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Original Article

Simple Local Wastewater Treatment Unit for Isolated Inhabited Areas to Produce Reusable Water for Irrigation

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Abstract - *In Egypt, the coverage of water delivery and sanitation varies greatly; just 34% of people in rural areas have access to sanitation services, whereas 99% of people in urban areas have. This gap has led to significant environmental deterioration since untreated wastewater is often released into the environment, harming both surface and groundwater. Due to the severe water scarcity in the country, particularly in rural areas, there is an urgent need for affordable and sustainable wastewater treatment technologies. Centralized treatment systems are often impractical in these areas due to their high construction, operating, and maintenance costs [8, 9]. Anaerobic treatment technologies offer a workable decentralized solution to the wastewater management issue when included in modified septic systems. These systems are affordable, low-maintenance, and capable of treating wastewater for rural communities [11, 12]. This article examines how modified septic tank systems and anaerobic treatment technologies might improve wastewater treatment efficacy and promote water reuse in rural Egypt [10].*

Keywords - *Wastewater Treatment, Septic Tank, Reusable Water, Simple Local Treatment, Anaerobic Biological Filter, Slow Sand Filter.*

1. Introduction

The water supply coverage rate in Egypt is exceptionally high, with 99% of the population in inhabited regions having access to water. However, just 34 percent of rural residents have access to sanitary facilities. This wide gap in sanitation coverage results in untreated effluent being dumped into the environment, seriously contaminating surface and groundwater resources. Egypt's expanding environmental issues and water scarcity, particularly in rural areas, have made sustainable wastewater treatment solutions more important than ever [1, 8].

Home wastewater contains various chemicals, minerals, and bacteria that may harm the environment and cause waterborne infections; therefore, improper wastewater disposal can lead to several health issues. The issue of providing appropriate sanitation services in rural regions is worldwide, with 82% of rural people in poor countries without access to basic sanitation services [2].

Egypt's position is particularly troubling because of its reliance on freshwater resources like the Nile River. Most rural populations dwell near the Nile, where untreated wastewater contaminates groundwater and seeps into the soil, putting human health and agricultural productivity at risk [9], [3]. Sustainable wastewater treatment solutions that can satisfy the expanding needs of rural areas are desperately needed to address this problem. Due to the high construction, operation, and maintenance expenses, traditional centralized wastewater treatment systems are expensive and technically difficult to operate in rural regions [4].

Decentralized treatment methods have, therefore, become a practical option. Anaerobic treatment procedures incorporated into modified septic systems are one example. These low-cost, low-maintenance systems provide the potential for wastewater reuse in agriculture, which is especially important in a water-scarce nation like Egypt [5, 6].

Anaerobic treatment systems are the subject of this review, emphasizing their benefits in lowering organic pollutants, limiting sludge generation, and producing methane as a possible energy source. The evaluation also covers several ways to improve the performance of conventional septic tanks and offer a sustainable wastewater treatment option in rural Egypt, such as using up-flow filters and dual operating conditions. Egypt can solve its sanitation and water shortage issues by implementing decentralized, economically viable treatment systems that would drastically lower environmental pollution, safeguard public health, and guarantee the sustainable reuse of water in agriculture [10, 13].

2. Problem Formulation

Groundwater and other bodies of water are widely contaminated as a result of Egypt's rural areas' poor wastewater treatment facilities. There are serious threats to the ecosystem and human health since domestic wastewater in these locations is frequently released into the environment untreated.

Traditional treatment methods are expensive to build and maintain, making them unfeasible in remote locations with limited access to centralized wastewater treatment plants. As a result, raw sewage has been inappropriately disposed of, damaging agricultural fields and sources of drinking water and accelerating the development of waterborne illnesses.

3. Materials and Methods

The pilot design took the following considerations into account.

1. The pilot served one house for people ranging from 2 to 15 people with an average 7 persons.
2. The unit's design criteria were taken according to the Egyptian code for wastewater works in rural areas; also, the water consumption was 100 litres/day.
3. The unit was designed to have consisted of the following parts:
   - The first tank is a septic tank with a volume of 500 liters with a Diameter = 83 cm and a height of 100 cm, as shown in Figure 1.
   - The second tank is a biological filter of 200 liters size with a Diameter = 60cm and a height of 100cm, as illustrated in Figure 2.
   - The third tank is a slow sand filter using a tank of 200 liters with a volume of Diameter = 60cm and height of 100cm, as illustrated in Figure 3.

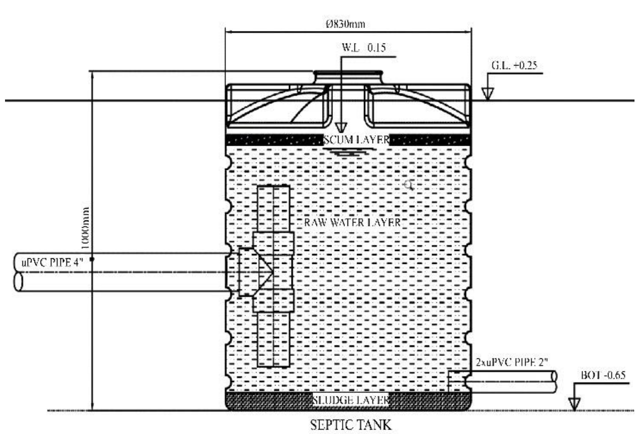

Fig. 1 Septic tank plan

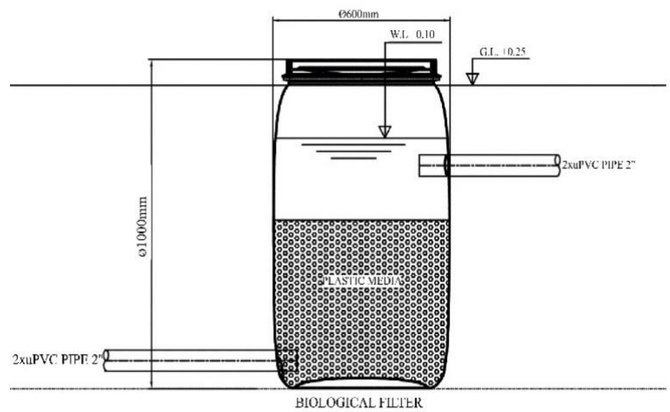

Fig. 2 Biological filter plan

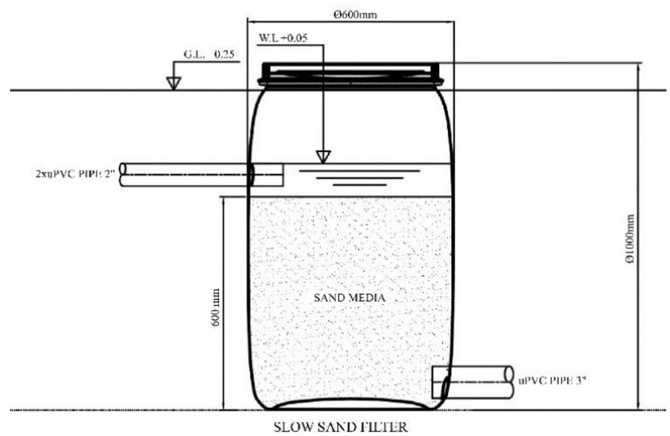

Fig. 3 Slow sand filter plan

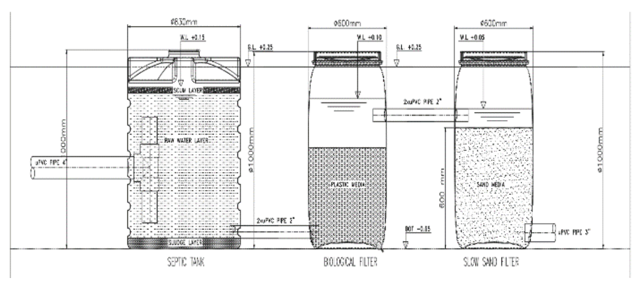

Fig. 4 Integrated system

4. Operation Program

The unit was designed for five users and connected exclusively to toilet base wastewater. It consists of three sequential tanks: a 500 L septic tank, a 200 L biological filter, and a 200 L slow sand filter.

The septic tank was sized based on the Egyptian Code, which states that wastewater should remain in the tank for 24 to 72 hours to ensure adequate retention and initial treatment. Since the average water usage per person is 100 L/day, a 500 L capacity ensures a minimum retention time of 24 hours for five users.

The system was installed at the Faculty of Engineering, Ain Shams University. The first tank was filled after one day of operation, while the second and third tanks were filled by the second day. Once stabilized, treated effluent was discharged into a sequential irrigation system.

Samples were taken twice a week during the operation period. Six samples were taken in each run. Each sample covered four locations in the pilot, considering the retention time in each unit to ensure the effect of each treatment step. The illustration of run results is shown hereafter**.**

5. Results

Tables 1 to Table 5 and Figures 5 to 12 show all sample analysis results in this run as follows.

Table 1. Results of the first run

Run no.		Location	pH	TDS (mg/l)	TSS (mg/l)	COD (mg/l)
1	Maximum	influent	6.93	560.00	95.00	2,000.00
		septic effluent	7.04	672.00	80.00	197.00
		biological effluent	7.23	662.00	49.00	180.00
		pilot effluent	7.12	642.00	26.00	153.00
	Minimum	influent	6.80	550.00	88.00	1,950.00
		septic effluent	6.93	650.00	70.00	180.00
		biological effluent	7.02	650.00	40.00	158.00
		pilot effluent	7.00	630.00	22.00	139.00
	Average	influent	6.88	555.33	91.17	1,987.33
		septic effluent	7.00	663.33	74.83	190.50
		biological effluent	7.15	655.17	44.93	162.17
		pilot effluent	7.08	635.83	24.03	145.83

Table 2. Results of the second run

Run no.		Location	pH	TDS (mg/l)	TSS (mg/l)	COD (mg/l)
2	Maximum	influent	6.83	611.60	132.00	2,031.70
		septic effluent	7.10	682.00	83.60	343.20
		biological effluent	7.20	687.50	61.60	239.80
		pilot effluent	7.50	729.30	31.90	85.80
	Minimum	influent	6.60	500.40	108.00	1,662.30
		septic effluent	6.80	558.00	68.40	280.80
		biological effluent	6.83	562.50	50.40	196.20
		pilot effluent	7.10	596.70	26.10	70.20
	Average	influent	6.75	553.68	119.50	1,839.30
		septic effluent	6.95	617.42	75.68	310.70
		biological effluent	7.00	622.40	55.77	217.09
		pilot effluent	7.24	660.24	28.88	77.68

Table 3. Results of the third run

Run no.		Location	pH	TDS (mg/l)	TSS (mg/l)	COD (mg/l)
3	Maximum	influent	6.87	644	315	1,923.90
		septic effluent	7.20	737	90	334.40
		biological effluent	7.20	770	35	315.70
		pilot effluent	7.30	737	26	128.70
	Minimum	influent	6.60	526.50	257.40	1,574.10
		septic effluent	6.80	603.00	73.80	273.60
		biological effluent	6.90	630.00	28.80	258.30
		pilot effluent	6.81	603.00	21.60	105.30
	Average	influent	6.78	582.56	284.81	1,741.71
		septic effluent	6.98	667.21	81.66	302.73
		biological effluent	7.02	697.08	31.87	285.80
		pilot effluent	7.12	667.21	23.90	116.51

Table 4. Results of the fourth run

Run no.		Location	pH	TDS (mg/l)	TSS (mg/l)	COD (mg/l)
4	Maximum	influent	6.83	717.20	468.60	1,887.60
		septic effluent	7.10	732.60	44.00	291.50
		biological effluent	7.10	728.20	107.80	224.40
		pilot effluent	7.30	730.40	79.20	113.30
	Minimum	influent	6.50	586.80	383.40	1,544.40
		septic effluent	6.70	599.40	36.00	238.50
		biological effluent	6.85	595.80	88.20	183.60
		pilot effluent	7.00	597.60	64.80	92.70
	Average	influent	6.62	649.28	424.23	1,708.85
		septic effluent	6.85	663.23	39.83	263.90
		biological effluent	6.94	659.24	97.59	203.15
		pilot effluent	7.13	661.23	71.70	102.57

Table 5. Results of the fifth run

Run no.		Location	pH	TDS (mg/l)	TSS (mg/l)	COD (mg/l)
5	Maximum	influent	6.70	628.10	332.20	1,925.00
		septic effluent	6.90	721.60	59.40	308.00
		biological effluent	6.90	715.00	35.20	233.20
		pilot effluent	7.20	721.60	28.60	116.60
	Minimum	influent	6.50	513.90	271.80	1,575.00
		septic effluent	6.70	590.40	48.60	252.00
		biological effluent	6.80	585.00	28.80	190.80
		pilot effluent	6.95	590.40	23.40	95.40
	Average	influent	6.62	568.62	300.74	1,742.71
		septic effluent	6.78	653.27	53.78	278.83
		biological effluent	6.85	647.29	31.87	211.12
		pilot effluent	7.04	653.27	25.89	105.56

6. Discussion

The following points have been raised from previous results for the treatment system influent and effluent for pH, TDS, TSS and COD concentrations.

- The pH results indicate a slightly basic to neutral effluent (average pH = 7.12), typical of well-operated biological and physical treatment systems. The pH range of 6.81 to 7.5 mg/L shows slight fluctuations, but overall, the effluent remains within a suitable range for agricultural irrigation, where a pH of 6.5 to 8.5 is often ideal for most crops.
- In five runs, the influent Total Dissolved Solids (TDS) concentrations ranged from 500 to 717.2 ppm, averaging 581.9 ppm. The effluent TDS concentrations ranged from 590.4 to 737 ppm, averaging 655.56 ppm. The difference between the influent and effluent TDS concentrations varied from +10 ppm to +117 ppm, with an average increase of +73.6 ppm. This increased TDS concentrations, with a range of +2.00% to +19.00% and an average increase of +13.00%.
- The integrated system did not succeed in removing Total Dissolved Solids (TDS) as outlined in the Egyptian Code for Waste Water Treatment (WWT) [7]. Despite the system's design, the TDS concentrations increased rather than decreased, which indicates that the system did not achieve the expected level of treatment for this parameter.
- In five runs, the influent Total Suspended Solids (TSS) concentrations ranged from 88 to 468.6 ppm, averaging 244.09 ppm. The effluent TSS concentrations ranged from 21.6 to 79.2 ppm, averaging 34.88 ppm. The difference between influent and effluent TSS concentrations varied from 65 ppm to 389 ppm, with an average reduction of 208.6 ppm. This resulted in a removal efficiency ranging from 74.00% to 92.00%, with an average removal efficiency of 83.00%.
- In this study, the removal efficiency of Total Suspended Solids (TSS) was found to be 92.00%. This value is higher than the typical removal efficiency range of 50% to 70% expected in conventional septic tanks, and it exceeds the 70% limit specified by the Egyptian Code for WasteWater Treatment (WWT) [7].
- In five runs, the influent Chemical Oxygen Demand (COD) concentrations ranged from 1544.4 to 2031.7 ppm, averaging 1803.98 ppm. The effluent COD concentrations ranged from 70.2 to 153 ppm, with an average of 109.63 ppm. The difference between influent and effluent COD concentrations varied from 1451 ppm to 1945 ppm, with an average reduction of 1694.1 ppm. This resulted in a removal efficiency ranging from 92.50% to 96.00%, with an average removal efficiency of 94.00%.
- This study's average COD removal efficiency was 96%, significantly higher than the typical removal efficiency of 50% to 70% for conventional septic tanks, as specified by the Egyptian Code for WasteWater Treatment (WWT) [7].
- Despite the low TDS removal efficiencies, the treated effluent from the integrated system, with its high COD and TSS removal efficiencies, may still be suitable for certain types of agricultural irrigation, particularly for non-food crops, forage crops, and ornamental plants. According to the FAO guidelines, treated wastewater with relatively high TDS can be used to irrigate non-food crops as long as the other parameters, such as COD and TSS, are within acceptable limits.
- In particular, crops like eucalyptus, alfalfa, and cotton can be irrigated with treated wastewater from this system, while food crops like potatoes and sugar beets may also be irrigated if the effluent quality meets the required standards. However, the suitability of treated wastewater for direct irrigation of food crops will depend on the specific crop type and its tolerance to the levels of dissolved solids, which may require further investigation.
- In conclusion, while the system showed high efficiencies in removing organic matter and suspended solids, TDS removal remains a challenge, and further improvements or additional treatment processes may be required to enhance the removal of dissolved solids, especially if the treated effluent is to be used for irrigation of food crops.

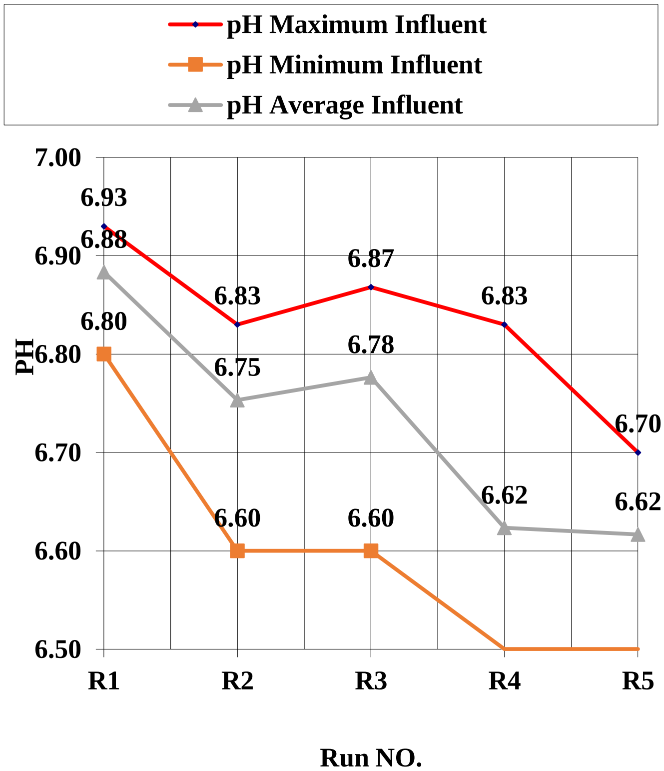

Fig. 5 pH influent value variation through the pilot units in 5 Runs

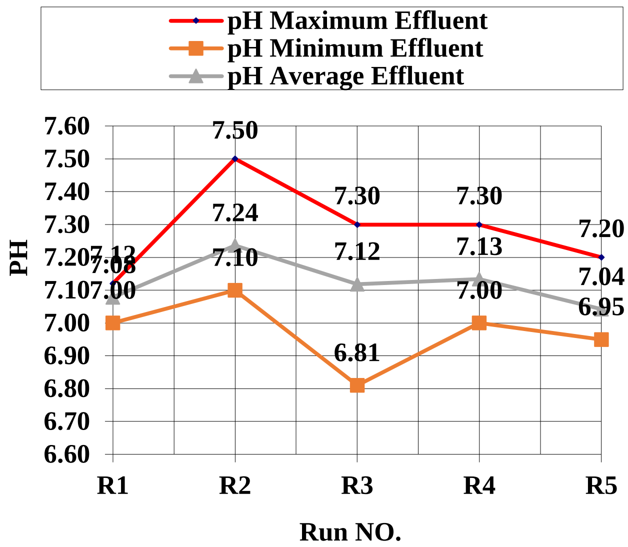

Fig. 6 pH effluent value variation through the pilot units in 5 Runs

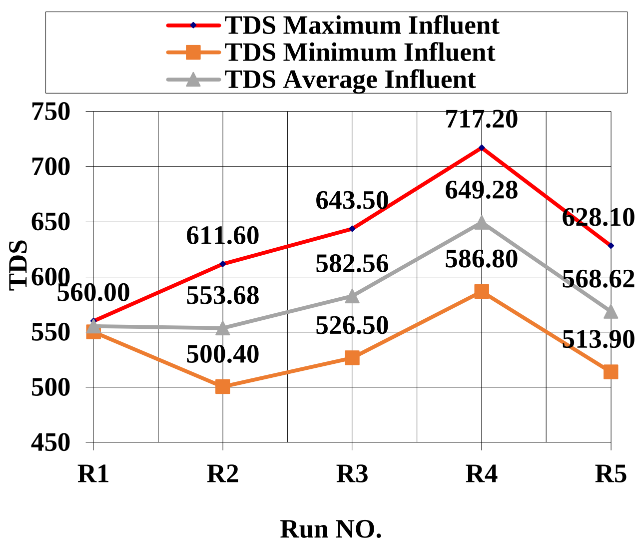

Fig. 7 TDS influent value variation through the pilot units in 5 Runs

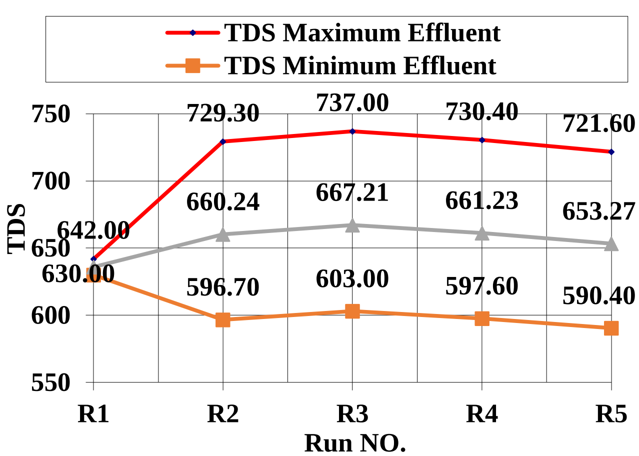

Fig. 8 TDS effluent value variation through the pilot units in 5 Runs

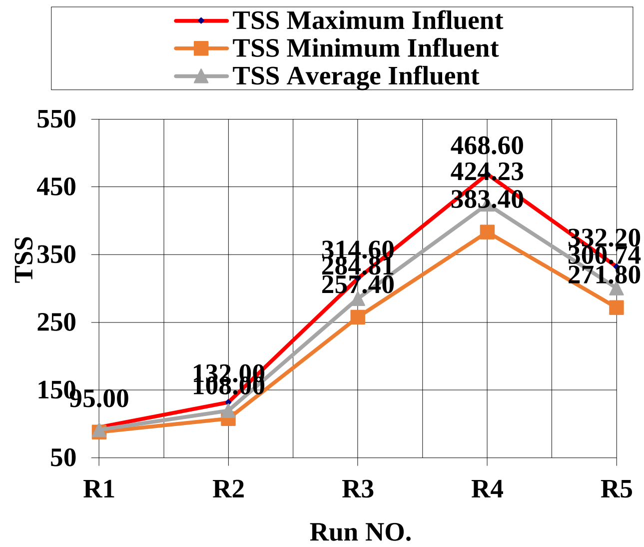

Fig. 9 TSS influent value variation through the pilot units in 5 Runs

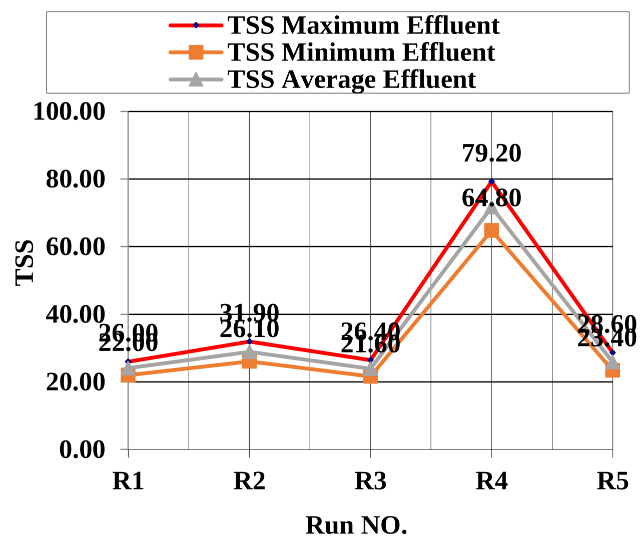

Fig. 10 TSS effluent value variation through the pilot units in 5 Runs

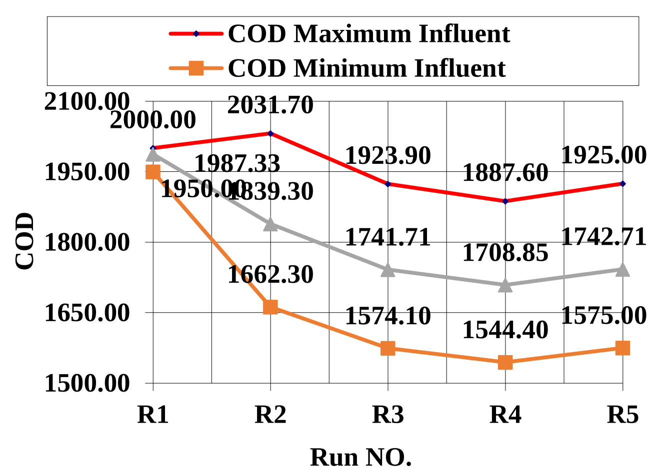

Fig. 11 COD influent value variation through the pilot units in 5 Runs

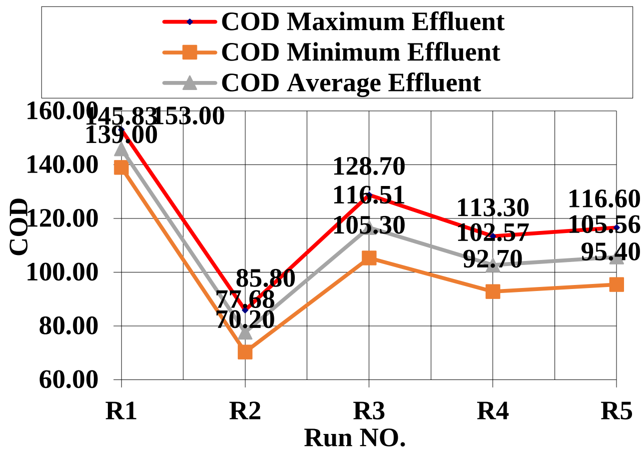

Fig. 12 COD effluent value variation through the pilot units in 5 Runs

7. Conclusion

This study examined how effectively a combined wastewater treatment system works. This system includes three parts: a septic tank, an anaerobic biological filter, and a slow sand filter. It was tested to see if it can clean wastewater and recycle it in an environmentally safe way. Researchers looked at the stability of pH levels and how well the system removed Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and Total Dissolved Solids (TDS).

7.1. COD Removal

The system was highly effective at removing COD, achieving an average removal rate of 94%. This is much higher than the usual removal range of 50% to 70% for regular septic tanks and exceeds the 70% removal rate required by the Egyptian Code for wastewater treatment. The successful removal of COD indicates that the system is suitable for situations needing high COD reduction.

7.2. TSS Removal

The system also showed TSS removal efficiency ranging from 74% to 92%, with a mean efficiency of 83%. This level of performance is above the 70% standard established by the Egyptian Code for WWT and is higher than the typical septic tank removal efficiency, which is 50% to 70%. The high percentage reduction of suspended particles proves the system's ability to enhance the purity and quality of the treated effluent.

7.3. TDS Removal

The system did not reduce TDS concentrations, contrary to its performance regarding COD and TSS. Rather than being reduced, the effluent TDS concentrations averaged an increase of 13%, with a range of +2.00% to +19.00%. This indicates that the system did not achieve the removal efficiency set by the Egyptian Code for wastewater treatment. The buildup of dissolved solids indicates that further treatment procedures, such as ion exchange or advanced filtration, might be necessary to achieve TDS removal requirements.

7.4. pH Stability

The effluent possessed a consistent average pH of 7.12, which was within the acceptable limit for the reuse of treated wastewater. The system could produce a neutral to slightly alkaline effluent suitable for use in irrigation, as shown by pH values that ranged between 6.81 and 7.5.

7.5. Overall System Evaluation

Regarding COD and TSS removal, the combined treatment system worked much better than traditional septic tanks. It was ineffective in reducing TDS, though, so other adjustments or treatment processes need to be implemented to help enhance the overall quality of water. The system sustained the pH so that the treated water would still be compatible with the irrigation of non-root crops. Additional changes are needed to reduce TDS buildup and maximize overall performance despite the system's potential decentralized applications for wastewater treatment.

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