Hydrologic System Protection by Decentralized Wastewater Treatment Technologies in Jordan

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The nine different technologies are constructed at the pilot scale in one experimental site at Al-Balqa Applied University and use the same wastewater characteristics as the inlet. Monthly samples were collected from the inlet and outlet of nine different decentralized wastewater treatment technologies for three years (June 2016-June 2019). The samples were analyzed for physical, chemical, and biological parameters including TSS, Turbidity, pH, COD, DO, NH_4, NO_3, TN, BOD, and *E. coli*. Removal efficiencies for the nine technologies are obtained for COD, BOD, TN, and TSS to be above 95%. NH_4 the removal efficiencies for the nine technologies vary and found to be in the range of 27 to 76% while for the *E. coli* in the range of 65 to 95%. Further, data on energy consumption were collected for each technology and found for the nine investigated technologies in the range of 0.03 to 0.30 Jordan Dinars per treated cubic meter. The investigated technologies were evaluated, and the best options were endorsed. It is concluded that the adaptation of decentralized wastewater treatment will certainly help protect the hydrologic system in Jordan especially in the high lands where significant groundwater recharge occurs and a considerable amount of surface water flows towards Jordan Valley and collection dams.

Keywords: Wastewater, decentralized wastewater treatment, contamination, pollution, innovative technologies, removal efficiency.

Introduction

Jordan depends mainly on groundwater for domestic uses and blended reclaimed water with surface water for irrigation (Fach *et al*, 2010). Major cities are served with centralized wastewater collection systems but this is not the case in rural areas. Establishing and operating collection and treatment systems in rural areas are not economically feasible because the users are highly scattered and the topography is significantly variable (Brunner *et al.*, 2018). The situation is further complicated because most of Jordan’s renewable groundwater resources are located in the high lands, mostly on top of limestone aquifers. These aquifers are vulnerable to groundwater contamination by cesspits (Burde *et al.*, 2001). Lately, the government of Jordan is dedicating part of their attention and budget to promote decentralized wastewater treatment as an option for groundwater protection and therefore sustainable hydrologic system (Hussein, 2019).

Decentralized wastewater systems are considered for communities up to 5000 inhabitants (Nanninga *et al.*, 2012). For more than this number, centralized wastewater collection and treatment systems are more suitable (Massoud *et al.*, 2008). To be specific, decentralized wastewater systems are suitable for communities in remote areas, hotels, industries, and households in rural areas (Chong *et al.*, 2012). Another important aspect of decentralized wastewater treatment is the reuse part (MWI 2016). Due to the water shortage, it is very useful for residents and farmers to have access to reclaimed water that can be used for supplementary irrigation. However, what is the type of technology end-users should adopt and what cost, and whether it is safe and sustainable (Khattiyavong *et al.*, 2019). Based on these facts, this research is performed to partially answer these questions and to provide feasible clarifications that may help academia, managers, and end-users form an adequate decision based on a scientific approach.

Non-conventional water resources can be used for food production systems after proper treatment for the rehabilitation of marginal and degraded lands in the Middle East and North Africa (Hussain *et al.*, 2019). Different wastewater technologies are commercially used for the treatment of municipal as well as industrial wastewater (MWI, 2016).

Wetland technologies, SBR, septic tank, modified septic tank, and biofilm systems are successfully implemented in Jordan in one of the important demonstration research centers and in several cities in Jordan (Wang *et al.*, 2019). Furthermore, it is necessary to ensure the local water quality required, a cost-effective treatment, sustainability, and protection of public health. The development and adaptation of these technologies and solutions have considered the local conditions and climate change (MWI, 2019).

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The general classification of decentralized wastewater treatment systems includes the following (Singh *et al.*, 2014):

- Natural treatment systems

Aerobic systems: Suspended growth, attached growth, and Combined suspended and attached growth. Anaerobic systems: Suspended growth, Attached growth. Combined (aerobic/anaerobic/natural) systems. Anaerobic–aerobic, Anaerobic–natural, and Anaerobic–aerobic–natural

Following is a brief description of the investigated technologies constructed at the research facility at Al-Balqa Applied University during this research:

- Septic Tanks and Modified Sept Tanks Systems

The system is based on a modification of the conventional septic tank by including an integrated aerated-settling chamber. Two modules of bacterial growth (suspended and attached) are tested to treat domestic wastewater (Abbasi *et al.*, 2018). Unlike the suspended growth reactor, the anaerobic/aerobic fixed bed reactor contains corrugated plastic sheets, where the microorganisms are attached to the surface of the packing material (Ambica and Raman, 2015).

- Sequencing Batch Reactor (SBR) Systems, SBR is a discontinuously operated fill- and draw-activated sludge process. The unit consists of a clear water pump, aerator and de-sludging pump (Beuna *et al.*, 1999). All the reactors are operated in the mode with feed, anaerobic, aerobic, settling and decanting phases and therefore all biological, oxidation, sedimentation, nitrification, and de-nitrification processes occur in a single tank. On the other hand, a continuous batch reactor designed to reduce electrical consumption. Two settling tanks designed in a way to separate the suspended solids from the treated water. Aeration, de-sludging, and feeding are done by a small compressor.

a. Wetland Systems: Multi-stage Single-pass Vertical Filter system that was designed to produce high-quality effluent passively. The system consists of a septic tank (primary treatment), first stage vertical filter (secondary treatment and nitrification), organic denitrification reactor (removal of nitrate), and a second stage vertical filter (pathogen reduction and further polishing) (Vymazal, 2005).

b. A recirculating vertical filter system that is consists of a septic tank for primary treatment, followed by a recirculation tank. Effluent is pumped from the recirculation tank onto the vertical filter before then flowing through a flow splitting device from where a portion of the effluent is returned to the recirculation tank while the rest leaves the system and is used for irrigation. The system is designed to treat 2 m³/day (Vymazal, 2010) and (Masia and Martinuzzi, 2007).

- French Systems

The French version of vertical-flow constructed wetlands is characterized by treating directly raw wastewater on a first-stage filter (Prost-Boucle and Molle, 2015). The advantage of the French system is that it takes raw sewage directly to its first stage and treats the primary sludge on the surface of the first stage beds. This greatly facilitates sludge management as compared to systems which need to deal with primary sludge (Esser *et al.*, 2014).

1Materials and Methods

1.1 Experiment Design

The experiments were designed to critically analyze and discuss data and results obtained from experimental methods to assess the microbial population dynamics in wastewater treatment technologies, and to evaluate the process performance and characteristics of physical, chemical, and biological wastewater treatment processes. This research is carried out in the above-mentioned research facility at Al-Balqa Applied University. Samples were collected on the same day and time each month, and the analysis was carried out in the laboratory which is prepared with all necessary equipment and test kits. The data is examined, validated, and finally approved before its stored and used for analysis. Some tests were occasionally re-taken to ensure data reliability and accuracy. The technologies monitored were selected to be all the available technologies in the facility, the inlet, and outlet sampling points were the same for the entire period of sampling to ensure consistency.

The design parameters were selected to cover all concerns and to answer all possible research questions Domestic raw water in the research facility is unlikely to have heavy metals or pharmaceutical residuals. However, one test was made at the beginning of the sampling period to confirm this fact. The samples were analyzed for physical, chemical, and biological parameters including Total Suspended Solids (TSS), Turbidity, Potential Hydrogen (pH), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Ammonium (NH_4), Nitrate (NO_3), Total Nitrogen (TN), Biological Oxygen Demand (BOD), and *Escherichia coli* (*E. Coli*) all in mg per liter. Further, data on energy consumption were collected for each technology. As mentioned above, the experiments carried out over three years on nine different decentralized wastewater technologies installed in the research facility. The systems dimensions are standards for the nine technologies with 3 meters long, 2 meters width and 1.5 meters depth. The flow rate is calibrated to be 2 cubic meters per 24 hours and controlled with the control panel.

1.2 Analysis

The main objective of this research is highly connected to the identification of the most efficient technology considering technical and economical constraints. Hence, it is important to compare the analysis across the different technologies, with proper interpretations and reasonable conclusions. It is worth mentioning that the effluent not only controlled by the process itself but with external conditions such as climatic conditions and raw wastewater characteristics (Almanaseer *et al* , 2012). Hence, it is important to consider these facts when trying to establish trends and variability among the different variables. The correlation was considered, graphical representation as well. More elaboration on this and pictorial representations are presented in the result section.

2 Results and discussion

Table 1 shows a summary of the average monthly values for the different parameters throughout this research (June 2016–June 2019). Significant variations in effluent water quality are observed among different technologies. However, all the technologies fulfill the required standards for reclaimed water reuse. Also, **Figure 1** shows graphical representations of the performance for the nine different technologies. The performance is calculated based on eight parameters relative to the water quality of the raw water before and after treatment. All parameters are found below the reuse standard. But, there is noticeable variability among the different technologies in terms of their performance. This is normal since different technologies operate different principals and advanced processes and influenced differently by local conditions such as raw wastewater characteristics and climatic variations. Table 2 shows the average, minimum, maximum, and standard deviation of the monthly data for the nine examined technologies

Table 1 Long-term average values for the different technologies

Technology	COD	BOD	TN	NH_4	NO_3	TSS	DO	pH	Turbidity
Septic Tank	54.0	16.2	65.3	14.1	1.2	20.3	2.8	7.3	13.2
Modified Septic Tank	69.9	18.6	63.1	45.5	1.4	32.5	2.9	7.5	11.7
Sequencing Batch Reactor with Ultraviolet (SBR-UV)	61.4	15.8	93.0	30.4	6.8	32.5	3.2	7.5	12.8
Sequencing Batch Reactor with Ultraviolet manufactured by PUROO Company (SBR-PUROO)	46.8	16.8	46.1	26.7	1.7	24.8	3.3	7.6	12.0
Vertical Wetland (V-Wetland)	25.0	10.0	105.2	0.9	65.2	19.2	5.0	7.6	2.5
Recirculated Wetland (R-Wetland)	106.0	21.5	84.6	9.8	47.6	34.3	3.2	7.3	19.3
Aerated Wetland	20.7	11.0	46.6	0.6	36.6	18.0	7.0	8.0	3.5
Second wetland	34.1	16.3	33.3	4.1	27.1	16.6	4.6	8.0	2.8
French aerated wetland	15.8	8.3	30.1	0.9	25.1	16.6	7.4	8.3	1.5
Raw wastewater	863.0	612.3	128.4	69.7	0.7	805.5	0.6	7.1	331.2

On the other hand, the removal efficiency as a percentage showed slight variations among the different technologies but overall the removal efficiency is high and promising. For TN, the removal efficiency is less but this is suitable for reuse where reclaimed water is rich with nitrogen to compensate for fertilizers necessary for plant growth. Removal for DO, pH, and Turbidity is not considered since the focus is on the biochemical parameters. The energy consumption varies where wetland technologies consume less energy in comparison to the septic tank and SBR technologies and the removal efficiency of the nine technologies (Table3).

Table 2 Minimum, maximum, and standard deviation of the monthly data for the nine technologies

Technology	Statistics	COD	BOD	TN	NH_4	NO_3	TSS	E-coli	DO	pH	Turbidity
Septic Tank	Average	54.0	16.2	65.3	14.1	1.2	20.3	94354	2.8	7.3	13.2
	STD	4.7	2.6	10.0	7.4	1.3	4.7	23273	0.7	0.8	4.0
	Max	60.8	22.0	81.3	29.4	4.7	30.0	158500	4.7	7.7	22.1
	Min	44.3	12.0	50.8	4.8	0.3	14.0	67600	2.0	4.7	8.2
Modified Septic Tank	Average	69.9	18.6	63.1	45.5	1.4	32.5	70685	2.9	7.5	11.7
	STD	9.2	2.8	6.8	9.5	1.4	8.2	24674	0.6	0.1	3.7
	Max	86.9	25.0	72.0	63.1	5.2	44.0	133400	3.7	7.7	16.4
	Min	54.6	14.0	50.2	28.6	0.3	12.0	43100	2.0	7.2	4.3
SBR-UV	Average	61.4	15.8	93.0	30.4	6.8	32.5	547	3.2	7.5	12.8
	STD	13.2	5.8	20.2	7.9	3.5	9.7	115	0.7	0.2	9.9
	Max	77.7	29.0	138.6	39.4	13.2	50.0	805	5.3	7.9	44.2
	Min	27.2	10.0	51.3	8.6	2.2	16.0	359	2.1	7.1	4.4
SBR-PUROO	Average	100	30	45	0.0	30	50	100	2	9	10
	STD	500	200	70	0.0	45	200	1000	0.0	9	0.0
	Max	150	60	70	0.0	80	60	1000	1	9	0.0
	Min	50	15	45	5	30	50	2	2	9	2
V-Wetland	Average	25.0	10.0	105.2	0.9	65.2	19.2	569	5.0	7.6	2.5
	STD	3.8	2.9	19.0	0.6	18.6	3.6	68	1.0	0.2	1.3
	Max	34.6	15.0	132.8	2.0	101.2	26.0	670	6.5	7.8	6.2
	Min	20.4	6.0	61.1	0.2	42.6	14.0	471	3.5	7.3	1.2
R-Wetland	Average	106.0	21.5	84.6	9.8	47.6	34.3	285962	3.2	7.3	19.3
	STD	20.8	2.6	15.2	10.1	12.5	5.4	76874	0.6	0.2	5.2
	Max	140.0	25.0	127.6	33.4	69.2	44.0	435200	4.0	7.6	25.6
	Min	55.4	16.0	68.6	2.6	31.6	28.0	160200	2.5	7.0	12.3
Aerated Wetland	Average	20.7	11.0	46.6	0.6	36.6	18.0	600	7.0	8.0	3.5
	STD	6.7	2.3	2.4	0.3	4.2	13.4	58	0.9	0.1	1.7
	Max	35.0	15.0	49.6	1.1	44.8	50.0	693	7.9	8.1	6.3
	Min	13.3	8.0	42.6	0.0	31.2	8.0	512	5.2	7.7	1.3
Second wetland	Average	34.1	16.3	33.3	4.1	27.1	16.6	4796	4.6	8.0	2.8
	STD	3.0	1.2	2.1	1.2	2.0	4.6	409	0.4	0.0	0.3
	Max	38.4	18.0	37.5	6.2	30.4	24.0	5580	5.2	8.1	3.1
	Min	28.0	14.0	30.4	2.8	24.4	10.0	4360	4.0	7.9	2.1
French aerated wetland	Average	15.8	8.3	30.1	0.9	25.1	16.6	327	7.4	8.3	1.5
	STD	5.8	2.0	1.7	0.5	4.3	4.6	54	0.6	0.3	0.2
	Max	25.6	12.0	32.9	1.9	31.4	24.0	402	8.0	8.7	1.8
	Min	10.0	6.0	27.7	0.2	18.4	10.0	259	6.2	7.9	1.2

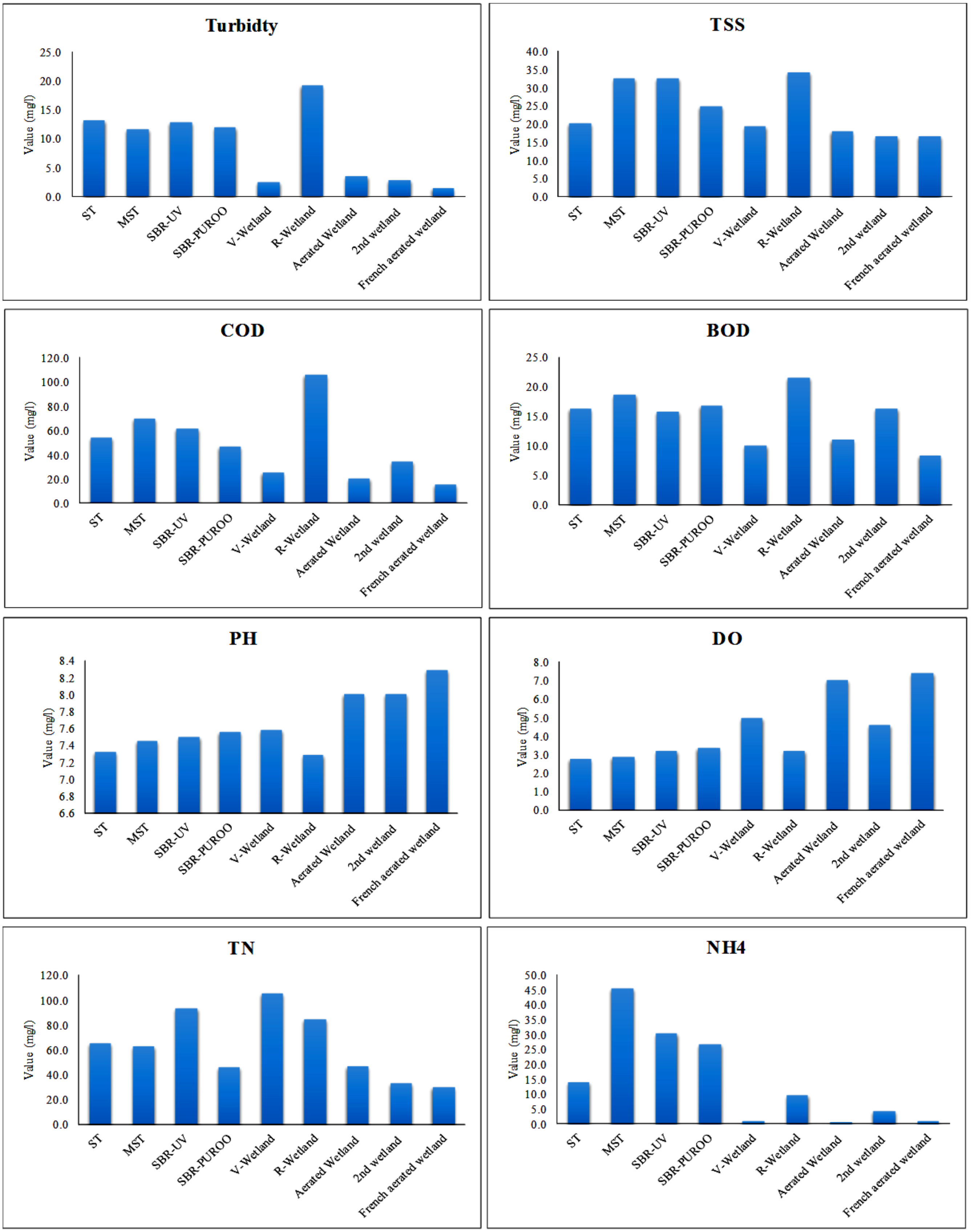

Fig. 1 Performance of different technologies

Table 3 Removal efficiency (%) and energy consumption (Jordan Dinar, JD)

Technology	COD	BOD	TN	NH4	*E. Coli*	TSS	Energy consumption (JD*/m^3)
Septic Tank	94.1	97.4	99.5	49.14	79.4	97.47	0.30
Modified Septic Tank	91.1	95.96	99.6	50.9	73.4	95.97	0.30
SBR-UV	92.8	96.4	99.9	27.6	65.54	95.97	0.23
SBR-PUROO	94.5	97.3	99.9	64.11	80.86	96.93	0.25
V-Wetland	97.7	98.8	99.9	38.1	68.72	97.6	0.05
R-Wetland	92.7	96.5	99.6	34.14	75.72	95.74	0.08
Aerated Wetland	97.5	99.03	99.9	63.75	89.18	98.79	0.03
2nd wetland	96.5	98.6	99.9	74.1	94.03	98.89	0.03
French aerated wetland	98.1	99.3	99.9	76.55	92.6	99.44	0.04

1 (Jordanian Dinar, JD)= 1.4097 USD

The removal efficiency follows the same trend for the different parameters but with different magnitudes. For example, *E-Coli* has the highest removal efficiency which is promising followed by TSS which is very important since the water re-use normally practiced using dripping irrigation. Lessor no TSS helps in avoiding pipes clogging. Overall, this similarity in removal pattern for all the parameters indicates consistency in the treatment processes for the nine technologies and therefore, more selection criteria are necessary to choose the best option. Energy consumption is one possible selection criterion. Finally, and concerning the treated wastewater standards, the efficiency of each technology was calculated as the percentage of removal. This indicator reflects the ability of each technology to remove the loads and hence to purify the wastewater. The effluent was compared to standards category A, B, and C to ensure the reliability of treated wastewater but also as a measure of efficiency. Table 4 shows the treated wastewater standards.

Table 4 Treated wastewater reuse standards

Standards	COD	BOD	TN	NH4	NO$_3$	TSS	*E. coli*	DO	pH	Turbidity
Irrigation-Class A	100.0	30.0	45.0	N/A	30.0	50.0	100	2.0	9.0	10.0
Irrigation-Class B	500.0	200.0	70.0	N/A	45.0	200.0	1000	N/A	9.0	N/A
Water discharge	150.0	60.0	70.0	N/A	80.0	60.0	1000	1.0	9.0	N/A
Artificial recharge	50.0	15.0	45.0	5.0	30.0	50.0	2	2.0	9.0	2.0

Figure 2 shows a pictorial representation of the possible relationship between COD and BOD for the nine investigated technologies. Although the points are only nine and not enough to establish strong statistical significance, still we can have an idea about the possible correlation between COD and BOD. These significant correlations indicate that the processes are working successfully and the collected samples and analysis are valid. COD tends to follow COD in wastewater treatment processes. On the other hand, TN is significantly correlated with NH4 indicating efficient nitrogen removal. However, a good amount of nitrogen remains in the treated wastewater which is good for re-use. Overall, this high level of removal ensures hydrologic system protection, both when we discharge the treated wastewater to rivers, or when we use for irrigation. The quality of the treated wastewater is suitable for groundwater recharge (Hubbard *et al.*, 2016). However, this statement needs more analysis and not within the scope of this paper.

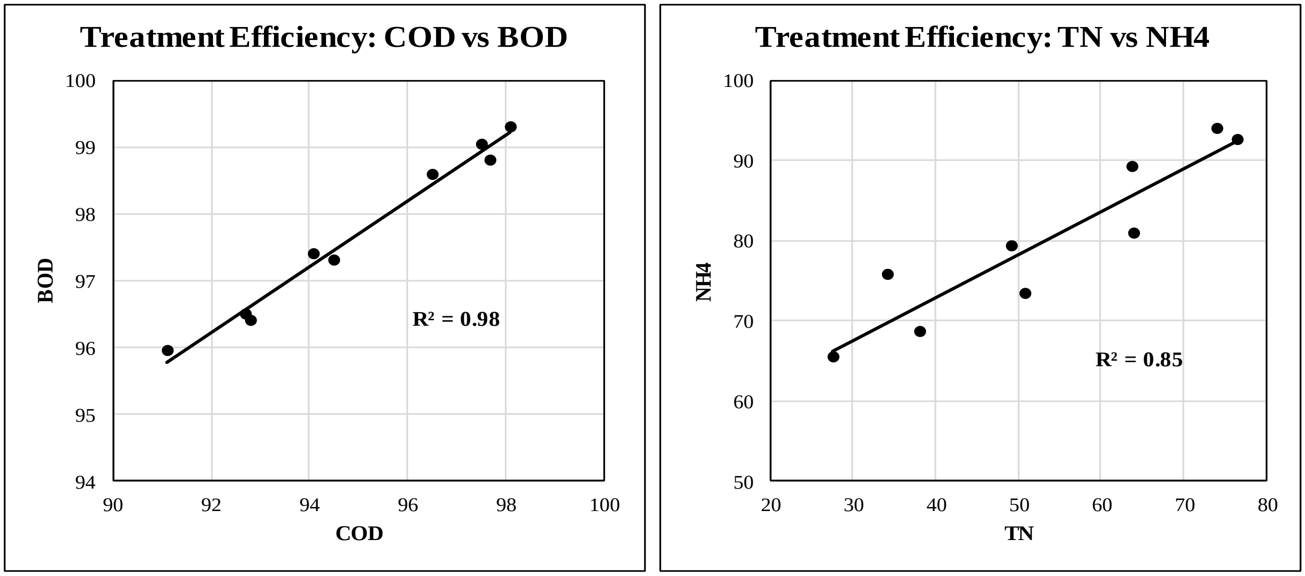

Fig. 2 Treatment efficiency (%) for COD vs BOD (left) and TN vs NH_4 (right) for nine technologies

Conclusions

Adopting decentralized wastewater treatment options has great potential for protecting soil and water resources from contamination. Cesspits continue to pollute water resources in Jordan, especially in rural areas, and hence an integrated water resources plan should include decentralized wastewater as one of its alternative strategies to consider wastewater as an opportunity rather than a challenge. Most of the renewable groundwater resources in Jordan are distributed within karst limestone aquifers which are highly vulnerable to contamination by raw wastewater. The collection and on-site treatment of raw water will certainly alleviate the potential contamination of soil and groundwater. As an output of this research, the results show clearly that the investigated technologies perform well for organic matter removal and nitrification and make sludge management easy. Following are five lessons learned:

1- Three years of continuous monthly data is considered a decent amount of data to examine the performance of decentralized wastewater treatment technologies. The collected monthly data over three years allowed us to derive solid conclusions and reliable results. However, it is difficult to compare the technologies concerning their costs because it depends on the local economic conditions.
2- Centralized wastewater options are not feasible in rural areas where communities are scattered. Hence, adopting decentralized wastewater treatment options will certainly protect the hydrologic system; surface water and groundwater, and will provide treated wastewater for supplementary irrigation and therefore alleviate the stress on domestic water resources.
3- The collected data is proven consistent and reliable, and hence we can build solid conclusions and decisions on the analysis, especially for the comparison between the different technologies in terms of their performance. Wetland technologies seem to be more feasibly subject to the availability of space.
4- The energy consumption varies from 0.04 to 0.30 JD per cubic meter of treated wastewater. This is not the only cost item, operation and maintenance require additional cost too. Overall, the cost varies across different technologies but the wetland system is more economically feasible.
5- Treatment was very efficient in terms of E-Coli and TSS which are the most important parameters. Also, technologies show consistency in their performance which makes the decision on the best technology easier. The excellent removal of E-Coli ensures health protection and the removal of TSS ensures efficient irrigation systems with less maintenance.

Finally, if we consider the German experience, nearly 1.5 million decentralized wastewater treatment units are installed in rural areas, mainly to protect the hydrologic system. In Jordan, there are approximately 240 units mostly operating in houses, farms, hotels, and police offices in remote areas. This is a humble number and cannot help protect our hydrologic and environmental systems. This research shows the successful efficiency of the various technologies under Jordanian conditions using a scientific approach based on observations rather than estimations or simulations. The future in Jordanian rural areas is certainly for decentralized wastewater treatment technologies, and this is proven as a successful approach to protecting the hydrologic system.

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Nomenclature

Acronyms

AS	=Activated Sludge	[-]
BOD	=Biochemical Oxygen Demand	[-]
COD	=Chemical Oxygen Demand	[-]
CSTR	=Continuous stirred-tank reactor	[-]
E	=Effluent	[-]
OF	=Overflow	[-]
PD	=Pre-Denitrification	[-]
S	=Dissolved material concentration	[mg COD/l]
SE	=particulates separation coefficient	[-]
Si	=Dissolved material concentration in the feed	[mg COD/l]
SI	=Soluble inert organics concentration	[mg COD/l]
TKN	=Total Kjeldahl Nitrogen	[-]
UF	=Underflow	[-]
W	=Waste	[-]

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