PRINT ISSN 1119-8362
Electronic ISSN 2659-1499

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 29 (2) 667-672 Feb. 2025

Causes of Collapsed On-Site Wastewater Management Systems within Benin City, Edo State, Nigeria

OSUNBOR, JE; EVBARU-OKHUAIHESUYI, GE; *EHIOROBO, JO

Department of Civil Engineering, University of Benin, Nigeria

**Corresponding Author: Jessica.osunbor@eng.uniben.edu*
**ORCID: https://orcid.org/0009-0007-5241-1986*
**Tel: +2348115066782*

Co-authors Email: gloria.evbaru-okhuaihesuyi@uniben.edu; jacehi@uniben.edu

ABSTRACT: On-site wastewater management systems play a pivotal role in domestic wastewater management. However, their structural failure poses significant risks to human lives and can result in environmental hazards. Hence the objective of this paper was to investigate the causes of collapsed on-site wastewater management systems within Benin City, Edo State, Nigeria using appropriate standard techniques after collecting soil samples from 3 collapsed on-site wastewater management systems within the area of study. Data obtained reveals that the soil types investigated alternated between A-2-4 and A-2-6 Silty and Clayey soils according to AASHTO classification. Specific gravity test result values ranged from 2.54 to 2.62, and the gradation test from 9.87 to 17.25 for the 0.75micron sieve. The liquid limit ranges from (21.34 to 30.99) % and the plasticity index ranges from (0 to 17.44) %. Compaction results show that the soil has its maximum dry density (MDD) ranging from (1.79 to 1.90) g/cm^3 and its optimum moisture content from (8.8 to 14.0) %. While the triaxial test has its cohesion ranging from (2 to 26) % and its angle of internal friction as (8.03 to 20.54) ^{o}C. Reasons deduced to have been the cause of the observed variations in the strength properties and cohesion values of the soil samples of the same location include differences in soil composition, stress history, sample collection technique, and laboratory testing variability.

DOI: https://dx.doi.org/10.4314/jasem.v29i2.39

Cite this Article as: OSUNBOR, J. E; EVBARU-OKHUAIHESUYI, G. E; EHIOROBO, J. O. (2025). Causes of Collapsed On-Site Wastewater Management Systems within Benin City, Edo State, Nigeria. *J. Appl. Sci. Environ. Manage.* 29 (2): 667-672

Dates: Received: 23 December 2024; Revised: 27 January 2025; Accepted: 09 February 2025; Published: 28 February 2025

Keywords: Wastewater; Septic tanks; Geotechnical properties; Soil failure; Wastewater treatment system

The connection between wastewater and sustainability has created a research bias (Silva2023) and this research interest thrives to proffer solutions for a better, cleaner, and healthier planet. In this context, that means giving room for the prevalence of studies carried out in hopes of minimizing or eliminating the effect of On-site wastewater treatment system (OWTS) failures on the environment and public health. These studies have been carried out because it is evident that when failure of an OWTS occurs, seepage through the subsoil is expected, leading to the contamination of groundwater, and wreaking havoc on the environment and lives (Pradhan *et al*., 2023; Dowling *et al*., 2024). Septic tank failure has become a norm in certain regions across the world and one of the reasons that supports the lack of active governmental involvement as a means to curb these rising problems was discovered in a study stating that even when these systems have obvious signs of failure, they still remain in use way beyond the design intention. (Albright *et al*., 2024) The study further revealed that this is so because residents hold concerns that they could be subjected to fines for not being able to maintain broken septic systems or be required to install new systems if household- level research data

**Corresponding Author: Jessica.osunbor@eng.uniben.edu*
**ORCID: https://orcid.org/0009-0007-5241-1986*
**Tel: +2348115066782*

is published and made known to appropriate bodies. With the focus on a region of Nigeria, records show that Benin City, the capital of Edo State, Nigeria, has experienced rapid urbanization and population growth in the past decade (Olayiwola, and Igbavboa 2014). With the advent of this increase in population comes problems associated with growth and expansion such as poor development control and poor waste management. With continuing increase in population and housing development, the need for more effective on-site wastewater management systems has grown critical (Hasan*et al.,* 2022). Domestic wastewater and organic solid waste (feces) are one sort of waste that are unavoidable for the modern-day man (Lu *et al*., 2024). The use of on-site wastewater treatment systems is a way designed to manage the issue of waste separation, particularly concerning domestic waste. These systems are frequently employed in areas with insufficient or nonexistent centralized sewer infrastructure. On-site wastewater treatment systems, however, can pose serious health risks and water quality risks (Mbae*et al.,* 2024; Saadatinavaz*et al.,* 2024) hence the great need for proper construction and maintenance.

For any Civil engineering project, however big or small, it is essential that a proper field survey and a very detailed geotechnical investigation be done, and the purpose of the geotechnical study is to learn more about the static and dynamic properties of the soil and rock surrounding a site (Rawat and Mohanty 2022). The concept entails that the surrounding soil strata is sampled and examined as part of a below-ground inquiry to determine the characteristics and how they may affect a Civil Engineering project. Often, the conceptual stage of on-site wastewater treatment systems attached to low-rise buildings such as residential homes receive little or no detailed attention as it is a means to cut costs on the technical assessment of the ground (Zumrawi 2016) If proper protocols are not followed in the conceptual stage, who is to say these systems will be properly designed? An improperly designed septic system is a failure waiting to happen (Withers *et al.,* 2014). People may come into contact with waste in ways that risk their health and lives in circumstances when there is a lack of proper infrastructure for managing waste. Typically, domestic waste is moved to other locations by waste management infrastructures that function covertly. Its efficacy is determined by how well the activities and processes remain undetectable, much like other infrastructures within the framework of domestic waste management (Reno2015).

Pollution is one risk associated with the use of septic tanks, soak-away pits, and drain fields. The ineffective operation of these systems may cause soil pollution, possible groundwater contamination, and the release of dangerous microorganisms into the environment (Mester*et al*. 2023). On-site wastewater management systems structurally fail if they are not properly built or maintained, posing a serious risk to human life by allowing untreated effluent to contaminate nearby groundwater supplies. And in adverse scenarios a collapse can lead to the death of unsuspecting adults and children as they can fall into the collapsed system. Other studies have investigated the impact of septic tank effluent on groundwater quality like the study by Nwugha*et al.* (2021) that investigated septic tank leakages on groundwater quality using Owerri, Nigeria as a study area. The deviating method employed instead for this study aims to address On-site wastewater management system collapse from a root cause, focusing on soil characteristics and other geotechnical factors that influence the structural integrity and performance of cementitious-based on-site wastewater management systems. Hence the objective of this paper was to investigate the causes of collapsed on-site wastewater management systems within Benin City, Edo State, Nigeria

MATERIALS AND METHODS

Study Area: Ekosodin community is positioned to the east of Isihor within the Ovia North-East Local Government Area (LGA) of Edo State. It is situated within the coordinates of 5° 451 to 6° 151 east longitude and 5º 151 to 6º 451 north latitude, within the central province of Edo State. As of the 2006 census conducted by the National Population Commission, a population estimate of 7,000 people was made with an area of 2301 km^2. (Imarhiagbe, *et.al.* 2023; Rawlings and Seghosime 2022). The study area is in border sharing proximity to a famous landmark, the University of Benin. It is an erosion-prone area with an elevation that ranges between 44mm to 88mm above mean sea level.

Data Collection: The method for acquiring data for this study was a combination of primary and secondary data collection methods. Field surveys, including site inspections and the collection of soil samples, were used to acquire primary data. Secondary information was acquired from pertinent books, scholarly articles, and past relevant studies on on-site wastewater treatment systems and waste management. Samples were collected using the hand auger method. Three collapsed soak-away pits and septic tanks were explored in total. Soil was collected at two different spots within each location making it a total of six filled sample bags. All at a depth of 1m. The samples after collection were transported to the soil laboratory of the University of Benin, Benin City, Edo state. The Natural moisture content test, Sieve analysis test, Atterberg limit test, compaction test, and triaxial test were all conducted. To ascertain the correlation between soil qualities, structural integrity, and waste management it was necessary to conduct soil investigation around the sample sites and do a structural assessment by eyesight of the collapsed septic tanks.

Natural Moisture Content Test: The moisture content examination followed the guidelines outlined in BS 1377:1990, Part 2 (Darley and Carder 1998; Mir 2021) using an empty container, which had been cleaned and dried, and carefully weighed with precision to the nearest 0.1g. Subsequently, a representative portion of the soil was placed into the container, and the combined weight of the container and soil sample was promptly recorded. The container, along with the soil sample, was then subjected to drying in an oven for a duration of 24 hours. Following the oven drying process, both the container and the soil sample inside it were weighed once more and moisture content of the soil specimen was determined from equation 1.

$$\left(Moisture\ content\ (\%\%) = \frac{m_2 - m_3}{m_3 - m_1}\right) \times 100\% \quad (1)$$

Where; M_1 = mass of container (grams); M_2 = mass of container + wet soil (grams); M_3 = mass of container + dry soil (grams)

Specific Gravity Test: The specific gravity of soil using the bottle method, following the procedure specified in B.S. 1377:1990(Darley and Carder 1998; Mir 2021).

Particle Size Distribution Test (SIEVE ANALYSIS): The sieve analysis or particle size distribution was done according to the procedure outlined in BS 1377:1990 (Darley and Carder 1998; Mir 2021) and AASHTO T27-70

Atterberg's Limit Test: Atterberg's limit test were determined following the procedures outlined in BS 1377:1990 (Darleyand Carder 1998; Mir 2021) Test 7 and AASHTO T180-70 (BS 1377:1990, Tests 2 and 3), respectively.

Compaction Test: This test adhered to the guidelines outlined in BS 1377:1990 (Darley and Carder 1998; Mir 2021) Test 12 and AASHTO T180-70 as utilized by some case studies (Nematzadeh, *et. al.* 2017)

Triaxial Test: The triaxial shear test was conducted in accordance with the procedures outlined in B.S 1377:1990 Test 7 and ASTM Standard D4767.

RESULTS AND DISCUSSION

Results acquired from the various tests conducted from the experiment are presented below. All results obtained during this study were properly analyzed by considering vital aspects that influenced the collapse of the On-site wastewater management systems. The result of the specific gravity (GS), sieve analysis, and consistency limits (i.e., liquid limit and plastic limit) test used for the classification of the soils is presented in Table 1. From the results obtained, it is observed that the soils in the study area according to the AASHTO classification are Silty Clayey soils. The specific gravity test ranges from 2.54 to 2.62, and the gradation test from 9.87 to 17.25 for the 0.75-micron sieve. The liquid limit ranges from 21.34 to 30.99 percent and the plasticity index ranges from 0 to 17.44 percent. The compaction results show that the soil has its maximum dry density (MDD) ranging from 1.79 to 1.90 g/cm3 and its optimum moisture content from 8.8 to 14.0%. While the triaxial test has its cohesion ranging from 2 to 26% and its angle of internal friction as8.03 to 20.54^{o}c. Again, the swell potential is also very small indicating that the clay content present in the location soil is not problematic. It was noticed that the bearing capacity of the sample obtained from Edo Street 1 and Gully Road 2 were low as they were the only values below 100.

Table 1: Soil Classification Test

S/ N	Sample ID	Depth (m)	Gs	% Passing Sieve No.200	Consistency Limit LL	PI	AASHTO Class	Plasticity
1	Edo Street 1		2.62	9.87	21.37	0	A-2-4	ML
2	Edo Street 2		2.63	10.22	21.34	0	A-2-4	ML
3	Gully Road1		2.54	13.52	21.86	13.96	A-2-4	CL
4	Gully Road2		2.57	17.24	30.99	17.41	A-2-6	CL
5	Market Road 1	1.0	2.59	10.20	29.40	9.41	A-2-6	CL
6	Market Road 2		2.55	10.46	23.51	0	A-2-4	ML

The specific gravity results in Table ranges from 2.54 - 2.63. sieve passing sieve no 200 ranges from9.87 - 17.24 %, the liquid limit (LL) ranges from 21.34 – 30.99%, and the plasticity index range from 0 – 19.98 % all these shows that the constituent material of the soil is silt and clay respectively. The compaction test and the Triaxial test were conducted to determine the strength of the soil samples collected from the study area.

Compaction Test: The compaction test results are presented in Table 2 and figure 1.From Table 2 the optimum moisture contents (OMC) range from 8.8% to 14.0% and the maximum dry density (MDD) ranges from 1.79 to 1.9 which shows soil with water-retaining properties and minimum dryness.

Table 2: Compaction Test Results

S/N	Sample ID	Depth (m)	MDD (g/cm^3)	OMC (%)
1	Edo Street 1	1.0	1.85	9.6
2	Edo Street 2		1.83	8.8
3	Gully Road 1		1.79	13.3
4	Gully Road 2		1.80	12.8
5	Market Road 1		1.84	14.0
6	Market Road 2		1.90	10.4

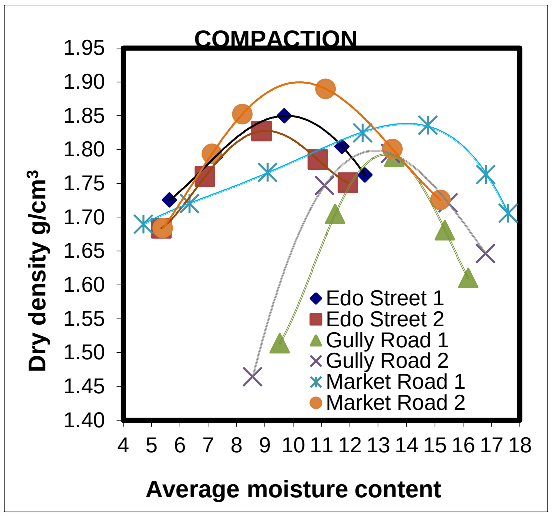

Fig 1: compaction Curves of Samples from the Study Area

Triaxial Test: The results of the shear strength parameters (c′ and φ') obtained from the unconsolidated undrained (U-U) triaxial test and the soil unit weight (γ) were used to calculate the ultimate and allowable bearing capacity (qall) using a factor of safety of 3.0 and are presented in Table 3. The test was carried out following BS 1377:75 Test 13 and BS EN 1997-2-2007. The ultimate bearing capacity was calculated for an assumed 1.0m square pad footing using Meyerhof's equations 2 to 10.

$$q_{ult} = cN_c s_c d_c + \gamma D N_q s_q d_q + 0.5\gamma B N_\gamma s_\gamma d_\gamma \quad (2)$$

$$N_q = ex\,p(\pi\,tan\,tan\emptyset)\,tan^2\left(45° + \frac{\emptyset}{2}\right) \quad (3)$$

$$N_c = \left(N_q - 1\right)cot\,cot\emptyset \quad (4)$$

$$N_\gamma = \left(N_\gamma - 1\right)tan\,tan(1.4\emptyset) \quad (5)$$

$$s_c = 1 + 0.2K_p B/L \quad (6)$$

$$s_q = s_\gamma = 1 + 0.1K_p B/L \quad (7)$$

$$d_c = 1 + 0.2\sqrt{K_p}D/B \quad (8)$$

$$d_q = d_\gamma = 1 + 0.1\sqrt{K_p}D/B \quad (9)$$

$$K_p = tan^2(45 + \emptyset/2) \quad (10)$$

Where: qult = Ultimate bearing capacity; C = Cohesion; φ = Angle of internal friction; γ = Bulk unit weight of soil; Nc, Nq, Nr = Bearing capacity factors; ic, iq, ir= inclination factor; sc, sq, sr = Shape correction factors; dc, dq, dr = Depth correction factors

Table 3: Triaxial Test Result and Shear Strength

S/N	Sample ID	Depth (m)	c′(kN/m^2)	φ'(°)	γ (kN/m^3)	qult(kN/m^2)	qall(kN/m^2)
1	Edo Street 1		2.0	15.91	16.64	300	100
2	Edo Street 2		3.5	8.03	16.68	186	62
3	Gully Road 1		26.0	13.18	17.93	873	87
4	Gully Road 2	1.0	22.0	14.49	17.48	826	143
5	Market Road 1		6.0	9.52	16.53	261	276
6	Market Road 2		20	20.54	15.57	429	291

From Table 3 it is observed that most of the cohesion values and internal friction for the soils were very low which is likely to be based on the plasticity of the soil hence the resulting low bearing capacity**.**

Conclusion: Analysis reveals that key geotechnical properties such as load bearing capacity, soil consistency, cohesion, and texture influence the stability of on-site wastewater management systems. The soil load bearing capacity is critical for supporting both the system and its pipes. Variation in capacity between Edo Street and Market Road indicates that some areas have low capacity resulting in a collapse of the tank. Soil consistency was determined to be loose based on cohesion values observed at Edo Street and the gully area. The proportion of sand, silt, and clay determines soil texture. Soils in the area were identified as A-2-4 and A-2-6 silty clayey soils, which offer good drainage but may lack adequate cohesion. The findings suggest that a thorough geotechnical investigation was omitted or based on an assumption of uniform soil properties. System overuse from car parking and indiscriminate waste burning contributed to the collapse.

Declaration of Conflict of Interest: The authors declare no conflict of interests

Data Availability Statement: Data are available upon request from the first author or first co-author.

REFERENCES

Albright, EA; Flower, CC; Randall, AK; Erika, SW (2024). Failing Septic Systems in Lowndes County, Alabama: Citizen Participation, Science, and Community Knowledge. *Local Environ.* 29(2): 135-142. DOI:https://doi.org/10.1080/13549839.2023.2267066

British Standards Institution (1990). British Standards Methods of Test for Soil for Civil Engineering Purposes. BS1377, London, p. 37.

Darley, P; Carder, DR (1998). Consultation Document on Suitability Tests for Stress Absorbing Layers behind Integral Bridge Abutments Prepared for Quality Services (Civil Engineering), Highways Agency, pp. 1 – 8.

Dowling, MJ; Amador, JA; Anderson, S; Bengtson, S; Hemphill, K; Loomis, GW (2024). Relationship between Groundwater Nitrate Concentration and Density of Onsite Wastewater Treatment Systems: Role of Soil Parent Material and Impact on Pollution Risk. *J. Sustain. Water Built Environ.* 10(3): 747. DOI: https://doi.org/10.1061/JSWBAY.SWENG-547

Hasan, S; Sazadul, MD; Trapp, J; Geza, M (2022). Improvement of Onsite Wastewater Systems Performance: Experimental and Numerical Investigation. *Clean Technol.* 4(3): 824-840. DOI: https://doi.org/10.3390/cleantechnol4030051

Huffman, J; Simonetti, S; Herbert, R (2018). Onsite Sewage Systems: Background, Framework, and Solutions. Virginia Coastal Policy Center, p. 2.

Imarhiagbe, EE; Onwudiwe, CC; Akahomhen, M (2023). Water, Sanitation, Hygiene and Health Status of Ekosodin Community Residents, Benin City, Edo State, Nigeria. *J. Appl. Sci. Environ. Manage.* 27(11): 2611-2618. DOI: https://doi.org/10.4314/jasem.v27i11.33

Lu, M; Chuanbin, Z; Chenghao, W; Robert, BJ; Christopher, PK (2024). Worldwide scaling of waste generation in urban systems. *Nat. Cities.* DOI: https://doi.org/10.1038/s44284-023-00021-5

Mbae, M; Hansen, P; Way, C; Mills, F; Willetts, J; Foster, T; Evans, B. (2024). Onsite sanitation systems and contamination of groundwater: A systematic review of the evidence for risk using the source-pathway-receptor model. *PLOS Water*, 3(7), e0000167. https://doi.org/10.1371/journal.pwat.0000167

Mester, T; Szabó, G; Sajtos, Z; Baranyai, E; Kiss, E; Balla, D (2023). Assessment of Groundwater Decontamination Processes around a Dismantled Septic Tank Using GIS and Statistical Analysis. *Wat.* 15(5): 884. DOI: https://doi.org/10.3390/w15050884

Mir, BA (2021). Manual of Geotechnical Laboratory Soil Testing. p. 102. DOI: https://doi.org/10.1201/9781003200260

Nematzadeh, M; Panam, Z; Mehdi, N (2017). Investigating Laboratory Parameters of the Resistance of Different Mixtures of Soil – Lime – Fume Using the Curing and Administrative Method. *Case Stud. Constr. Mater.* 7: 263-279. DOI: https://doi.org/10.1016/j.cscm.2017.08.002

Nwugha, VN; Okeke, PI; Emeronye, PR (2021). Impacts of Pollution: Leaking Septic Tanks on Groundwater Quality in Owerri Southeastern, Nigeria. *Curr. Approach. Sci. Tech. Res.* 5: 103-

111. DOI: https://doi.org/10.9734/BPI/CASTR/V5/2521E

Olayiwola, AM; Igbavboa, OE (2014). Land Use Dynamics and Expansion of the Built-up Area in Benin City, Nigeria. *Mediterr. J. Soc. Sci.* 5(20): 2506-2516. DOI: https://doi.org/10.5901/mjss.2014.v5n20p2506

Pradhan, B; Sujata, C; Sasmita, C; Prangya, RR; Sushanta, KN (2023). Emerging Groundwater Contaminants: A Comprehensive Review on Their Health Hazards and Remediation Technologies. *Groundw. Sustain. Dev.* 20: 100868. DOI: https://doi.org/10.1016/j.gsd.2022.100868

Rawat, P; Mohanty, S (2022). Parametric Study on Dynamic Characterization of Municipal Solid Waste Fine Fractions for Geotechnical Purpose. *J. Haz. Tox. Radioact. Wast.* 26(1): 04021047. DOI: https://doi.org/10.1061/(ASCE)HZ.2153-5515.0000659

Rawlings, A; Seghosime, S (2022). Evaluation of Water Supply, Sanitation and Hygiene Facilities in Ekosodin Community of Ovia North-East LGA, Benin City, Edo State, Nigeria. *Nig. J. Tech.* 41(4): 632-643. DOI: https://doi.org/10.4314/njt.v41i4.1

Reno, J (2015). Waste and Waste Management. *Annu. Rev. Anthropol.* 44(1): 557-572.DOI: https://doi.org/10.1146/annurev-anthro-102214-014146

Saadatinavaz, F., Alomari, M. A., Ali, M., Saikaly, P. E. (2024). Striking a balance: Decentralized and centralized wastewater treatment systems for advancing Sustainable Development Goal 6. *Advanced Energy and Sustainability Research*, 5(10), 2400097. https://doi.org/10.1002/aesr.202400097

Silva, JA (2023). Wastewater Treatment and Reuse for Sustainable Water Resources Management: A Systematic Literature Review. *Sustainability.* 15(14): 10940. DOI: https://doi.org/10.3390/su151410940

Withers, PJA; Philip, J; Linda, M; Helen, PJ; Nancy, ED (2014). Do Septic Tank Systems Pose a Hidden Threat to Water Quality? *Front. Ecol. Environ.* 12(2): 123-130. DOI: https://doi.org/10.1890/130131

Zumrawi, M (2016). Effects of Inadequate Geotechnical Investigations on Civil Engineering Projects. *Int. J. Sci. Res.* 2319-7064. DOI: https://doi.org/10.13140/RG.2.2.36129.68966