water

MDPI

Article

Modified Septic Tank: Innovative Onsite Wastewater Treatment System

Bassim E. Abbassi [1,*], Raihan Abuharb [2], Bashaar Ammary [2], Naser Almanaseer [2] and Christopher Kinsley [3]

[1] School of Engineering, University of Guelph, Guelph, ON N1G2W1, Canada
[2] Department of Water Resources and Environmental Management, Al-Balqa Applied University, 19117 Al-Salt, Jordan; raihan_abuharb@yahoo.com (R.A.); bammary@bau.edu.jo (B.A.); almanaseer@bau.edu.jo (N.A.)
[3] Civil Engineering Department, University of Ottawa, Ottawa, ON K1N 6N5, Canada; ckinsley@uottawa.ca
* Correspondence: babbassi@uoguelph.ca

Received: 13 February 2018; Accepted: 26 April 2018; Published: 29 April 2018

check for updates

Abstract: This research documents two innovative designs of septic tanks used for onsite wastewater treatment. The designs were implemented and tested as part of a research project focused on innovative decentralized wastewater treatment solutions. The modified septic tanks were tested at different hydraulic loading rates for sufficient periods to effectively evaluate their performance. The two systems were designed with successive anaerobic and aerobic chambers and were differentiated between attached and suspended growth. The systems were operated at detention times of 4.3, 3.2, and 2.6 days. High removal of organic load was achieved under all loading criteria in both systems. Effluent BOD_5 concentration at lower and higher loading rates were found to be less than 15 and 25 mg/L, respectively, representing a removal rate of more than 95%. Nitrogen was also removed but at a lower rate. The highest TN removal was achieved (59%) in the attached growth system at the lowest loading rate. Although two logs of *E. coli* removal (99%) were achieved in all systems, *E. coli* numbers were high enough to necessitate further tertiary treatment. The modified septic tanks proved to be a cost-effective technology with low energy and O&M requirements.

Keywords: onsite wastewater treatment; decentralized wastewater; septic tank; aerobic; anaerobic; attached growth; suspended growth

1. Introduction

There is a growing need for the development of sustainable and cost-effective technologies to treat wastewater [1,2]. Within the context of adaptive water resources management, centralized wastewater treatment is an appropriate approach for large communities [3]. In small communities, however, centralized wastewater collection and treatment systems are not feasible because of the relatively high cost of capital investment and intensive operation and maintenance requirements [4–6]. Decentralized solutions in wastewater management are recognized as cost-effective alternatives to centralized systems, which could be effectively integrated into rural as well as urban settings. This can significantly support future water resources management plans [7–9]. Moreover, extension of wastewater management services to small communities is essential to address serious concerns in water scarcity, pollution, and public health. Accordingly, decentralized wastewater treatment has been recognized as an effective solution allowing the sanitation requirements to be met [10–12].

In Ontario, Canada, about 10% of the population uses onsite systems for wastewater sanitation, where most of these systems are conventional septic systems (i.e., septic tank and leaching bed) [13]. Similarly, 12% of the population in Australia relies on septic systems [14]. In the United States, around

60 million people are connected to onsite wastewater treatment systems with the majority use of conventional onsite systems [15]. In Germany, about 15% of the population use onsite wastewater treatment systems [16]. In Jordan, 32% of the population is not connected to a sewer system. Most of them rely on cesspits for wastewater disposal [9]. Hence, onsite wastewater systems are common and can be replicated to help serve smaller communities. Meuler et al. [16] described septic tanks as a poor pretreatment system and a source of groundwater pollution, where dissolved pollutants, nutrients and pathogens may remain in the effluent causing serious threat to human health and accelerated deterioration to the environment including air, water and soil. One study has even reported a significant increase in *Escherichia coli* (*E. coli*) concentration in the septic tank effluent [17].

It is evident that there is a need for more efficient and reliable decentralized wastewater treatment solutions. Modifications of septic tank design have been proposed in different studies in order to improve onsite wastewater system performance. For example, changing septic tank retention times and including packing materials have been suggested [6,18,19]. Other studies investigated the effects of baffles on the treatment process and the results showed that increased number of baffles resulted in enhanced treatment performance [6,20,21]. Generally, most septic tank modifications were suggested to enhance the performance of the septic system. However, if a septic tank is recognized as a stand-alone treatment unit, rational modification should be considered. This paper aims at evaluating the performance of two modified septic tanks (MSTs) designed as onsite systems for treating domestic wastewater. This project demonstrates a modern low-cost onsite wastewater treatment technology tested at varying hydraulic loading rates with both attached growth and suspended growth biological treatment.

2. Materials and Methods

This paper reflects actual experimental work ranging from developing the idea, to designing and constructing onsite systems, to testing and analyzing the performance of these systems. The two onsite treatment units were designed and constructed within the Competence Facility for Decentralized Wastewater Management—SMART Project in Jordan [22]. The two units were built using reinforced concrete with proper mechanical and electrical connections. Each unit has a total working volume of 5700 L and consists of four equally sized chambers connected in series; with the first three chambers operated under anaerobic conditions with a total volume of 4275 L. The fourth chamber consists of an aeration chamber and settling tank with working volumes of 950 and 475 L, respectively. Water depth in all chambers was 1.5 m. Air is supplied for 15 min intermittently (every other 15 min) to the aeration chamber via a plate diffuser using a 0.18 KW blower. Figure 1 shows the general layout of the MST system.

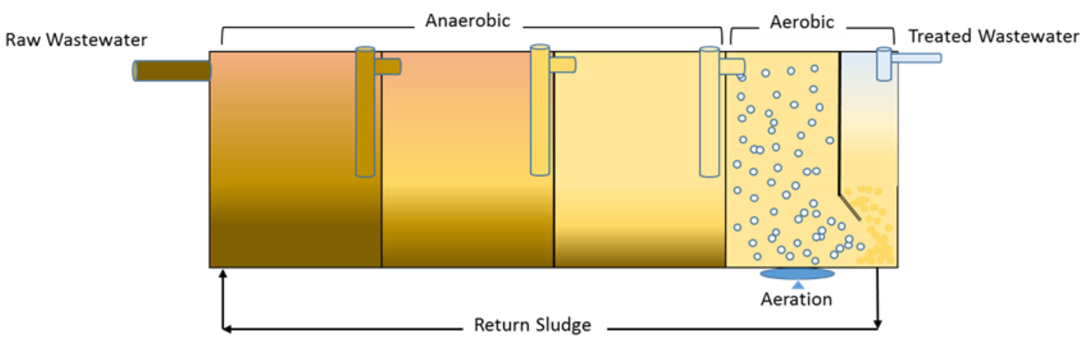

Figure 1. Schematic diagram of the modified septic tank (MST) system.

The MST is designed to allow gravity flow between the compartments. The treatment in one MST was designed as a suspended growth system (MST-S), while the other one was designed as an attached growth system (MST-A). In the MST-A system, all chambers (except the first one) were filled with fixed bed media (corrugated plastic media with a specific area of 100 m^2/m^3) filled to 2/3 of the tank working capacity. Both of these MSTs were operated in parallel, so that their performances can be compared.

The MST systems were initially designed to receive an average wastewater flow of 1.2 m^3/d. Raw wastewater was obtained from the forebay of a nearby centralized domestic wastewater treatment plant after bar screening and grit removal. The wastewater dosing was controlled by an electromagnetic flowmeter connected to programmable logic controller (PLC) SIEMENS-SIMATIC S7-200. Within the MST, the water flow pattern between the chambers resembles the plug flow pattern to minimize short circuiting. While oxygen is limited in the anaerobic chambers, oxygen concentration in the aeration chamber was set to remain above 2 mg/L during the aeration period to ensure that oxygen is not a limiting factor in the treatment process. The aerated chamber is equipped with an integrated settling tank, so that the mixed liquor suspended solids are settled and the supernatant (effluent) is flowing free of solid downstream to the irrigation tank. The configuration of aeration and settling tank was designed such that the settled sludge is returned continuously to the aeration tank. The plants were equipped with several by-passes, fittings, and valves, so that the mode of operation can be easily changed and adjusted.

Initially, the MST systems were operated with a hydraulic loading of 1.2 m^3/d (Phase 1). However, the systems were further investigated under higher loading rates of 1.6 and 2.0 m^3/d (Phases 2 and 3, respectively). At each loading rate, the investigation was carried out for a period of 26 weeks. Between any two loading phases MSTs were not sampled for a period of four weeks in order to allow the systems to develop a steady state condition. Table 1 shows the summary of the hydraulic loading rates and the detention times in the MST chambers for each investigation phase.

Table 1. Wastewater loading at different investigation phases.

Phase	Loading Rate (m^3/d)	Detention Time in Anaerobic Chambers (d)	Detention Time in the Aerobic Chamber (d)
1	1.2	3.56	0.79
2	1.6	2.67	0.59
3	2.0	2.14	0.47

Inflow and outflow of MST-S and MST-A were monitored weekly and evaluated for a number of parameters. A wastewater sample volume of 500 mL from each system was collected and analyzed for temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), and Oxidation Reduction Potential (ORP). A WTW multi-meter was used to measure ORP and DO, while a WTW ProfiLine-Cond 3110 (Xylem Analytics, Weilheim, Germany) probe was used to measure the EC, pH and temperature. Subsequently, 25 mL of wastewater samples were filtered (using a 0.45 µm membrane filter) for further analysis of chemical oxygen demand (COD), ammonia (NH_4^+), nitrate (NO_3^-), and orthophosphate (PO_4^{3-}) using LCK test kits and HACH spectrophotometer model 2800. Biochemical oxygen demand (BOD_5) was measured using OxiTop® manometric OC 100, following the German standard DIN 38 409 H52. Total suspended solid (TSS) concentration was analyzed according to the Standard Methods for Examination of Water and Wastewater [23]. Finally, *E. coli* was measured using the IDEXXTM Colilert-18 Quanti-tray method according to the manufacturer's specifications.

3. Results and Discussion

The analysis results of pH, EC, DO, ORP, turbidity, and TSS for the three phases are summarized in Table 2. Each value in this table represents an average of 26 weeks of investigation. Under all loading conditions, pH values were found to be in an acceptable range for wastewater effluent (pH values of 6–9) [24]. It was also observed that no significant changes in pH values during the treatment process were noted compared with raw wastewater pH values, indicating a good buffering capacity of the wastewater. Effluent EC values also showed no reduction during treatment but consistently remained below the Jordanian Standards No. JS893/2006, for reclaimed domestic wastewater; indicating acceptable salt content in the wastewater for reuse purposes (EC < 3000 µS/cm) [25].

Table 2 shows also the development and change of the ORP at the different phases. The higher negative ORP values of raw wastewater indicate clearly the anaerobic character of the influent water. Due to the aeration in the last chamber, ORP values in both systems were significantly increased indicating a well aerated effluent. However, a slightly higher ORP values in MST-A compared to MST-S indicates a higher treatment efficiency of MST-A [26]. Table 2 shows the temperature of wastewater over the entire phases of investigation. The average temperature of raw wastewater during the three phases (78 weeks) was 19.8 ± 3.8 °C. The location where the systems were installed and tested exhibits moderate climate with low inter-annual variability in temperature. Thus, temperature had minimal influence on the tested parameters.

The results in Table 2 also show that both systems were able to produce clear water based on low TSS concentrations and turbidity as opposed to the conventional septic tank, where high effluent solids represent the main cause for most dysfunctional septic systems [7]. The results show two trends of solid concentration in the effluent. TSS concentrations and turbidity were significantly lower in MST-A than in MST-S effluents, suggesting that the attached growth media plays a significant role in either filtering or trapping suspended solids. Lower TSS concentrations were observed as hydraulic loading increased for MST-A, but remained almost constant for MST-S. There was no clear correlation between turbidity and hydraulic loading, however.

One of the main objectives of this investigation was to evaluate the MST systems for their capacity to reduce the organic loading. Accordingly, the pilot plants were monitored for carbonaceous oxygen demand in the effluents. Figures 2 and 3 show the results of BOD_5 and COD concentrations for MST-A and MST-S under a hydraulic loading rate of 1.2 m^3/d over the entire investigation period. It is clearly observed that both systems were able to significantly reduce carbonaceous content of wastewater (BOD_5 and COD) to a secondary treatment level [27]. The wastewater effluent quality even meets the strict Jordanian Reuse Standards for Irrigation (JS893/2006) [25] of BOD_5 and COD concentrations of 30 and 100 mg/L, respectively.

Table 2. Results of physical wastewater parameters for all treatment systems and phases.

Phase	Parameter	Raw Wastewater	MST-A Effluent	MST-S Effluent
1	pH	7.9 ± 0.1	8.0 ± 0.1	8.1 ± 0.2
	EC (µS/cm)	1864 ± 516	1798 ± 588	1917 ± 542
	DO (mg/L)	0.1 ± 0.1	3.7 ± 0.6	2.1 ± 1.0
	ORP (mV)	−236 ± 27	−57 ± 73	149 ± 65
	TSS (mg/L)	314 ± 168	7 ± 4	18 ± 8
	Turbidity (NTU)	997 ± 225	9 ± 6	59 ± 10
	Temperature (°C)	19.9 ± 3.3	19.5 ± 3.9	19.4 ± 3.7
2	pH	7.5 ± 0.2	7.7 ± 0.2	7.5 ± 0.3
	EC (µS/cm)	2470 ± 399	2357 ± 578	2468 ± 389
	DO (mg/L)	1.0 ± 1.3	3.6 ± 1.9	3.3 ± 1.3
	ORP (mV)	−208 ± 49	−1 ± 108	−107 ± 98
	TSS (mg/L)	239 ± 107	13 ± 6	18 ± 10
	Turbidity (NTU)	317 ± 161	30 ± 26	43 ± 61
	Temperature (°C)	18.2 ± 2.8	17.8 ± 3.5	17.6 ± 3.2
3	pH	7.2 ± 0.2	7.7 ± 0.2	7.5 ± 0.2
	EC (µS/cm)	2016 ± 513	2125 ± 624	2011 ± 680
	DO (mg/L)	0.8 ± 0.3	3.2 ± 1.5	3.5 ± 2.9
	ORP (mV)	−239 ± 31	−39 ± 126	−120 ± 110
	TSS (mg/L)	267 ± 360	16 ± 4	19 ± 6
	Turbidity (NTU)	283 ± 76	22 ± 17	34 ± 24
	Temperature (°C)	21.4 ± 3.3	21.4 ± 3.5	21.3 ± 3.3

Moreover, Figures 2 and 3 show also that in spite of highly fluctuating quality of the influent wastewater, the effluent quality remained stable over the period of investigation. This shows the capacity of the MST systems to absorb the normal shock loading usually experienced in onsite systems [28]. It is also clearly seen that the MST-A produced a slightly better quality effluent than MST-S, which is attributed to the robustness of attached growth systems [29]. As opposed to the conclusion of Meuler et al. [16], who stated that only about 40% of the BOD_5 is removed in septic tanks, both of MST systems have gone much further and achieved removal rates of more than 95%.

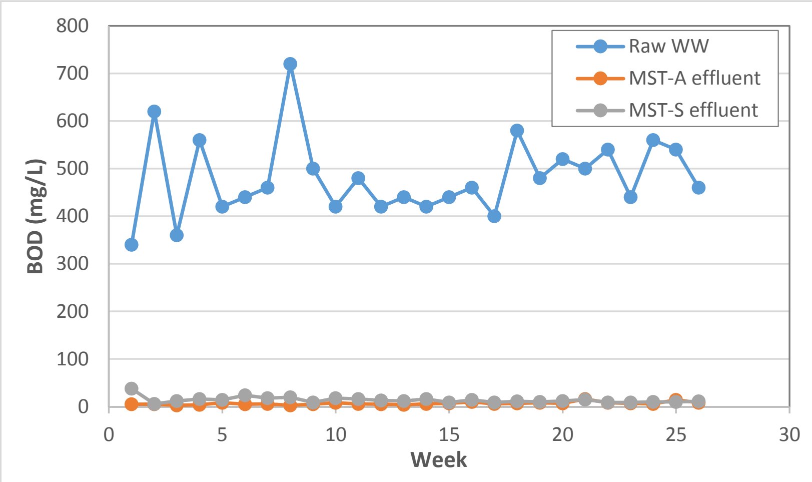

Figure 2. BOD_5 concentration with time in attached growth system (MST-A) and suspended growth system (MST-S) at hydraulic loading of 1.2 m^3/d.

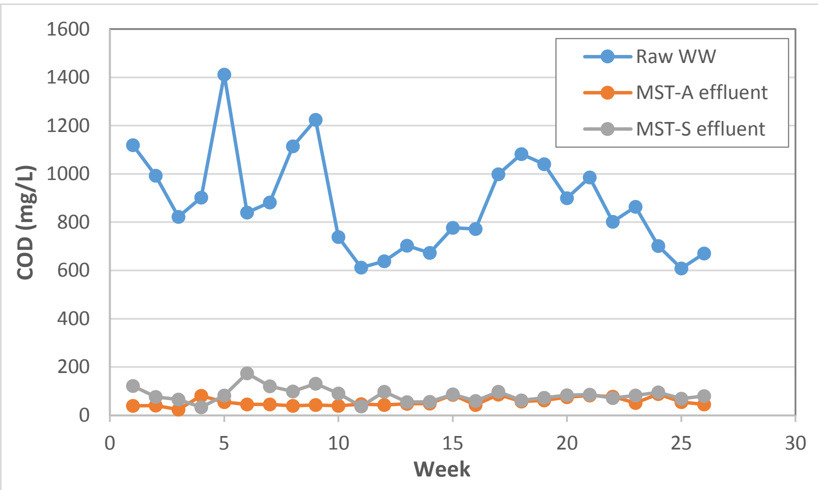

Figure 3. Chemical oxygen demand (COD) concentration with time in MST-A and MST-S at hydraulic loading of 1.2 m^3/d.

As a result of increased interest in nutrient concentrations in wastewater effluent, the monitoring included both nitrogen and phosphorous constituents. Nitrate is a very important parameter that indicates the efficiency of a treatment system to remove nitrogenous compounds from wastewater [30]. The results of nitrate (NO_3-N) concentration for both systems under a hydraulic loading of 1.2 m^3/d over the entire investigation period are shown in Figure 4. The very low nitrate concentration in the influent wastewater is expected in domestic wastewater as most of the nitrogen compounds are present as organic nitrogen or ammonia nitrogen [30]. The increase in the nitrate concentration in the effluents reflects the nitrification capacity of both systems. Nitrification in the attached growth system is, however, more stable than in the suspended growth system. This is attributed to the numerous nitrifying bacteria in the biofilm in the attached growth systems compared to those in the bioflocs of the suspended growth system [11]. Under a hydraulic loading of 1.2 m^3/d, the average effluent nitrate concentrations for MST-A and MST-S are 14.9 and 8.2 mg/L, respectively. Though these values seem to be relatively low, some nitrate-vulnerable areas requires certain measures to further decrease the nitrate concentration (i.e., denitrification). In many areas around the world, where water is scarce and wastewater is deemed to be a resource for irrigation, high nitrate concentrations can be beneficial for agriculture and reduce the dependence on chemical fertilizers [30].

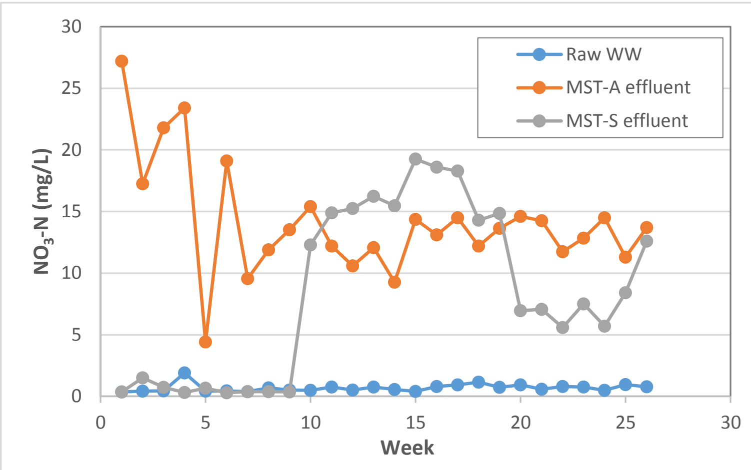

Figure 4. NO_3-N concentration with time in MST-A and MST-S at hydraulic loading of 1.2 m^3/d.

Total nitrogen (TN) concentrations were also monitored and the results for the two systems operated at hydraulic loading of 1.2 m^3/d are shown in Figure 5. The results clearly show that both systems were able to reduce the total nitrogen concentration with higher (better) performance for the MST-A. Nevertheless, if more TN reduction is required, measures to enhance denitrification should be considered. As previously mentioned, each MST is equipped with a return line connecting the aerobic chamber with the first anaerobic compartment. This line was not utilized in this investigation and should be used in future research work.

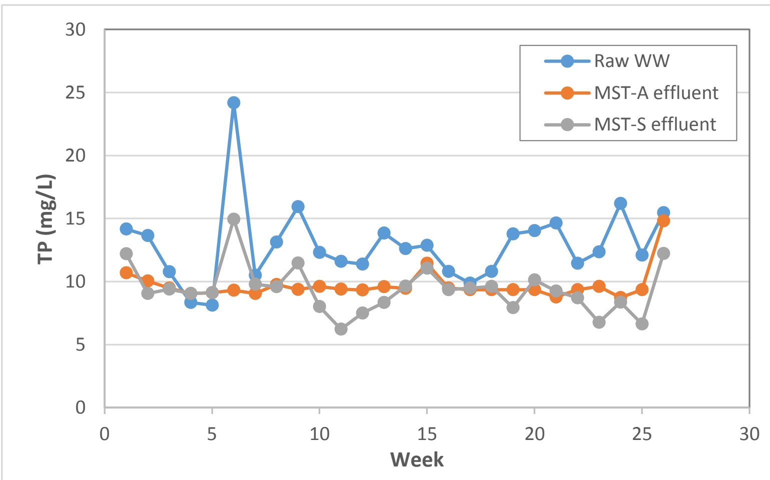

Figure 5. Total nitrogen (TN) concentration with time in MST-A and MST-S at hydraulic loading of 1.2 m^3/d.

Similarly, phosphorous concentration was monitored and the results of total phosphorous (TP) for both systems operated at hydraulic loading of 1.2 m^3/d are shown in Figure 6. The results show that there were small decreases in TP concentration in both systems. This can be seen by comparing the average TP concentration in raw wastewater (12.9 $\pm$ 3.1 mg/L) with the effluent average of MST-A and MST-B (9.7 $\pm$ 6.7 and 9.4 $\pm$ 1.9 mg/L, respectively). The 24–27% average reduction in TP is likely due to the settling of organic phosphorus associated with TSS.

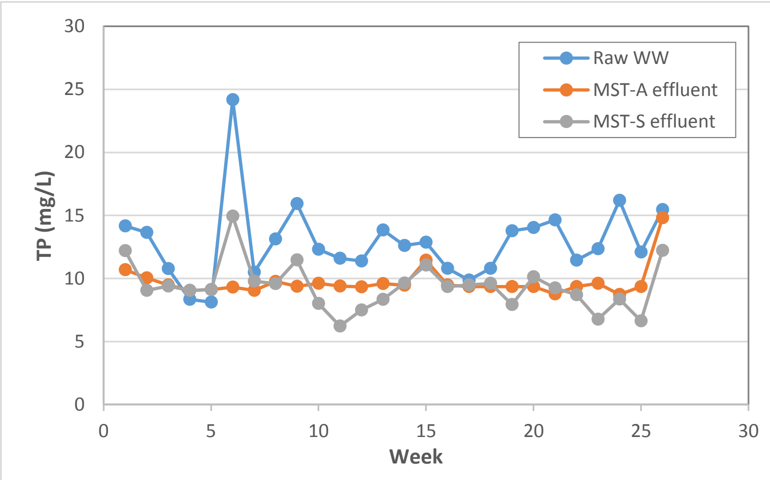

Figure 6. Total phosphorous (TP) concentration with time in MST-A and MST-S at hydraulic loading of 1.2 m^3/d.

Bacteriological load in the form of *E. coli* was another parameter used to evaluate the system's performance. The results of *E. coli* monitoring for both systems operated at 1.2 m^3/d are shown in Figure 7. Logarithmic values were plotted in order to graphically show the log reduction in *E. coli* concentrations. The results show clearly that both MST systems were able to significantly decrease the *E. coli* concentration. Two logs of *E. coli* reduction was achieved by MST-S, while only approximately one log was achieved for MST-A. The higher *E. coli* reduction in MST-S could be attributed to the formation of bioflocs that can agglomerate the free swimming bacteria, including *E. coli*, and settle them out in the sedimentation tank. Though the MST-S showed higher performance compared to the MST-A, *E. coli* concentrations in both effluents were very high and thus tertiary treatment is required.

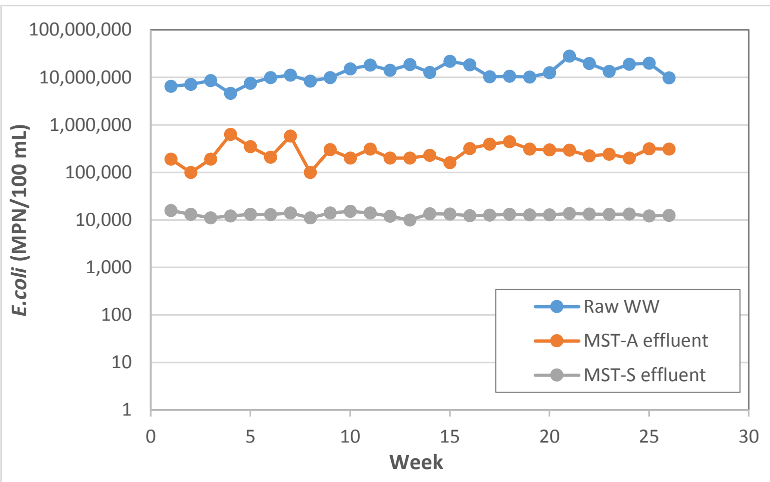

Figure 7. *Escherichia coli* (*E. coli*) concentration with time in MST-A and MST-S at hydraulic loading of 1.2 m^3/d.

The investigations in Phases 2 and 3 are similar to those carried out in Phase 1 and were designed to examine the capability of the treatment systems to operate under elevated hydraulic loadings (1.6 and 2.0 m^3/d). The purpose of this investigation was to reveal the upper limits of the system at which wastewater can be properly treated. This can significantly affect the construction cost and energy consumption for the treatment systems.

The results of the three investigation phases for both systems are summarized in Table 3. Each value in this table represents an average of 26 weeks of investigation. The results show that both MST systems were able to operate under elevated hydraulic loadings with almost double the design capacity. The quality of the wastewater effluent was found to comply with the Jordanian standards except for *E. coli* [27]. This nonconformity is expected in most decentralized systems and, therefore, tertiary treatment is usually suggested (ex. UV, hypochlorite or chlorine disinfection) whenever reuse is required [31].

Table 3. Results of chemical and biological wastewater parameters for all treatment systems and phases.

Phase	Parameter	Raw Wastewater	MST-A Effluent	MST-S Effluent
1	BOD_5 (mg/L)	481 ± 83	8 ± 3	14 ± 6
	COD (mg/L)	918 ± 314	55± 18	84 ± 30
	TN (mg/L)	114.0 ± 29.6	46.6 ± 26.5	81.1 ± 21.9
	NH_4-N (mg/L)	69.9 ± 32.3	8.8 ± 31.9	6.7 ± 18.7
	NO_3-N (mg/L)	0.7 ± 0.3	14.9 ± 6.7	8.2 ± 7.0
	TP (mg/L)	12.9 ± 3.1	9.7 ± 6.7	9.4 ± 1.9
	PO_4-P (mg/L)	7.7 ± 3.7	8.1 ± 3.3	7.4 ± 2.7
	E. coli (MPN/100 mL)	$1.3 \times 10^7 \pm 5.6 \times 10^6$	$2.6 \times 10^5 \pm 1.3 \times 10^5$	$1.3 \times 10^4 \pm 1.2 \times 10^3$
2	BOD_5 (mg/L)	336 ± 64	18 ± 15	14 ± 11
	COD (mg/L)	627 ± 158	58 ± 20	70 ± 26
	TN (mg/L)	64.7 ± 14.8	43.5 ± 15.4	73.9 ± 34.1
	NH_4-N (mg/L)	52.2 ± 14.0	23.2 ± 15.1	13.4 ± 11.7
	NO_3-N (mg/L)	0.4 ± 0.2	7.2 ± 5.1	13.1 ± 15.2
	TP (mg/L)	7.1 ± 2.0	6.7 ± 1.5	6.6 ± 1.4
	PO_4-P (mg/L)	5.7 ± 2.2	6.8 ± 1.6	6.6 ± 1.4
	E. coli (MPN/100 mL)	$1.3 \times 10^7 \pm 3.0 \times 10^5$	$4.2 \times 10^5 \pm 3.3 \times 10^5$	$3.2 \times 10^4 \pm 4.3 \times 10^4$
3	BOD_5 (mg/L)	469 ± 62	25 ± 5	23 ± 36
	COD (mg/L)	770 ± 183	88 ± 35	95 ± 36
	TN (mg/L)	84.6 ± 24.5	62.8 ± 17.1	66.1 ± 15.9
	NH_4-N (mg/L)	70.8 ± 15.6	39.8 ± 22.2	39.2 ± 19.6
	NO_3-N (mg/L)	0.5 ± 0.1	7.4 ± 6.7	9.3 ± 11.2
	TP (mg/L)	9.8 ± 2.8	9.5 ± 2.5	9.0 ± 2.2
	PO_4-P (mg/L)	8.0 ± 2.9	8.3 ± 2.7	8.2 ± 2.3
	E. coli (MPN/100 mL)	$3.0 \times 10^7 \pm 3.0 \times 10^6$	$2.2 \times 10^5 \pm 8.4 \times 10^4$	$2.7 \times 10^4 \pm 1.5 \times 10^4$

Table 3 also shows that the effluent quality of the MST-A system was better than the MST-S system. The difference in the system performance can be clearly seen in the nitrate and total nitrogen concentrations. Under a hydraulic loading of 1.2 m^3/d (Phase 1), the total nitrogen concentration was almost 50% less in the attached growth system than in the suspended growth one. The enhanced nitrogen removal suggests both nitrifying and denitrifying biofilm on the media [32].

The MSTs were also analyzed for their energy requirements. As wastewater flows by gravity in and out of the systems, the only energy-consuming part in both tanks are the blowers. Equation (1) is used to calculate the specific power consumption based on the capacity of the blowers and the served population equivalent.

$$sPC = \frac{P_B \cdot N}{PE} \tag{1}$$

where sPC is the specific power consumption per capita per year (KW/c.y), P_B is the power capacity of the blower (kW), N is the number of operational hours in a year (h), and PE is the population equivalent.

The energy consumption in the different phases described as kilowatt hours per person per year (kWh/c.y) was calculated using Equation (1) based on the blower capacity, time of operation, and population equivalent. The results are shown in Table 4. As clearly observed, energy requirement for the modified septic system operated at elevated hydraulic loading can be notably reduced making this system a low cost technology. The energy consumption of the MST under a hydraulic loading rate of 2 m^3/d is very well matched with accepted values in modern wastewater treatment facilities [33]. Beside the advantage of low energy requirement, the MST systems demonstrated less operation and maintenance requirements and lower construction and operation costs than more mechanized systems.

Table 4. Comparison of energy requirements under different hydraulic loadings.

Hydraulic Loading, m^3/d	Energy Requirement, kWh/c.y
1.2	65
1.6	49
2.0	39

4. Conclusions

Two innovative modified septic tank systems were designed as stand-alone technologies to treat domestic wastewater. Configurations with and without attached growth media were evaluated and demonstrated significant treatment capacities with 95–98% BOD and 92–98% TSS removal observed at hydraulic retention times ranging from 2.6 to 4.4 days. Significant nitrogen removal of 59% was observed in the attached growth system at 2.6 d HRT, while results varied between 26–33% removal at higher loading rates and between 0–29% in the suspended growth configuration. Effluent quality met secondary wastewater quality criteria as well as the Jordanian standard for wastewater reuse for all parameters except for *E. coli*, where further disinfection is required. Corrugated plastic fixed growth media showed a slight improvement in system performance over the suspended growth alternative. This study revealed that the modified septic tank system can be used as a low cost system due to its low energy requirement.

Author Contributions: Bassim E. Abbassi developed the MST system as well as conceived and designed the experiments; Raihan Abuharb performed the experiments; Bassim E. Abbassi and Naser Almanaseer supervised the field experiments; Bassim E. Abbassi, Bashaar Ammary, and Christopher Kinsley analyzed the data; all authors wrote the paper.

Acknowledgments: This work was funded by the Research Plan of the Deanship of Scientific Research at Al-Balqa' Applied University through a MSc contract to Raihan Abuharb and the German Federal Ministry of Education and Research (BMBF) through the Dead Sea 02WM0845 and SMART 02WM1080 research projects.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Mousa, S.M. Water strategies and potential of desalination in Jordan. *Desalination* **2007**, *203*, 27–46.
2. Parkinson, J.; Tayler, K. Decentralized wastewater management in peri-urban areas in low-income countries. *Environ. Urban.* **2003**, *15*, 75–89. [CrossRef]
3. Gikas, P.; Tchobanoglous, G. The role of satellite and decentralized strategies in water resources management. *J. Environ. Manag.* **2008**, *90*, 144–152. [CrossRef] [PubMed]
4. Mazumder, D.; Roy, B. Low cost options for treatment and reuse of municipal wastewater. *Indian J. Environ. Prot.* **2000**, *20*, 529–532.
5. Wang, S. Values of decentralized systems that avoid investments in idle capacity within the wastewater sector: A theoretical justification. *J. Environ. Manag.* **2014**, *136*, 68–75. [CrossRef] [PubMed]
6. Nasr, F.A.; Mikhaeil, B. Treatment of domestic wastewater using modified septic tank. *Desalin. Water Treat.* **2015**, *56*, 2073–2081. [CrossRef]
7. Withers, P.J.; Jordan, P.; May, L.; Jarvie, H.P.; Deal, N.E. Do septic tank systems pose a hidden threat to water quality? *Front. Ecol. Environ.* **2014**, *12*, 123–130. [CrossRef]
8. Capodaglio, A.G. Integrated, Decentralized Wastewater Management for Resource Recovery in Rural and Peri-Urban Areas. *Resources* **2017**, *6*, 22. [CrossRef]

9. Abbassi, B.; Al Baz, I. Integrated wastewater management: A review. In *Handbook Efficient Management of Wastewater*, 1st ed.; Al Baz, I., Ed.; Springer: Berlin, Germany, 2008; pp. 29–40.
10. Flasche, K. Possible Applications and Performance of Small-Scale Wastewater Treatment Plants. Ph.D. Thesis, University of Hanover, Hanover, Germany, 2002.
11. Green, W.; Ho, G. Small scale sanitation technologies. *Water Sci. Technol.* **2005**, *51*, 29–38. [PubMed]
12. Wilderer, P.A. UN water action decade: A unique challenge and chance for water engineers. *Water Sci. Technol.* **2005**, *51*, 99–107. [PubMed]
13. Ontario Mninstry of Environment and Climate Change. Status of the Hauled Sewage Industry & Costing Toward the Development of Environmental Standards for Hauled Sewage in Ontario. Hauled Sewage Costing Summary Report; 2017. Available online: http://oasisontario.on.ca/wp-content/uploads/2017/05/DRAFT-Summary-of-Costing-Report.pdf (accecced on 4 February 2018).
14. Ahmed, W.; Neller, R.; Katouli, M. Evidence of septic system failure determined by a bacterial biochemical fingerprinting method. *J. Appl. Microbiol.* **2005**, *98*, 910–920. [CrossRef] [PubMed]
15. Bradley, B.R.; Daigger, G.T.; Rubin, R.; Tchobanoglous, G. Evaluation of onsite wastewater treat-ment technologies using sustainable development cri-teria, Clean Technol. *Environ. Policy* **2002**, *4*, 87–99.
16. Meuler, S.; Paris, S.; Hackner, T. Membrane bio-reactors for decentralized wastewater treatment and reuse. *Water Sci. Technol.* **2008**, *58*, 285–294. [CrossRef] [PubMed]
17. Appling, D.; Habteselassie, M.Y.; Radcliffe, D.; Bradshaw, J.K. Preliminary Study on the Effect of Wastewater Storage in Septic Tank on *E. coli* Concentration in Summer. *Water* **2013**, *5*, 1141–1151. [CrossRef]
18. Sharma, M.K.; Kazmi, A.A. Anaerobic onsite treatment of black water using filter-based packaged system as an alternative of conventional septic tank. *Ecol. Eng.* **2015**, *75*, 457–461. [CrossRef]
19. Anil, R.; Neera, A.L. Modified Septic Tank Treatment System. *Proc. Technol.* **2016**, *24*, 240–247. [CrossRef]
20. Nasr, F.A.; Mikhaeil, B. Treatment of domestic wastewater using conventional and baffled septic tanks. *Environ. Technol.* **2013**, *34*, 2337–2343. [CrossRef] [PubMed]
21. Nguyen, V.A.; Nga, P.T.; Nguyen, H.T.; Morel, A. Improved septic tank and, a promising decentralized wastewater treatment alternative in Vietnam. In Proceedings of the GMSARN International Conference on Sustainable Development: Issues and Prospects for GMS, Hanoi, Vietnam, 6–7 December 2006.
22. Klinger, J.; Goldscheider, N.; Hötzl, H. *SMART-IWRM: Integrated Water Resources Management in the Lower Jordan Rift Valley*; Project Report 2nd Phase; KIT Scientific Reports; KIT Scientific Publishing: Karlsruhe, Germany, 2015; ISBN 978-3-7315-0393-4.
23. APHA; AWWA; WEF. *Standard Methods for Examination of Water and Wastewater*, 21st ed.; American Public Health Association; American Water Works Association; Water Environment Federation: New York, NY, USA, 2005.
24. Igbinosa, E.O.; Okoh, A.I. Impact of discharge wastewater effluents on the physico-chemical qualities of a receiving watershed in a typical rural community. *Int. J. Environ. Sci. Tech.* **2009**, *6*, 175–182. [CrossRef]
25. Department of Standards and Measures. *Jordanian Standards No. JS893/2006, Regulation and Standards for Reclaimed Domestic Wastewater*; Department of Standards and Measures: Amman, Jordan, 2006.
26. Ávila, C.; Reyes, C.; Bayona, J.M.; García, J. Emerging organic contaminant removal depending on primary treatment and operational strategy in horizontal subsurface flow constructed wetlands: Influence of redox. *Water Res.* **2013**, *47*, 315–325. [CrossRef] [PubMed]
27. Massoud, M.A.; Tarhini, A.; Nasr, J.A. Decentralized approaches to wastewater treatment and management: Applicability in developing countries. *J. Environ. Manag.* **2009**, *90*, 652–659. [CrossRef] [PubMed]
28. Sarathai, Y.; Koottatep, T.; Morel, A. Hydraulic characteristics of an anaerobic baffled reactor as onsite wastewater treatment system. *J. Environ. Sci.* **2010**, *22*, 1319–1326. [CrossRef]
29. Abbassi, B. Performance Evaluation of Decentralized Wastewater Treatment and On-Site Wastewater Reuse at Jordan Traffic Institute. *J. Food Agric. Environ.* **2008**, *6*, 518–523.
30. Diaz-Elsayed, N.; Xu, X.; Balaguer-Barbosa, M.; Zhang, Q. An evaluation of the sustainability of onsite wastewater treatment systems for nutrient management. *Water Res.* **2017**, *121*, 186–196. [CrossRef] [PubMed]
31. Agidi, S.; Vedachalam, S.; Mancl, K.; Lee, J. Effectiveness of onsite wastewater reuse system in reducing bacterial contaminants measured with human-specific IMS/ATP and qPCR. *J. Environ. Manag.* **2013**, *115*, 167–174. [CrossRef] [PubMed]

32. Feng, L.; Yang, G.; Yang, Q.; Zhu, L.; Xu, X.; Gao, F. Enhanced simultaneous nitrification and denitrification via addition of biodegradable carrier *Phragmites communis* in biofilm pretreatment reactor treating polluted source water. *Ecol. Eng.* **2015**, *84*, 346–353. [CrossRef]
33. Hreiz, R.; Latifi, M.A.; Roche, N. Optimal design and operation of activated sludge processes: State-of-the-art. *Chem. Eng. J.* **2015**, *281*, 900–920. [CrossRef]