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Evaluation of on-Site Sanitation Systems: Efficiency of Baffled Septic Tanks

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Abstract

Domestic wastewater from homes without sewerage is discharged directly into the ground, rivers or streams, which generates health and pollution problems. Septic tanks are used as an on-site treatment by a significant fraction of the world's population. This study aimed to evaluate the efficiency of domestic wastewater treatment using septic tanks with baffles implemented in rural households. The septic tanks were built and evaluated as part of a research project, focused on decentralized domestic wastewater treatment systems at the rural level. The septic tanks operated with detention times of 4.44; 2.67 and 1.90 days. The data was obtained through five monitoring campaigns with a fortnightly frequency, taking water samples at the entrance and exit of each septic tank. After sample collection, concentration levels of BOD_5, COD, total suspended solids (TSS), nitrates, and phosphates were determined according to Standard Methods for the Examination of Water and Wastewater. A BOD5 removal of 31.28±8.69%, COD removal of 30.52±7.89%, TSS removal of 39.39±11.90% was obtained, while there was an increase in nitrates of 41.41±3.85% and an increase in phosphates of 46.89± 36.77%. The removal values were affected by the retention time and the initial concentration of the parameters. The data could be useful in designing and operating on-site septic tanks, characterizing strictly domestic contamination, as well as incorporating them into future research or innovations related to single-family homes. Likewise, these data could be entered into the databases used for the evaluation of septic tanks with baffles.

Keywords: Baffles; Decentralized treatment; Nutrients; Septic tanks; Wastewater treatment

1. Introduction

Untreated domestic wastewater (DWW) discharges are contaminating the surface and groundwater [1,2]. The presence of dispersed houses and very far from populated centers prevents the treatment of their DWWs in centralized systems [3]. This has forced the adoption of measures to promote individual solutions that allow these households to access acceptable safe water and sanitation services. An important challenge in the treatment of DWWs for small towns, which, both urban and rural, may lack sewerage [4]. To deal with this problem, on-site treatment systems are a viable option for sanitation in rural areas and are generally characterized by offering the required treatment results in the most practical way possible, simple, easy to operate and minimum cost [4,5].

On-site sanitation systems play a crucial role in promoting health and well-being in communities worldwide [6]. These systems are necessary in areas where there is no access to centralized sewer systems or wastewater treatment infrastructure [7]. They provide a localized and efficient solution for the safe disposal of domestic wastewater [3]. The efficiency of septic tanks can be improved through the use of baffles [4]. Baffles are internal structures installed in the receiving chamber of the septic tank to promote better separation of solids and liquids, and increased retention of solids in the digestion chamber [8]. In many rural and peri-urban areas of developing countries, septic tanks are the most common form of wastewater management. However, they are also used in urban areas where there is no access to centralized sewer systems [9].

Evaluating the efficiency of septic tanks with baffles is important to ensure proper treatment of wastewater. This involves taking measurements and analyzing relevant parameters such as suspended solids concentration, organic matter concentration, and contaminant removal efficiency [8]. These studies can provide valuable information to improve the design and operation of septic tanks, as well as to develop installation and maintenance guidelines and standards [4]. Therefore, on-site sanitation systems, such as septic tanks, play a vital role in the proper management of wastewater in areas where centralized sewer systems are not available [3]. Septic tanks with baffles can enhance the efficiency of wastewater treatment, thus helping to prevent environmental pollution and safeguard community health. The evaluation of these systems is essential to ensure their optimal functioning and promote sustainable sanitation practices [10].

Among the most widely applied in situ systems are the septic tank, which in recent years has been optimized by implementing baffles that allow longer retention time [4,11]. Septic tanks are commonly used to treat wastewater from families living in towns that do not have sewerage services [12].

One of the main objectives of the septic tank is to create hydraulic stability, which allows the sedimentation by the gravity of heavy particles [13]. Settleable solids in raw

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wastewater form a sludge layer at the bottom of the septic tank. Fats, oils and other light materials tend to accumulate on the surface, forming a floating layer of scum on top and a layer of settled sludge on the bottom [14]. The liquid passes through the septic tank between two layers made up of foam and sludge. The organic matter contained in the layers of mud and foam is decomposed by anaerobic bacteria, and a considerable part of it is converted into carbon dioxide, methane and hydrogen sulfide [15,16]. The settled material (the solids) forms a layer of sludge at the bottom of the tank, which is biologically degraded by the residence time and the action of microorganisms [17].

Septic tanks can only slightly remove contaminants from wastewater, therefore they cannot be used as a stand-alone unit for wastewater treatment and septic tank effluent must be fully treated [11,18]. There is greater efficiency in reducing organic matter in septic tanks with piston flow with respect to complete mixing systems [11]. Very little research has currently been done on the implementation of baffled septic tanks for DWW treatment in low-income countries [19]. Some promising results have been reported in South Africa [20,21]. However, there are still knowledge gaps in this regard, such as the optimal number of baffles and the addition of complementary treatment steps. Septic tank retention time is the time that water remains in this unit [22]. A septic tank is working properly when it has sufficient "settling time" or "retention time" to allow solids to settle as sludge or attach to the floating scum layer on top of the septic tank [23]. Baffles in the tank prevent floating slag from escaping the tank, an event that would lead to rapid system failure [4,14].

According to what was mentioned above, to modify the hydraulic flow regime in septic tanks, some measures must be taken to obtain a plug flow and thus improve its efficiency in wastewater treatment. This study aims to evaluate the performance of conventional septic tanks for the treatment of DWW through the introduction of vertical baffles in the tank. These results allow us to provide information in the field of domestic wastewater treatment using septic tanks. Based on this information, further research can be carried out to improve these on-site wastewater treatment systems.

2. Materials and Methods

2.1. Location

Septic tanks were implemented in three rural homes in the city of Cuenca, Ecuador. These homes do not have a sewer. They are located in the Plane coordinates with UTM projection zone 17 South with Datum WGS84, home 1 X:715910, Y:9677375; home 2 X:715925, Y:9677369; home 3 X:716213, Y:9674837. Three houses were chosen based on certain conditions, so it was considered as the first factor that the house does not have a sewage system; that the houses are in different geographical locations to be able to evaluate the effectiveness of the sanitation system in a variety of contexts, in this case, the average ambient temperature in house 3 varies between 10 and 16 °C, while in houses 1 and 2 the average room temperature in the houses 1 and varies between 13 and 20 °C. Additionally, homes that had between 4 and 6 people residing were considered; In addition to these demographic and geographic factors, other criteria were also considered, such as the willingness of the participants to participate in the study. It should be noted that, before the project, these houses directly discharged wastewater without any treatment to an adjacent stream.

2.2. Design and Construction of the Septic Tanks

To determine the size of the septic tank, the methodology recommended by [4, 24, 25] was used. For the sizing, a design flow of 0.75 m^3/d was used, considering five residents per family and a wastewater production of 150 liters/day per resident. A 2 m long, 0.8 m wide and 1.55 m high tank with 1.25 m useful height was obtained. Obtaining a hydraulic retention time (HRT) of 2.67 days for the dwelling with 5 residents (Home 2). Meanwhile, a retention time of 4.44 days (Home 1) and 1.90 days (Home 3) were obtained.

For the construction, the cleaning and extraction of the weeds from the site were carried out, later the necessary area for the construction of the tanks was delimited. The excavation activities were carried out according to the measures established in the design. The floor was built of concrete, and the side walls and the baffles were built of brick with their respective plastering and waterproofing. The wastewater feed from the house to the septic tank was carried out through 110 mm diameter PVC pipes and fittings. The cover was built with removable concrete covers to facilitate sampling and maintenance.

A schematic of the septic tank implemented in each dwelling is presented in Fig. 1. This system is an improved septic tank, built with alternating baffles, which directs wastewater to flow under and over it as the water moves from inlet to outlet. This design ensures a longer contact time of the wastewater with the sludge and therefore increases efficiency.

This septic tank has two compartments. The wastewater will enter the first compartment where the heavier materials will be placed by their weight in the lower part of the tank and the lighter one's float above the water level. The water will pass into the second compartment, thus ensuring that the materials settled in the first compartment cannot pass into the next. Anaerobic degradation of organic matter will take place in both compartments.

At the top is a layer of scum. In the middle is a layer of water, while at the bottom of the tank is a layer of sludge formed from decomposed solid waste (Fig. 1).

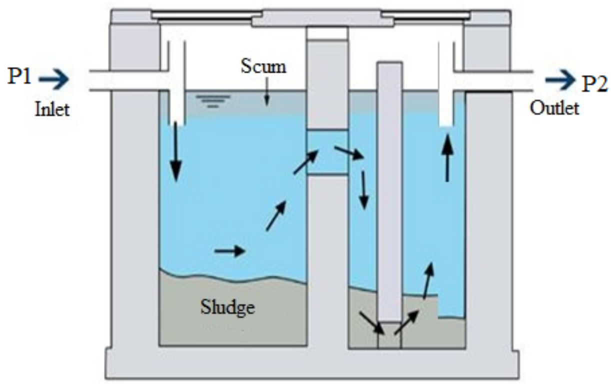

Fig. 1. Septic tank with deflector implemented in the three houses.

Septic tanks are a better-known primary treatment technique for on-site wastewater treatment [4]. Septic tanks remove most settleable solids and function as an anaerobic bioreactor that promotes partial digestion of organic matter [18]. The first septic tank was installed in a family home with three adult residents. The second house was made up of five adult residents; meanwhile, the third family was made up of seven residents between children and adults. The term "resident" refers to anyone who normally occupies the dwelling as their principal residence [26].

2.3. Collection of samples and analysis

Once the tanks came into operation, samples were taken fortnightly for three months, taking the first sample the third week after the tank was filled. The samples were preserved at a temperature below 4 °C before performing the analysis. Water samples were collected at two points: at the entrance (P1) and at the exit (P2) of the septic tank, as shown in Fig. 1. At each sampling point, 1 liter of the sample was collected. Water analysis was performed by the Standard Methods for the Examination of Water and Wastewater [27]. BOD_5 was measured with Oxytop head gas sensors after five days of incubation at 20°C. COD, nitrates (NO_3) and phosphates (PO_4) were measured by spectrophotometric technique. Total Suspended Solids (TSS) were determined by the gravimetric method.

2.4. Data analysis

Each parameter's removal efficiency (RE) was determined using the following equation 1 [28]. In this equation, Ci represents the initial concentration of the parameter in the wastewater that entered the septic tank and Cf is the final concentration of the parameter in the treated water that left the septic tank.

$$RE = \frac{C_i - C_f}{C_i} \times 100 \quad (1)$$

3. Results and Discussion

3.1 Characteristics of Raw Wastewater

Table 1 shows all the input and output parameters measured in the three septic tanks with baffles implemented in the different houses. Data measured during the tests include the Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Nitrate (NO_3) and Phosphates (PO_4).

The results of the DWW monitoring during this study indicated that the average concentration of COD, BOD_5, TSS, phosphates and nitrates for home 1 were 380.8, 200.2, 447.4, 0.63 and 14.43 mg/L, respectively (Table 1). The COD: BOD_5 ratio was around 1.90:1, which agrees with that indicated by Metcalf and Eddy [29], who stated that for domestic wastewater the COD/BOD_5 ratio varies from 1.5 to 2. The average COD, BOD_5, TSS, phosphates and nitrates concentrations for home 2 were 426.6, 238.6, 508.0, 1.73 and 89.91 mg/L, respectively (Table 1). The COD/BOD_5 ratio was around 1.79:1, which is also consistent with that reported by Metcalf and Eddy [29]. The average COD, BOD_5, TSS, phosphates and nitrates concentrations for home 3 were 1411.8, 754.0, 442.0, 4.77 and 30.04 mg/L, respectively (Table 1). The COD/BOD_5 ratio was around 1.87:1, which also agrees with that indicated by Metcalf and Eddy [29]. There was a higher BOD_5 content in home 3 because the contribution of organic matter is due to 7 residents; meanwhile, the lowest BOD_5 content was found in home 1 since there are only three residents.

Likewise, in Table 1, it can be seen that the effluents from the three septic tanks indicated a reduction in BOD_5, COD and TSS. In so many, the values of nitrates and phosphates had increased, due to the fact that anaerobic digestion is a mineralization process; consequently, little nitrogen and phosphorus removal can be expected.

3.2. Baffled Septic Tank Performance

The results of monitoring the performance of septic tanks with different HRT of 4.44 days (home 1), 2.67 days (home 2), and 1.91 days (home 3) (Fig. 2) indicated a higher BOD_5 removal efficiency of 40.2%. for an HRT of 1.91 days, decreasing to 30.81% for an HRT of 2.67 days, and decreasing to 22.83% for an HRT of 4.44 days. As can be seen, the BOD_5 removal increased while the HRT decreased, the opposite of what was obtained by Wanasen [30] operating the septic tank at different HRT. It must be considered that the concentration of BOD_5 in the influent was higher in the septic tank of house 3, obtaining a higher removal despite having a shorter retention time. Meanwhile, the concentration of BOD_5 in the influent from the septic tank of home 1 was lower and the removal was also lower despite having a longer retention time.

Table 1. Data on BOD_5, COD, TSS, nitrates and phosphates from the influent and effluent from the three septic tanks.

N° Monitoring	Parameter	Unit	Home 1 (HRT= 4.44d)		Home 2 (HRT= 2.67d)		Home 3 (HRT= 1.90 d)	
			Influent	Effluent	Influent	Effluent	Influent	Effluent
1	BOD_5	mg/L	192	141	255	196	727	508
2	BOD_5	mg/L	196	140	246	195	804	536
3	BOD_5	mg/L	205	133	216	165	823	555
4	BOD_5	mg/L	201	131	242	188	900	503
5	BOD_5	mg/L	207	147	234	177	516	202
	Average		*200.2*	*138.40*	*238.60*	*184.20*	*754*	*460.8*
1	COD	mg/L	356	263	427	315	1321	959
2	COD	mg/L	354	254	448	358	1464	1005
3	COD	mg/L	416	291	392	312	1497	1047
4	COD	mg/L	380	238	441	335	1837	1039
5	COD	mg/L	398	286	425	324	940	366
	Average		*380.8*	*266.40*	*426.60*	*328.80*	*1411.8*	*883.2*
1	TSS	mg/L	390	279	535	360	445	240
2	TSS	mg/L	415	260	475	343	420	175
3	TSS	mg/L	501	272	500	364	560	155
4	TSS	mg/L	515	264	550	342	440	221
5	TSS	mg/L	416	270	480	357	345	215
	Average		*447.4*	*269.00*	*508.00*	*353.20*	*442*	*201.2*
1	Phosphates	mg/L	0.61	1.21	1.47	2.28	5.92	6.98
2	Phosphates	mg/L	0.37	0.73	1.75	2.11	6.52	6.53
3	Phosphates	mg/L	0.67	1.24	1.3	1.75	3.36	4.28
4	Phosphates	mg/L	0.8	1.2	2.2	3.1	4.5	4.6

5	Phosphates	mg/L	0.69	1.42	1.92	2.66	3.57	4.62
	Average		*0.63*	*1.16*	*1.73*	*2.38*	*4.774*	*5.402*
1	Nitrates	mg/L	6.55	8.7	78.33	111.85	27.85	39.2
2	Nitrates	mg/L	12.3	16.7	77.75	117.8	22.8	29.15
3	Nitrates	mg/L	8.55	11.59	77.45	117.35	24.3	32.45
4	Nitrates	mg/L	18.45	27.05	79.8	122.55	34.15	49.3
5	Nitrates	mg/L	26.3	38.6	136.2	176.8	41.1	60.8
	Average		*14.43*	*20.53*	*89.91*	*129.27*	*30.04*	*42.18*

Table 2 shows the average values of the parameters measured in each septic tank, which were compared with the Ecuadorian norm corresponding to the discharge limits to a body of fresh water. It can be observed that the BOD_5, COD and TSS do not comply with the regulations in any of the homes; meanwhile, despite having an increase in phosphates, they comply with the norms in all homes, while the nitrates abide by the norm except for home 2. These results confirm that secondary treatment is necessary after the septic tank.

Table 2. Comparison of the average values of the parameters measured in each septic tank with the Ecuadorian regulations.

Parameter	Unit	Home 1	Home 2	Home 3	Normative
BOD_5	mg/L	138.4±6.47	184.2±13.14	460.8±14.61	100
COD	mg/L	266.4±22.14	328.8±18.62	883.2±291.20	200
TSS	mg/L	269±7.35	353.2±10.08	201.2±35.03	130
Phosphates	mg/L	1.16±0.26	2.38±0.52	5.402±1.25	10
Nitrates	mg/L	20.53±12.28	129.27±26.84	42.18±12.95	50

The data on the efficiency of the water quality obtained in this type of septic tank is presented in Fig. 2; where it can be seen that the removal of contaminants was moderate, with a reduction in BOD_5, COD and TSS. Meanwhile, there was an increase in nitrates and phosphates, which corroborates that conventional on-site wastewater treatment systems are not effective in removing nitrate and phosphorus compounds or in reducing pathogenic organisms [4]. According to these data, the treatment of domestic wastewater in single-family homes using septic tanks should be complemented with secondary processes.

The results of this study indicated that there was no removal of nitrates or phosphates. Since anaerobic digestion takes place in the septic tank, little nitrogen and phosphorus removal can be expected [29]. These results are lower than those obtained by Mahmoud et al. [31], who attributed the lower phosphorus removal achieved to the relatively low biomass production in anaerobic systems. Septic tanks are primarily designed for the removal of solids and the degradation of organic matter [8]. However, they are not efficient in removing nutrients such as phosphates and nitrates [31]. These compounds can pass through the septic tank treatment process without significant removal. The observed increase in nitrates and phosphates in septic tank effluent has important implications for water bodies and the environment. In addition to eutrophication, excess nutrients can alter the composition of aquatic communities and favor the growth of unwanted species, such as toxic algae or invasive species. This can unbalance ecosystems and affect the food chain, as well as reduce the quality of water for other uses [32].

Nasr et al. [33] in their study consisting of a series of vertical baffles divided into five identical compartments, found that the overall COD removal efficiency in a septic tank with 24 hours of TRH was 82%. Kennedy and Barriault [34] reported that at 39 h HRT, COD removal in compartment one was the highest, reaching 71%. Also, Uyanik [35] indicated that the highest COD removal occurred in the first compartment at the TRH of 48 hours. Boopathy [36] found that four- and five-chamber septic tanks appear to be slightly more efficient in converting solids and biogas compared to two- and three-chamber systems.

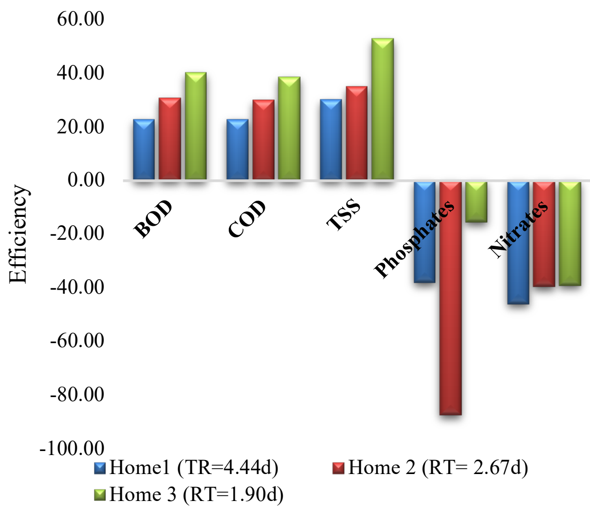

Fig. 2. Comparison of removal efficiency in the three septic tanks.

Table 3 shows the results of the BOD_5 removal obtained in other studies; it is evident that the BOD_5 removals were higher than those obtained in this study. This low performance could be due to the fact that the place where these three septic tanks were implemented is located in an Andean region, where the ambient temperature varies between 5 and 20 °C with an average annual temperature of 12.4 °C. Low temperatures cause changes in the properties of wastewater reducing biological activity; while, at higher temperatures, part of the accumulated organic matter is also converted into biogas and sludge production is reduced [37].

3.3. Application of the Results for Future Research

This article presented data obtained from the efficiency of baffled septic tanks as a decentralized treatment. These results allow us to provide information in the field of domestic wastewater treatment using septic tanks. Based on this information, new research can be carried out to improve these on-site wastewater treatment systems. These baffled septic tanks should be able to increase BOD_5 removal to meet effluent discharge standards. In this field there is still to be investigated: the methodology to calculate the number of baffles needed to achieve maximum efficiency, which can be used as an independent wastewater system and techniques to improve the removal of nitrogen and phosphorus in these anaerobic systems. Likewise, the influence of temperature, retention time, concentration of the influent on efficiency should be investigated; all the aforementioned at the field level, since most of the studies have been carried out at the laboratory level.

To minimize risks due to the discharge of effluents from septic tanks, it is convenient to carry out a secondary treatment to further reduce BOD_5; COD; TSS and to remove nutrients. Therefore, septic tanks cannot be used as the only treatment and disposal option. Requiring some additional treatment to improve the quality of the effluent and thus ensure compliance with discharge requirements.

Table 3. BOD_5 removal results in previous studies.

HRT (d)	% Removal	Reference
0.33	62	Nasr et al. (2009) [33]
0.5	52.31	Ittiusupornrat et al. (2014) [38]
1.0	60.87	Ittiusupornrat et al. (2014) [38]
1.0	68.75	Crites and Tchobanoglous (1998) [24]
1.0	53.50	Nasr and Mikhaeil (2014) [4]
1.0	82	Keshtgar et al. (2019) [11]
1.0	64.00	Wanasen (2003) [25]
1.0	78	Nasr et al. (2009) [33]
1.90	40.2	Present study
2.0	75.52	Wanasen (2003) [25]
2.0	58.16	Nguyen et al. (2007) [19]
2.0	57.00	Nasr and Mikhaeil (2014) [4]
2.67	30.81	Present study
3.0	68.4	Nasr and Mikhaeil (2014) [4]
4.44	22.83	Present study
5.0	84.79	Koottatep et al. (2014) [21]
7.0	93.60	Koottatep et al. (2014) [21]
9.0	94.53	Koottatep et al. (2014) [21]
16.0	95.68	Koottatep et al. (2014) [21]

4. Conclusions

It has been shown that baffled septic tanks can be applied as low-cost, decentralized wastewater treatment systems in rural areas. These systems have shown an adequate capacity for the removal of suspended solids and the reduction of the organic load in wastewater. However, some limitations in the performance of baffled septic tanks have also been identified. In particular, reduced efficiency in the removal of nutrients, such as nitrogen and phosphorus, has been observed. These results suggest that the implementation of secondary treatment options is required to address these limitations and ensure the protection of public health and the environment. It is recommended to promote the implementation of baffles in septic tanks; consider using baffles that maximize solids retention and promote proper sedimentation in the septic tank. It is also advisable to carry out regular monitoring of the system, for which periodic inspections and analysis of the treated wastewater can be carried out to evaluate the performance of the septic tank with baffles. This will make it possible to identify possible problems and take timely corrective measures. To address the limitations observed in the removal of nutrients and pathogens, the implementation of secondary treatment systems, such as biological filters, infiltration ditches or constructed wetlands, is recommended. These technologies can complement the septic tank process and improve the quality of the treated effluent. These recommendations are relevant to policymakers, professionals and people who use septic tanks, as they will contribute to improving the effectiveness and sustainability of wastewater treatment systems in rural areas.

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