International Water Resources Association
Water International, Volume 32, Number 2, Pg. 310-324, June 2007
© 2007 International Water Resources Association

Sustainability of Natural and Mechanized Aerated Ponds for Domestic and Municipal Wastewater Treatment in Palestine

Rashed Al-Sa`ed
Water Studies Institute (WSI), Birzeit University
P.O. Box 14, Birzeit, West Bank, Palestine
Telefax: +972-2-298 20 70, E-mail: rsaed@birzeit.edu

Abstract: *More than half of the current wastewater treatment facilities constructed in Palestine are waste stabilization ponds (WSP) and have several problems in their operation. This article evaluates three selected case studies on the various pond systems including WSP, algae- and duckweed-based ponds (ABP and DBP, respectively) and one mechanically aerated lagoon (AL) system. The effects of various design and operating parameters on the pond system's performance, with special emphasis on nitrogen removal, are discussed. The effluent quality of WSP and AL complies only with BOD limits, but not with microbiological limits prescribed for agricultural purposes, as determined by national standards. ABP and DBP achieved nitrogen removal only under high surface area demand (5-7 m2capita-1). Suitable plans for modifying existing aerated lagoons or for upgrading natural lagoons are suggested in order to comply with microbiological standards for effluent use in restricted irrigation. Finally, the suggested sustainability criteria for the evaluated pond systems may help the decision makers, as well as their designers and donor countries, to better select and design low-cost treatment options for sustainable wastewater management in developing countries.*

Keywords: *aerated lagoons, domestic sewage, natural treatment, nutrient removal, sanitation sustainability*

Introduction

Palestine faces significant water and sanitation challenges resulting from both rapid urbanization development and population growth. Low average per capita freshwater resources and inadequate water and sanitation services exacerbate increasing water pollution problems. The use of natural and mechanized treatment processes for the removal of organic pollutants and nutrients from domestic and urban wastewater is attracting increasing interest. Among many wastewater treatment alternatives, waste stabilization ponds (WSP), including algae and duckweed ponds, as well as aerated lagoons, have become popular in both rural and urban communities worldwide. Several national and international experts and professional agencies recommended the application of these treatment technologies in the Middle East region (US EPA, 1992; Shelef and Kanarek, 1995; Yagoubi *et al.,* 2000; Mara, 2001; Zimmo *et al.,* 2002; Abis and Mara, 2005).

The efficiency of natural purification and mechanized treatment processes, reflecting one core issue of sustainable sanitation facilities, strongly depends on the reactor design, process monitoring and operating conditions. However, technical design data gained from practical experience and from the process performance analysis of treatment technologies in the Mediterranean zone in general, and particularly in Palestine, are still lacking. In developing countries, several sanitation projects fail to deliver long-term benefits to society due to poor understanding of the impacts and sustainability of these projects (Carter *et al.,* (1999). Similarly, Hoffmann *et al.,* (2000) considered the analysis of the particular community's local context as one of the core issues for achieving sustainable sanitation facilities and indicated that no treatment technology is *de facto* sustainable.

The design of wastewater collection, treatment and disposal systems in Palestine is usually based on assumed design parameters and imported as ready-made treatment schemes from international engineering firms abroad. In the absence of local data, foreign planners and sewage works designers tend to adopt their own classical parameter values to design local wastewater treatment facilities. The common result is either the over-sizing of the treatment systems or, at the other extreme, under-designing of the treatment unit operations. In both cases, the system fails when put into operation (Theodory and Al-Sa`ed, 2002). According to Mahmoud *et al.,* (2003) the characteristics of wastewater in Palestine have not been subjected to thorough analysis and, hence, not enough reliable data are available. Furthermore, the selection of a given treatment technology of an overloaded sewage treatment works depends on the characteristics of the wastewater under question (Mahmoud *et al.,* 2003).

In laboratory-scale batch experiments, Zimmo *et al.,* (2002) have monitored the efficiency of duckweed (*Limna gibba*)-based and algae-based wastewater containers under different concentrations of total nitrogen (50 and 100 mg Nl^{-1}). They realized that nitrogen loss, probably due to denitrification and ammonia volatilization, represents 40% of the total nitrogen content of algae-based and duckweed-based containers. However, in duckweed-based containers only 28% of N-loss was observed in containers with higher initial N-content. In another experiment, a pilot plant experiment was carried out to assess differences in environmental conditions and treatment performance in two systems for wastewater treatment: algae-based ponds (ABP) and duckweed-based (*Lemna gibba*) ponds (DBP). During the summer period, the average removal rate in total nitrogen was more in ABP (80%) compared with DBP (55%). However, lower values were measured during the winter period. Seasonal nitrogen reductions in DBP were significantly different, where about 33% and 15% of the total nitrogen was incorporated by duckweed biomass and removed from the system via duckweed harvesting during the summer and winter period, respectively. Plausible scientific explanations as to why there was not more significant nitrogen removal in the latter ponds for both systems was not given; similarly, the impact of C:N ratio on the stability of denitrification capacity in both systems was not explored. No concrete design guidelines were made with regard to optimal design parameters to achieve adequate nitrification and denitrification rates, or to the feasibility of these natural ponds as a sustainable low-cost treatment option were made.

To increase practical knowledge on the key design and operational data of natural treatment systems and oxidation ponds, this study evaluates the process performance of three selected WSP pond systems and one mechanically aerated lagoon facility in the West Bank, Palestine.

Materials and Methods

Physical description of selected sanitation facilities

Four wastewater treatment facilities -- a waste stabilization pond (WSP), algae- and duckweed-based ponds (ABP and DBP respectively), and one mechanized municipal aerated ponds -- were studied, all of which are located in the West Bank, Palestine. Sites were selected because of well-established institutions and because, historically, these sites have been regarded as adequate for research purposes. Furthermore, the aerated ponds represent the oldest type of treatment technologies in use and one third of all installed urban sewage works in the West Bank.

Talitha Kumi Waste stabilization ponds (WSPs):

The treatment system consists of a series of 10 rectangular reinforced concrete ponds; the first is an anaerobic pond (LxWxD: 15x1.5x 2m) followed by seven facultative ponds (LxWxD: 15x1.5x1.5m), where the last two ponds act as polishing lagoons (LxWxD: 15x1.5x1m). A fixed precast concrete mixing partition with 0.5m depth below surface water is constructed in the middle of each pond to enhance the hydraulic mixing. Talitha Kumi WSPs were monitored during three intervals. During the first phase, ten weekly visits to the plant were performed following the commissioning date (11 March- 25 May 2000) to monitor the start-up phase. The second phase was during the summer up until the beginning of the school semester in September. A similar methodology was followed in the winter season (third phase) during January 2001.

Pilot Scale Algae- and Duckweed-Based Ponds (ABP and DBP):

The pilot scale pond system has been located on the Birzeit University (BZU) campus since 1998. The pilot plant was built using reinforced concrete walls to ensure water tightness. It consists of a septic tank (2.2 m length, 1.3 m width and 1.9 m depth) followed by two parallel systems: algae-based ponds (ABP) and duckweed-based ponds (DBP). Each system consists of a sequence of 4 equal ponds (3 m length, 1m width and 0.9 m depth) in series (Figure 1). The pilot plant was monitored for 30 days in May and June 2001, where about 0.8 m^3 of sewage was pumped daily to the septic tank from an aerated equalization basin, which is part of the central BZU activated sludge plant (4000 students and staff members), applying the contact stabilization process. A peristaltic pump pumped the wastewater from the holding tank at equal rates (0.4 m^3d^{-1} to each system) to the ABP and DBP. The total hydraulic retention time (HRT) in the entire ponds was 28 days, while it was only 3 days for the septic tank. Duckweed-based ponds were started with *Lemna gibba* species at a density of 600 g fresh weight/m^2.

The overall nitrification and denitrification rates were measured for the whole water body and sediment layer in all ponds (ABPs and DBPs). Two batch reactors consisted of PVC plastic tubes of 0.1 m diameter and 1.0 m length were used. Under continuous flow mode of operation, about 7.1 m^3 of liquid and sediment portions were incubated for 24 hours in each reactor, where a nitrification inhibitor was added in one of them to measure the actual nitrification rate. After mixing both water and sediment in each batch reactor, duplicate samples of 100 ml were taken and analyzed for ammonium, nitrite and nitrate. The nitrification and denitrification rates were determined as described by Ghneim (2003).

Ramallah Wastewater Treatment Plant (RWWTP):

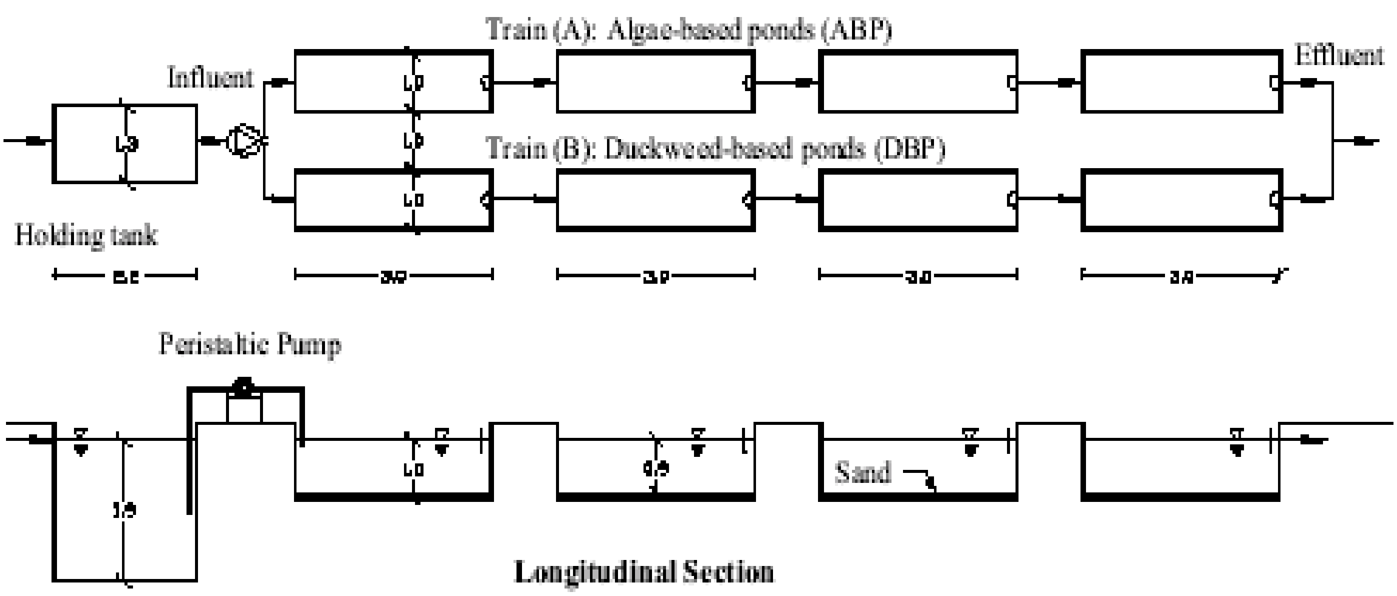

Figure 1. A schematic flow diagram of the pilot plant at BZU campus (dimensions in meter)

Detailed data on the design of the treatment units of RWWTP (two aerated lagoons and two facultative ponds) and technical plans for process upgrading can be found in the technical report on possible upgrading alternatives (Ramallah Municipality, 1993). RWWTP was designed in 1973 and put into operation in 1975 to serve a population of about 13000 inhabitants (50% sewer connected). The ultimate planning horizon for this project was 1993, at which time the maximum population to be served was estimated at 22000 persons (70% sewer connected). Figure 2 illustrates the schematic flow diagram of RWWTP after an upgrading phase in 2002, where the old non-functioning preliminary treatment units were replaced by new screening and aerated grit chamber units (Figure 3a and 3b). The two operated, aerated lagoons were also provided with new surface aerators and the two facultative ponds were de-sludged and lined. Due to non-technical reasons, a chlorinating room was planned, but never equipped or put into operation. It was supposed to be used to treat effluents for agricultural purposes, but this has not been implemented due to both technical and non-technical issues.

Although the treatment efficiency of the aerated ponds was investigated by Awadallah (2002), he made no analysis of the design parameters, operation or maintenance of the treatment schemes. After the upgrading phase of the aerated lagoon system in 2003, the nature and scale of a number of negative impacts resulting from the changes were clearly evident. Due to the installation of aerated grit chambers, severe odor emissions became noticeable and were exacerbated by septage disposal at the inlet head works. Due to weak financial resources by the municipality, no attempt is being made to reduce or abate the odor emissions at the site.

Water sampling and analytical methods

Water sampling in all sites was conducted on a weekly basis. Wastewater temperature and pH levels were measured onsite using alcohol thermometer and using an EC10 pH meter (Hach), respectively. Total suspended solids (TSS), Kjeldahl nitrogen (TKN), ammonium (NH_4-N), nitrite (NO_2-N), nitrate, total PO_4, ortho-and PO_4-P, were all analyzed in accordance with the Standard Methods (APHA, 1992). Raw samples analyzed for measuring total COD, were filtered using 4.4 mm folded papers of Schleicher and Schüll 5951/2, Germany.

Results and Discussion

Characteristics of domestic and municipal wastewater

The average values of all parameters analyzed for Palestinian raw sewage are presented in Table 1. According to wastewater quality classifications suggested by Metcalf and Eddy (1991), the data presented in the Table reflect high-strength domestic

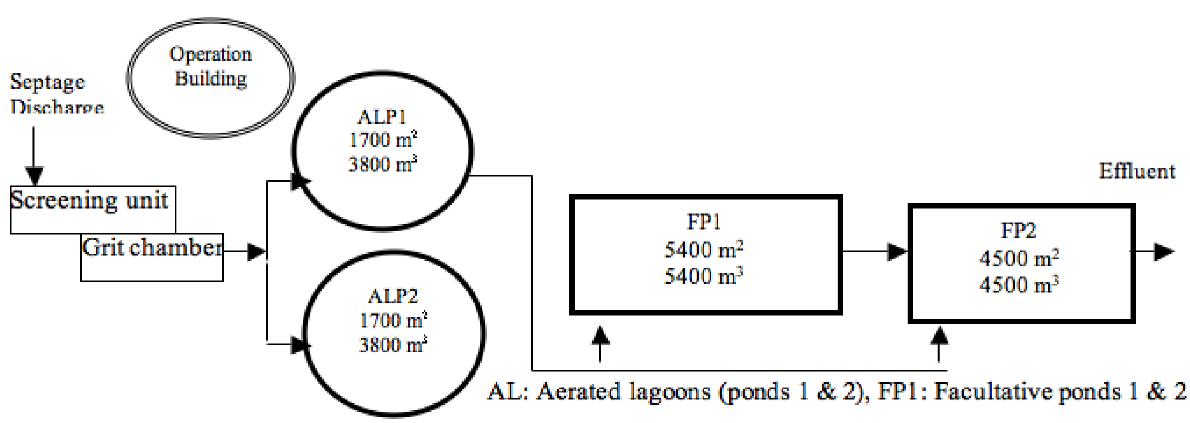

Figure 2. A schematic flow diagram of Ramallah wastewater treatment plant (RWWTP).

and municipal wastewaters in Palestine. The domestic wastewater from Talitha Kumi School revealed high nitrate levels due to the excessive use of nitrogen-rich detergents and disinfecting agents. Similarly, a high TSS content in the raw wastewater was noticed, which might be explained by the disposal of sand and grit swept from the schoolyards into the sewer networks.

Physical Design of Selected Treatment Facilities
Talitha Kumi WSP

The treatment facility is designed to serve 800 students, including 36 boarding school students and a 100-bed guesthouse. The maximum dry weather flow rate is estimated to reach about 45 m^3d^{-1}. With the measured average daily flow rate of 38 m^3d^{-1} the hydraulic retention time (HRT) in the anaerobic, facultative and polishing ponds was around 1.2, 4.4 and 1.2 days, respectively. The original design of the unit operations of the WSP was not based on real data of wastewater analysis but on assumed values. The actual design data obtained after commissioning the treatment facility revealed that the anaerobic, facultative and

Figure 3a. View of RWWTP before unit operations retrofits.

Figure 3b. View of RWWTP after treatment units retrofits in 2002.

polishing ponds were overloaded. This was clear after applying the design equations for WSP design as suggested by Mara (2001). Based on the results obtained from the monitoring phase, Table 2 lists the theoretical and operation design data for an adequately treated effluent.

As the polishing ponds would have no role in the overall treatment efficiency of WSP systems, the design of these units was not re-checked. From Table 2, it is obvious that the WSP would not properly function as intended.

Parameter	**Domestic sewage (Talitha Kumi Shool)**[b]	**Domestic sewage (Birzeit Campus)**[c]	**Municipal sewage (Ramallah city)**[d]
BOD_5	467 (261)	167 (3.0)	872 (351)
T_{water} (^oC), annual	17.7 (4.8)	19.0 (3.0)	19.3 (6.6)
pH (-)	7.7 (0.33)	7.7 (0.2)	7.45 (0.39)
COD	657 (267)	302 (56)	2180 (663)
Total-P	24.8 (7.3)	4.3 (0.3)	12.8 (2.2)
PO_4-P	(-)	(-)	12.4 (3.8)
TSS	2282 (1914)	230 (66)	729 (127)
NH_4-N	56 (16.2)	60 (6.0)	58 (8.5)
NO_3-N	17.9 (11.3)	0.2 (0.2)	0.49 (0.48)
Total coliform (CFU.100 ml^{-1})	$15x10^5$	(-)	4.8×10^8
Fecal coliform (CFU.100 ml^{-1})	$2.4x10^5$	$2.24x10^4$	(-)

a All parameters are measured in duplicates and their units are in mgl-1 otherwise stated, data are means (standard errors), b n = 17, c n = 8, d n = 10, (-) no data available, CFU = Colony forming unit

Table 1. Characterization of Palestinian raw domestic and municipal sewage a

Design Parameter	Unit	Anaerobic Pond (AnP)		Facultative Ponds (FP)	
		Calculated	Effective	Calculated	Effective
Dry weather flow rate	$m^3.d^{-1}$	38			
Surface area (A)	m^2	22.5		157.5	
Water depth (WD)	m	2		1.1	
Hydraulic retention time (HRT)	d	2	1.2	11	4.5
Volumetric organic loading rate	g BOD.$(m^3.d)^{-1}$	186	307		
Surface organic loading rate	kg BOD.$(ha.d)^{-1}$			167	540

Table 2. Calculated and operation design data of Talitha Kumi WSP

The outcome is clear: cost savings on the design would never pay off under real conditions and under what is established in the national standards. Shelef and Azov (2000) reported that recirculation of facultative ponds effluent followed by a 2-stage rock filter improved the overall performance of WSP and reduced algal biomass in the effluent. Theodory and Al-Sa`ed (2002) suggested an upgrading scheme for the WSP, where multilayer fixed film materials (sand and gravel) in some facultative ponds should be installed to create additional surface area without extra civil works or further financial investments. Recently, Shipin *et al.,* (2005) reported feasible total nitrogen (TN) removal in integrated natural treatment systems (WSP-Trickling filters and WSP-Constructed wetlands), where low levels of TN (10 mg/l) at loading rates ranging from 5 to 80 TN g(m^3/day)$^{-1}$ could be reliably achieved.

Algae- and Duckweed-Based Ponds

The treatment train, as depicted in Figure 1, revealed that the pollution load reaching the main biological units has actually experienced partial reductions. These reductions were encountered due to partial aeration in the equalization basin of BZU central treatment plant and to a prolonged hydraulic retention time in the holding tanks preceding the septic tank. This is reflected by the unbalanced C:N ratios (less than 3) in the facultative ponds, where no further improvement in the nitrogen removal rates in both ABP and DBP series (ABP4 and DBP4) was achievable. Also, it is not clear if the autotrophic denitrifiers are behind the nitrate reduction in the DBP series (DBP2 to DBP4), as the required C:N ratio for heterotrophic denitrifiers was below 3. No attempts were made to clarify this hypothesis. The design of the ABP and DBP was made to serve about 5 inhabitants. The design parameters for the ABP and DBP are summarized in Table 3.

Ramallah WWTP

In addition to the untreated and uncontrolled industrial discharge, RWWTP also receives about 100 m^3 of domestic and industrial septage daily. The wastewater characteristics of Ramallah city can be classified as of high strength sewage, due to high COD and BOD content. The main technical design data are listed in Table 4. The ratio between COD:BOD (3.0-2.6)

Design parameter	Unit	ABP1	DBP1	ABP2	DBP2	ABP3	DBP3	ABP4	DBP4
Water temperature	°C	20.8	19.7	21.7	20.5	23.6	22.7	22.9	22.7
pH	(-)	8.3	7.8	8.5	7.9	8.6	8.0	8.8	8.1
Specific surface area	m^2.capita^{-1}	2.3	2.4	3.7	4.5	6.1	6.9	7.4	7.0
BOD Surface loading rate	g BOD.(m^2.d)$^{-1}$	26.1	25.3	16.3	13.4	9.8	8.7	8.1	8.1
NH_4-N Surface loading rate	g NH_4-N.(m^2.d)$^{-1}$	8.0	8.9	6.3	7.1	3.7	5.7	2.6	4.5
C:N ratio	(-)	3.3	2.9	2.6	1.9	2.6	1.5	3.2	1.8
Nitrification rate	mg NH_4-N.(m^2.d)$^{-1}$	343	284	459	303	549	366	500	400
Nitrification efficiency	(%)	4.3	3.2	7.3	4.3	14.7	6.5	19.4	8.9
Denitrification rate	mg NO_3-N.(m^2.d)$^{-1}$	352	302	432	312	513	348	446	364
Denitrification efficiency	(%)	4.4	3.4	6.9	4.4	13.8	6.2	17.3	8.1

Table 3. Design parameters for pilot scale ABP and DBP systems at Birzeit University

is also very high, reflecting a high presence of industrial discharges. The study made by Ramallah Municipality (1993) revealed that the oxidation ponds were already overloaded. The overall removal efficiency was only about 57.7% in BOD pollution load. The aerated ponds removed about 43.3% of the BOD load, whereas the facultative ponds removed only 26.2% of the load. New attempts made by the municipality to upgrade the treatment system by installing new surface aerators and preliminary treatment units (coarse screen and aerated grit chamber) failed to improve the overall treatment capacity of the aerated ponds. This was the result of misconceived technical designs and consideration of non-technical issues (Al-Sa`ed, *et al.,* 2004). According to the author, job creation as a major justification behind upgrading the current RWWTP is insignificant when compared to the financial investment involved in upgrading the public sewer networks through new connections to Ramallah suburbs, such as the Atirah or Beitunia communities.

The industrial wastewater, produced daily, is discharged without control or pretreatment causing several operational problems within the public sewer networks, as well as negative impacts on the biological processes in RWWTP. It is recommended that pretreatment units should be installed at heavy industrial pollution sites in order to reduce the organic and inorganic pollution loads from industrial discharges into public sewer networks. A recent survey on heavy polluters´ daily water consumption made by the author (2003) revealed that both stone cutting and car washing consumed about 1000 m^3, food industry consumed 750 m^3, and the pharmaceutical, soap and detergents industries consumed more than 1000 m^3. Development of an industrial registry, the application of cleaner production, resource recovery, and water recycling are suggested options to control and minimize the industrial pollution loads.

Efficacy of Treatment Processes

Talitha Kumi WSP

During the monitoring period, the anaerobic pond with a short hydraulic retention time of 1.2 days was able to achieve a reduction of 38% and 45% in both total BOD and filtered BOD, respectively. A removal rate of 41% was also recorded for both total and filtered COD. A positive trend in organic matter removal was noticed during the summer period. This is depicted in Figure 4, where during the start-up phase 1 and 2 (summer season) better COD effluent values were achieved compared to the winter period (phase 3). Our results are in compliance with those findings reported by Yagoubi *et al.,* (2000) on the waste stabilization pond system of Boujaâd, a town in Morocco, which

Design Parameter	Unit	Aerated Ponds (2 AeP)		Polishing Ponds (2 PP)	
		1973	2002	1973	2002
Dry weather flow rate	$m^3.d^{-1}$	390	2654	390	2654
Surface area (A), total	m^2	3400		11880	
Water depth (WD)	m	2.24		1.2	
Hydraulic retention time (HRT)	d	19.5	2.9	30.5	4.5
Organic surface loading rate	kg BOD.(ha.d)$^{-1}$	210	680	150	235

Table 4. Technical design data of RWWTP (start up 1973 and upgrading phase 2002)

experienced similar weather and organic loading rates.

In the same range, removal rates of nutrients were noticed. For ammonium, nitrate and total phosphate, reduction rate of 42%, 46% and 9% were achieved, respectively, whereas only 39% of the TSS was achieved in the anaerobic pond. The effluent quality of the facultative and maturation ponds was very poor. There was an increase in total BOD, total COD and filtered COD concentrations in the effluent. The removal rate for phosphorus and ammonium were 30% and 12%, respectively. It was noticed that there was a slight increase in the nitrate concentration. Finally, an increase in the TSS concentration was also noticed. The obtained results from this research study showed that the performance of the anaerobic, facultative and maturation ponds were not satisfactory. The reasons behind the unsatisfactory results can be summarized as follows:

- All the ponds were connected in series with a very short hydraulic retention time (1.6 days per pond).
- The ponds arrangement failed to absorb at the maximum allowable surface organic loading rate. According to De Oliveira and Mara (1996), each pond in a series of facultative ponds should be able to undertake the maximum allowable BOD surface loading.
- Ponds were anaerobic during the entire investigation, where algal biomass was also washed out causing an increase of total suspended solids in the effluent.

Average surface BOD loads applied in waste stabilization ponds in France and Germany show figures in the range of 100 kg (ha.d)$^{-1}$ (Mara 2001). Again, it can be stated that the facultative ponds of the Talitha Kumi WSP were also operated well beyond their design loads, as well as above their actual operation loads (Table 2).

Holes were bored in the baffle in the second pond to increase flow velocity and to utilize this pond as an anaerobic pond. A total volume for the anaerobic pond should be around 78 m^3 instead of 45 m^3. This will result in a reasonable organic loading rate of about 180 g(m^3.d)$^{-1}$ at 14 ºC. The newly hydraulic retention time in both ponds is about 2 days. The installation of additional surface area in the first 5 facultative ponds will provide a total liquid volume of about 113 m^3. By a selected average surface organic loading rate of 15 g(m^2.d)$^{-1}$ and a liquid waste temperature of about 14 ºC, an additional surface area of almost 350 m^2 must be provided. Without additional civil works and large investment costs, this can be achieved via the installation of plastic boxes filled with coarse and medium size gravels and stones (4 m^3). The specific surface area of the fixed bed material is between 80 and 100 m^2/m^3. This will make about 6-8 boxes, which can be distributed within the first two

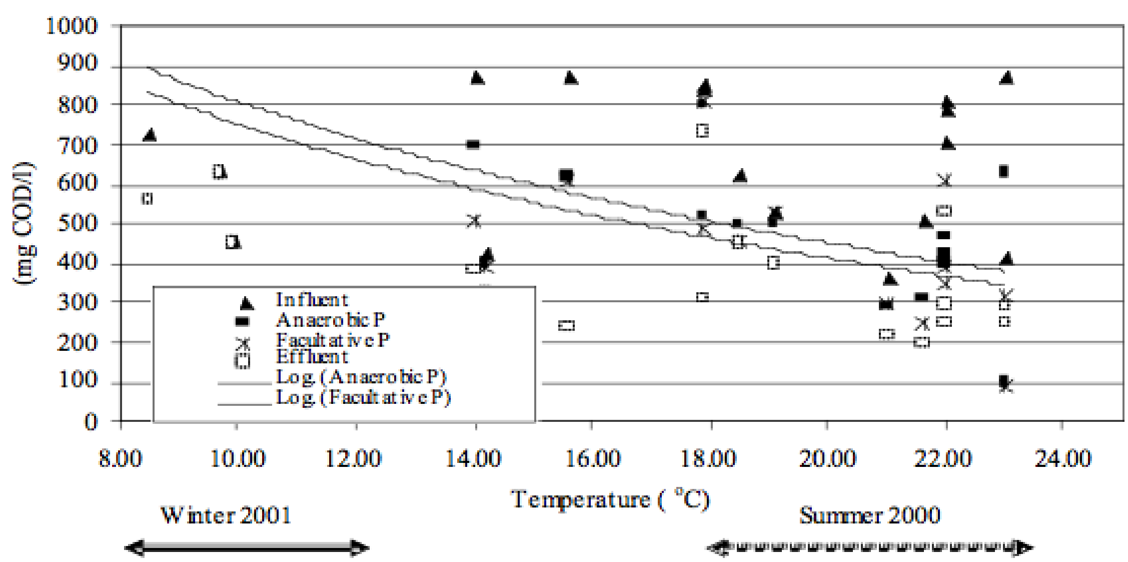

Figure 4. Efficiency of COD removal during various study periods (Phases 1, 2 and 3)

facultative ponds. The total hydraulic retention time in these ponds will be about 3 days. Because maturation ponds and reedbeds require large land areas to upgrade facultative pond effluents, Johnson and Mara (2005) installed aerated rock filters *post* to facultative ponds and achieved effluent quality (BOD and TKN < 5 mg/l). Initial results of ongoing research at our Institute on using rock biofilters *within* facultative ponds delivered positive BOD and TKN removal in a pilot-scale WSP system located at Birzeit University.

Ramallah Aerated Ponds (RWWTP)

Investigations made by Awadallah (2002) on the operational parameters of RWWTP revealed that the volumetric organic loading rate in the aerobic ponds was 470 g $BOD_5(m^3.d)^{-1}$ and the average hydraulic retention time for each one was 2-3 days. He designated the function of the aerobic ponds as if they were anaerobic lagoons, which is actually justified: Mara (2001) suggested a range for the design of anaerobic ponds between 100-400 g $BOD(m^3.d)^{-1}$ to avoid odor problems. As the ponds system is organically overloaded, the removal mechanisms proceed through settling and subsequent anaerobic mineralization. The COD removal efficiency was about 33% while the overall removal did not exceed 45% of the initial COD pollution load. The uncontrolled aeration capacity of newly installed aerators caused biosolids floatation on ponds surface and embankments, which might reduce the active bacterial fraction in the aerated lagoons. Aerated lagoons characterized by low biomass concentration (see, for example, Surampalli *et al*. 1999) indicated that temperature change was one of the critical factors that affected the performance of such treatment systems. The facultative ponds were also overloaded, as indicated by low dissolved oxygen (0.6 mgl^{-1}) within the top water column, by weak algal photosynthesis and by high turbidity within the water body of the ponds. Actually, the effective water volume is largely decreased due to the high depth of the sludge layer (65 cm). The measured hydraulic retention time ranged between 1.5 and 2.5 days. Nameche *et al.,* (2000) reported that aerated and facultative lagoons designed at an average volumetric loading rate of 34 and 9 g $BOD(m^3.d)^{-1}$, respectively, produced an effluent that complied with the 25 mg $BODl^{-1}$ maximum set in European Council Regulation (EEC) 91/271. Abis and Mara (2005) reported similar results on the impacts of BOD loading rate with regards to facultative ponds performance during winter season. An average organic loading rate of 8 g $BOD(m^3.d)^{-1}$ was recommended for temperate UK climates to achieve an effluent quality of less than 25 mg $BODl^{-1}$.

In 2002, Ramallah Municipality received a donation of 300,000 EURO for upgrading the overloaded aerated four-stage pond system that was originally designed to serve 25,000 PE. Through the years, the organic load increased up to around 38,500 PE. After a complete sludge removal and an installation of 2 new aerators into aerated lagoons, slight positive effects on the achievable degradation efficiency degrees had been observed. Ongoing pilot scale research studies will provide evidence on the effectiveness of using local natural (rock filter) and low-cost synthetic material (waste plastic) as biofilters to improve the performance of WSP at Birzeit University. The results will be disseminated in large scale studies at RWWTP. Review of published works (Saidam *et al.,* 1995; Shelef and Azov, 2000; Johnson and Mara, 2005; Wang *et al.,* 2005) on using constructed wetlands, rock filters, activated sludge systems and aerated rock filters, delivered technical evidence on sustainability of such upgrading approaches in overloaded WSP and aerated lagoons.

Aerobic lagoons normally contain dissolved oxygen throughout the water depth and act essentially as carbon conversion systems. Aerobic heterotrophic bacteria degrade influent waste organic matter and the resulting carbon dioxide (or bicarbonate) and algal cells use nutrients to photosynthesize. Oxygen released by algae in this process is the major source of oxygen required to satisfy the demand in the aerobic bacterial biodegradation process. The combined and mutually beneficial action of algae and bacteria in this process is termed algal-bacterial symbiosis. There is no net loss of influent carbon in the system, just the transformation of waste organic matter into living cells, mainly algae and bacteria. About 80 to 95% of the soluble BOD could be removed in this system (US EPA, 1992; Mara, 2001).

Gutzeit *et al.,* (2002) observed that algae-bacterial flocs in a lab-scale reactor might be enhanced via mixing and return sludge flow, where removal efficiencies of 93%, 46% and 25% for COD, total nitrogen and total phosphorus, respectively. This innovative technology can be applied as an upgrading option for RWWTP, provided that a desludging process of biosolids from both facultative ponds is practiced. Also, a return sludge pump and mixing devices should be installed to secure healthy flocs of algal-heterotrophic bacterial biomass. However, the very high algal concentration in the unfiltered effluent could result in a very high BOD concentration. Therefore, to produce a good effluent, the algae need to be removed.

Algae- and Duckweed Based Ponds

The aesthetic quality of pond effluents may be lower than that produced by other secondary processes, because algae contribute with high concentrations of both suspended solids and BOD. However, natural oxidation ponds can be as effective in nutrient removal as nitrogen and phosphorus, if they are preceded by well-designed pre-treatment units (Yagoubi *et al.,* 2000; Shilton and Mara, 2005). Based on the results obtained from our research study, a conventional one-compartment septic tank would achieve reasonable nitrogen removal efficiencies in algae- and duckweed-based ponds systems. As illustrated in Figure 5a, the efficiency of the nitrification process in ABPs and DBPs has increased, with a lower tendency in surface organic loading rates. This might be explained by the nature of nitrifiers as low growing autotrophic bacteria that prefer low BOD surface loading rates.

Compared with that for DBPs, the nitrification efficiency was higher in ABPs (ABP3 and ABP4) by almost 10%. At a similar surface organic loading rate in both systems, increasing the surface area for the nitrifiers in DBPs had no positive impact on the overall ammonium oxidation. This can be attributed to less nitrifier fractions prevailing within the DBPs compared to ABPs, where nitrifiers might be attached to the free-swimming algal biomass. In ABPs, nitrification and denitrification rates increased until pond number 3 and then decreased, with higher nitrogen removal efficiencies measured in ABPs compared with DBPs (Figure 5b). The higher denitrification rates in ABPs can be explained by higher average in C:N ratios, which is necessary for the heterotrophic denitrifiers.

Though the denitrification efficiency in DBPs was below 10%, it was not clear what type of microorganisms are responsible for nitrate reduction under C:N ratios below 2. The measured denitrification rates in ABPs and DBPs ranged between 352-513

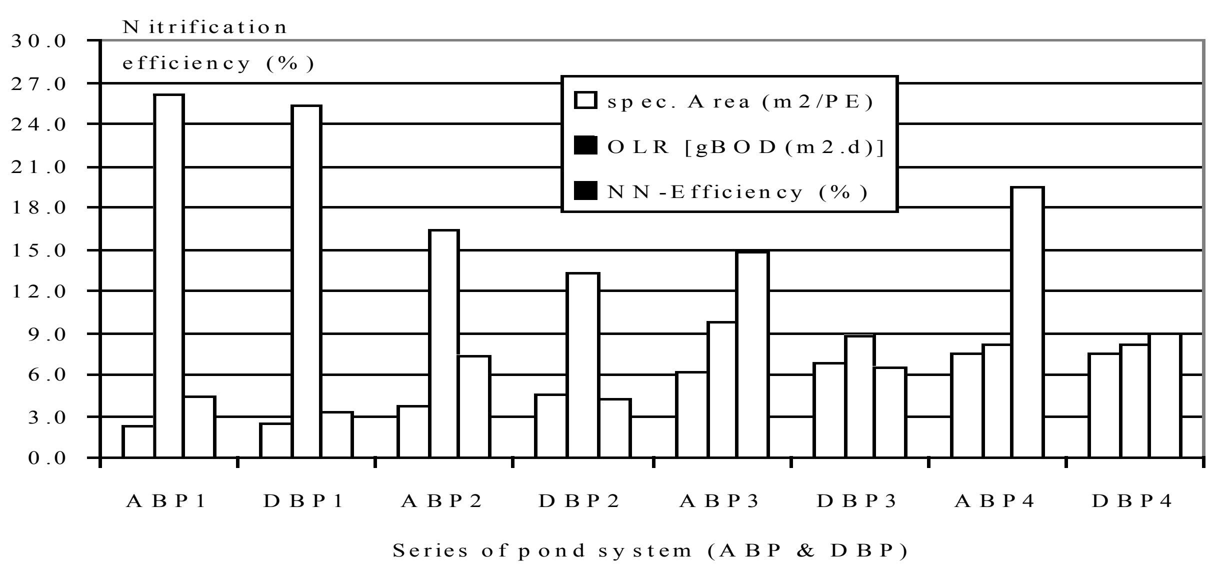

Figure 5a. Effect of organic surface loading on nitrification efficiency in ABPs & DBPs

mg N(m^2.d)$^{-1}$ and 302-364 mg N(m^2.d)$^{-1}$ respectively. Similar values (470 mg N(m^2.d)$^{-1}$ were reported by Christensen *et al.,* (1996) for denitrifiers' activity in river sediments. Contradictory results were recently published by Zimmo *et al.,* (2005) as to the impacts of organic loading rates on nitrogen removal processes in ABPs and DBPs. Thus, the obtained nitrogen removal efficiencies in ABPs and DBPs were not easy to compare with published literature data.

Rural and old urban sanitation facilities in Palestine are inefficient due to high strength wastewaters, inadequate technical design and lack of proper maintenance and monitoring. As shown in Table 3, nitrogen removal can be achieved in waste stabilization ponds preceded by enhanced primary treatment. This, however, has high specific demands in terms of area (5-7 m^{2}capita^{-1}), which is against these technologies being low-cost treatment options.

Conclusions and Recommendations

Old sanitation projects often failed to achieve significant impacts on public health and aquatic environment, and most of these systems are overloaded and broken down. Due to political constraints, Palestinian communities have rarely had the capacity to manage properly their own infrastructure; instead, these facilities have been managed by inexperienced and un-motivated operational staff and inefficient management at the top level; all this has exacerbated the inadequacy of urban and rural sanitation services. An analysis of the design and operational data of two natural and one aerated lagoon systems in Palestine reaches the following conclusions about the sustainability of such treatment systems for domestic and municipal wastewater treatment:

- The overall performance of the current waste stabilization and aerated lagoon systems is very much affected by the design and operation of such treatment systems. In WSP and AL, the treatment capacity has been exceeded and overloaded due to inadequate design and lack of maintenance and operation programs.
- The selected WSP systems under study were designed using the organic load removal criteria. Effluent quality neither complies with local regulations for discharge into receiving water bodies nor could be used for irrigation purposes. No routine or periodical monitoring of influent and effluent water quality was observed.
- It is necessary to maintain the pre-treatment unit in RWWTP and to install a biofilter to abate odor emissions and to have a periodical wastewater quality-monitoring program and also a periodical de-sludge routine and embankment maintenance.

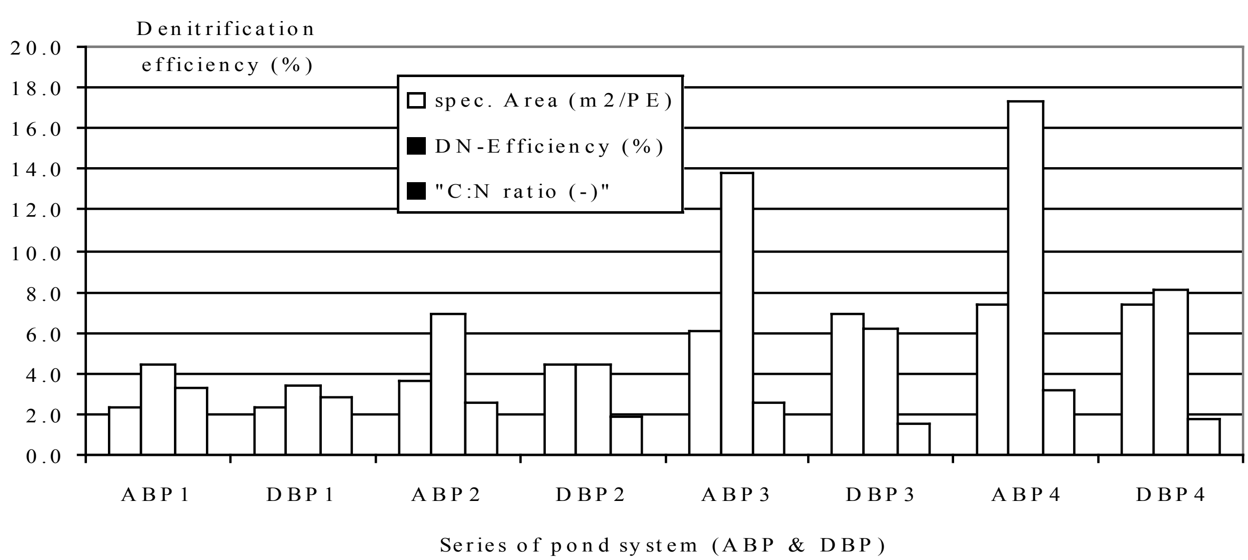

Figure 5b. C:N ratio and specific surface area effect on denitrification in ABPs & DBPs

- To upgrade the existing pond systems and to comply with national regulations for irrigation (nitrogen removal, faecal coliforms and helminth eggs) it is necessary to construct either additional ponds or modify the current ponds into an integrated rock-filter pond system or constructed wetland based WSP technology. Future research is needed to study the effects that influence the hydraulic behavior in such integrated WSP-fixed film biofilters.
- The financial and environmental sustainability of waste stabilization systems and aerated lagoons can only be achieved through technically feasible design, adequate operation and effective utilization of limited available financial resources. Innovative upgrading concepts and dissemination of reliable research findings on a large scale can also help natural treatment systems overcome their dependency on land area.
- Sustainability of the existing pond systems is threatened by numerous institutional, technical, attitudinal and political factors, where the availability of financial aid from donor agencies alone is no guarantee of success. Sustainable sanitation facilities require systematically adequate planning, functioning design, and environmentally responsible management in order to help communities achieve sustainable development.

Acknowledgments

Results are partially derived from WASCAPAL (*Wa*ter *S*ector *Ca*pacity Building in *Pal*estine) project supported by the Dutch Government through SAIL (Dutch Agency for International Cooperation), project reference SAIL-IOP/SPP. Graduate scholarships were given to Nuha Ghneim and Johny Theodory within the framework of this research project.

About the Author

Rashed Al-Sa´ed (Associate Professor in Environmental Engineering and Science) is involved in environmental education and applied research at the Water Studies Institute (WSI) of Birzeit University in the West Bank, Palestine. Over the past years he worked as a consulting engineer in Germany, where he planned and built up small and urban wastewater treatment plants. His present research fields at the WSI concentrate on nutrient recovery and removal, waste management and pollution control, onsite sanitation, and environmental education and training. Dr. Al-Sa´ed is working as advisor for several Palestinian water and environmental institutions and provides technical advice for both local NGOs and international agencies.

References

Abis, K.L., and D.D. Mara. (2005) "Primary facultative ponds in the UK: the effect of operational parameters on performance and algal populations." *Water Science and Technology* 51, No. 12: pp. 61-67.

Al-Sa`ed, R., M., Issa, and Helwah, H. (2004) "Development of Sustainable Rehabilitation Measures for Ramallah Wastewater Treatment Plant." B.Sc. Graduation Project, unpublished, Faculty of Civil Engineering, Birzeit University, Birzeit, West Bank, Palestine.

APHA (American Public Health Association). (1992) *Standard Methods for the Examination of Water and Wastewater*, 18th edition, APHA, Washington D.C., USA.

Awadallah, W. (2002) "Municipal waste stabilization ponds performance and pollutants fluxes in the West Bank/ Palestine." *PHG Water and Environment J*. 7: pp. 22-32.

Carter, R., S. Tyrrel, and P. Howsam. (1999) "Impact and sustainability of community water supply and sanitation programs in developing countries." *J. Char. Inst. Wat. & Env. Manag.*, 13: pp. 292-296.

Christensen, S., Simkins, S., Tiedje, M. (1990) "Spatial variations in denitrification: dependency on the soil environment." *Soil Sci. Soc. Am. J*. 54: pp. 1608-1613.

De Oliveira, R., and D.D. Mara. (1996) "The performance of a pilot-scale series of ten ponds treating municipal sewage in Brazil." *Water Science and Technology* 33, No. 7: pp. 57-61.

Ghneim, N. (2003) "Quantification of Nitrification and Denitrification Rates in Algae Based and Duckweed Based Waste Stabilization Ponds." M.Sc. Thesis, Faculty of Graduate Studies, Birzeit University, West Bank, Palestine.

Gutzeit, G., U. Neis, D. Lorch, W. Weber, and M. Engels. (2002) "Wastewater treatment with symbiotic algae-bacteria-biomass: an innovative technology for arid and tropical regions." *Proceedings of the IWA Regional Symposium on Water Recycling in Mediterranean Region*, Iraklion, Greece.

Hoffmann, B., S.B. Nielsen, M. Elle, S. Gabriel, A.M. Eilersen, M. Henze, and P.S. Mikkelsen. (2000) "Assessing the sustainability of small wastewater treatment systems. A context-oriented planning approach." *Env. Impact Ass. Rev.*, 20: 347-357.

Johnson, M., and D.D. Mara. (2005) "Aerated rock filters for enhanced nitrogen and faecal coliform removal from facultative waste stabilization pond effluents". *Water Science and Technology* 51, No. 12: pp. 99-102.

Mahmoud, N., M. Amarneh, R. Al-Sa'ed, G. Zeemana, H. Gijzen, and G. Lettinga. (2003) "Sewage characterisation as a tool for the application of anaerobic treatment in Palestine." *Environmental Pollution* 126, No. 1: pp. 115-122.

Mara, D.D. (2001) "Appropriate wastewater collection, treatment, and reuse in developing countries." *Municipal Engineer* 145, No. 4: pp. 299-303.

Metcalf and Eddy, Inc. (1991) *Wastewater Engineering: Treatment, Disposal and Reuse*, 3rd Ed., G. Tchobanoglous and F.L. Burton, eds., McGraw-Hill, Toronto, USA.

Nameche, T., O. Dufayt, H. El Ouarghi, and J.L. Vasel. (2000) "Performance of a system combining aerated lagoons and waste stabilization ponds in a temperate climate". *Water Science and Technology* 42, No. 10/11: pp. 23-34.

Picot, B., T. Andrianarison, J. Gosselin, and F. Brissaud. (2005) "Twenty years of monitoring at Me`ze stabilisation ponds. I – Removal of organic matter and nutrients." *Water Science and Technology* 51, 12: pp. 23–31.

Ramallah Municipality. (1993) *Ramallah Wastewater Treatment Plant: Feasibility and Preliminary Upgrading Design*. ECPD Center, Birzeit University, West Bank, Palestine.

Saidam, M., S. Ramadan, and D. Butler. (1995) "Upgrading waste stabilization pond effluents by rock filters." *Water Science and Technology* 31, No. 12: pp. 369–378.

Shelef, G., and A. Kanarek. (1995) "Stabilization ponds with recirculation." *Water Science and Technology* 31, No. 12: pp. 389–398.

Shelef, G., and Y. Azov. (2000) "Meeting stringent environmental and reuse requirements with an integrated pond system for the twenty-first century". *Water Science and Technology* 42, No. 10/11: pp. 299–305.

Shilton, A., and D. Mara. (2005) "Pond process design-a historical review." In *Pond Treatment Technology*, A. Shilton (Ed.): IWA Publishing, London, UK, pp. 145-167.

Shipin, O., T. Koottatep, N.T.T. Khanh, and C. Polprasert. (2005) "Integrated natural treatment systems for developing communities: low-tech N-removal through the fluctuating microbial pathways." *Water Science and Technology* 51, No. 12: pp. 299-306.

Surampalli, R.Y., S. Ninaroon, and S.K. Banerji. (1999) "Performance evaluation of aerated lagoon in summer and winter conditions." *J. Cold Regions*

Engineering 13, No. 3: pp. 153-163.

Theodory, J., and R. Al-Sa`ed. (2002) "Performance evaluation and monitoring of an appropriate low-cost wastewater treatment technology for small Palestinian communities." *Proceedings of the IWA Regional Symposium on Water Recycling in Mediterranean Region,* Iraklion, Greece.

US Environmental Protection Agency. (1992) *Wastewater Treatment/ Disposal for Small Communities*, US EPA 625/R-92-005, Washington DC, USA.

Wang, X., X. Bai, J. Qiu and B. Wang. (2005) "Municipal wastewater treatment with pond–constructed wetland system." *Water Science and Technology* 51, No. 12: pp. 325–329.

Yagoubi, M., L. Echihabi, A. Foutlane, L. Bourchich, J. Jellal, C. Wittland, and M. El Yachioui. (2000) "The performance of the waste stabilization pond system at Boujaâd, Morocco." *Water Science and Technology* 42, No. 10/11: pp. 9-16.

Zimmo, O., R. Al-Sa`ed, P. van der Steen, and H. Gijzen. (2002) "Process performance assessment of algae-based and duckweed-based wastewater treatment systems." *Water Science and Technology* 45, No. 1: pp. 91-101.

Zimmo, O., P. van der Steen, and H. Gijzen. (2005) "Effect of organic surface load on process performance of pilot-scale algae and duckweed-based waste stabilization ponds." *Journal of Environmental Engineering* 131, No. 4: pp. 587-594.