Application of Biopori Technology for Sustainable Management of Household Organic Waste

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Abstract Management of household organic waste is very important, especially in urban areas, because improper disposal causes the environment to become unhealthy. This research aims to determine the adoption and application of bio pore technology for sustainable organic waste management in Sleman Regency, Yogyakarta. The method used is descriptive quantitative using survey techniques, participatory action research (PAR), and focus group discussions (FGD) to determine public perceptions and the effectiveness of technology. The analysis was carried out descriptively using indicators of relative advantage, compatibility, complexity, trialability, and observability of biopori technology. The research results using the Wilcoxon-Rank test analysis showed a significant difference in Knowledge, Attitudes, and Practices (KAP) scores before and after training. The public assesses waste processing using bio-Pori technology based on relative advantage, compatibility, complexity, trialability, and observability very good. Biopori technology is compatible with previous technologies, easy to learn, accepted, applied, and successfully tested. The application of Biopori technology improves soil quality , reduces organic waste, and provides benefits to society both from an economic and technical perspective. The research results have implications for the acceptance and feasibility of bio-Pori technology as a sustainable solution for managing household organic waste of household

1 Introduction

Consumerist culture tends to exploit natural resources, which also reduces the quality of the environment due to increasing solid waste (garbage), liquid, and gas [1][2] [3]. In Indonesia, the largest contributor to waste is household waste (62%), with the main component of household waste being food waste or organic waste (44%) [4]. Sleman Regency is a district with lots of tourism and universities, and so many immigrants live there, which produces a lot of waste, 304 tons per day. Regarding waste management, Sleman Regency issued Regulation 030 of 2022 concerning the Movement to Sort Waste from Home. If these regulations can be appropriately implemented, waste management will be done directly by reducing, reusing, and recycling. One organic waste source is household or household waste, the most significant contributor to environmental damage. Some examples of organic waste

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include food waste, Vegetables, fruit, and leaves. For this reason, organic waste needs to be handled by cutting off the flow of waste distribution to the landfill and managing organic waste at the household level [5].

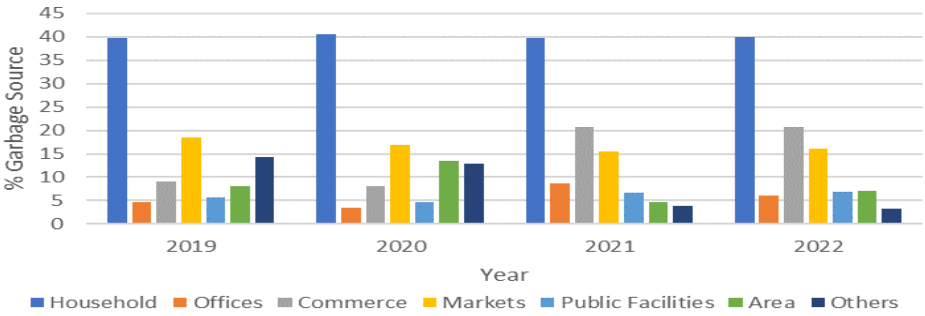

Fig. 1. Composition of waste based on source in Indonesia.

Urban areas such as Kocoran Hamlet and Karngwuni Hamlet, Catur Tunggal Village, Depok District, Sleman Regency face significant challenges in managing the increasing volume of household organic waste. Improper organic waste disposal causes environmental pollution and health risks and increases landfill problems. Traditional waste management systems require innovative and sustainable solutions to overcome waste problems. Biopori technology is appropriate to help overcome flooding by repairing water absorption capacity and converting organic waste into compost. Biopori can help reduce dryness and waste load in landfills. Biopore absorption holes not only as a water catchment but also as soil fertilizer, reducing the accumulation of rubbish that causes various health problems. Kamir R. Brata developed biopore technology in Indonesia. These biopore absorption holes absorb water into the soil, collect organic waste, and preserve soil fauna. The shape is a cylindrical hole on the ground surface with a diameter of only 10 centimetres and a depth of 1 meter. [6]. Previous research has shown that biopore technology effectively increases nutrient and water absorption [7] [8] [9].

Sustainable and innovative methods have been explored in response to the global challenge of managing organic waste to reduce environmental impact. Biopore technology, a relatively innovative, has received significant attention for its ability to manage organic waste and increase soil fertility effectively. Making biopore absorption holes in urban areas is very easy and only requires low costs. The method is to dig a small hole in the ground and fill it with organic waste. These holes are very effective in absorbing water and function to reduce the amount of organic waste thrown into landfills. By utilizing small holes and organic waste, urban areas that look dry will be transformed into environmentally friendly areas. Apart from that, organic waste stored in the hole can be used as a source for making compost which can be used to fertilize plants [10] [11].

Several studies highlight the effectiveness of Biopore technology in processing organic waste.. The application of Biopore technology in urban areas resulted in a reduction in waste volumes of up to 40% within six months, along with marked improvements in soil fertility indicators, such as increased water content. organic carbon and nitrogen [9] [12]. Biopori technology has great potential, but only some want to adopt and accept it. The community gained knowledge of biopore technology from counseling, printed media in the form of leaflets, and demonstrations of making biopore holes. Based on the information obtained, the public then perceives and begins to assess the innovation based on the nature

of the innovation, the relative advantage of the innovation (relative advantage), the suitability of the innovation (compatibility), the complexity of the innovation (complexity), the ease of the innovation to try (triability) and the ease of seeing the results of the innovation. (observability). This research examines public knowledge, attitudes, and perceptions of Biopori technology in sustainable organic waste management. Knowing the public's perception of biopore technology can also be used as an indication of technological components that must be improved if the technology is to be developed on a wider scale, according to the needs of the adopting community.

2. Methodology

2.1. Study Area and Participants (respondent)

Research and community service was carried out in Kocoran Hamlet and Karangwuni Hamlet, Catur Tunggal, Depok District, Sleman Regency, because this area has a high population density with many boarding houses and food stalls, thus contributing significantly to waste generation (Table 1). The sample was taken purposively by as many as 30 participants: housewives, food stall owners, and boarding house administrators [17][18].

Table 1. Waste Generation in DIY 2020-2023 (tons)

Regency	Year			
	2020	2021	2022	2023
Kulon Progo	61,774.21	63,713.67	64.654,31	64.730,71
Bantul	220,910.15	192,021,91	133.629,74	133.629,74
Gunung Kidul	131,671.16	131.671,61	138.468,71	138.468,71
Sleman	255,188,17	256.210,07	268.481,59	269.628,46

Source: Ministry of Environment and Forestry Directorate General of Waste Management, Waste and B3 Directorate of Waste Management

2.2. Data Collection Procedures

a. The Preparation and survey stage identifies land characteristics and physical conditions of the residential environment. Mapping open areas both in the yard and outside open spaces in residential areas that can be made into holes bio pore. Then, determine the target location for making bio pores by the community.
b. Socialization using the presentation method. So that community partners know, understand, and are more responsive in using the page his house as a water absorption hole.
c. Training stage for making bio pores, namely conducting counselling and workshops regarding introduction to the equipment and materials that need to be prepared for making bio pores, as well as training in making bio pores in groups.
d. The implementation stage of the bio pore-making activity, namely making holes bio pores in residential environments, especially in areas that have been selected and agreed upon together.

2.3. Data Analysis

The qualitative data from FGDs and interviews were analysed thematically to identify key themes related to the adoption and implementation of bio pore technology. The quantitative data from the KAP surveys and innovation attribute assessments were analysed using the Wilcoxon Rank Test to determine whether there were statistically significant differences in participants' knowledge, attitudes, and practices before and after the training, as well as to evaluate the overall perception of the innovation attributes. The Wilcoxon Signed-Rank Test formula used in this research is designed to produce data in the form of descriptive statistics, rankings for pretest and post-test scores, and the results of the Wilcoxon Signed-Rank Test [19] [20] [21]. This analysis will determine whether the null hypothesis (H_0) or the alternative hypothesis (H_1) is accepted. The formula is outlined as follows [22]
Ho: The median difference between the paired observations is zero. In other words, there is no significant difference in the participants' knowledge, attitudes, and practices (KAP) scores before and after the training on Biopore technology
Hi: The median difference between the paired observations is not zero. This implies that the training on Biopore technology) has had a significant effect on the KAP scores.

$$Z = \frac{(W_s - (\frac{n(n+1)}{4}))}{\sqrt{(\frac{n(n+1)(2n+1)}{24})}} \qquad (1)$$

where n is the reduced samples, size excluding any differences of zero, and ws is the smaller in absolute value of the signed ranks for a two-tailed test, the sum of the positive ranks for a left-tailed test, or the sum of the negative ranks for a right-tailed test. The sample size n is the reduced sample size not including any differences of zero. If the calculated Z value is greater than or equal to the critical Z value from the table, the null hypothesis (H_0) should be rejected.

To evaluate the community's perception of biopore technology for sustainable household organic waste management, an analysis was conducted using specific indicators, namely Relative Advantage, Compatibility, Complexity, Trialability, and Observability. These indicators are critical in understanding how the community views the adoption and practicality of biopore technology compared to traditional waste management methods. By assessing these factors, the study aims to provide insights into the community's readiness and willingness to adopt biopore technology as a sustainable solution for managing organic waste.

Table 2. Category Average Score and Achievement Score of Public Perception of Innovation Biopore Technology in Organic Waste Processing

Variable	**Category**	
	Average Score 1,00 – 2,49 Score Achievement 0-49,99	**Average Score 2.50-4.00 Score achievement of 50.00-100.00**
Relative Advantages	Unprofitable	Auspicious
Compatibilty	Not Suitable	Appropriate
Complexity	Complicated	Easy
Trialability	Difficult	Easy
Observabilty	Difficult	Easy

3 Results and Discussion

3.1. Household Waste Management

Households significantly contribute to the overall volume of waste generated, but household waste can be reduced considerably through proper waste management practices. Effective waste management systems must actively engage housewives and adhere to Government Regulation Number 81 of 2012, which outlines the guidelines for managing household waste and similar types of waste. Waste management is categorized into two main areas: the first focuses on managing household waste and similar types, while the second addresses managing specific types. The government primarily manages particular waste, while household waste management encompasses waste reduction and handling. Waste reduction efforts include minimizing waste generation, recycling, and reusing materials. In this framework, the central government, local authorities, businesses, and communities each play distinct and vital roles.

The role of households in waste management includes:

a. Minimize waste generation by reducing the consumption of single-use plastic products, such as plastic bottles, bags, and cups, and avoid using Styrofoam.
b. Reuse inorganic waste that has the potential for repurposing.
c. Sort waste into four categories: organic, inorganic, residual, and hazardous (B3).
d. Provide separate waste bins with clear labels or symbols for easy identification, ensuring all family members can participate effortlessly.
e. Divert inorganic waste to a Waste Bank, waste collection app, or local collector, preventing it from ending up in temporary disposal sites.
f. Deliver the sorted waste to the designated collection officer, local disposal site, or depot.
g. Pay the waste management or sanitation service fees to the Environmental Agency.

Community waste sorting practices still need to be widely adopted. However, community involvement in reducing waste volume by sorting at the source is crucial. Households contribute significantly to the waste generated in Sleman Regency, accounting for 65.15% of the total waste. This makes household participation in waste sorting a critical factor in the success of overall waste management efforts. Only 23.33% of respondents consistently sort their waste, while 30% never engage in sorting. The main reasons cited for not sorting waste include the perception that it is inconvenient, the belief that it is pointless, the lack of separate trash bins, or simply being unaccustomed to the practice. Additionally, many find it time-consuming and often need to remember to do it.

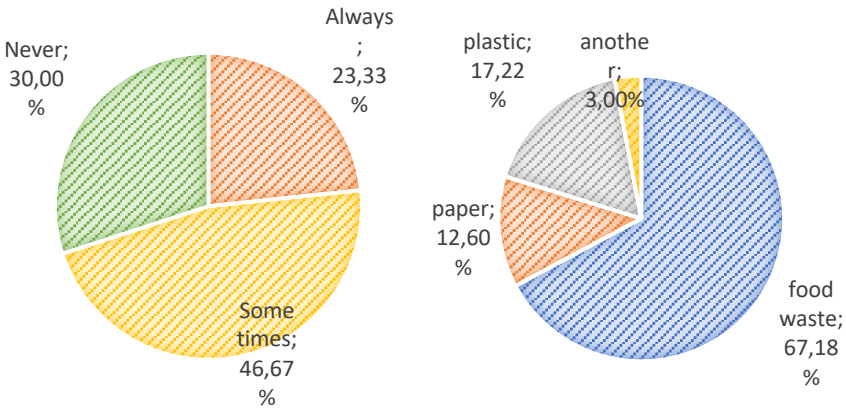

Fig. 2. Types of waste and household behavior in sorting waste

Household waste consists of solid waste of organic and inorganic materials deemed no longer helpful and requires proper management to avoid environmental harm. A significant portion, 67.18%, of household waste is organic and can be repurposed into liquid and solid fertilizers through further processing. As primary waste producers, households should take responsibility for managing their waste effectively, starting from the point of origin. Household members should actively manage their waste as part of their responsibility. Organic kitchen waste, for example, can be converted into compost, eco-enzyme, or maggot feed using methods such as Takakura, stacked buckets, or bioprocess.

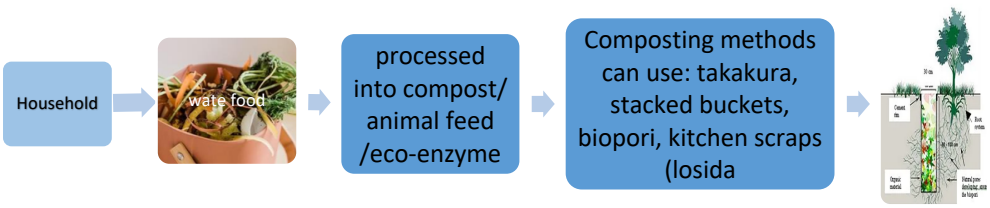

Fig. 3. Organic Waste Management

This technology, which involves creating vertical holes in the ground to increase water infiltration and facilitate the d Biopore, is a simple technology used to improve water infiltration into the soil and speed up the decomposition process of organic material. This technology involves making vertical holes in the ground with a diameter of about 10-30 cm and a depth of about 80-100 cm. These holes are then filled with organic materials such as leaves, food scraps, and compost, which will decompose naturally in the soil composition of organic materials, offering a practical solution to the increasing challenges of waste management, especially in urban areas such as the hamlets of Kocoran Baru and Karangwuni, Caturtunggal, Depok, Sleman Regency.

The process of making bio pores is concise and accessible. After selecting a suitable location, the next step is drilling or perforating. The steps that must be taken are as follows:

a. Make a cylindrical hole into the ground using a drill with a diameter of 10-30 cm and a depth of around 100 cm, or it is recommended that it does not exceed the depth of the groundwater at the bottom of the channel or groove that has been made. The distance between holes can be made 50-100cm.
b. The mouth of the hole can be strengthened with cement mortar 2-3 cm wide and 2 cm thick around the mouth of the hole, or it can be closed with a steel ring.
c. Immediately fill the hole with prepared organic waste from plant residues from tree leaves, grass clippings, or kitchen waste.
d. Organic waste must always be added to holes whose contents have been reduced or shrunk due to the process of decomposing waste by organisms.
e. Compost produced in bio pore holes can be taken at the end of each dry season at the same time as hole maintenance [23].

Bio pores were first introduced to improve soil health by enhancing natural processes such as water infiltration and organic matter decomposition. Early studies focused on using biopores in agricultural settings to improve soil structure and fertility [24] [25]. Over time, the application of biopore technology expanded to include waste management, particularly the processing of organic waste into compost. This evolution reflects a broader recognition of the potential for bioprocess to address both soil degradation and waste disposal challenges.

Biopore technology has been widely adopted for the management of organic waste in both rural and urban settings. Studies have shown that bio pores can effectively reduce the

volume of organic waste by facilitating its rapid decomposition into compost [26] [27]. In urban areas, biopore technology has been used to manage household organic waste, reducing the burden on municipal waste disposal systems and providing a sustainable source of compost for urban agriculture [28].

3.2. Results of Knowledge and community response to Counseling and training on processing organic waste using Biopori technology

One of the indicators used before and after Counseling and training is related to knowledge, attitude, and practice (perception), which is then called the KAP survey. This survey was carried out by distributing questionnaires to all participants in training and assistance activities for processing organic waste using bio pore technology. The purpose of the survey is to find out their knowledge regarding waste management, especially organic waste. Survey results both before and after mentoring.

The results of this study provide valuable insights into the effectiveness of counselling and training programs aimed at enhancing community knowledge and practices related to organic waste management using bio pore technology. The significant improvements observed across all KAP (Knowledge, Attitude, and Practice) survey indicators highlight the positive impact of these interventions on the participants' understanding and their readiness to adopt bio pore technology in their daily lives.

The marked increase in the participants' understanding of bio pore technology, as evidenced by the rise from 96.67% pre-test to 100% post-test, indicates that the training program was highly effective in conveying the necessary knowledge. This is crucial for ensuring that the participants can correctly implement bio pore technology for organic waste management. The findings are consistent with studies such as Smith et al. (2021), which found that well-structured training programs significantly enhance the adoption of environmental technologies.

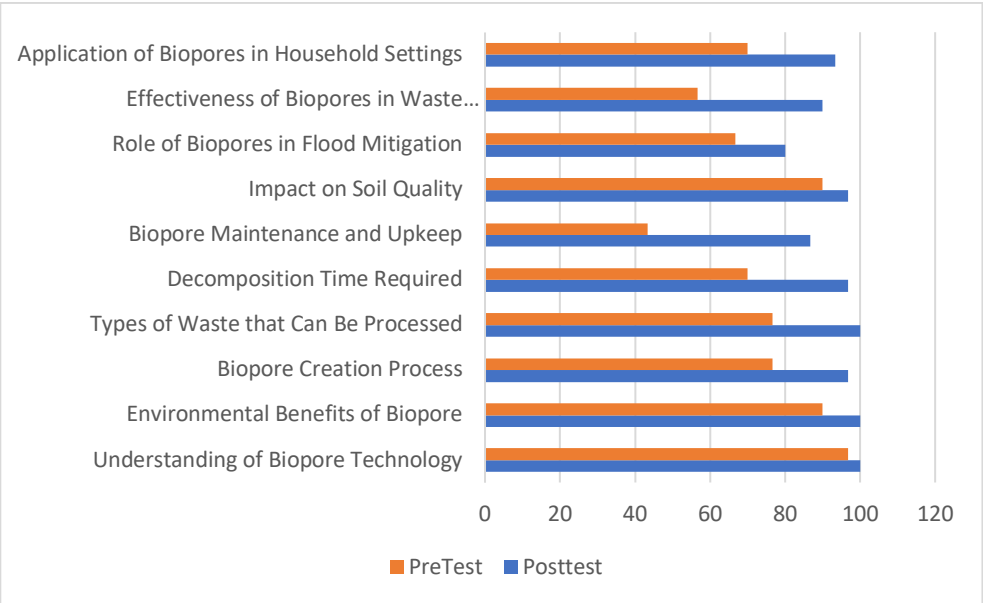

Fig. 4. Percentage of respondents who know about processing organic waste using bio pore technology before and after training.

The 100% post-test result regarding the environmental benefits of bio pore technology underscores the success of the training in raising awareness about the broader implications of organic waste management. Participants' improved understanding of how bio pore technology can contribute to environmental sustainability aligns with the goals of the [29] report, which emphasizes the importance of community-based initiatives in achieving global sustainability targets.

The substantial improvement in knowledge about the bio pore creation process (from 76.67% to 96.67%) and the types of waste that can be processed (from 76.67% to 100%) reflects the effectiveness of the practical components of the training. However, the lower initial understanding of bio pore maintenance and upkeep, which only increased from 43.33% to 86.67%, suggests that ongoing education and support are necessary. This finding is supported by Jones et al. (2022), who noted that the sustainability of environmental practices often depends on continuous support and reinforcement.

Participants' increased awareness of the impact of biopore technology on soil quality (from 90% to 96.67%) and its role in flood mitigation (from 66.67% to 80%) is particularly significant. These aspects are critical in regions prone to environmental degradation and flooding. The improvement in understanding these roles suggests that participants are better equipped to apply biopore technology in ways that contribute to broader environmental resilience. This aligns with findings by Martinez et al. (2020), who highlighted the importance of community knowledge in enhancing environmental resilience through sustainable practices.

The overall increase in the KAP score from 7.37 to 9.40, with a reduction in standard deviation from 1.86 to 0.89, indicates a more uniform and enhanced understanding among participants post-training. This demonstrates the training's success in not only increasing knowledge but also in reducing knowledge gaps among participants. However, the study also highlights areas where further education and support may be needed, particularly in the maintenance and practical application of biopore technology. Future programs could benefit from incorporating more detailed and hands-on sessions focused on these aspects to ensure long-term sustainability and effectiveness of the practices taught. To evaluate whether there is a significant difference in the Knowledge, Attitude, and Practice (KAP) survey results before and after the training on biopore technology for organic waste management, the Wilcoxon rank test was utilized. The Wilcoxon rank test is a non-parametric statistical test that is particularly useful for comparing paired samples, such as pre-test and post-test scores, where the data may not follow a normal distribution. By analysing the differences in KAP scores before and after the intervention, this test helps determine the effectiveness of the training in improving participants' knowledge, attitudes, and practices regarding biopore technology. The results of the Wilcoxon rank test analysis are shown in Table 3.

Table 3. Wilcoxon Rank Test

		N	Mean Renk'S	Sum Rank'S
Pretest-posttest	Negative Rank's	1	5.00	5.00
	Positive Ranks	24	13.33	320.00
	Ties	5		
	Total	30		
Test Statistics Z-Value	-4.274			
Z Table (α =0.05)	1.96			
Assymp Sign	0.000			

The Wilcoxon rank test results revealed a significant difference in the KAP scores before and after the training. Out of 30 participants, 24 showed positive ranks, indicating an improvement in their scores, while only 1 participant had a negative rank, suggesting a decrease in their KAP score post-training. Additionally, 5 participants had ties, meaning their

scores remained unchanged. The test statistic (Z-value) was calculated as -4.274, and the corresponding p-value was 0.000, which is less than the significance level of 0.05. This indicates that the improvement in KAP scores is statistically significant, allowing us to reject the null hypothesis that there is no difference between pre-test and post-test results.

The results indicate that the counseling and training sessions significantly increased participants' knowledge and understanding of biopore technology. The significant improvements in most indicators suggest that participants left the training with a firmer grasp of how biopores can be utilized for waste management, environmental sustainability, and soil quality improvement. These findings align with previous research highlighting the importance of educational interventions in enhancing community knowledge and engagement in sustainable practices [30] [31]. Studies have consistently shown that targeted training and awareness programs are crucial for successfully adopting environmentally sustainable technologies, such as bio pores [32]. The improvement in understanding bio pore maintenance and the practical application of bio pores in households also echoes findings by [33], who emphasize the need for practical, hands-on training to increase adoption rates

Biopore technology has emerged as an innovative and sustainable solution for organic waste management, particularly in urban and densely populated areas. This technology involves the creation of small vertical holes in the ground, which are filled with organic waste to enhance the natural decomposition process and improve soil health. Despite its potential benefits, the adoption of biopore technology is highly dependent on public perception and understanding of its advantages, suitability, and ease of use. Understanding community perception is crucial as it directly influences the willingness to adopt and consistently apply biopore technology in daily waste management practices.

The results of the study, as illustrated in Table 4, provide a robust understanding of public perception regarding the adoption of biopore technology for organic waste management. The findings reflect a comprehensive analysis across five key indicators: Relative Advantage, Compatibility, Complexity, Trialability, and Observability. These indicators collectively offer a clear picture of the community's readiness to adopt biopore technology and the factors influencing this decision.

Table 4. Average Score and Achievement Score of Public Perception of Innovation Biopore Technology in Organic Waste Processing

Variables	**Average score**	**Score Achievement (%)**	**Categories**
Relative Advantages	3.075	69.17	Profitable
Compatibilty	3.425	80.83	Suitable
Complexity	2.925	64.17	Easy
Trialability	3.092	69.73	Easy
Observabilty	3.100	70.01	Easy

The study shows that biopore technology has a significant Relative Advantage, with an average score of 3.075 and a score achievement of 69.17%. This high score indicates that the community perceives biopore technology as advantageous, particularly when compared to conventional waste management practices. Recent research by [34] supports this finding, demonstrating that innovations perceived as offering substantial environmental and economic benefits are more likely to be adopted by communities

The Compatibility indicator, with an average score of 3.425 and a score achievement of 80.83%, indicates that biopore technology aligns well with the community's existing values, practices, and needs. This finding is supported by [35], who emphasized that the success of environmental innovations largely depends on their compatibility with local cultural and operational contexts. The high level of compatibility suggests that biopore technology is not only suitable but also easily integrates with the community's current waste management practices.

The Complexity indicator scored an average of 2.925, with a score achievement of 64.17%, indicating that biopore technology is perceived as relatively easy to understand and implement. This low perceived complexity aligns with findings by [36], who found that the simplicity of environmental technologies significantly reduces barriers to adoption, especially in communities with limited technical expertise).

The Trialability indicator received an average score of 3.092 with a score achievement of 69.73%. This score indicates that the community finds it relatively easy to experiment with biopore technology before committing to full-scale adoption. [37] highlighted that the ability to trial a new technology is crucial for reducing the perceived risk associated with its adoption, a finding that is consistent with the results of this study. Encouraging small-scale trials could effectively promote broader adoption of biopore technology.

The Observability indicator, with an average score of 3.100 and a score achievement of 70.01%, suggests that the results and benefits of biopore technology are visible and tangible to the community. [38] emphasized that the visibility of positive outcomes is a critical factor in sustaining the adoption of environmental technologies. The ability to see immediate benefits, such as improved soil quality and reduced organic waste, reinforces the community's positive perception of biopore technology. The study concludes that biopore technology is generally well-received by the community, with strong positive perceptions across all key indicators. The perceived relative advantage, compatibility with existing practices, ease of use, and the ability to trial and observe the technology's benefits suggest that biopore technology has a strong potential for widespread adoption in managing household organic waste.

4. Conclusions

This study confirms that biopore technology is a viable and sustainable method for managing household organic waste, particularly in urban areas such as Sleman Regency. The significant improvements in community Knowledge, Attitude, and Practice (KAP) following targeted training programs underscore the technology's potential for broader adoption. Statistical analysis, validated by the Wilcoxon rank test, demonstrated that these improvements are not only significant but also impactful in enhancing participants' understanding and application of biopore technology. The community's positive perception of the technology, especially in terms of its compatibility with existing practices, ease of use, and observable environmental benefits, suggests that biopore technology can effectively contribute to waste reduction and soil quality improvement. However, the study also highlights the necessity for continuous education and support to maintain the long-term effectiveness and adoption of biopore systems. Ongoing efforts should focus on addressing remaining knowledge gaps, particularly in the areas of system maintenance and practical application. These findings contribute valuable insights to the field of sustainable waste management and offer practical recommendations for policymakers and environmental practitioners seeking to implement biopore technology on a larger scale. Continued research and community engagement are essential to ensuring that biopore technology can fulfill its potential as a cornerstone of sustainable waste management strategies.

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References

1. V. Arsanti and R. Giyarsih, **4**, 55 (2012).
2. P. R. Yaashikaa, P. S. Kumar, T. C. Nhung, R. V Hemavathy, M. J. Jawahar, J. P. Neshaanthini, and G. Rangasamy, Chemosphere **309**, 136627 (2022).
3. S. Khan, R. Anjum, S. T. Raza, N. Ahmed Bazai, and M. Ihtisham, Chemosphere **288**, 132403 (2022).
4. J. Semilu Rosesar and G. Andari Kristanto, IOP Conf. Ser. Mater. Sci. Eng. **909**, (2020).
5. A. Islam, P. K. Singh, and K. Mausam, Mater. Today Proc. **45**, 3318 (2021).
6. R. kamir and N. A. Brata, *Lubang Resapan Biopori* (2018).
7. K. B. S. K. Putra, I. P. K. Pramana, A. Angeline, A. A. Golung, and N. L. P. Sariani, To Maega J. Pengabdi. Masy. **5**, 337 (2022).
8. S. U. Dewi, F. H. Jaya, M. E. Tosulpa, and D. N. Afni, Jompa Abdi J. Pengabdi. Masy. **3**, 29 (2024).
9. S. Nugroho and W. Hadi, IPTEK J. Proc. Ser. **0**, 324 (2019).
10. E. M. Oliveira, R. Wittwer, M. Hartmann, T. Keller, N. Buchmann, and M. G. A. van der Heijden, Geoderma **447**, 116927 (2024).
11. G. Bodner, A. Zeiser, K. Keiblinger, C. Rosinger, S. K. Winkler, C. Stumpp, and T. Weninger, Soil Tillage Res. **234**, 105862 (2023).
12. E. U. Lolo, R. I. Gunawan, A. Y. Krismani, Y. S. Pambudi, C. Sudaryantingsih, Widianto, and Ripi, East Asian J. Multidiscip. Res. **2**, 1675 (2023).
13. J. A. Hidalgo-Crespo, A. Velastegui-Montoya, M. Soto, J. L. Amaya Rivas, P. Zwolinski, A. Riel, and P. Rivas-García, Waste Manag. Res. (2024).
14. J. Supriatna, M. R. Setiawati, R. Sudirja, C. Suherman, and X. Bonneau, Sci. World J. **2022**, (2022).
15. I. Rachman, Q. M. B. Soesanto, H. Khair, and T. Matsumoto, J. Community Based Environ. Eng. Manag. **4**, 75 (2020).
16. B. A. Esmail and L. Suleiman, Sustain. **12**, (2020).
17. A. O. El-Kholei and G. A. Yassein, Archnet-IJAR Int. J. Archit. Res. **17**, 459 (2023).
18. F. Abunna, G. Gebresenbet, and B. Megersa, Heliyon **10**, e25713 (2024).
19. R. J. Freund, W. J. Wilson, and D. L. Mohr, in edited by R. J. Freund, W. J. Wilson, and D. L. B. T.-S. M. (Third E. Mohr (Academic Press, Boston, 2010), pp. 689–719.
20. D. R. Cooper and P. Schindler, *Business Research Methods* (Mcgraw-hill, 2014).
21. A. Vierra, A. Razzaq, and A. Andreadis, in *Handb. Des. Conduct. Clin. Transl. Res.*, edited by A. E. M. Eltorai, J. A. Bakal, P. C. Newell, and A. J. B. T.-T. S. Osband (Academic Press, 2023), pp. 165–170.
22. L. R. Webb, LibreTexts 239 (2021).
23. N. Karuniastuti, J. Forum Teknol. **04**, 64 (2014).
24. D. L. Jones, G. Edwards-Jones, and D. V Murphy, Soil Biol. Biochem. **43**, 804 (2011).
25. M. Esfandbod, I. R. Phillips, B. Miller, M. R. Rashti, Z. M. Lan, P. Srivastava, B. Singh, and C. R. Chen, Ecol. Eng. **98**, 157 (2017).
26. S. Santosa, J. Phys. Conf. Ser. **979**, (2018).
27. F. Bulqis Muzakar, Smart City **2**, (2022).
28. I. V. Simanjuntak, Setiyadi, A. S. Mulyani, and L. E. Hutabarat, IOP Conf. Ser. Earth Environ. Sci. **878**, (2021).

29. D. Wilson, (2015).
30. K. Rambaree, M. C. F. Powers, and R. J. Smith, *Ecosocial Work in Community Practice* (2022).
31. Y. Ramli, D. Kurniawan, E. S. Imaningsih, T. Yuliantini, S. Anah, and A. J. Ali, Int. J. Energy Econ. Policy **13**, 518 (2023).
32. T. Sultana, R. Rokis, and F. Al-attas, **6256**, 238 (2024).
33. D. Alonso-Martínez, B. Jiménez-Parra, and L. Cabeza-García, Environ. Sustain. Indic. **23**, 100434 (2024).
34. E. M. ROGERS, J. Health Commun. **9**, 13 (2004).
35. L. Karki, J. Lieu, M. Xylia, M. Laub, D. Ismangil, L. Virla, E. Rahn, B. A. Bilbao, S. N. Indriani, P. Martin Gallego, A. K. A. Suleiman, R. Schaldch, T. Takama, J. R. Marques da Silva, and F. X. Johnson, Environ. Res. Lett. **18**, (2023).
36. M. Grubb, W. McDowall, and P. Drummond, Energy Res. Soc. Sci. **33**, 21 (2017).
37. M. A. Almaiah, R. Alfaisal, S. A. Salloum, F. Hajjej, R. Shishakly, A. Lutfi, M. Alrawad, A. Al Mulhem, T. Alkhdour, and R. S. Al-Maroof, Electron. **11**, 1 (2022).
38. D. Pan, J. Tang, L. Zhang, M. He, and C.-C. Kung, J. Clean. Prod. **280**, 124340 (2021).