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Environmental Engineering Approach to Septic Tank Design for Domestic Sewage Management: A Case Study

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Abstract

Septic tank is the most commonly used treatment facility for treating domestic sewage in developing countries. However, it has been noted that most of them did not operate efficiently in treating the sewage due to many factors including wrong sizing caused by poor or no design. Hence, this article applied environmental engineering principles and standards to determine the capacity and dimensions of a septic tank that could efficiently treat domestic wastewater using a newly built apartment as a case study. The septic tank which was designed for ten users had two chambers with a total capacity of 2.82 m^3 at a desludging frequency of 3 years with an overall length, width and depth of 1.94 m, 0.97 m and 1.5 m respectively, in addition to a freeboard of 0.3 m, making a total depth of 1.8 m. Necessary factors of safety were considered and dimensions of all appurtenance such as manholes, vent pipe, baffle wall as well as inlet and outlet pipes were all designed in accordance with public health and environmental engineering standards. In addition, the engineering drawings (orthographic and isometric views) of the designed facility were all provided to ease construction. Hence necessary recommendations were made.

Keywords: Baffle, Design, Drawings, Sewage, Sludge

Introduction

The adverse effects of discharging raw sewage directly into the environment without any form of treatment has long been identified by many researchers including Onu *et al*. (2023), Ogbozige and Nwobu (2021), Wear *et al.* (2021) and Preisner (2020). Hence different methods of treatment have evolved over the years. The various treatment methods could be done either in a centralized system or decentralized system. The former is usually carried out in a large scale for a properly planned town were the various houses generating the wastewater are linked to a central treatment facility through sewerage pipe network (Peter *et al.,* 2017). On the other hand, the later (i.e. decentralized system) is suitable in poorly planned communities where a well sewerage pipe network is not achievable, hence each building is usually provided with a small on-site treatment facility (Ogbozige, 2024; Massoud *et al.*, 2009). Thus, decentralized system of sewage treatment is very common in developing countries since most communities and towns in developing countries are poorly planned. The most common treatment facility for domestic sewage in developing country is septic tank. A septic tank is an insitu underground container usually made of concrete, which treats sewage generated at homes, hotels and workplaces. The sewage that flows into the septic tank could be solely from toilets or a combination of sewage from toilets and other sources such as kitchen sinks and bathrooms. Once the sewage flows into the first chamber of the septic tank, the heavy solids settled at the bottom while the lighter substances such as tissue papers as well as oil and greasy substances floats as scum. Since septic tanks are completely closed, the digestion or decomposition of the organic matters in the sewage happens anaerobically, thus converting the solids into sludge at the bottom of the tank, together with gases. The liquid part of the sewage which flow into the other chamber(s) are either conveyed into soak pit or sewerage network while the gases are removed through a vent pipe.

A properly designed, constructed and operated septic tank could treat domestic sewage that will meet effluent discharge standards (Shrestha, 2020; Barnett and Ormiston, 2010) however, most septic tanks especially in developing countries are not designed with respect to the environmental point of view. Poor design will definitely lead to wrong sizing of the facility and consequently, users will not know the right time to desludge the septic tank (Nnajia and Agunwamba, 2012). In most of such cases, septic tanks are only desludged once users noticed backflow of sewage. This affect the performance efficiency of septic tanks. Researchers including Nakarmi *et al.* (2023), Cruddas *et al.* (2022) and Daija *et al.* (2016) have also shown that hydraulic retention time and temperature are major factors influencing the efficiency of septic tanks. These factors can only be addressed if the septic tanks are properly designed, and not the usual practice of construction without design as done by quacks. In fact, even some trained engineers are not bothered about the environmental consideration in designing septic tanks. This is because most of the few designed septic tanks only focussed on the structural aspect for it not to collapse. Since septic tanks are structures meant for treating sewage to meet certain levels of environmental standards, it is very necessary to incorporate environmental engineering principles in their designs especially in terms of sizing which governs the timing for desludging, being a crucial factor. Undersizing of septic tanks will lead to frequent desludging which will consequently increase the operating cost while oversizing will reduce the desludging interval but certainly increase the construction cost. In either case, if the capacity of the septic tank is not designed in line with environmental engineering standards, users will not know the right time to desludge the facility but will either wait to experience backflow or adopt certain time interval which may not be optimal with respect to the constructed facility. Hence, this research considered a case study of sizing a septic tank for a newly built apartment using basic environmental and general engineering approach in the design.

Materials and Methods

The number of persons to use the facility (septic tank) was obtained from the client and the per capita water consumption was determined. In most design of sewage treatment facilities, the per capita water consumption or demand is usually assumed within a range of values usually in litres, recommended by WHO, UN, EPA, etc. This is suitable in cases were the water that flows to the individual houses comes from a central municipal water supply through pipe networks. However, most communities and towns in developing countries especially Nigeria lack functional municipal water supply, thus the main sources of water supply to houses are either through water vendors in jerrycans, open wells, manually or motorised pumped boreholes, streams and rivers, rainfall (seasonal) as well as sachet and bottled water (mainly for drinking). Hence, the main source of water supply to the client was identified to be an individual motorised pump borehole which pump and store water in a storage tank commonly known as GP tank. Thereafter, the per capita water consumption or demand was calculated using Equation (1) as follows:

$$q = \frac{1}{n}\left(\frac{C}{t}\right) \quad (1)$$

Where: q is the per capita water consumed or demand in L/day, n is number of persons in the house, C is the capacity of the water storage tank (GP tank) in litres and t is the average time taken by the entire household to empty the filled storage tank in days.

The total daily water consumed was converted to wastewater equivalent in m^3/day through Equation (2) as reported in Shrestha (2020):

$$Q = \left(\frac{nq}{1000}\right) f_c \quad (2)$$

Where: Q is the volume of wastewater in m^3/day, n and q remain the number of persons in the house and the per capita water consumed in L/day respectively while f_c is a factor for converting water consumed to wastewater which ranges from 0.8 – 0.9 (Ogbozige, 2024). However, the wastewater volume was increased by 10% to cater for visitors. Thus a safety factor of 1.1 was considered to obtain the designed wastewater volume (Q_d) as shown in Equation (3) as:

$$Q_d = 1.1(Q) \tag{3}$$

The flow pattern of domestic wastewater into a septic tank does not remain constant. Usually the flow is peak during the morning and evening hours when the usage of water is high for bathing, cleaning of bathrooms, toilet flushing and washing, food preparation, washing of kitchen utensils and laundry. Hence the peak flowrate was determined through Equation (4). Thereafter, the liquid layer volume of the septic tank was calculated by means of Equation (5) as follows:

$$Q_p = \frac{Q_d}{t_p} \tag{4}$$

$$V_l = Q_p(HRT) \tag{5}$$

Where: Q_p is the peak flowrate in m^3/hour, Q_d remains the designed volume of wastewater in m^3/day, t_p is the period of peak flow in hour/day, V_l is the liquid volume while HRT is the hydraulic retention time in hours.

During treatment of sewage in septic tanks, sludge are usually formed at the bottom of the liquid layer while light-weight solids (lighter than water) such as grease, soap films, oil, etc. which are collectively called scum floats above the liquid layer. The total volume of both sludge and scum was gotten using the Pickford model expressed in Equation (6) as:

$$V_s = \frac{n \times S_a \times t(f_s)}{1000} \tag{6}$$

Where: V_s is the volume of sludge and scum in m^3, n is the number of persons to use the septic tank, S_a is the sludge and scum accumulation rate in litres per capita per year, t is the desludging frequency in years while f_s is a sizing factor which depends on desludging frequency and ambient temperature as shown in Table 1. Hence, the capacity of the septic tank was obtained by adding Equations (5) and (6) as expressed in Equation (7) thus:

$$V = V_l + V_s \tag{7}$$

Where: V is the volume or capacity of the septic tank while V_l and V_s remains the liquid volume and volume of both sludge and scum respectively, all measured in m^3.

Table 1: Values of sizing factor (f_s) for estimation sludge and scum volume

Desludging frequency	**Ambient temperature**		
(years)	**> 20°C**	**> 10°C**	**< 10°C**
1	1.3	1.5	2.5
2	1.0	1.15	1.5
3	1.0	1.0	1.27
4	1.0	1.0	1.15
5	1.0	1.0	1.06
6 or more	1.0	1.0	1.0

Source: WHO (1992)

Treatment of sewage in septic tanks follows anaerobic digestion hence, a depth of 1.2 m – 2.2 m is usually considered, depending on the available area of land. This is because the minimum depth of 1.2 m could encourage anaerobic digestion process while depths beyond 2.2 m may cause some difficulties during operation and maintenance (Shrestha, 2020). Therefore, a depth within the standard range was adopted and was used in determining the length and breadth of the septic tank as shown in Equation (8). However, it was ensured that the ratio of the length to breadth was between the range of 2 and 4. A baffle wall was provided to create two chambers such that the length of the first chamber is two-third (2/3) of the total length while the second chamber was made one-third (1/3) of the total length.

$$V = l \times b \times d \tag{8}$$

Where: V is the volume or capacity of the septic tank in m^3, b is the breadth in meter, l is the length in meter which must be 2 to 4 times of the breath, while d is the depth which must lie between 1.2 m to 2.2 m. Thereafter, a freeboard space of 0.3 m was added to the calculated depth to obtain the total depth(d_t). Dimensions of all necessary appurtenances such as manholes, vent pipe as well as inlet and outlet pipes were provided in accordance with the standards in deign manuals recommended by Shrestha (2020), Barnett and Ormiston (2010) as well as Garg (2010). The engineering drawings (orthographic and isometric views) of the designed septic tank were produced based on the designed or calculated dimensions using 2023 AutoCAD software. This was done with the intention to ease construction by masons or technicians, though to be supervised by a qualified engineer.

Design Calculations and Drawings

Volume of wastewater and hydraulic retention time

$Number\ of\ users\ (n) = 10$

The design considers a septic tank that will treat all domestic wastewater generated in the apartment (i.e. wastewater from toilets, kitchen sink, bathrooms and laundry).

$Per\ capita\ water\ consumed\ (q) = 55L/day$

$Conversion\ factor\ of\ water\ consumed\ to\ wastwater\ (f_c) = 0.8$ (the value ranges between 80 – 90% hence 80% being 0.8 was adopted).

$$Volume\ of\ wastewater\ (Q) = \left(\frac{nq}{1000}\right) f_c = \left(\frac{10 \times 55}{1000}\right) 0.8 = 0.44\, m^3/day$$

The wastewater volume was increased by 10% as factor of safety to cater for visitors. That is;

$$Designed\ volume\ of\ wastewater\ (Q_d) = 1.1Q = 1.1(0.44\, m^3/day) = 0.484\, m^3/day$$

The peak flow of domestic sewage/wastewater usually occur between 5:30am to 9:30am and between 6:30pm to 8:30pm) thus, the duration of peak flow (t_p) was taken as 6hours/day. Therefore,

$$Peak\ flow\ \left(Q_p\right) = \frac{Q_d}{t_p} = \frac{0.484m^3/day}{6hours/day} = 0.08\, m^3/hour$$

The hydraulic retention time for septic tanks varies from 12 hours to 36 hours however, Pussayanavin *et al.* (2020) recommended an optimal hydraulic retention time (HRT) of 24 hours thus;

$$Liquid\ \ layer\ volume\ (V_l) = Q_p(HRT) = 0.08\, m^3/hour\ (24\ hours) = 1.92\, m^3$$

Sludge and scum volume

The desludging frequency of septic tanks varies as it depends on many factors however, Jaiswal *et al.* (2022), Mehta *et al.* (2019) as well as the research report of EPA (2018) recommends a desludging frequency (t) of 3 years. The ambient temperature of the area proposed for the septic tank ranged between 21.6 ºC to 30.5 ºC while the corresponding sizing factor (f_s) based on the information in Table 1 is 1.0. Also, the sludge and scum accumulation rate (S_a) for septic tanks designed for both toilet water and sullage is 30 litres per capita per year (Garg, 2010) thus;

$$Sludge\ and\ scum\ volume\ (V_s) = \frac{n \times S_a \times t(f_s)}{1000} = \frac{10person \times 30litres/person/year \times 3year(1.0)}{1000} = 0.9\, m^3$$

Capacity and dimensions of septic tank

$Capacity\ of\ septic\ tank\ (V) = V_l + V_s = 1.92\, m^3 + 0.9\, m^3 = 2.82\, m^3$

By assuming a depth (d) of 1.5m since the standard depth ranged from 1.2 m to 2.2 m, and also setting the ratio of length (l) to breadth (b) as 2 since the ratio ranged between 2 to 4, it implies; $l = 2b$.

$\therefore Volume\ (V) = 2.82 = l \times b \times d = 2b \times b \times 1.5$

$$=> b = \sqrt{\frac{2.82}{2(1.5)}} = 0.97\ m = 970\ mm = (3.2\text{ ft})$$

$l = 2b = 2(0.97m) = 1.94m = (6.4\text{ft})$

By adding a free-board space of 0.3m, the total depth (d_t) becomes,

$d_t = 1.5\,m + 0.3\,m = 1.8\,m = 1800\,mm$ (≅ 6.0 ft)

$length\ of\ first\ chamber = \frac{2}{3} of\ total\ length = \frac{2}{3} \times 1.94\,m = 1.29\,m = 1290\,mm$ = 4.2 ft

$length\ of\ second\ chamber = \frac{1}{3} of\ total\ length = \frac{1}{3} \times 1.94\,m = 0.65\,m = 650\,mm$ = 2.13 ft

In other words, the baffle wall should be built at a distance of 1290 mm (4.2 ft) away from the wall carrying the inlet pipe. However, the height of the baffle wall should be 1200 mm so that it will be 0.3 m below the scum layer. It is important to state here that the dimensions calculated above were internal dimensions (i.e. between inside walls). Hence during excavation, additional spaces should be provided to accommodate the thickness of the concrete side walls and baffle wall. Also, the designed septic tank is to be desludged by means of pump hence the floor was not sloped.

Dimensions of appurtenances

Two rectangular manholes meant for inspection and desluding were provided with the dimensions *610 mm* by *455 mm* while a vent pipe of *2000 mm* length and 4 inches (*101.6 mm*) diameter was included in the design to enable evacuation of gases formed in the septic tank. Both the inlet pipe for the raw sewage and the outlet pipe for the effluent were of the same diameter 4inches (*101.6 mm*), and the baffles of both pipes (T-joints) extends up to *200 mm* upward above the scum layer but stopped at *300 mm* below the covering slab in order to permit free movement of gases. However, the T-joint for the inlet pipe penetrated *300 mm* downward below the scum layer while that of the outlet pipe penetrated downward up to *600 mm* below the scum layer, which is 40% of the design depth of sewage.

Engineering drawings

The orthographic and isometric drawings of the designed septic tank are shown in Figure 1 and Figure 2 respectively, keeping all dimensions in mm.

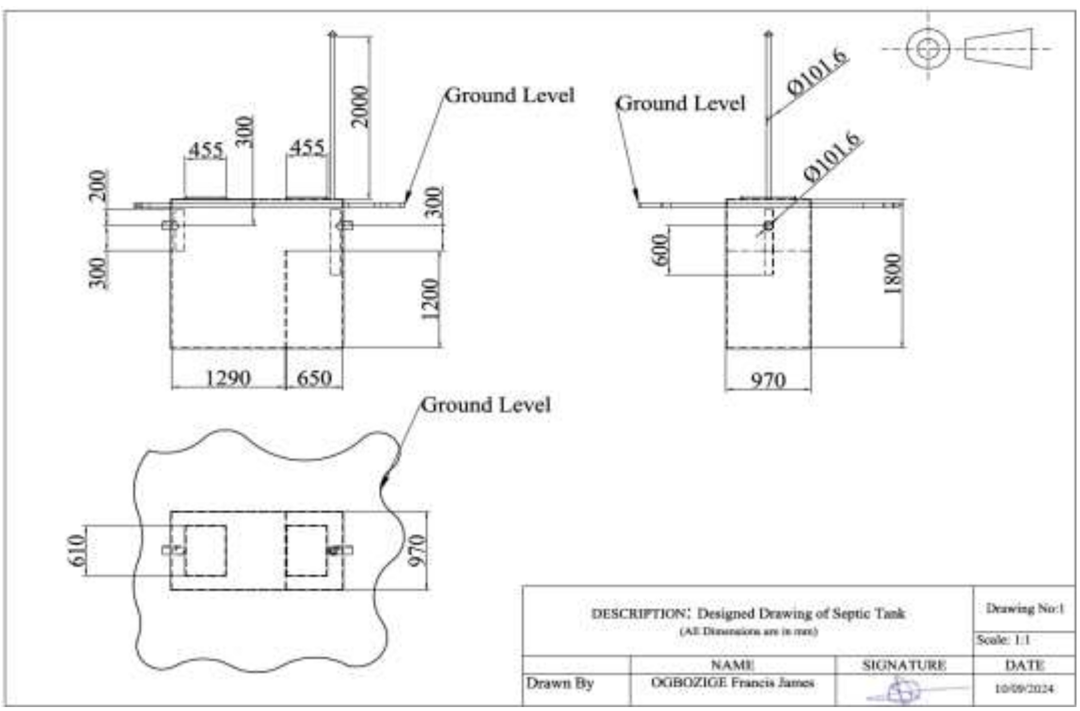

Figure 1: Orthographic projection (3rd angle) of septic tank

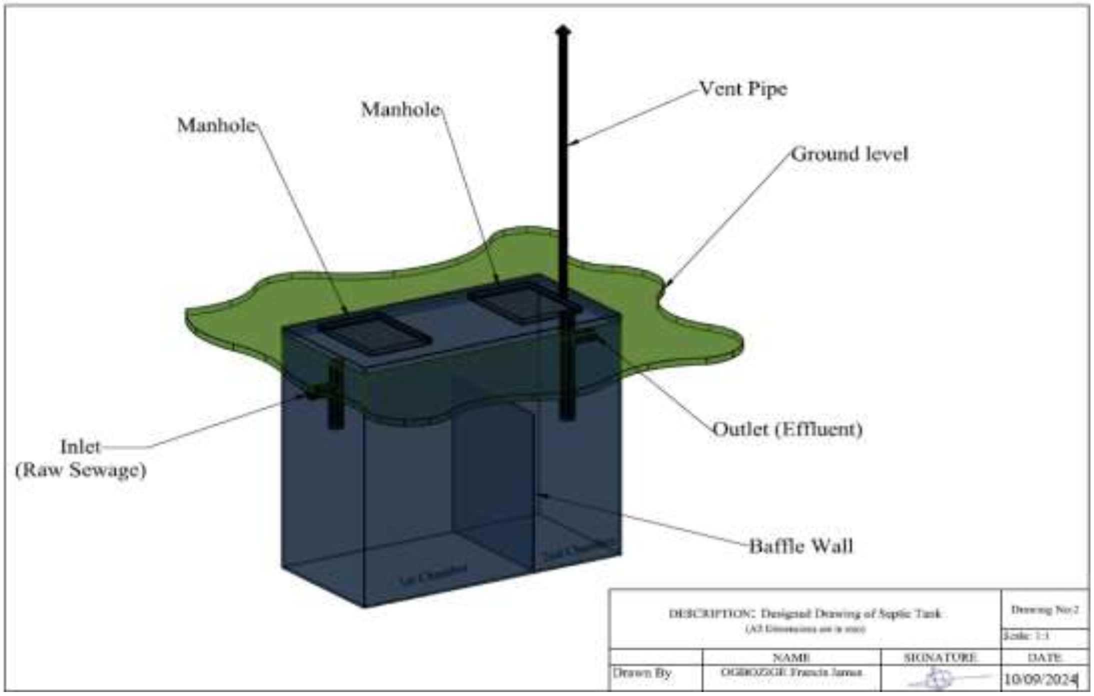

Figure 2: Isometric view of septic tank

Conclusion

This paper has successfully designed the appropriate size of a septic tank in accordance with environmental engineering principles and standards. Peculiar factors associated with the area meant for the installation of the septic tank such as realistic per capita water demand and ambient temperature were well captured. The design calculations were well detailed and simplified for proper understanding by masons and technicians, relevant engineering students, civil engineers, contractors as well as prospective researchers. Hence, it is highly recommended as a guide to related design by ensuring proper adjustments or moderations to suit the reality of the case being considered.

References

Barnett, H. and Ormiston, S. (2010). *Manual for On-site Wastewater Systems Design and Management, Horizons Regional Council*. McGraw Hill, Boston, USA.

Cruddas, P.H., Asproulis, N., Antoniadis, A., Best, D., Collins, G., Porca, E., Jefferson, B., Cartmell, E. and McAdam, E.J. (2022). The Impact of Hydraulic Retention Time on the Performance of two Configurations of Anaerobic Pond for Municipal Sewage Treatment. *Environmental Technology*, 43(25), 3905–3918, https://doi.org/10.1080/09593330.2021.1937331

Daija, L., Selberg, A., Rickmann, E., Zekker, I., Tenno, T., and Toomas, T. (2016). The Influence of lower Temperature, Influent Fluctuations and Long Retention Time on The Performance of an Upflow Mode Laboratory-Scale Septic Tank. *Desalination and Water Treatment*, 57(40), 18679 – 18687. https://doi.org/10.1080/19443994.2015.1094421

EPA (2018). Desludging Rates and Mechanisms for Domestic Wastewater Treatment System Sludges in Ireland. A Research Report Prepared by Environmental protection Agency (EPA), Dublin.

Garg, S.K. (2010). *Sewage Disposal and Air Pollution Engineering (Environmental Engineering Vol. II).* Khanna Publishers, New Delhi, India.

Jaiswal, J., Mehta, D. and Mehta, M. (2022). Impacts of Scheduled Desludging on Quality of Water and Wastewater in Wai city, India. *Urban Analytics and City Science*, 49(8), 2216–2229. https://doi.org/10.1177/23998083221078596

Massoud, M. A., Tarhini, A., Nasr, J.A. (2009). Decentralized approaches to wastewater treatment and Management: Applicability in Developing Countries. *Journal of Environmental Management (Elsevier)*, 90(1), 652 – 659. https://doi.org/10.1016/j.jenvman.2008.07.001

Mehta, M., Mehta, D. and Yadav, U. (2019). Citywide Inclusive Sanitation through Scheduled Desludging Services: Emerging Experience from India. *Frontiers in Environmental Science*, 7, 1 – 10. https://doi.org/10.3389/fenvs.2019.00188

Nakarmi, K.J., Daneshvar, E., Manttari, M., Bhatnagar, A. (2023). Removal and Recovery of Nutrients from Septic Tank Wastewater Using Microalgae: Key Factors and Practical Implications. *Journal of Environmental Management*, 345 (2023) 118922. https://doi.org/10.1016/j.jenvman.2023.118922

Nnajia, C.C. and Agunwamba, J.C. (2012). A Rational Approach to Septic Tank Design. *Nigerian Journal of Technology*, 31(1), 68–78.

Ogbozige, F.J. (2024). Design of Waste Stabilization Ponds for Municipal Effluent Treatment in Sobi Cantonment, Ilori, Nigeria. *Engineering and Technology Journal* 42 (05), 582-592. http://doi.org/10.30684/etj.2024.146992.1698

Ogbozige, F.J and Nwobu, H.U. (2021). Biosorption of Ni^{2+} and Cr^{3+} in Synthetic Sewage: Adsorption Capacities of Water Hyacinth (*Eichhornia crassipes*). Environmental Research and Technology 4(4), 342 – 351. https://doi.org/10.35208/ert.980490

Onu, M. A., Ayeleru, O.O., Oboireien, B. and Olubambi, P.A. (2023). Challenges of Wastewater Generation and Management in Sub-Saharan Africa: A Review. *Environmental Challenges*, 11, 1 – 21. https://doi.org/10.1016/j.envc.2023.100686

Peter, M.K., Alfa, M.I., Datau, G., Aluwong, K.C., Hadi, K.C. (2017). Design, Development and Performance Evaluation of an Anaerobic Plant. *American Journal of Engineering Research.* 6(4), 28 – 33.

Preiner, M. (2020). Surface Water Pollution by Untreated Municipal Wastewater Discharge Due to a Sewer Failure. *Environmental Process (Springer)*, 7, 767 – 780. https://orcid.org/0000–0001–9795–4086

Pussayanavin, T., Koottatep, T., Dinh, L.M., Khamyai, S., Sangchun, W. and Polprasert, C. (2020). Organic Matter, Solid and Pathogen Removals from Black Water in a Pilot-Scale Solar Septic Tank. *Applied Environmental Research*, 42(2), 74 – 83. https://doi.org/10.35762/AER.2020.42.2.6

Shrestha, R. (2020). *Septic Tank Design Manual.* A publication of Environmental and Public Health Organization (ENPHO), New Baneshwor, Nepal.

Wear, S.L., Acuna, V., McDonald, R. and Font, C. (2021). Sewage Pollution, Declining Ecosystem Health, and Cross-Sector Collaboration. *Biological Conservation (Elsevier)*, 255(109010), 1 – 9. https://doi.org/10.1016/j.biocon.2021.109010

WHO (1992). *A Guide to Development of On-Site Sanitation*. A publication of World Health Organization, Geneva, Switzerland.