharas and Al-Aroub enable the production of aerated effluent while that of septic tanks-biofilters at Deir Samit produces a yellowish anaerobic effluent due to absence of aerobic treatment stage.

It seems that the UASB-Wetland system at Kharas town is more efficient in the reduction of pollutants. This indicates good treatment proceeding and enables the production of an effluent that can be reused for different purposes and is complying with many regional and local standards in terms of COD.

Appropriate wastewater treatment

Wastewater treatment should be reliable to give an effluent fit for irrigation following the guidelines and Palestinian standards. Land treatment is not recommended due to the large area requirement and possibility of ground water contamination. Advanced and mechanized wastewater treatment is also not recommended due to the high investment cost of equipments, high energy requirements and the need for skilled operators.

Based on the results of this work, it is important to include anaerobic treatment as the first step, since wastewater is highly concentrated. Upflow Anaerobic Sludge Blanket (UASB) has been recommended by the work team. And in order to increase the removal efficiency, it is suggested to follow (UASB) by wetland or ponds, so the treated water can be used for irrigation purpose. We recommend the use the use of a 1 day settling tank before UASB, this will allow reduction of the high value of TSS entering the UASB.
CONCLUSIONS

Recent data indicate that the raw sewage of the sewered rural areas of the West Bank are characterized by COD value of 1768 mg/l, total suspended solid value of 1567 mg/l, total dissolved solid 1448 mg/l, and ammoniumm of 157 mg/l. This reveals that the rural sewage is less concentrated than municipal sewage.

The UASB was capable of treating domestic sewage at an acceptable level and at low cost. A well operated and maintained UASB could ensure removal of about two third of COD load at about 1.5 days hydraulic retention time or even less. The UASB anaerobic technology is simple in design implementation and operation with minimum maintenance requirement and cost. If the effluent of the UASB is treated in a wetlands system, a final effluent COD of less than 100 mg/l could be obtained.

At optimal conditions, the septic tank-biofilter and duckweed ponds systems can ensure more than 70% COD removal which means that only 30% of the organic pollution is allowed to leave the system via the effluent. The key factors are the frequent desludging and filter backwashing; otherwise the efficiency may fall down to less than 50%. These systems are a good choice for replacing the existing cesspits and could serve a cluster of houses.

The success of sewage treatment systems reported in this project make us more confident to apply these technologies in other rural communities. UASB anaerobic system followed by wetland is recommended in this study.

REFERENCES


