Original Article

Modeling and Comparison of the Modified Ludzack–Ettinger Process with Septic Tank Integration for Wastewater Treatment in Small Communities Using GPS-X

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Abstract

Aim: Wastewater treatment in small-population communities has challenges. The current study aims to modeling and comparison of the Modified Ludzack–Ettinger (MLE) process with septic tank (SEP) integration for wastewater treatment in small communities using GPS-X. **Methods:** In this study, two scenarios MLE and SEP-MLE processes for wastewater treatment were simulated using the data of the Noshabad city wastewater treatment plant as a small community and GPS-X software. In this model, the removal of total suspended solids (TSS), chemical oxygen demand (COD), total nitrate (TN), and total phosphorus (TP), the effect of quantitative and quality variations of influent wastewater in shock load conditions on the effluent quality were investigated. **Results:** Removal efficiency of TSS, COD, TN, and TP for SEP-MLE processes were 96.7, 92.8, 68.3, and 47.1%, and for MLE were 98, 93.6, 69.3, and 52.9%, respectively. The SEP-MLE process demonstrated superior quantitative shock resilience (40%) compared to the MLE process (18%), whereas both processes displayed comparable qualitative shock resilience (17%). The MLE process generated a larger volume of sludge (21 m^3/day) with a lower concentration (0.8%) and volatile solids reduction (35%) compared to the SEP-MLE process (2.5 m^3/day, 5%, and 38%). Furthermore, the SEP-MLE process incurred reduced initial investment costs ($1084 compared to $1328) and decreased operational costs ($32 compared to $34) relative to the MLE process. **Conclusions:** According to the results, a septic tank and MLE combination were an effective process for wastewater treatment in small communities.

Keywords: GPS-X, Ludzack–Ettinger, septic tank, small communities

Introduction

Urbanization and industrial expansion have resulted in an increase in the volume of wastewater directed to treatment plants.[1] Wastewater contains constituents that are harmful to both human health and the environment. In contrast, water scarcity is one of the major challenges faced by societies in the 21st century.[2] Wastewater treatment plants (WWTPs) play a vital role in sustainable water resource management, focusing on the recovery of valuable resources through a variety of treatment processes.[3] Too, in light of the global scarcity of water resources, utilizing wastewater as an accessible and reliable source is essential. Traditional wastewater treatment employs a combination of physical and biological techniques to remove solids, nutrients, and organic matter from wastewater. In conventional sewage treatment, the most essential stage is the secondary treatment, which relies on biological processes involving diverse microorganisms within a controlled environment.[4] Wastewater treatment in small communities encounters numerous challenges due to fluctuations in both the quantity and quality of wastewater. In addition, communities often have limited financial and human resources to comply with effluent and sludge discharge standards. In small communities, various methods are employed for wastewater treatment, including septic systems, constructed wetlands,

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lagoons, packaged treatment plants, membrane bioreactors, sequencing batch reactors, trickling filters, rotating biological contactors (RBCs), aerated lagoons, activated sludge systems, and the modified Ludzack–Ettinger (MLE) process.[5] Activated sludge has been a widely utilized wastewater treatment system globally for several decades. One of the primary advantages of an activated sludge system is the ease of management and operation. However, these systems can be influenced by fluctuations in influent wastewater, seasonal temperature variations, and long-term changes in dissolved oxygen (DO) levels.[6,7] The MLE process is a type of activated sludge treatment used in wastewater management that differs from the conventional activated sludge (CAS) system. Compared to the CAS system, the MLE process may offer greater efficiency in nitrogen reduction. The benefits of the MLE process include enhanced nitrogen removal, operational flexibility, and reduced chemical usage. Septic tanks are commonly utilized in small communities, particularly in rural or suburban areas where centralized sewage systems are either unavailable or prohibitively expensive to implement.

The applications and benefits of septic tanks in communities include cost-effectiveness, space savings, self-sufficiency, environmental protection, sustainable waste management, flexibility, and ease of installation and removal. However, challenges such as maintenance requirements and the potential for groundwater contamination must also be considered.[8] The combination of a septic tank system with the MLE process provides several advantages, including improved treatment efficiency, reduced load on the MLE system, enhanced resilience and adaptability, environmental benefits, and cost-effectiveness in implementation. Simulation software, such as GPS-X (Hydromantis,Environmental Software Solutions, Inc., Hamilton, ON, Canada), v8.0, has been developed for activated sludge modeling.[9] The purpose of this research was using simulator (GPS-X) software to simulate a MLE process and its combination with a septic tank on the basis of Noshabad municipal WWTP data. Moreover, energy consumption, required land, initial investment, and operating costs also were analyzed.

Materials and Methods

The study area

The design of WWTP for Noshabad city, as a small communities in central Iran (at coordinates 34° 4′ 47″ N, 51° 26′ 9″ E) was done. Figure 1 illustrates the location area of study. Tables 1 and 2 show the quality and quantity of the wastewater.

Design of wastewater treatment plant

This research was conducted using simulations in GPS-X (Hydromantis, Enviromental Software Solutions, Inc., Hamilton, ON, Canada), v8.0. The simulation included two systems: (1) the MLE process with nitrogen removal as the control system and (2) a septic tank combined with an activated sludge system (SEP-MLE). The operational units in the MLE option consist of screening, an aerated grit chamber, flow equalization, an oxygen and aeration tank, a sedimentation tank, a disinfection unit (for the liquid phase), and sludge drying beds (for the solid phase). In the SEP-MLE process, operational units include screening, an aerated grit chamber, a septic tank, an anoxic and aeration tank, a sedimentation tank, a disinfection unit (for the liquid phase), and sludge drying beds (for the solid phase). The specifications for each unit in both the MLE and SEP-MLE processes are shown in Table 3. The characteristics of the units were defined according to the book "Wastewater Engineering: Treatment and Resource Recovery, 5th Edition" by Metcalf and Eddy (2014).[10] Parameters such as mixed liquor suspended solid (MLSS), solid retention time (SRT), and DO were regulated based on the effluent quality standards for discharge into surface waters in Iran.[11] The excess sludge was stabilized by returning it to the septic tank. After 60 days, the sludge met the quality standards for B-class sludge and was discharged from the tank.[10] The condensed sludge was then transferred to sludge drying beds. Another portion of the sludge precipitated in the sedimentation tank was returned to the aeration tank to maintain the biomass concentration and achieve the effluent standard for nitrogen. In addition, a fraction of the wastewater exiting the aeration tank was transferred to the beginning of the biological system.

Simulation of wastewater treatment plants

In general, simulation involves several steps. The first step is collecting the data required for GPS-X modeling. The second step involves depicting the current plant based on the physical and operational data of the process units. The third step is characterizing the influent wastewater quality parameters and adjusting the influent fractions using the GPS-X influent advisor to achieve an acceptable state and balance mass variables. In the fourth step, the model is executed. The fifth and final step involves optimizing the model over a time series by fine-tuning kinetic and stoichiometric parameters. In this study, MLE and SEP-MLE were modeled using GPS-X software to evaluate and optimize the design of units. The input data for the software includes influent flow, flow lines, the return internal effluent flow of the anoxic unit, excess sludge flow, return sludge flow, return supernatant flow to the beginning of the WWTP, and coefficients related to the quality parameters of the influent wastewater for hydraulic modeling of the WWTP flow.

The quality parameters are calibrated, and then the units of the WWTP are modeled in the software environment. The hypotheses encompass reaction kinetic coefficients, wastewater temperature, the elevation of the WWTP above sea level, and concentrations of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total phosphorus (TP), and total nitrate (TN). Operational parameters including DO, oxygen transfer efficiency, and aeration coefficients (alpha and beta) are illustrated in Table 4. The critical parameters in the biological design of the WWTP are SRT and MLSS, with the septic tank temperature set at 15°C. Under steady-state conditions in both systems, effluent, and biosolids characteristics were evaluated and compared to

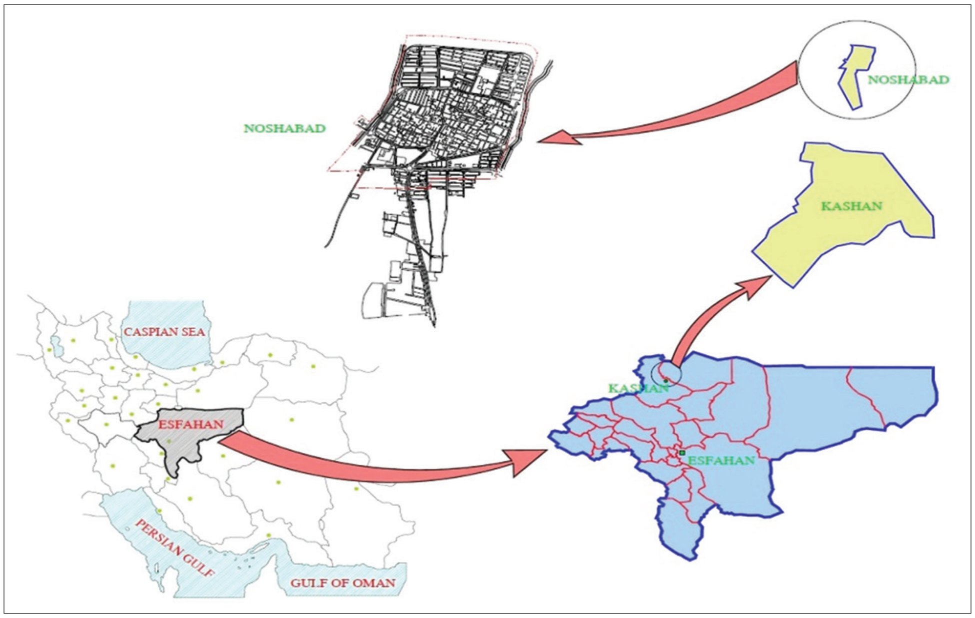

Figure 1: The map of the study area

ensure compliance with standards. Volatile solids reduction in sludge, expressed as a percentage, is used as a key indicator of compliance with biosolids standards.[10] The effluent quality was assessed based on the Environmental Protection Agency),[12] World Health Organization,[13] and Iran standards for discharge into surface water,[11] standards are shown in Table 5. The flow diagrams of the two designed systems are presented in Figures 2 and 3. Finally, the initial investment costs for constructing the sewage treatment plant, including land acquisition, construction work, and equipment (mechanical, electrical, and precision instruments), along with operational costs such as labor, electricity consumption, repairs and maintenance, and chemical materials, have been assessed.

Cost analysis

Present worth amount (PWA) and annual equivalent amount (AEA) are used to compare the value of cash flows at different times, especially when evaluating the economic viability of projects. Therefore, the PWA and AEA have been calculated using Equations 1 and 2:[14]

$$P_W(\mathrm{i}) = \sum_{t=0}^{n} f_t(P / f,i,t) \quad (1)$$

Where: P_w: the present value f_t: Investment cost at a certain time i: Interest rate – download.

$$AE(i) = P_W(i)(A / P,i,n) \quad (2)$$

Where: Pw: present value i: Interest rate – download, n: Time, f_t: Investment cost at a certain time.

Results

Removal efficiency

As demonstrated in Figure 4, COD, TSS, TP, and TN removal efficiency in the MLE and SEP-MLE processes were evaluated under stable conditions. In addition, using GPS-X software, the effluent quality (TP, TN, and COD) for both processes was assessed at a constant flow rate over 30 days, as presented in Figure 5.

Table 1: Quantitative characteristics of the wastewater

Parameter	Amount
Q (m^3/day)	800
BOD_5 (mg/L)	228
COD (mg/L)	486
TSS (mg/L)	261
VSS (mg/L)	167
TN (mg/L)	30
TP (mg/L)	7
Temperature (°C)	20
Alkalinity (mg/L as $CaCO^3$)	352

COD: Chemical oxygen demand, TSS: Total suspended solids, VSS: Volatile suspended solids, TN: Total nitrate, TP: Total phosphorus

Table 2: Qualitative characteristics of wastewater

Parameter	Amount
Population (person)	4766
Height sea (m)	900
Annual rainfall (mm)	138.4
Minimum temperature (°C)	4.9
Maximum temperature (°C)	32.8
Relative humidity (%)	40.5
Evaporation (mm)	2057

Quantity shock

During the simulation under quantity shock conditions, the influent wastewater flow rate varied by 200%, and the impact on the removal efficiency of COD, TSS, TP, and TN

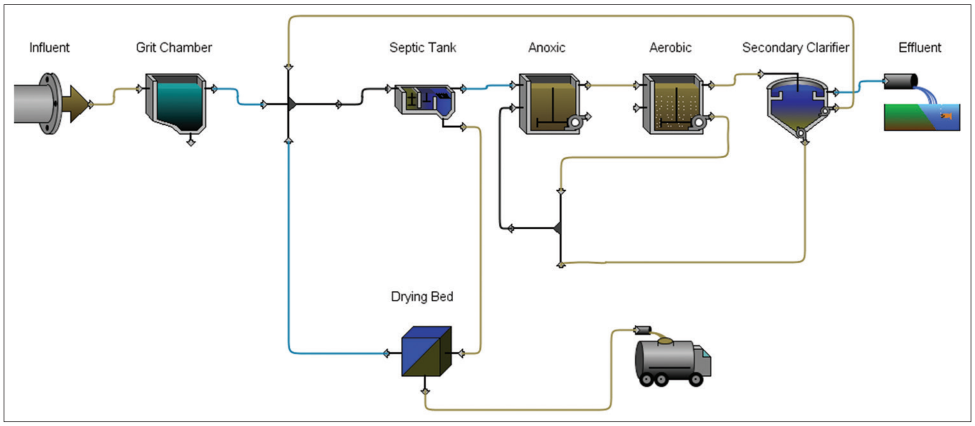

Figure 2: Flow diagram of Modified Ludzack–Ettinger Process

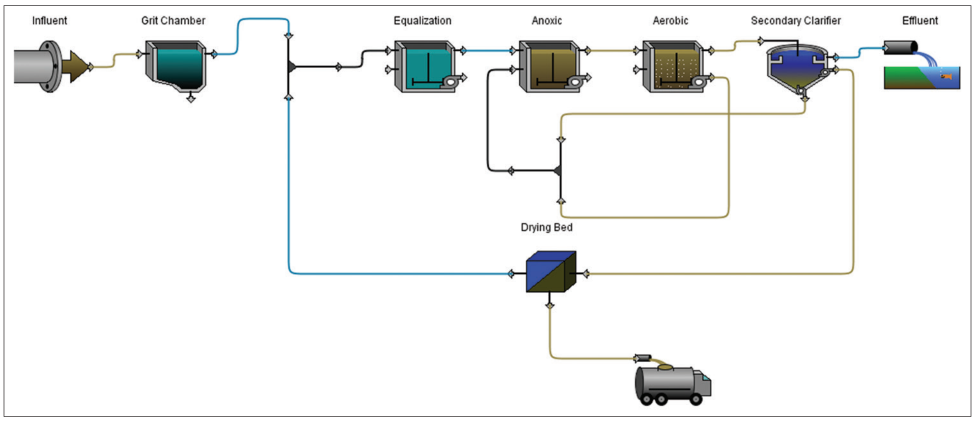

Figure 3: Flow diagram of septic tank-Modified Ludzack–Ettinger process

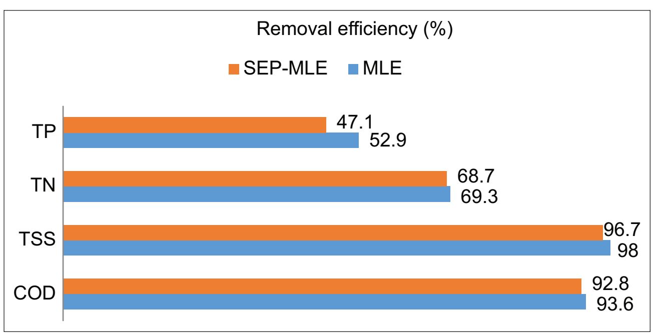

Figure 4: Comparison of removal efficiencies for chemical oxygen demand, total suspended solids, total phosphorus, and total nitrate in the modified Ludzack–Ettinger (MLE) and septic tank-MLE processes. MLE: Modified Ludzack–Ettinger, SEP-MLE: Septic tank-MLE, TSS: Total suspended solids, TN: Total nitrate, TP: Total phosphorus, COD: Chemical oxygen demand

was assessed. Based on an influent flow rate of 1600 m^3/day (200% higher than the baseline flow rate of 800 m^3/day), the results showed that the concentrations of COD, TSS, TN, and TP in the effluent of the MLE process were 36 mg/L, 11 mg/L, 12.5 mg/L, and 3.4 mg/L, respectively. For the SEP-MLE process, the concentrations were 50 mg/L for COD, 20 mg/L for TSS, 13 mg/L for TN, and 3.5 mg/L for TP. An MLSS concentration between 2800 and 6500 mg/L is required to achieve compliance with effluent standards during a quantity shock in the MLE process. However, under the same conditions in the SEP-MLE process, the MLSS concentration is maintained between 3100 and 4600 mg/L. According to the simulation, as shown in Figure 6, the quantitative shock resilience in the MLE and SEP-MLE processes was approximately 18% and 40%, respectively.

Quality shock

During the simulation under quantity shock conditions, the influent wastewater concentration increased by 200%, and the impact on the removal efficiencies of COD, TSS, TP, and TN was investigated. As shown in Figure 7, with increasing concentrations of the parameters, the MLSS required for both processes gradually increased. Under shock conditions, the removal efficiency in the MLE process was 88.1% for COD, 96.9% for TSS, 50% for TN, and 77.1% for TP. In the SEP-MLE process, the removal efficiency was 86% for COD, 95.8% for TSS, 63.3% for TN, and 67.1% for TP. According to the simulation, the quality shock resilience in the MLE and SEP-MLE processes is the same, with both achieving approximately 17%.

Sludge production

The sludge in WWTPs is generated from several sources, including preparation (grit and scum), primary

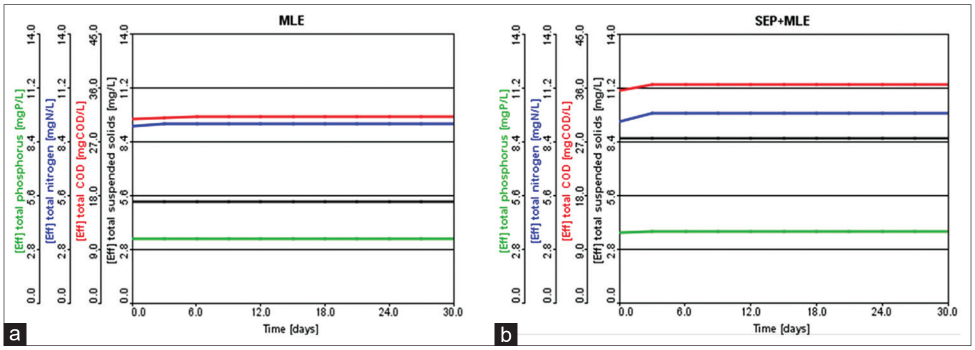

Figure 5: The effluent quality of the chemical oxygen demand, total suspended solids, and total phosphorus (the time simulation is 20 days). (a) MLE: Modified Ludzack-Ettinger (b) SEP-MLE: Septic tank-MLE

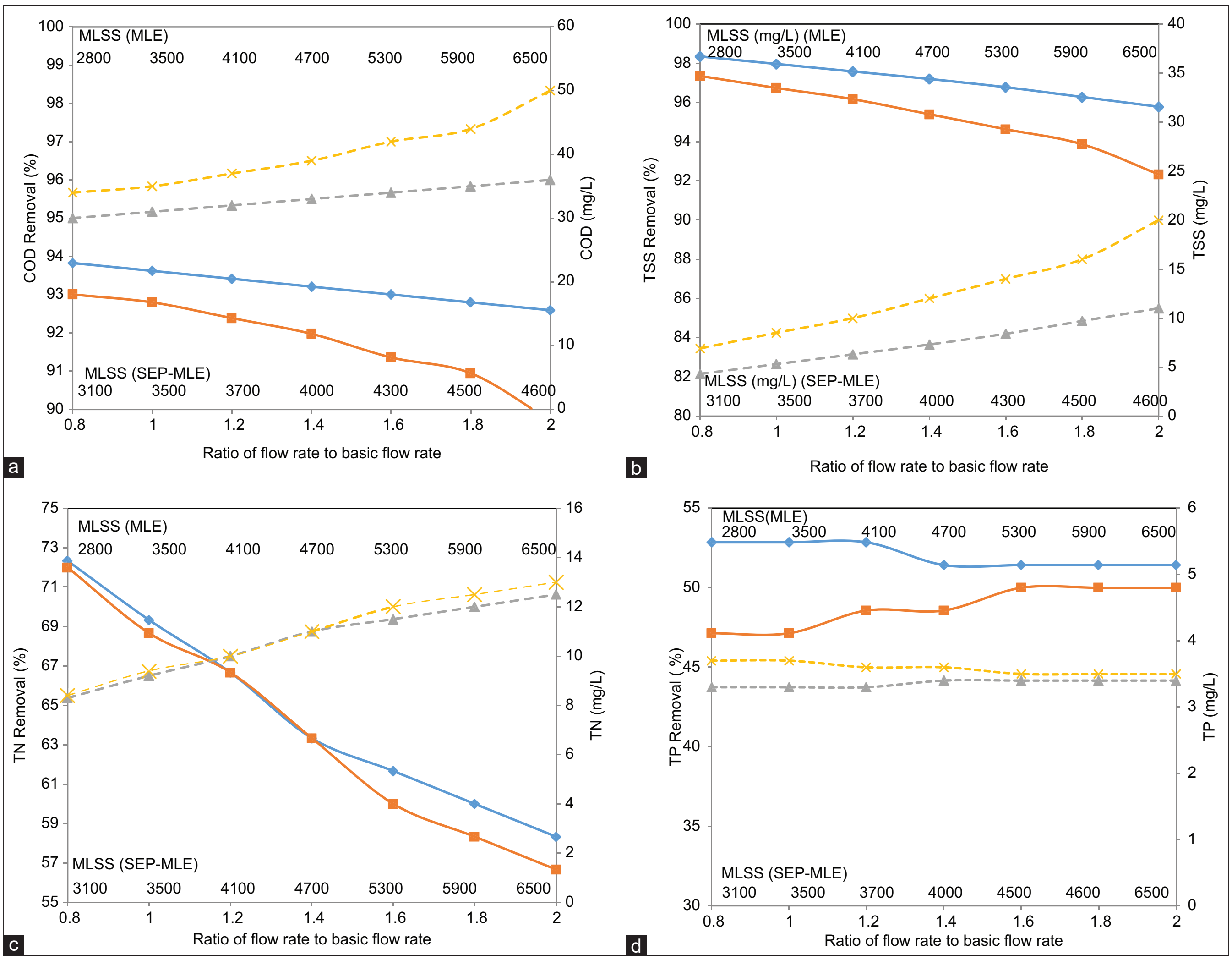

Figure 6: Removal efficiency (%), mixed liquor suspended solid amount, and (a) Chemical oxygen demand (b) Total suspended solids (c) Total nitrate (d) Total phosphorus concentration of the modified Ludzack–Ettinger (MLE) and septic tank-MLE processes with influent wastewater concentration increase (200%). MLSS: Mixed liquor suspended solid, SEP: Septic tank, MLE: Modified Ludzack–Ettinger

sedimentation (primary and sum), and biological treatment (secondary and scum). To compare the characteristics of the sludge produced in the MLE and SEP-MLE processes, the amount of dry biosolids and the percentage of volatile suspended solids in the biosolids entering and exiting the sludge drying beds are presented in Table 6. As can be seen, the sludge amount has been produced in the SEP-MLE and MLE processes 2.5 and 21 m^3/day, respectively. The percentage of dry solids (%) and (5, 0.8) volatile reduction (%) have also been calculated (38, 35).

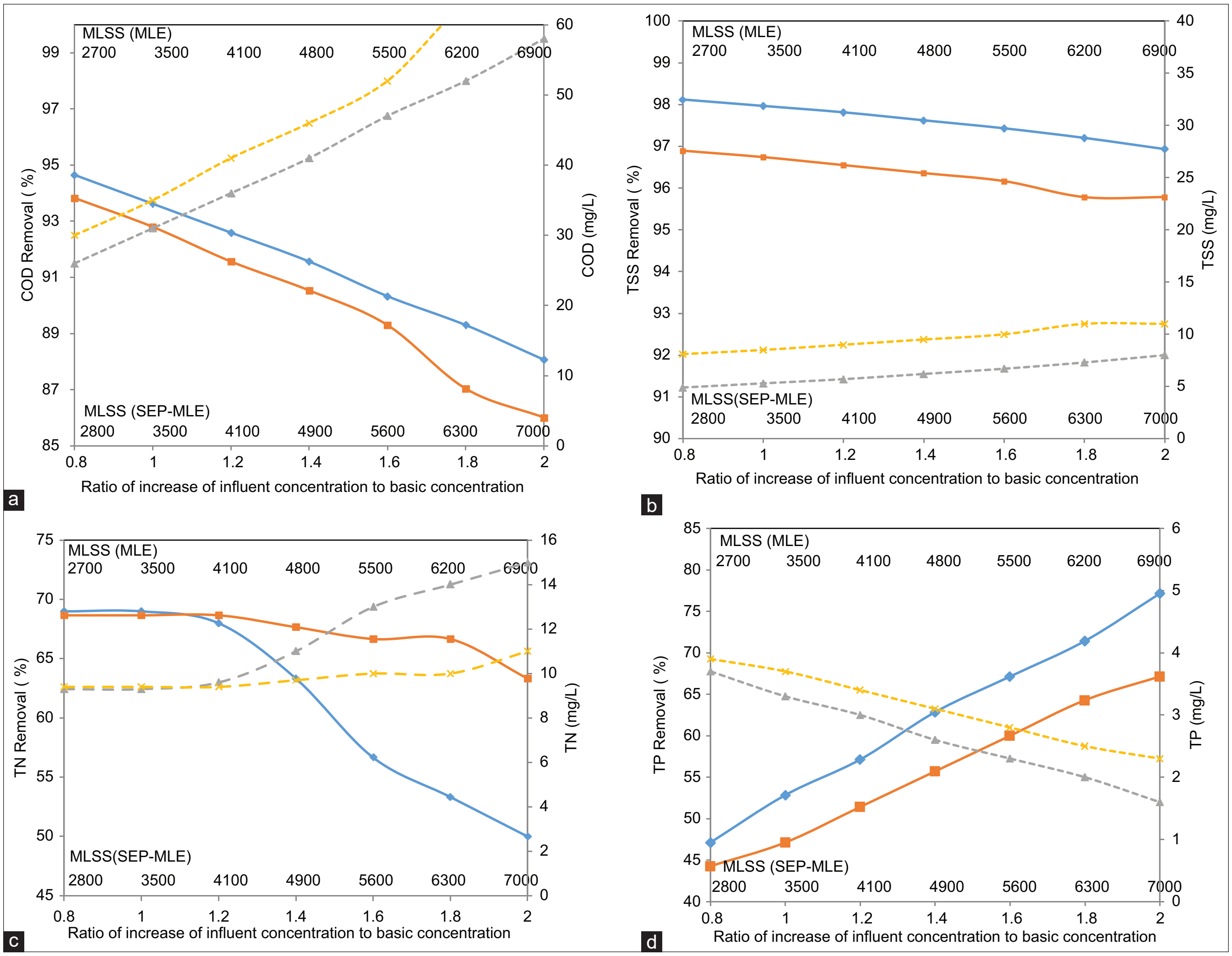

Figure 7: Removal efficiency, mixed liquor suspended solids and a) chemical oxygen demand, b) total suspended solids, c) total nitrate, and d) total phosphorus concentration of the modified Ludzack-Ettinger (MLE) and septic tank-MLE processes with influent wastewater concentration increase (200%). SEP: Septic tank, MLE: Modified Ludzack–Ettinger, MLSS: Mixed liquor suspended solids

Economic analysis

Economic analysis has evaluated the performance of WWTPs in both processes. Based on the list price-Iran for the year 2024, the equations for the PWA and the AEA have been estimated as initial investment costs and the operating cost for each m^3 of wastewater treatment. As illustrated in Figure 8, an initial investment of \$1084 was made in the SEP-MLE option and \$1328 in the MLE option. The operation cost for the MLE option was \$34, whereas for the SEP-MLE option it was \$32 per m^3 of wastewater. Too, Figure 9a,b illustrates initial investment and operation costs including calculated itemes. In addition, the study compared the amount of energy consumed by both options as an economic and environmental parameter. As seen in Figure 10a, the amount of energy consumed per m^3 of wastewater in the SEP-MLE process (1.29 kWh/day) was less than MLE (1.82 kWh/day). The results from the comparison of the required amount of land for the SEP-MLE process and the MLE process are shown in Figure 10b. The results indicate that for every m^3 of wastewater treated, the SEP-MLE process requires less land (6 m^2) than the MLE process (7.22 m^2).

Discussion

The MLE process is an adaptive method for the removal of contaminants from wastewater, and effectively reduce the concentrations of NH_4, PO_4, TSS, COD, and BOD_5 in the effluent.[15] As observed, the removal efficiency of parameters in the MLE process is slightly higher than that of the SEP-MLE process because the microorganisms have entered the degradation phase due to the longer SRT (sludge retention time), leading to a slight increase. To put it another way, longer SRTs promote the growth of slower-growing microorganisms, which enhances the breakdown of complex organic materials and improves nitrogen removal through nitrification and denitrification processes.[10] Abbassi *et al.*[16] studied two modified septic systems with successive anaerobic and aerobic chambers with attached and suspended growth, and

Table 3: Design criteria

Section	Parameter	Unit of SI	SEP-MLE	MLE
Grit chamber	NO	-	1	1
	Length × width (L × W)	m	1.3×13	1.3×13
	Effective depth	m	1.6	1.6
	Q_{air}	m^3/h	31	31
Septic	Number of tank	unit	1	-
	Volume (V)	m^3	700	-
	HRT	d	1	-
	Q_{sludge}	m^3/day	2.5	-
Equalization	NO	-	-	1
	Height (H)	m	-	4
	V	m^3	-	213
Anoxic	NO	-	2	2
	Area (A)	m^2	20	20
	H	m	4.5	4.5
	V	m^3	90	90
	HRT	h	2.7	2.7
	Q_{IR}	m^3	1200	860
Aeration	NO	-	2	2
	A	m^2	40	210
	H	m	4.5	4.5
	V	m^3	180	944
	HRT	hr	5.4	28
	MLSS	mg/L	3500	3500
	SRT	day	5	20
	F/M	day^{-1}	0.25	0.09
	OLR	kg/m^3/day	0.6	0.2
	Q_{air}	m^3/min	9.6	16.8
Sedimentation	NO	-	2	2
	H	m	4.5	4.5
	A	m^2	50	100
	OFR	m^3/m^2/day	16	8
	SLR	$kg/m^2/h$	4	2
	Q_{RE}	m^3/day	620	638
	Q_{WA}	m^3/day	15	21
	IR	-	1.51	1.05
	Q_{IR}	-	1208	861
	RAS	-	0.78	0.78
Chlorination	NO	-	2	2
	L × W	m	4.4×2.2	4.4×2.2
	H	m	2	2
	V	m^3	38.7	38.7
	HRT-peak flow	min	21	21
Drying bed	NO	unit	1	4
	L × W	m	20×8	20×8
	Q_{sludge}	m^3/day	2.5	21

RAS: Return activated sludge, OFR: Over flow rate, SLR: Solid loading rate, MLSS: Mixed liquor suspended solids, SRT: Sludge retention time, F/M: Food to microorganism, OLR: Organic loading rate, IR: Line return, Q_{RE}: Quantity of retuen sludge, Q_{WA}: Quantity of waste sludge, Q_{IR}: Internal recycle quantity, HRT: Hydraulic retention time, Q_{air}: Quantity of air, Q_{sludge}: Quantity of sludge, NO: Number of tank, MLE: Modified Ludzack–Ettinger, SEP: Septic tank

the results showed that the TN was removed by 95% and 59% by suspended and attached growth, respectively. Moussavi *et al*.[17] conducted a study on up-flow septic tanks, which

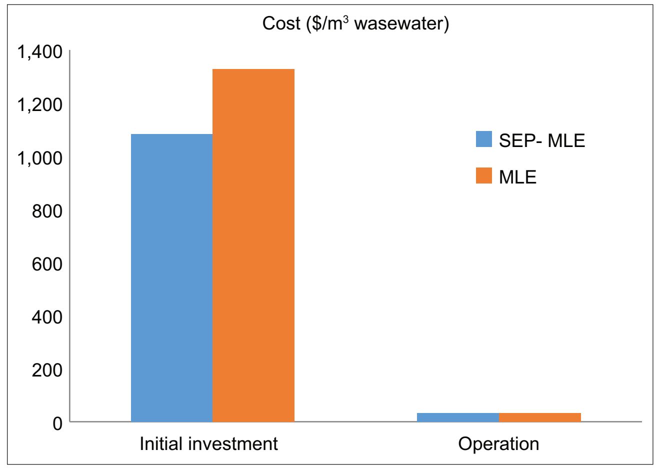

Figure 8: Initial investment and operation costs for both of the processes. SEP: Septic tank, MLE: Modified Ludzack–Ettinger

showed that the process removed BOD_5 85%, COD 77%, and TSS 86%. Makowska *et al*.[18] used a combined septic tank and moving bed biological reactor (MBBR) for wastewater treatment. They reported that the septic tank-MBBR system removes about 88% and 64% of carbon and nitrogen from wastewater, respectively. The above studies have confirmed septic tank influence combined with other processes such as moving bed biofilm reactor (MBBR), up-flow anaerobic sludge blanket, and other activated sludge processes. Quantitative and qualitative shocks in sewage refer to abrupt and substantial changes in the characteristics or conditions of wastewater entering a treatment facility. These shocks disrupt the treatment process, potentially resulting in reduced parameters removal efficiency or failure to comply with effluent standards. The results of the quantity shock showed that the SEP-MLE process is slightly more resistant to shock than the MLE process. There are two approaches to controlling shocks in WWTPs: design and operational approaches. Factors such as effluent standards, environmental conditions, investment and operating costs, and potential environmental impacts must be carefully considered to effectively manage shocks.[19] The SPE-MLE process due to the equalization tank has caused stability flow. Bugajski *et al*.[20] studied an effective septic tank with the aim of optimizing the stable operational percentage of a WWTP. The results showed that the variability and fluctuations of organic pollution in the sewage mixture depended more on the percentage of septic tank sewage than on the level of organic pollution within the sewage. A study conducted by He *et al*.[21] has examined the shock effect of inorganic suspended solids in the surface runoff on the A^2O process. The study showed that the concentration of sludge increased while the mixed liquor volatile suspended solids/MLSS ratio decreased, which disrupted the normal operation of the WWTP. Abbassi *et al*.[16] stated that shock loads have a destructive effect on the operation of the processes investigated in sewage treatment facilities. Sludge production management in sewage treatment plants is costly and often leads to operational issues. To minimize the costs, implementing a

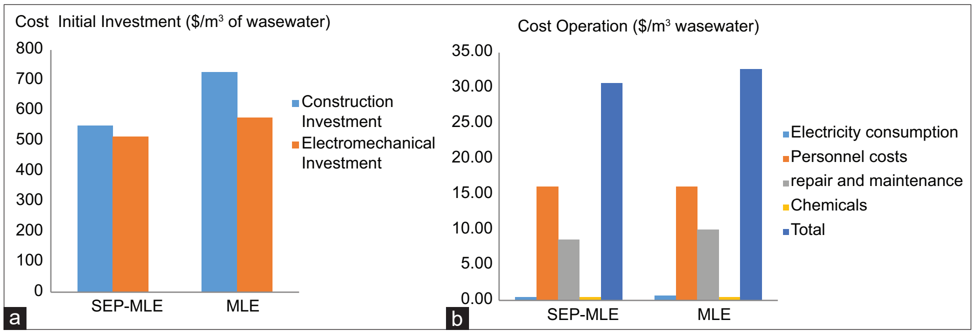

Figure 9: (a) Comparison of initial investment (calculated items) and (b) Operation costs (calculated items); for modified Ludzack–Ettinger (MLE) and septic tank-MLE processes. SEP: Septic tank, MLE: Modified Ludzack–Ettinger

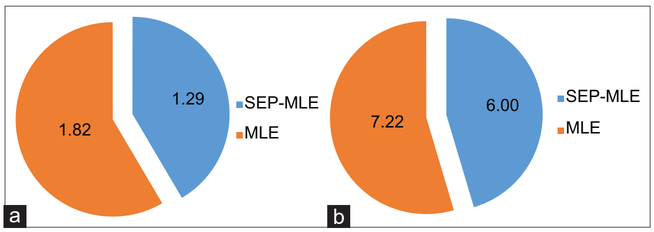

Figure 10: (a) Energy consumption (kwh/day) and (b) Area (m²) for Modified Ludzack–Ettinger (MLE) and septic tank-MLE processes. MLE: Modified Ludzack–Ettinger, SEP: septic tank

treatment method to reduce sludge production is essential.[22,23] Hence, the MLE process results in higher sludge production with a lower concentration and reduced volatile content compared to the SEP-MLE. As a result, the sludge produced by the SEP-MLE process has been classified as Category B and can be safely used as fertilizer for raw products. In contrast, the MLE process achieves a lower degree of sludge stabilization compared to the SEP-MLE process, resulting in sludge of inferior quality. Sharma *et al.*[24] designed a septic tank-anaerobic filter system for domestic wastewater treatment, with their study corroborating the findings of the present research. In fact, the results indicate that the SEP-MLE option provides adequate time for sludge stabilization within the septic tank, leading to improved sludge quality and higher concentration. As a result, a significant reduction in the excess volume of sludge in the septic tank was observed, consistent with the findings of Ohsaka.[25] Wastewater treatment processes in Iran have been economically justified due to the country's lower energy costs compared to other nations.[26] In addition, the SEP-MLE has lower initial capital and operating costs compared to the MLE, rendering it a suitable option for communities with smaller populations and available land. A study utilized an artificial neural network to develop an optimal energy consumption model for a WWTP. The results indicated that an increase in organic load significantly elevated energy consumption.[27] Indeed, aeration systems represent a significant component of wastewater management costs. In mechanical or surface aeration systems, electricity consumption ranges from 0.18 kWh/m³ and 0.8 kWh/m³.[28] In conclusion, energy consumption is a key factor in the economic analysis of water and wastewater treatment processes. The results indicated that the initial investment and annual operating costs for the MLE option were higher than those of the SEP-MLE process, making SEP-MLE the more cost-effective alternative. The difference between these two processes is based on the design parameters provided in Table 3. The SRT for the SEP-MLE and MLE processes are set at 5 days and 20 days, respectively. The aeration tank

Table 4: Specifications of the aeration system of the wastewater treatment plant

DO (mg/L)	2
Alfa factor (α)	0.6
Beta factor (β)	0.95
Diffuser fouling factor (F)	0.9
SOTE	0.21

SOTE: Standard oxygen transfer, DO: Dissolved oxygen

Table 5: The standard of the effluent of the wastewater treatment plant to discharge to surface water

Parameter (mg/L)	Standard of EPA	Standard of WHO	Standard of Iran
BOD_5	<30	<6	<30
COD	<250	<30	<60
TSS	<100	<0.75	<40
TN	<16	>16	<16
TP	<5	>3.5	<6

EPA: Environmental protection agency, WHO: World Health Organization, COD: Chemical oxygen demand, TSS: Total suspended solids, TN: Total nitrate, TP: Total phosphorus

Table 6: Characteristics of sludge drying beds of the Modified Ludzack-Ettinger and septic tank - Modified Ludzack-Ettinger processes

Process	SEP-MLE		MLE	
Bed area (m²)	160		640	
Volatile reduction (%)	38		35	
Characteristics	**Input**	**Output**	**Input**	**Output**
Q sludge (m³/day)	2.5	0.6	21	0.6
Percent of dry solids (%)	5	20	0.8	20

MLE: Modified Ludzack–Ettinger, SEP: Septic tank volumes for the SEP-MLE and MLE processes are 180 m^3 and 944 m^3, respectively. The required oxygen demand for these processes is 9.6 m^3/min for the SEP-MLE and 16.8 m^3/min for the MLE process. Abbasi *et al*.[16] conducted a study on the cost of various treatment processes and found that modified septic tanks emerged as an economical solution, characterized by minimal energy requirements as well as low operational and maintenance demands. Moreover, Liu G *et al*.[15] demonstrated that models such as GPS-X are utilized for technical and economic simulations in WWTP management, facilitating comparisons between different processes. The limitations of modeling with GPS-X software include challenges in calibration, assumptions made in the data, and issues related to software updates and support. Moreover, conducting a sensitivity analysis is recommended to enhance the accuracy of the results.

Conclusions

This study compares the MLE process combined with a septic tank for wastewater treatment in small communities using GPS-X modeling. The removal efficiencies of COD, TSS, TN, and TP for both processes were high, with negligible differences, and met national and international standards. The aeration tank parameters of the SEP-MLE process, including volume, hydraulic retention time, and airflow rate (Q_{air}), are smaller than those of the MLE process. The results indicate reduced costs and simplified operation. Furthermore, compared to the SEP-MLE process, the MLE process exhibits higher levels of organic loading and F/M. The SEP-MLE process produces a lower sludge concentration compared to the MLE process. In addition, the sludge generated from the SEP-MLE process meets the Class B sludge standard, indicating a higher quality. Moreover, the energy consumption and land requirements of the SEP-MLE process are lower than those of the MLE process. The SEP-MLE process requires 19% less investment and incurs 10% lower operational costs per m^3 of wastewater treated compared to the MLE process. Therefore, the SEP-MLE process is a suitable option due to fluctuations in both the quantity and quality of wastewater in small communities.

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Ethical approval statement

Ethical approval for this study was not required, as the research was conducted entirely within the private company of Water and Wastewater Consulting Engineers (WWCE), Isfahan, Iran, and did not involve any human participants, animal subjects, or identifiable personal data.

Conflicts of interest

There are no conflicts of interest.

Authors' contributions

Mitra Hosseini: Conceptualization, Project administration, review and editing of the final manuscript; Saba Majidi: Methodology, Data Analysis, Writing of the original draft.

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