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Representation of Septic Tanks in Stormwater Management Model (SWMM)

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***Abstract*. Septic tank systems are commonly used for treating domestic wastewater and an essential part of decentralized wastewater management systems. Many studies have considered septic tanks in terms of their design, performance and their impact on the environment. However, studies that have modelled septic tanks to test their performance for the removal of biochemical oxygen demand (BOD) and total suspended solids (TSS) are scant. This paper presents an approach to model septic tanks using the Stormwater Management Model (SWMM).The developed approach has been then applied to assess the influence of septic tank design configurations on pollution reduction.**

***Keywords*: Decentralized sewerage system; treatment; efficiency; Septic tanks; Sirte; SWMM**

I. INTRODUCTION

In many countries around the world, there is an extensive number of households that are not connected to the mains sewerage systems. Even in developed countries where many houses are connected to the centralized sewerage systems, there are still households that depend on decentralized wastewater management techniques [1]. The most common method is the septic tanks which is especially pertinent in developing countries [2].This is due to the problem of population growth and urbanization which has overwhelmed the capacity of the existing sewerage systems and unplanned settlements.

Septic tanks (STs) are traditionally gravity flow systems [3]-[4].Their use is particularly common in rural or less densely populated areas where connections to main sewerage network systems are not available, or impractical and costly [5]. A septic tank (ST) is an anaerobic mechanical treatment unit, where some pollutants in domestic wasterwater such as suspended solids (SS) and suspended organics are removed by sedimentation. However, dissolved organics and nutrients such as nitrogen and phosphorus are not removed [4]. The extent of pollutant removal by ST depends on many factors: design, maintenance and the shape of the ST, inlet and outlet arrangements, the physical, biological and chemical processes inside the tank, wastewater retention time, site hydrology, soil, and climatic characteristics [6]. Moreover, the quality of effluent is dependent on the content of organic matter in the wastewater and the chemicals used in households which affect the growth of bacteria and ability to digest the organic matter in the septic tank [7]. Some studies have considered ST performance and pollutant removal. [8] reported that the reduction of BOD and TSS in ST were 52% and 85%, respectively. [4] stated that if a septic tank is properly designed, maintained and operated, its suspended solids (SS) and organic matter (BOD) removal efficiency range between 50 -70% and 25- 40% respectively.

In terms of performance, [9] showed that septic tanks with more than one compartment perform better than those with only one. However, other studies have contradicting findings as shown in Table 1.

Table 1: The removal of BOD and TSS in single and double-compartment septic tanks

Reference	[12]		[10]-[11]	
Parameter	Removal %		Removal %	
	Single compartment	Double compartment	Single compartment	Double compartment
BOD	54	46	32.3	31.1
TSS	81	48	79.5	81.5

The above studies used physical measurements to determine performance. There is no study that has modelled septic tanks to test their performance for the removal of biochemical oxygen demand (BOD) and total suspended solids (TSS). This paper presents an approach to model septic tanks using the Stormwater Management Model (SWMM). Moreover, the paper also compares the performance of septic tanks based on one and two compartments.

II. MATERIALS & METHODS

A. Case study selection

The city of Sirte, (Figure 1) is located in the north of Libya on 31° 12’ 32.11’’ North and 16° 35’ 19.18’’ East [22]

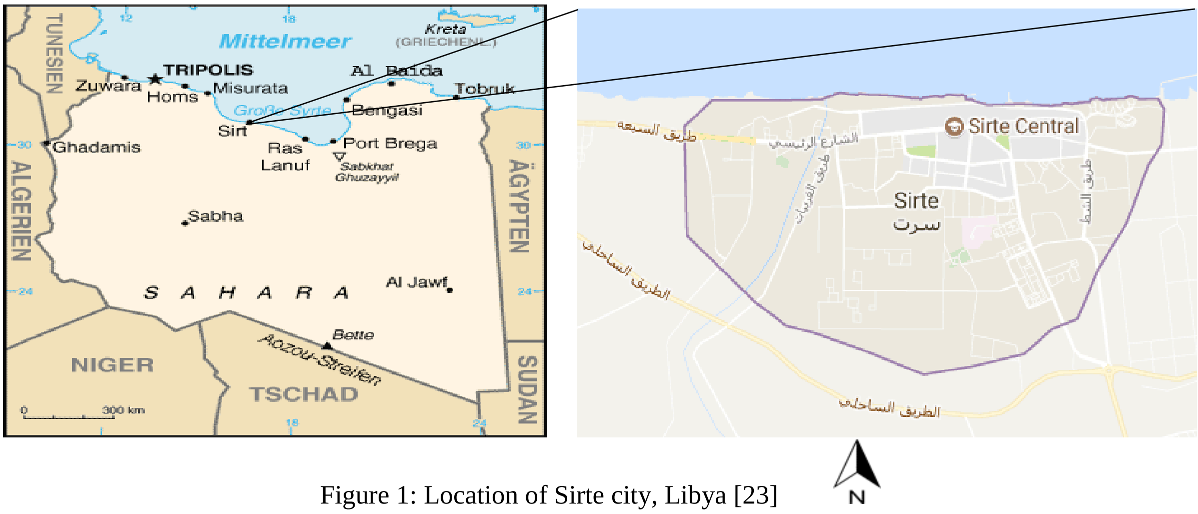

Figure 1: Location of Sirte city, Libya [23]

Sirte has a total population of around 157,747 inhabitants. The climate of Sirte city is classified as arid. It is affected by the Mediterranean Sea and the desert. This city was selected as a case study due to its high use of septic tanks even though there are mains sewer systems. In addition, the high population growth rate and urbanization in the city has led to people settling in new areas without accesses to centralized sewer systems. The septic tank simulation in SWMM will be extended to a full scale sewerage network model for the city.

B. The Storm Water Management Model (SWMM Version 5.0)

Stormwater Management Model (SWMM) is widely used throughout the world for planning, analysis, and design related to storm water runoff, combined sewer systems, and other drainage systems in urban areas [13]. It is a dynamic rainfall-runoff model used for single event or long-term simulation of runoff quantity and quality from primarily urban areas. It presents several options to simulate the build-up and wash-off of the pollutants in catchments, and different conditions in the combined sewer system. It is also an open source software. For these reasons, SWMM version, 5.0 was used in this study.

C. Flows into a septic tank

The amount of wastewater entering a septic tank can be determined by knowing the water consumption per person and the number of people in a household. In this study it was assumed that a typical Sirte household comprises about 7 people. The average daily amount of water consumption was taken to be 300 l/p/d. These values translate to 231×10^{-7} m^3/s as wastewater flow rate into a household septic tank. This was based on water consumptions for countries with similar climatic condition as Libya where water consumption has been reported to vary between 274 l/p/d and 560 l/p/d [20]-[21].

D. Septic tank design

Hydraulic retention time (HRT_d) is an important parameter for Septic tank design. [14] recommended retention times according to septic tank inflows as shown in Table 2.

Table 2 : Recommended retention time

Q (m^3/d)	HRT_d (hrs)
<6	24
6-14	33-1.5Q
>14	12

Q: Daily wastewater flow, HRT: Hydraulic retention time

According to [14], the volume of septic tank can be calculated using Equation 1

$$D = A + \mathrm{B} + \mathrm{C} \qquad (1)$$

Where: A is a space for the retention of the volume of liquid (settlement zone), B is storage space for sludge and scum, C is ventilation space and, D is the total volume of septic tank. These parameters were designed separately as shown by Equation 2 [14]

$$A = Q \times T/24 \qquad (2)$$

Where: A is the retention volume (m^3), Q is the volume of wastewater to be treated per day (m^3) and T is the average time wastewater is retained in the tank (hrs)

The required sludge and scum volume (m^3), B, can be calculated using Equation 3 [14].

$$B = P \times N \times F \times S_d \qquad (3)$$

Where: N is the number of years between desludging (2-5 years), P is the number of people in the house, F is the factor for sludge digestion rate and S_d is the annual rate of sludge and scum production (m^3/ person/year).

The value of S_d is based on commonly accepted figures for annual accumulation rates for a septic tank in constant use, which are 0,025 m^3/person/year for WC waste only and 0,04 m^3/person/year for WC waste and sullage [14]. However, $A + B$ Should never be less than 1.3m^3, as it is not possible to produce calm / quiescent condition in a septic tank smaller than this. C: is equal to 300 mm minimum air gap which should be left between the top of the liquid level and the bottom of the cover of a septic tank [14].

In this study the volume of wastewater was < 6 m^3/d, as a result the hydraulic retention time HRT was considered as 24 (hrs) as per the guidance given in Table 2. The annual rate of sludge and scum production was 0.04 m^3/person/year. The overall capacity of the septic tank, based on the above mentioned equations (1-3) and assumptions, was calculated to be 1.73 m^3. This equates to the tank dimensions of 1.8 m × 0.6 m × 1.6 m (L×W×H). The inlet to the tanks was placed 1.4 m above from the bottom of the septic tank and the outlet slightly below the inlet.

E. Presentation of ST in SWMM

In this research the pollutant removal by septic tanks was modelled. The ST was presented as a storage unit node within the SWMM drainage network model. The pollutant reduction effects were simulated through the mathematical models as shown below. Wastewater concentrations for two pollutants were specified in the model. These were biochemical oxygen demand (BOD) and total suspended solids (TSS). The values of these parameters used in this study were based on previous studies [15]-[16]-[17] as shown in Table 3

Table 3: Typical characteristics of untreated domestic wastewater

Reference	[15]			[16]			[17]		
Parameter	Concentration (mg/l)			Concentration (mg/l)			Concentration (mg/l)		
	LC	MC	HC	LC	MC	HC	LC	MC	HC
BOD	110	190	350	110	220	400	200	300	400
TSS	120	210	400	100	220	350	180	300	450

LC: Low Concentration, MC: Medium Concentration, HC: High Concentration

Basing on Table 3, the concentration of BOD and TSS in the influent wastewater to the tank were assumed as 300 mg/l and 350 mg/l respectively.

F. Mathematical Model used in SWMM

The TSS removal function in the ST is determined using Equation 4 [18]

$$R = G\, e^{-Mq} \qquad (4)$$

Where: R is effluent TSS concentration (mg/l), q is the flow per unit area of the septic tank (m^3/m^2), G and M are constants that are determined empirically, using Equations 5 and 6 [18]

$$G = 0.0004\, TSS + 0.6779 \qquad (5)$$

$$M = 0.2287 e^{(0.006\, T)} \qquad (6)$$

Where: T is the temperature (°C) of wastewater in septic tank. If the effects of temperature are ignored then, the value of M can range between 0.0020 and 0.123

The removal efficiency of total suspended solids can be calculated using Equation 7

$$E_{TSS} = \frac{S_i - R}{S_i} \times 100 \qquad (7)$$

Where, S_i is the influent TSS concentrations.

For a batch reactor, BOD removal in the ST can be determined using the first order reaction kinetics described by Equation (8) [1]-[17]-[19].

$$\frac{dL_t}{dt} = -KL_t \qquad (8)$$

Owing to the semi-continuous nature of the flow going to the tank, the batch reactor equation cannot be applied unless there is no flow to the tank for a prolonged duration. In our case, where the flow to the septic tank is intermittent, Equation 9 has been used in SWMM for BOD removal. [13] has proposed the use of Equation 9 to estimate the BOD removal.

$$C_e = C_i\left(1 - \exp\left(-\mu \times \frac{HRT}{24}\right)\right) \qquad (9)$$

Where: C_i and C_e are the influent and effluent BOD concentrations (mg/l) respectively, μ is the treatment constant and HRT is hydraulic residence time, calculated by SWMM as function of tank volume and inflow to the tank.

III. RESULTS

A. *First scenario-Single compartment septic tank with constant continuous inflow*

In order to see the impact of storage tank as the representation of a septic tank in SWMM, it was decided to provide a constant flow ($231 \times 10^{-7} m^3/s$) hydrograph with constant concentration of BOD (300mg/l) and TSS (350 mg/l) in the wastewater entering the tank. The septic tank was assumed to be of a single compartment. In the first scenario, the flow to the tank was assumed as constant. Figure 2 shows the presentation of the septic tank in SWMM. J1 is the first manhole which receives wastewater from the household. The wastewater is conveyed to the ST (SU1) though C1. J2 is the second manhole which transfers the wastewater from the ST to the outfall. C1, C2 and C3 are pipes through which wastewater is transported to the outfall. The wastewater elevation in the septic tank and connecting pipe is shown in Figure 3

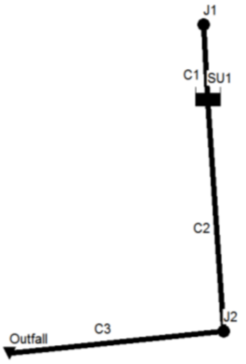

Figure 2: Presentation of ST in SWMM

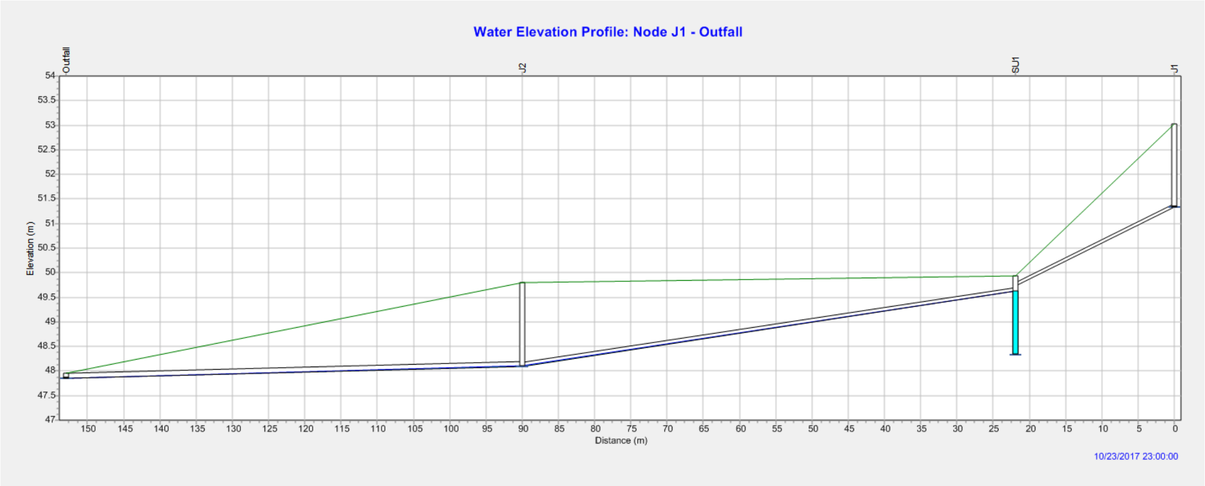

Figure 3: Water elevation profile in the system

Initially μ= 0.41 was used which considered the temperature of wastewater, but this resulted in a BOD removal efficiency of 97% which was higher than the reported values in literature. To reach the reported removal efficiency, this study assumed μ as a calibration parameter. Different values of μ were tested 0.005, 0.006, 0.007, 0.008, 0.009, 0.01, 0.02, and 0.03. The resulting removal efficiencies of ST were 18%, 21%, 24% 27%, 30%, 33%, 53%, and 65% respectively, of these, μ values from 0.008 to 0.02 were found to deliver BOD removal similar to the values reported in literature. In this scenario, μ =0.008 was selected. For this value of μ, the residual BOD in the ST was 218 mg/l and the removal efficiency was 27% as shown in Figure 4. For TSS removal, Equations 5 and 6 were used both with and without consideration of temperature. When the temperature was not considered, M was taken to be 2×10^{-3}. The residual TSS in the ST was 64 mg/l and the removal efficiency was about 82% in both cases as shown in Figure 5.

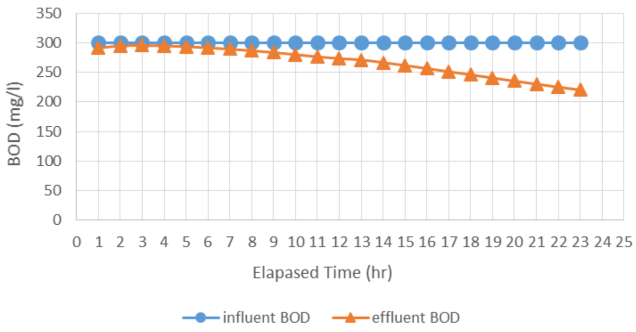

Figure 4: BOD removal in ST (at μ=0.008)

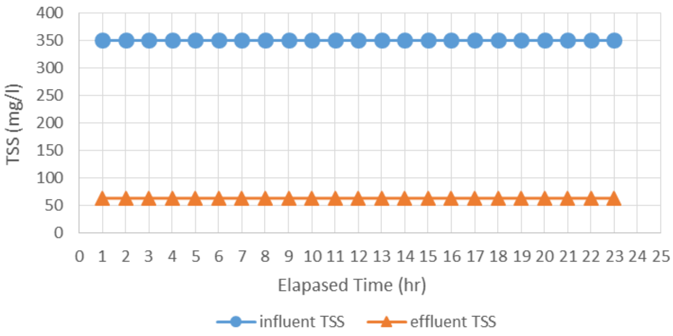

Figure 5: TSS removal in ST (at M= 0,002)

B. *The second scenario-Double compartment septic tank with larger first compartment and constant continuous inflow*

This scenario presented a double-compartment ST in SWMM. The double-compartment ST was implemented by arranging two ST in series as shown in Figure 6. The first tank and the second tank were two-thirds and one-third of the single ST volume respectively. The wastewater inflow was the same as in the case of a single compartment (231×10^{-7} m^3/s). Figure 6 shows the presentation of the double-compartment ST in SWMM. J1and J2 are manholes, SU1 and SU2 are first and second compartments of the ST and C1,C2,C3 and C4 are pipes that transport the wastewater. The wastewater elevation in the septic tank is shown in Figure 7

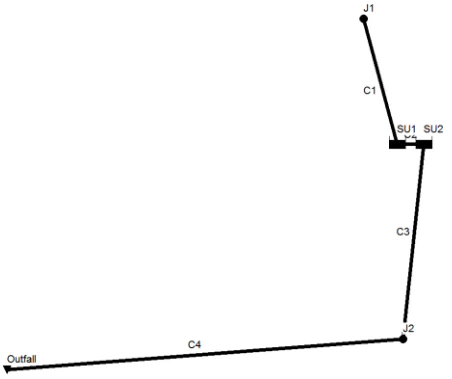

Figure 6: Presentation of double-compartment ST in SWMM

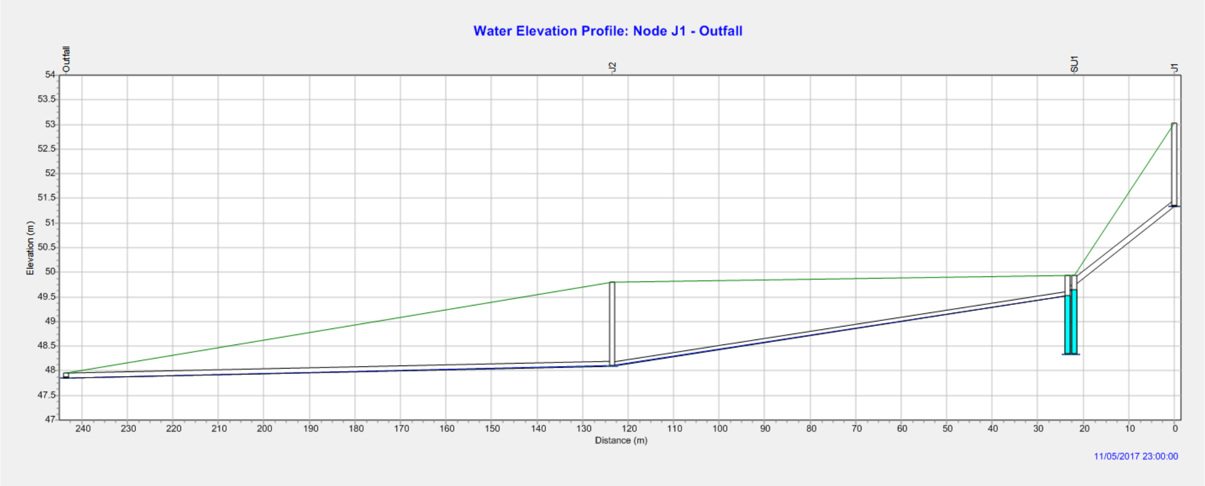

Figure 7: Water elevation profile of double-compartment ST in the system

In this scenario, the μ value used for the first compartment was similar to the first scenario (μ = 0.008). The residual BOD was 223 mg/l and the removal efficiency was 26%. However, for the second compartment, μ = 0.008 resulted in the BOD removal efficiency of 0 % as the result, the total removal of the tank was 26%. For this reason, different values of μ were used to evaluate the efficiency of the second compartment. These were 0.009, 0.01, 0.02, 0.03 and 0.04. The resulting ST removal efficiencies were 1.3%, 2%, 13% 22% and 30% and the total removal efficiencies of ST were 26%, 27%, 35%, 42% and 48% respectively. Among these μ values, for the second compartment, 0.01 was selected and the overall efficiency was 27% as shown in Figure 8.

With respect to TSS removal, both with and without temperature consideration analyses were performed using Equation 4. TSS remaining in the first and second compartment were 64 mg/l and 19 mg/l, the removal efficiency was 82% and 70% respectively. The total removal efficiency of the ST was 95% which was too high. To reach the optimal TSS removal efficiency of about 80%, parameters G, and M, the treatment equation, were varied as follows.

$G = 0.01 + 0.002 \times TSS$ and M= 1×10^{-3} for both compartment. The residual TSS in the first compartment was 102 mg/l and the removal efficiency was 71%. However, for the second compartment the residual TSS was 80 mg/l translating to a removal efficiency of 22%. The total removal efficiency in this scenario was 77% as shown in Figure 9. This was within the range reported in the literature.

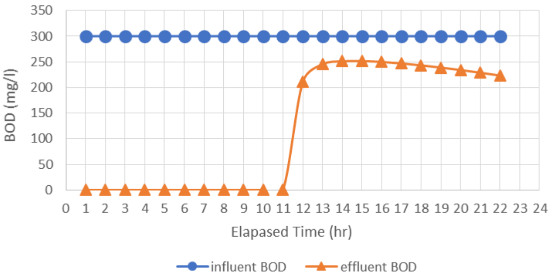

Figure 8: BOD removal in ST (at μ_1= 0.008 and μ_2=0.01)

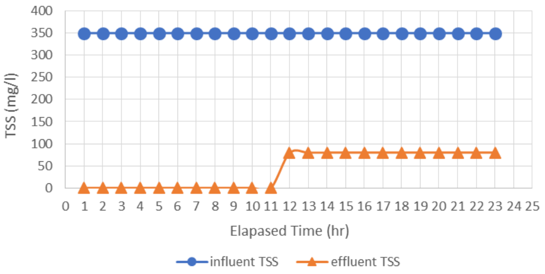

Figure 9: TSS removal in ST (at M_1= 0.001and M_2= 0.001)

For figures 8 and 9, the initial zero effluent reading of BOD and TSS are because the tank was assumed to be empty initially at the start of the SWMM simulation. After number of hours the tanks became full and hence the effluent from the tanks started discharging to sewer and therefore increasing effluent BOD and TSS concentrations. The variation of the time taken to fill the tanks depended on the size of the compartments which are described in the respective scenarios.

C. *Third scenario-Double compartment septic tank with both compartments of equal size and constant continuous inflow*

In this scenario the ST was designed to receive the same quantity of wastewater as in earlier scenarios. The ST was divided into two equal compartments and tested for the removal of TSS and BOD. The same values of µ which were used in the second scenario for both compartments were used. The residual BOD in the first compartment was 239 mg/l and the removal efficiency was 20%. However, in the second compartment the residual BOD was 220 mg/l and the removal efficiency was 8%. The overall removal efficiency in this scenario was 27% as shown in Figure 10. For TSS, The removal efficiencies in the first and second compartment were similar to those in the second scenario as shown in Figure 11.

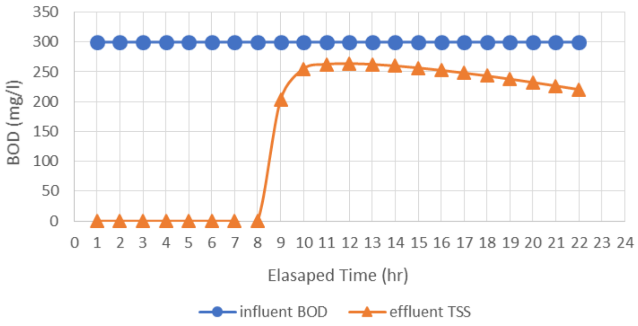

Figure 10: BOD removal in ST (at μ_1= 0.08 and μ_2= 0.01)

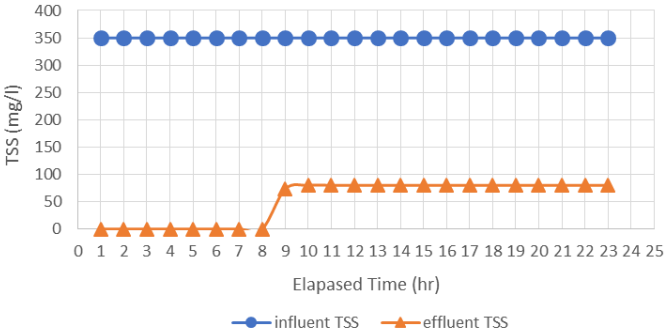

Figure11: TSS removal in ST (at M_1= 0.001and M_2= 0.001)

D. Fourth scenario-Double compartment septic tank with smaller first compartment

The ST was designed in such a way that the first tank and the second tank were one- third and two-thirds of the total volume respectively. The amount of wastewater inflows was the same as in the other scenarios. The same values of µ (as in the second and third scenarios) for both compartments were used. The residual BOD in the first and second was 258 mg/l and 210 mg/l and the removal efficiency was 14% and 19 % respectively. The total removal in this scenario was 30% as shown in Figure 12. The second compartment was more efficient than the first compartment due to its size, which was smaller than the second. However, TSS removal was similar to second and third scenarios (Figure13).

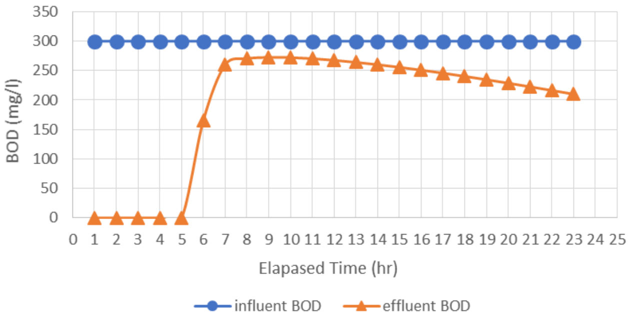

Figure 12: BOD removal in ST (at μ_1= o.oo8 and μ_2= 0.01)

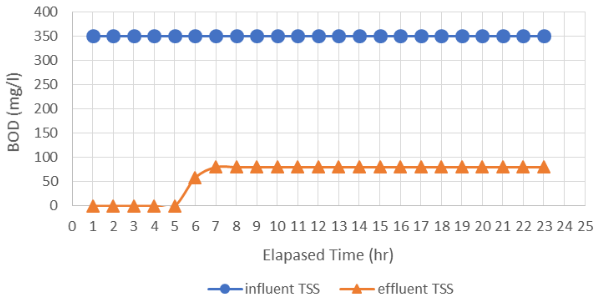

Figure 13: TSS removal in ST (at M_1= 0.001and M_2= 0.001)

E. Fifth scenario-Single compartment septic tank with diurnal flow pattern

In the fifth scenario the amount of water consumed during a day varied with time. Figure 14 Diurnal water flow pattern, as a typical diurnal water flow pattern. This variation also resulted in varying wastewater generation.

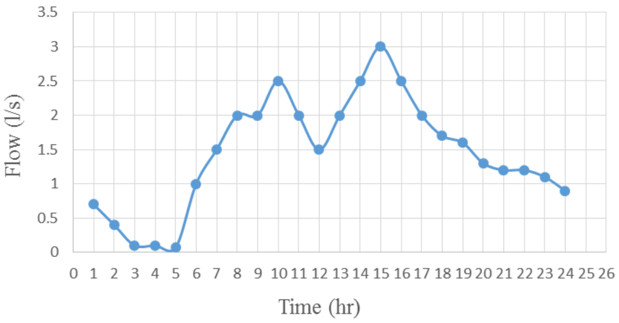

Figure14: Diurnal water flow pattern

In this scenario, µ= 0.41 was used as in the first scenario, but the removal efficiency of about 99% was too high. Then, µ = 0.008 which was used in the first scenario was tested, but it resulted in the removal efficiency of 58% which was higher than the percentages reported in literature for ST. For that reason different values of µ were tested. These were 0.007, 0.006.0.005, 0.004, 0.003 and 0.002 and the resulting BOD removal efficiencies of ST were 53%, 49%, 43%, 37%, 30% and 22% respectively. From these results, µ values from 0.003 to 0.002 were acceptable. In this scenario, µ =0.003 was used. The residual BOD in the ST was 209 mg/l and the removal efficiency was 30% as shown in Figure 15. For TSS removal, equation in the first scenario were used when temperature was taken into account. However, when the temperature was not considered, parameter M of the value 2×10^{-3} was used. The TSS removal efficiency results were about 71% in both cases as shown in Figure 16.

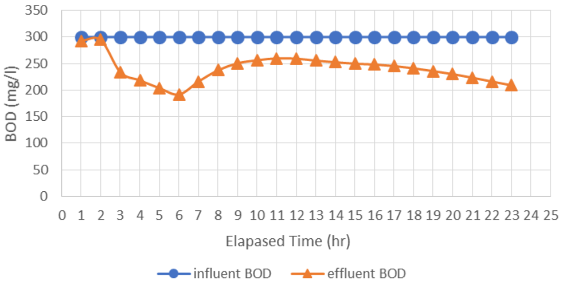

Figure 15: BOD removal in ST (at µ= 0.003)

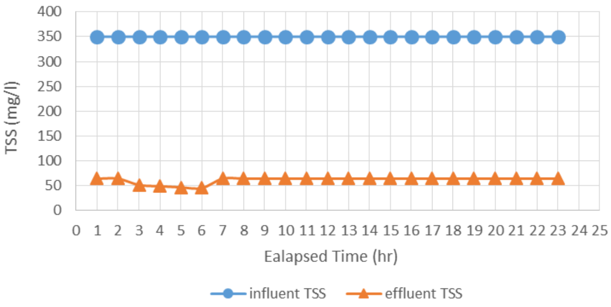

Figure 16: TSS removal in ST (at M= 0.002)

F. *The sixth scenario-Double compartment septic tank with larger first compartment and diurnal inflow*

This scenario presented a double-compartment ST in SWMM. The double-compartment ST were divied similar to the second scenario. In this scenario, the µ value used for the first compartment was similar to the fifth scenario (µ = 0.003). However, different values were used in the second compartment which are 0.0001, 0.001 and 0.002. The residual BOD were 165mg/l, 153 mg/l and 145 and the removal efficiencies were 47%, 49%, and 52% respectively. These efficiency values were acceptable range of 25-50%. In this scenario, µ = 0.003, 0.0001 were selected for the first and second compartment. The residual BOD was 124 mg/l and the removal efficiency was 59%. This efficiency values were higher than reported range of 25-50%. For that reason the values of (µ = 0.001, 0.0001) were used. The residual BOD was 135 mg/l and the removal efficiency was 55% as shown in Figure 17. With respect to TSS removal, the parameters G and M were changed to as used in the second scenario. The residual TSS in the first and second compartment was 275 mg/l and 40 mg/l and the removal efficiency was 71% and 61%. The overall removal efficiency was 88% as shown in Figure 18.

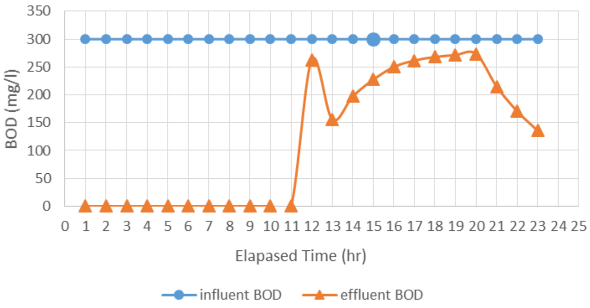

Figure 17: BOD removal in ST (at μ_1= 0.001and μ_2= 0.0001)

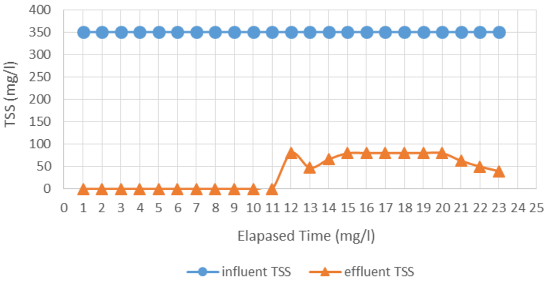

Figure 18: Removal of TSS in ST (at M_1= 0.001and M_2= 0.0001)

G. *Seventh scenario-Double compartment septic tank with equal compartments and diurnal inflow*

In this scenario the ST was desinged as the third scenario. The same µ values which were used in the fifth and sixth scenarios were used.The residual BOD in the first and second compartment was 283 mg/l and 170 mg/l the removal efficiency was 7% and 40%. The overall removal efficiency was 43% as shown Figure 19. For TSS, the same values of parameters G, and M in the sixth were used. The residual TSS in the first and second compartment was 102 mg/l and 50 mg/l and the removal efficiecy was 71 % and 51 % respectively. The overall removal efficiency was 86% as shown in Figure 20.

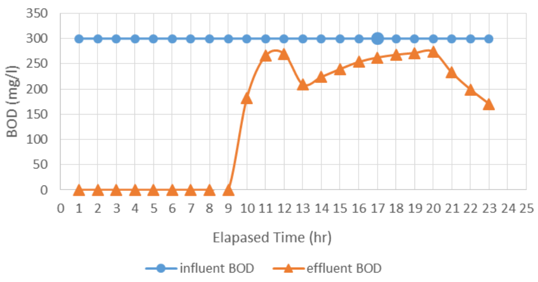

Figure 19: BOD removal in ST (at μ_1= 0.001 and μ_2=0.0001)

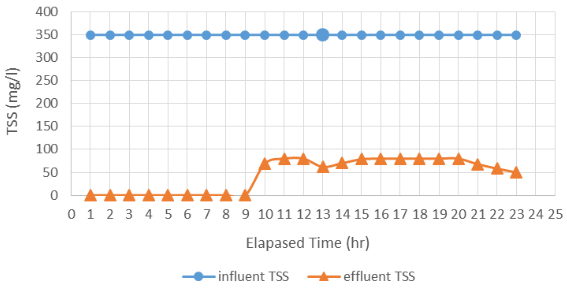

Figure 20: TSS removal in ST (at M1= 0.001 and M2= 0.0001)

H. *Eighth Scenario-Double compartment septic tank with smaller first compartment and diurnal inflow*

The ST was designed in the same way as that for the fourth scenario. The residual BOD in the first and second compartment was 291 mg/l and 193 mg/l the removal efficiency was 3% and 43%. The overall removal efficiency was 36% as shown Figure 21. The residual TSS in the first and second compartment was 102 mg/l and 46 mg/l and the removal efficiency was 71% and 56%. The overall removal efficiency was 87% as shown in Figure 22.

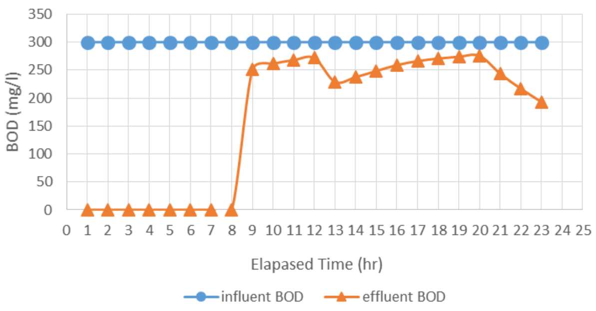

Figure 21: BOD removal in ST (at μ_1= 0.001 and μ_2=0.0001)

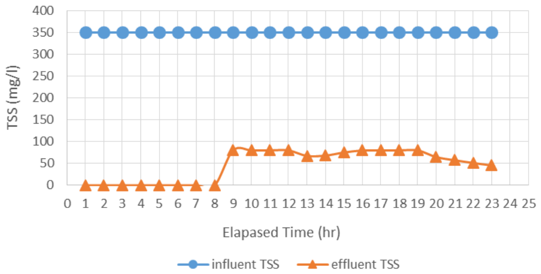

Figure22: TSS removal in ST (at M1= 0.001and M2= 0.0001)

IV. DISCUSSION AND CONCLUSION

A septic tank was presented in SWMM and tested for its efficiency in terms of TSS and BOD removal as a single and double-compartment unit. Eight scenarios were presented with different sizes of compartments which added to the same total volume. In the first four scenarios, the ST was analysed for BOD and TSS removal assuming constant wastewater flow while the remaining four scenarios used varying wastewater flows. The results are summaries in Table 4 as below.

Table 4: Septic tank efficiency at reducing BOD and TSS for different scenarios

Scenario	BOD		TSS		
	µ	Overall removal %	G	M	Overall removal %
1	0.008	27	0.82 0.71	0.263 0.002	82
2	0.008 (1st Compt.) 0.01 (2nd Compt.)	27	0.71	0.001 0.001	77
3	0.008 (1st Compt.) 0.01 (2nd Compt.)	27	0.71	0.001 0.001	77
4	0.008 (1st Compt.) 0.01 (2nd Compt.)	30	0.71	0.001 0.001	77
5	0.003	30	0.82 0.71	0.263 0.002	71
6	0.001 (1st Compt.) 0.0001 (2nd Compt.)	55	0.71	0.001 0.0001	88
7	0.001 (1st Compt.) 0.0001 (2nd Compt.)	43	0.71	0.001 0.0001	86
8	0.001 (1st Compt.) 0.0001 (2nd Compt.)	36	0.71	0.001 0.0001	87

The results suggest that it is possible to represent septic tank in SWMM and achieve pollutant removal efficiencies similar to the values reported in the literature. The calibration exercise for µ, G and M show that the values for calibration parameters are heavily influenced by the flow regime in the septic tank and its design configuration.

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REFERENCES

[1] M. L. Davis and D. A. Cornwell, *Introduction to Environmental Engineering*, 5 edition. New York: McGraw-Hill Education, 2012.

[2] S. E. Mbuligwe, ‘Applicability of a Septic Tank/Engineered Wetland Coupled System in the Treatment and Recycling of Wastewater from a Small Community’, *Environ. Manage.*, vol. 35, no. 1, pp. 99–108, Jan. 2005.

[3] G. Moussavi, F. Kazembeigi, and M. Farzadkia, ‘Performance of a pilot scale up-flow septic tank for on-site decentralized treatment of residential wastewater’, *Process Saf. Environ. Prot.*, vol. 88, no. 1, pp. 47–52, Jan. 2010.

[4] A. Kirjanova, M. Rimeika, and R. Dauknys, ‘Designing and testing a septic tank for a single household’, *Environ. Eng. Manag. J.*, vol. 13, no. 3, pp. 743–750, 2014.

[5] Y. Lu, C. Tang, J. Chen, and Y. Sakura, ‘Impact of septic tank systems on local groundwater quality and water supply in the Pearl River Delta, China: case study’, *Hydrol. Process.*, vol. 22, no. 3, pp. 443–450, Jan. 2008.

[6] ‘Septic Tank Impacts on Ground Water Quality and Nearshore Sediment Nutrient Flux - Reay - 2004 - Groundwater - Wiley Online Library’. [Online]. Available: http://onlinelibrary.wiley.com/doi/10.1111/j.1745-6584.2004.tb02645.x/full. [Accessed: 06-Oct-2017].

[7] M. Brandes, ‘Characteristics of Effluents from Gray and Black Water Septic Tanks’, *J. Water Pollut. Control Fed.*, vol. 50, no. 11, pp. 2547–2559, 1978.

[8] J. L. S. Hickey and D. L. Duncan, ‘Performance of Single Family Septic Tank Systems in Alaska’, *J. Water Pollut. Control Fed.*, vol. 38, no. 8, pp. 1298–1309, 1966.

[9] D. Butler and J. Payne, ‘Septic tanks: Problems and practice’, *Build. Environ.*, vol. 30, no. 3, pp. 419–425, Jul. 1995.

[10] A. Boyer and A. Rock (1992). Performance of septic tanks. Proceedings of the 7th Northwest On-Site Wastewater Treatment Short Course and Equipment Exhibition, Seattle, WA, pp.36-50.

[11] A. Rock and A. Boyer (1995). Influence of design on septic tank effluent quality. Proceedings of 8th northwest on-site wastewater treatment short course and equipment exhibition.

[12] W. Seabloom, A. Carlson and J. Engeset, (1982). Septic tank performance, compartmentation, efficiency and stressing. *Proceedings from the 4th northwest onsite wastewater short course—Implementation of new and old technologies*.

[13] C. Zoppou, ‘Review of urban storm water models’, *Environ. Model. Softw.*, vol. 16, no. 3, pp. 195–231, 2001.

[14] B. Reed, Septic tank and aqua privy design. 2011 [cited 2017 30 October]; Available from: https://wedc-knowledge.lboro.ac.uk/resources/booklets/G030-Septic-tank-and-aqua-privy-design-online.pdf.

[15] D. Doran and E. Dee (September, 2008) (updated October, 2011). Wastewater and Wastewater Treatment Very Basics Wastewater Characteristics, 1-7.

[16] S. Muttamara, (1996). Wastewater characteristics. Resources, conservation and recycling, 16(1-4), 145-159.

[17] D. Butler and J. Davies, Urban Drainage, Second Edition. CRC Press, 2004.

[18] M. Jover-Smet, J. Martín-Pascual and A.Trapote, (Jun,2017). Model of Suspended Solids Removal in the Primary Sedimentation Tanks for the Treatment of Urban Wastewater. Water, 9(6), p.448.

[19] R. Ramalho, *Introduction to Wastewater Treatment Processes*. Elsevier, 2012.

[20] H. Wa’el, A. Memon, and A. Savic, (Jul 2016). Assessing and modelling the influence of household characteristics on per capita water consumption. Water Resources Management, 30(9), pp.2931-2955.

[21] M.Taleb and S. Sharples, (2011). Developing sustainable residential buildings in Saudi Arabia: A case study. Applied Energy, 88(1), pp.383-391.

[22] Latitude.to 2017. Available from: http://latitude.to/map/ly/libya/cities/sirte (Accessed 03/11/2017)

[23] Google maps (2017). Available from: https://www.google.co.uk/maps/place/Sirte,+Libya/ (Accessed 1/10/2017)