JURNAL TEKNIK LINGKUNGAN
E-ISSN: 27146715
Journal homepage: www.envengjournal.com

Development of Waste Management Model at the District Level Based on Project-Based Learning: A Case Study of Jambi City

Hariestya Viareco*[1], Winny Laura Christina Hutagalung[1]

[1]Environmental Engineering Study Program, Faculty of Science and Technology, Universitas Jambi, Jl. Lintas Jambi-Muara Bulian KM15, Muaro Jambi, Jambi 36361, Indonesia.
*correspondence e-mail: hariestyav2@gmail.com

Abstract

Waste management in the city of Jambi requires an innovative approach to address sustainability and effectiveness challenges. This research was initiated to develop a waste management model at the district level in the city of Jambi, based on the Project-Based Learning (PjBL) approach. The research method employs a qualitative approach with a case study conducted in 11 districts of the city of Jambi. Measurements taken before and after the implementation of PjBL show a significant improvement in understanding waste management. From the evaluation of waste management in the 11 districts, several issues were identified, such as a lack of collaboration among relevant parties. The integration of PjBL in the development of the waste management model at the district level in the city of Jambi involves the establishment of SOP as a solution, along with the innovation of creating mini waste banks in each neighborhood (RT/RW) involving third parties such as state-owned enterprises (BUMN), regional-owned enterprises (BUMD), and private companies through Corporate Social Responsibility (CSR). It is hoped that this model can address the identified issues and serve as a solid foundation for the development of effective, responsive, and sustainable waste management at the district level in the city of Jambi.

Keywords: *Waste management model, project-based learning, standard operating procedures*

INFO ARTICLE

Citations: *Viareco, H., & Hutagalung, W. L. C. (2025). Development of Waste Management Model at the District Level Based on Project-Based Learning: A Case Study of Jambi City. Jurnal Teknik Lingkungan, 31(1), 1-9.*

Article History:
Received 2 Mar 2025
Revised 27 Apr 2025
Accepted 29 Apr 2025
Available online 30 Apr 2025

1. Introduction

Jambi City is one of the cities that has a sanitary landfill as a final processing site (TPA) for domestic waste located at the Talang Gulo Landfill. The Talang Gulo sanitary landfill is a development of the Talang Gulo Landfill that had previously reached its reservoir limit. According to the plan, the new Talang Gulo Landfill can operate for the next 40 years. However, to achieve this plan, it needs to be supported by better waste management at the sources.

Waste management at the sources involves the role of communities who are able to apply the 3R method independently. To be able to realize a 3R-independent society, cooperation among stakeholders involved in this case requires government participation at the RT, RW, sub-district, and village administrative levels. The Jambi city government has issued Regional Regulation No. 5 of 2020 concerning waste management, in which state apparatus starting from the RT, RW, sub-district, and village levels have the responsibility to foster the community in independent waste management (Ningsih et al., 2020).

Waste management models involving community and government cooperation have been widely applied in other regions such as waste care associations in Wonosobo (Subqi et al., 2019), Kang Pisman movements based on Rukun Warga in Cinambo (Sekarninngrum et al., 2020), community-based management in Bali (Armadi et al., 2020), empowerment of women's groups in Medan (Al Qamari et al., 2019), and centralized or scattered models in RT/RW in Bogor City (Samsuri et al., 2019).

Project-Based Learning (PjBL), or Project-Based Learning, can be interpreted as a learning approach that emphasizes the application of knowledge and skills derived from problems in the environment (Kim, 2021). PjBL encourages collaborative learning, enabling group work and cooperation between various parties such as local governments, communities, and the private sector. This has significant potential in fostering

communities towards independent waste management (Dayu et al., 2023). In higher education, Project-Based Learning method is a new type of teaching and learning that is includeed in curriculum and teaching reform, taking real life as a background and being driven by practical problems (Zhang & Ma, 2023). For the Solid Waste Management Course, the PjBL method has been chosen to increase student's ability to think critically about solid waste management problems and provide the solutions.

In the context of waste management, the existence of Standard Operating Procedures (SOPs) is imperative. SOPs serve as written guidelines to ensure that management activities are carried out consistently, effectively, and in accordance with applicable regulations (Tini & Yuliastina, 2021). SOPs in waste management play a key role in ensuring the quality and sustainability of these activities. Furthermore, the integration of SOPs in the PjBL model not only allows for contextual and interactive learning, but also results in more holistic and sustainable solutions. Thus, the combination of SOPs and PjBL forms a strong foundation for the development of an effective waste management model that is responsive to environmental and social changes.

This research was initiated with the belief that the development of a PjBL-based waste management model in the SOP format can be an innovative and sustainable step in overcoming waste management challenges at the Jambi City sub-district level. Thus, this approach is expected to not only improve the quality of waste management, but also encourage changes in behavior and culture related to waste among the people of Jambi City (Rahmawati et al., 2021)

2. Research Methodology

This research uses a qualitative approach to assess the implementation of Project-Based Learning Integration (PjBL) in the Solid Waste Management Course of the Environmental Engineering Study Program, University of Jambi, by producing a waste management model framework that refers to the operational standards of waste management procedures at the sub-district level. The design of this research will involves a case study with a research focus on designing a PjBL-based waste management model that is integrated with outputs in the form of waste management SOPs at the sub-district level.

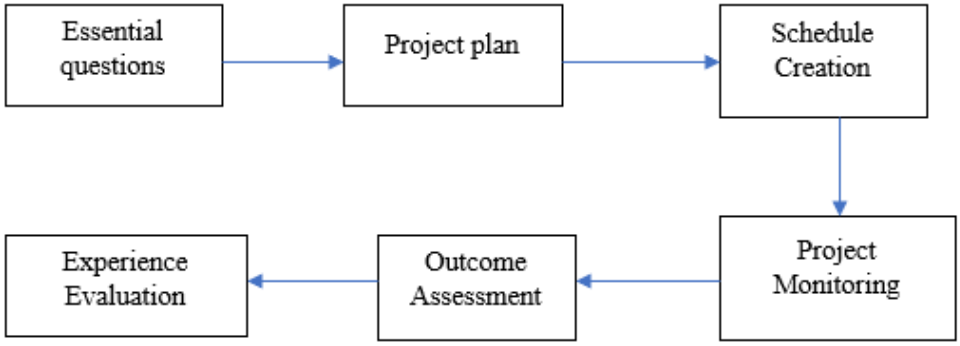

Figure 1. Project-based learning integration (PjBL) flow

The research was carried out in 11 sub-districts under the auspices of the Jambi City administration. The 11 sub-districts are Alam Barajo District, Danau Sipin District, South Jambi District, East Jambi District, Jelutung District, Kota Baru District, Pasar Jambi District, Pelayangan District, Telanaipura District, Lake Teluk District, and Paal Merah District. Data were collected using a stratified random sampling method from February to April 2023. Sampling stratification was based on the administrative structure of Jambi City and the academic grouping of student project teams. Data collection and validation were carried out by a research team consisting of lecturers and students. The entire research activity was monitored and evaluated by the Institute for Research and Community Service (LPPM), Universitas Jambi, as part of the university's internal research funding and quality-assurance mechanism.

The data collected in the 11 sub-districts were based on five aspects of waste management, namely legality, facilities, innovation, stakeholders, and monitoring and evaluation (Hendra, 2016). Legality is related to regulations and laws that regulate waste management practices. Facilities refer to the infrastructure and equipment used in waste management. Innovation shows the development of waste management technology and practices. Stakeholders refer to individuals and groups involved in waste management. Monitoring and evaluation include the ongoing assessment of waste management practices to ensure their effectiveness and efficiency. All of these data were taken using observation instruments and interviews with related parties.

In measuring the success of the implementation of project-based learning (PjBL) in Solid Waste Management courses, the instruments used were formative and summative evaluations. Formative evaluation was conducted using questionnaires in the pre and post-implementation phases of PjBL. The selection of the questionnaire sample size used the Slovin method with a margin of error of 0.2 for a small population (Swarjana, 2022). The questionnaire was created in the form of a Likert scale to facilitate data testing. From a total of 66 students, 19 respondents were randomly selected using the Slovin formula with a margin of error of 0.2. The questionnaire consisted of the following indicators:

Q1: Understanding of Standard Operating Procedures (SOP) for sub-district-level waste management.

Q2: Prior knowledge of solid-waste management practices at the sub-district level.

Q3: Previous experience related to waste handling and environmental activities.

Q4: Understanding of the Project-Based Learning (PjBL) model before participation.

Q5: Confidence and teamwork readiness in implementing PjBL-based projects.

The questionnaire was tested for validity and reliability using the Bivariate Pearson and Cornbach's Alpha methods. Questionnaire testing was assisted by SPSS software (Janna, 2021). The summative evaluation was conducted in the form of an assessment of the design of SOPs for waste management at the sub-district level. From the results of the data that were collected from each sub-district, the weaknesses were analyzed and developed into an optimal SOP for waste management at the sub-district level.

3. Results and Discussion

From the flow diagram in Figure 1, every students in the course can formulate the essential question for each group. They also create the project plan to observe the real-life existing data. Because this course is only for one semester, they created a schedule plan. Lecturers and students monitored the schedule plan together. Outcome assessment was conducted through presentations by each group. Then, the las step fot PjBL method is about experience evaluation. According to Kokotsaki et al. (2016), for successful PjBL Implementation, there are many essential keys, such as student support, teacher support, effective group work, balancing didactic instruction, emphasis on reflection in assessment, and self- and peer-evaluation.

The Solid Waste Management class consists of two classes with a total of 66 students. Of the 66 students, based on the Slovin method using a margin of error of 0.2, 19 students were randomly selected as respondents for pre- and post-implementation PjBL measurements. From Table 1, the validity and reliability were checked using the Bivariate Pearson and Cronbach's Alpha methods. The validity of the Pearson Bivariate method states that the questionnaire is valid if the $R_{pearson}$ value > R_{table}, where the R_{table} is based on the number of respondents and the level of significance (Hidayat, 2021). For this study, with 19 respondents and a significance level of 0.05%, the R_{table} value was 0.4555.

Table 1. Pre and post-PjBL questionnaire data

	Pre-PjBL						Post-PjBL					
Respond	Q1	Q2	Q3	Q4	Q5	Total Score	Q1	Q2	Q3	Q4	Q5	Total Score
R1	2	3	4	4	5	18	3	4	4	3	5	19
R2	2	3	5	5	4	19	4	5	4	3	4	20
R3	3	3	4	4	3	17	4	4	5	4	5	22
R4	2	3	4	4	5	18	5	5	4	5	5	24
R5	1	1	4	4	5	15	4	4	4	3	4	19
R6	2	2	4	5	4	17	5	4	4	5	4	22
R7	2	2	5	4	4	17	4	4	4	3	4	19
R8	2	2	5	5	5	19	4	4	3	4	5	20
R9	2	2	5	4	4	17	4	4	4	5	4	21
R10	2	2	3	5	5	17	4	4	4	4	4	20
R11	2	2	4	4	4	16	5	5	4	4	5	23

	Pre-PjBL						Post-PjBL					
Respond	Q1	Q2	Q3	Q4	Q5	Total Score	Q1	Q2	Q3	Q4	Q5	Total Score
R12	2	2	4	4	5	17	4	4	4	4	4	20
R13	2	3	4	4	4	17	5	4	5	5	5	24
R14	2	2	3	5	4	16	4	3	4	4	4	19
R15	2	1	5	4	3	15	5	5	5	4	5	24
R16	2	2	3	5	5	17	4	4	4	5	5	22
R17	2	1	3	3	2	11	4	5	4	4	5	22
R18	1	2	3	1	4	11	4	5	4	5	5	23
R19	2	2	3	3	5	15	4	5	5	5	5	24

Source: This research, 2023

For the Cronbach's alpha method, the questionnaire is considered reliable if the Cornbach's alpha value > R_{table} (Hidayat, 2021). The results of the validity and reliability analysis using SPSS can be seen in Table 2.

Table 2. Results of the validity test of the pre and post-PjBL implementation questionnaire

	Pre-PjBL					Post-PjBL				
Item	$R_{pearson}$	Itself.	Table	Sig. lvl	Information	$R_{pearson}$	Itself.	Table	Sig. lvl	Information
Q1	0.457	0.049	0.4555	0.05	valid	0.675	0.002	0.4555	0.05	valid
Q2	0.599	0.007	0.4555	0.05	valid	0.628	0.004	0.4555	0.05	valid
Q3	0.531	0.019	0.4555	0.05	valid	0.569	0.011	0.4555	0.05	valid
Q4	0.780	0.000	0.4555	0.05	valid	0.718	0.001	0.4555	0.05	valid
Q5	0.505	0.028	0.4555	0.05	valid	0.657	0.002	0.4555	0.05	valid

Source: This Research, 2023

Table 3. Results of the reliability test of the pre and post-PjBL implementation questionnaire

Phase	Cornbach's Alpha value	Table	Information
Pre-PjBL	0.494	0.4555	Reliable
Post-PjBL	0.651	0.4555	Reliable

Source: This research, 2023

Based on the results of the formative evaluation, it can be seen that there were changes from the pre-implementation phase, where students did not have a deep understanding of waste management, as indicated by a total questionnaire score that is still below 20 out of a maximum value of 25. In the implementation and post-implementation phases, the total average score was above 20. The results of the validity and reliability test for the pre- and post-PjBL questionnaires showed that the questionnaires used were valid and reliable. Therefore, the results sIndicate that the implementation of PjBLled to a significant increase in understanding of waste management.

In carrying out PjBL, 66 students were divided into 11 groups with each group responsible for one sub-district. Students were given basic questions about the existing waste management system in each sub-district. After that, each group made observations in each sub-district to map the existing waste management system. Primary data were obtained from interviews with stakeholders such as the Jambi City Environment Office, sub-district officials, the community, and cleaning staff. The results of the summative evaluation data for each sub-district are based on five aspects of waste management in Table 4.

Table 4. Results of primary data on waste management evaluation in 11 sub-districts of Jambi City

District	Legality	Facilities	Innovation	Stakeholders	Monitoring & evaluation
Alam Barajo	Parent to: • Mayor Regulation No. 54, 61 and 84 of 2018, • Jambi Regional Regulation no. 5 of 2020, • Jambi Regional Regulation No. 6 of 2006	33 TPS units, 1 3 R TPS unit, 1 truck dump unit, 1 arm roll unit	-	DLH and Sub-districts	• The community reports to the sub-district if there are complaints, • The sub-district monitors each respective area and coordinates with DLH regarding facilities and infrastructure, • DLH makes a report every 6 months to the national waste management information system (SIPSN) per city
Danau Sipin		1 unit of TPST 3R, 1 unit of dump truck, 2 units of motorboat cart	-	DLH and Sub-districts	
South Jambi		1 unit of armroll, 1 unit of dump truck, 1 unit of patrol car, 5 officers, 1 unit of garbage bank	Waste bank program, PKK recycling program	DLH, District, community	
East Jambi		17 TPS units, 1 garbage bank unit, 1 dump truck unit, 1 tub car unit	-	DLH and Sub-districts	
Jelutung		1 unit of waste bank, 55 units of TPS, 1 unit of Motorcycle cart, 1 unit of dump truck	-	DLH, District, community	
Kota Baru		8 TPS units, 1 dump truck unit, 1 motorcycle cart unit, 2 TPS 3R units, 1 garbage bank unit	-	DLH and Sub-districts	
Pasar Jambi		1 unit of dump truck, 1 unit of arm roll, 8 units of TPS	-	DLH and Sub-districts	
Pelayangan		1 unit of motorcycle cart, 1 unit of TPS, 1 unit of dump truck, 3 units of different color TPS	Mutual cooperation and socialization programs	DLH, District, community	
Telanaipura		3 units of 3R TPST, 4 units of TPS, 1 unit of dump truck	-	DLH, District, community	
Danau Teluk		66 TPS units, 1 depot unit, 1 dump truck unit, 1 motorcycle cart unit, 11 officers	-	DLH and Sub-districts	
Paal Merah		1 unit of TPST 3R, 1 unit of dump truck	-	DLH, District, community	

Source: This research, 2023

Based on the data that were obtained, it can be concluded that several problems exist in waste management across the 11 sub-districts of Jambi City, namely:

- The local government, in this case, has issued regulations that support waste management in Jambi City but these have not been implemented optimally. The apparatus below the City Administration level does not issue legal instruments that oversees their respective areas, so they only rely on existing regulations.
- Waste management in Jambi City is completely handed over to the Jambi City Environmental Agency, both related to facilities and administration. The DLH Jambi City possesses quite a lot of facilities, but these are not evenly distributed across all existing Kecamatan, so there is no adequate distribution of facilities.
- The lack of government role below the city administration level in waste management in their respective areas. Of the 11 sub-districts, only two have regular programs to improve waste management.
- Lack of community involvement in waste management in Jambi City. Current community involvement, in addition to simple waste reduction and independent processing, is mostly limited to cooperative programs such as waste banks, TPSTs, and local cleaning programs.
- There is already a reporting system from the public to the central government periodically (every six months) through SIPSN. However, the system that runs is only limited to administrative reporting. There has been no continuous monitoring and evaluation, so there are still many illegal disposal sites that cause environmental disturbances.
- There is not yat an optimal two-way management system where the government provides education as an intensive preventive measure.

Following the identification of major governance and educational gaps across Jambi's sub-districts, this discussion situates the findings within the broader evidence base by comparing them with prior studies on participation, circularity, technology, and education. This perspective verifies whether the observed gaps in Jambi (legality, facilities, stakeholder engagement, and monitoring) mirror broader patterns and whether the proposed solutions extend earlier approaches.

Field patterns in Jambi are found to align with other studies showing that durable outcomes depend heavily on the institutional integration of community actors and the informal sector (Paul et al., 2012; Raharjo et al., 2017; Kristanto et al., 2022). Furthermore, programs grounded in the circular-economy/zero-waste framework are reported to achieve better source segregation and stakeholder ownership, provided that participation is structured and inclusive (Kurniawan et al., 2021; Pottinger-Glass et al., 2024; Fatimah et al., 2020). On the systems side, technology-enabled efficiency—ranging from distributed MRFs to smart-recycling/IoT—has been proven to reduce landfill loads in areas where governance and infrastructure are ready (Muhamad et al., 2020; Maryono & Hasmantika, 2019; Mehta & Singh, 2024; Pech-Rodríguez et al., 2024). Complementing this, educational/behavioral interventions consistently show that knowledge must be coupled with experiential practice to close the attitude-behavior gap, particularly among youth (Brotosusilo et al., 2022; Boonchieng et al., 2023; Pulubuhu and Alhaqqi, 2019; Nisa et al., 2025; Marbun et al., 2025).

Through this model, students co-design sub-district SOPs with stakeholders, explicitly assigning community or informal roles, formalizing collaboration (sub-district–DLH–CSR), and staging technology adoption. Thus, the model operationalizes the success factors highlighted across prior studies within a single governance framework for Jambi City. Collectively, these comparisons confirm that the field patterns and learning outcomes are consistent with earlier evidence, while the PjBL-based SOP uniquely integrates participation, governance, and technology incrementally into one operational instrument at the sub-district scale. Building on these comparative insights, the next step translates the synthesized factors into a practical governance mechanism through the development of sub-district Standard Operating Procedures (SOPs).

Based on the results of the existing analysis and the problems that have been formulated, the solution that can be Implemented to overcome all existing problems is to develop standard operating procedures (SOPs) for waste management at the sub-district level by optimizing cooperation between the government and the community (Herlina et al., 2022). Cooperation can be carried out in the form of activities to form mini waste banks in each RT and RW (Andayani et al., 2023) . These mini waste bank is under the auspices of the main

waste bank or TPST, or TPST 3R at the sub-district and village levels. The establishment of mini waste banks, parent waste banks, TPST, and TPST 3R facilities often becomes constrained in the field due to limited funding if relying solely on government support. One way to address this is through cooperation with third parties such as SOEs, BUMDs, and private companies in the form of CSR. With the use of funds from third parties, the problem of uneven facilities in each sub-district can be overcome. Mini RT/RW and TPST waste banks at the sub-district/village level can serve as educational facilities for waste management from the source. The results of the integration of PjBL in the development of waste management models at the Jambi City sub-district level can be seen in Figure 2.

No.	Activities	Stakeholders				Time (day/hour)
		Community	NGOs/Communities	Administrative Structure of Government	Environment Agency	
1.	Waste generation production per house					Every day
2.	Self-processing from source (3R) per home					Once every 1 week
3.	Waste collection in each RT					Every day
4.	Waste management using 3Rs through mini waste banks in each RT					Once every 1 week
5.	Transportation of residual waste from RT to TPS in each RW					Every day
6.	Upcycling waste management through waste banks and TPST at the RW and Village levels					Once every 3 days
7.	Transportation of residual waste from each RW and Village to the landfill					Every day
8.	Communal waste end management					Every day
9.	Monitoring the collection and transportation of communal waste					Every day
8.	Evaluation of waste management system					Once every 1 week
9.	Education and support programs for self-management and communal management					Once every 1 week

Figure 2. SOP diagram flow for waste management at the sub-district level of Jambi City

The flow diagram in Figure 2 illustrates two alternative layouts depending on the inter-stage relationship. When each numbered activity (1 → 2 → 3, etc.) represents a dependent and time-ordered process—such as sequential approval or feedback—arrows are maintained to show progression. Conversely, if the listed activities operate as independent or parallel components (e.g., data collection, education, monitoring), the arrow connections should be removed or replaced with modular blocks to represent concurrent implementation. This distinction ensures the SOP can flexibly describe both procedural and collaborative processes within the PjBL framework. This modular/sequential distinction reflects evidence that governance and technology readiness evolve unevenly across districts, requiring flexible pathways consistent with prior practice-based studies.

4. Conclusion

From the results of the study, several problems in waste management in the 11 sub-districts of Jambi City were identified, including the lack of implementation of existing regulations, uneven distribution of facilities, the lack of governent involvement at the city administration level, and the lack of community involvement. Formative and summative evaluations showed an increase in students' understanding of waste management after the implementation of PjBL. By integrating PjBL, the development of waste management models at the sub-district level includes the establishment of Standard Operating Procedures (SOPs) that involve cooperation between the government and the community. The solution provided is the establishment of mini waste bank in each RT and RW, involving third parties such as SOEs, BUMDs, and private companies through Corporate Social Responsibility (CSR). It is hoped that this model can serve as a strong foundation for the development of more effective, responsive to environmental and social changes, and sustainable waste management at the Jambi City sub-district level. This model is illustrated through the SOP for Waste Management at the sub-district level, providing a foundation for efforts to improve the quality of waste management and promote cultural change related to waste among the people of Jambi City.

Acknowledgments

The completion of this research project would not have been realized without the very meaningful financial support from the Institute for Research and Community Service, University of Jambi. The author expresses his deepest gratitude for their financial support, which significantly contributed to the success of this research project. In addition, the author would like to express his appreciation to the Environmental Engineering Study Program and Environmental Engineering students who have made valuable contributions to this research.

References

Al Qamari, M., Manik, J. R., & Trisna Mei Br Kabeakan, N. (2019): Household Waste Management in Increasing Income in Asyiyah Women's Groups. PRODIKMAS, 4(3): 48–54.

Andayani, S., Zahra, F., Musafikah, W., & Qibtiyah, M. (2023): Waste Bank Procurement Strategy for Waste Management in Tamansari Village, Probolinggo Regency. Journal of Community Development, 4(4): 7265–7271.

Armadi, M., Suarna, W., Sudarma, M., Mahendra, M. S., & Sudipa, N. (2020): Community-Based Waste Management Model in Denpasar City. ECOTROPHIC, 14(2): 131–142.

Boonchieng, W., Intawong, K., Wungrath, J., Thongprachum, A., Naksen, W., Settheekul, S., Tarnkehard, S. & Songsin, N. (2023): Development of a school-based intervention program for waste management in a rural school in Northern Thailand. The Open Public Health Journal, 16(1): e187494452307180.

Brotosusilo, A., Utari, D., Negoro, H. A., Firdaus, A., & Velentina, R. A. (2022): Community empowerment of waste management in the urban environment: More attention on waste issues through formal and informal educations. Global Journal of Environmental Science and Management, 8(2): 209-224.

Dayu, G. O., Yulia, S. A., Putri, N. E., Hasyim, M. F., & Fauzi, A. (2023): Efforts to Empower the Community of Panjen Hamlet in the Context of Household Waste Management in the Smallest Scope Based on Project-Based Learning. Journal of Community Care, 5(3): 851–860.

Fatimah, Y. A., Govindan, K., Murniningsih, R., & Setiawan, A. (2020): Industry 4.0 based sustainable circular economy approach for smart waste management system to achieve sustainable development goals: A case study of Indonesia. Journal of cleaner production, 269: 122263.

Hendra, Y. (2016): Comparison of Waste Management Systems in Indonesia and South Korea: A Study of 5 Aspects of Waste Management. Aspiration, 7(1): 77–91.

Herlina, D. N., Wahyuni, Y. T., Santi, Anisa, F. Z., Purnomo, S. D., & Retnowati, D. (2022): Business Feasibility Test and Community-Based Waste Management Model in Kutasari Village, Banyumas District. Procedia of Social Sciences and Humanities, 3: 497–508.

Hidayat, A. A. (2021): Menyusun instrumen penelitian & uji validitas-reliabilitas. Health Books Publishing.

Janna, N. M. (2021): The Concept of Validity and Reliability Test Using Spss. Darul Da'wah Wal-Irsyad Journal (DDI), 18210047: 1–12.

Kim, Y. (2021): The Problem / Project-Based Learning (PBL / PjBL) at Online Classes. International Journal of Advanced Culture Technology, 9(1): 162–167.

Kurniawan, T. A., Avtar, R., Singh, D., Xue, W., Othman, M. H. D., Hwang, G. H., Iswanto, I., Albadarin, A. B., & Kern, A. O. (2021): Reforming MSWM in Sukunan (Yogjakarta, Indonesia): A case-study of applying a zero-waste approach based on circular economy paradigm. Journal of cleaner production, 284: 124775.

Kokotsaki, D., Menzies, V., & Wiggins, A. (2016): Project-based learning: A review of the literature. Improving schools, 19(3): 267-277.

Kristanto, G. A., Kemala, D., & Nandhita, P. A. (2022): Challenges confronting waste pickers in Indonesia: An on-field analysis. Waste Management & Research, 40(9): 1381-1389.

Marbun, Y. R., Artiawati, A., & Azaria, R. (2025): Behavioral Intention Model for Waste Sorting among Indonesian Urban Millennial Workers. North American Journal of Psychology, 27(3): 797-808.

Maryono, M., & Hasmantika, I. H. (2019): Preliminary study of smart urban waste recycling in Semarang, Central Java, Indonesia. In IOP Conference Series: Earth and Environmental Science. IOP Publishing, 248(1): 012048.

Mehta, S., & Singh, A. (2024): Real-Time Data and Waste Management Efficiency: Insights from IoT-Enabled Smart Bins. In 2024 10th International Conference on Electrical Energy Systems (ICEES). IEEE: 1-5

Muhamad, A. F., Ishii, K., Sato, M., & Ochiai, S. (2020): Strategy of landfilled waste reduction by a distributed materials recovery facility system in Surabaya, Indonesia. Waste Management & Research, 38(10): 1142-1152.

Ningsih, A. S., & Hilal, T. S. (2020): Factors Related to Household Waste Management in Danau Teluk District, Jambi City. Journal of Periodic Public Health Sciences, 2(2): 18–24.

Nisa, K., Aflahah, S., Aldeia, A. S., Witteveen, L., & Lie, R. (2025): Waste management literacy in Indonesian secondary schools: Assessing knowledge, attitudes, and behavior. Jurnal Cakrawala Pendidikan, 44(2): 324-336.

Paul, J. G., Arce-Jaque, J., Ravena, N., & Villamor, S. P. (2012): Integration of the informal sector into municipal solid waste management in the Philippines–What does it need?. Waste Management, 32(11): 2018-2028.

Pech-Rodríguez, W. J., Sahin, N. E., Suarez-Velázquez, G. G., & Rocha-Rangel, E. (2024): Industry 4.0: A New Window for the Future Waste Management Systems. In Environmental Engineering and Waste Management: Recent Trends and Perspectives. Cham: Springer Nature Switzerland, 685-714.

Pottinger-Glass, C., Vanhuyse, F., Asvanon, R., & Archer, D. (2024): Bangkok's waste metabolism: barriers and opportunities for inclusive circularity. Journal of Material Cycles and Waste Management, 26(2): 946-960.

Pulubuhu, D. A. T., & Alhaqqi, M. S. (2019): Planned behaviour theory for the science agency: the role of youth for sustainable waste management. In IOP Conference Series: Earth and Environmental Science. IOP Publishing, 343(1): 012101).

Raharjo, S., Matsumoto, T., Ihsan, T., Rachman, I., & Gustin, L. (2017): Community-based solid waste bank program for municipal solid waste management improvement in Indonesia: a case study of Padang city. Journal of Material Cycles and Waste Management, 19(1): 201-212.

Rahmawati, A. F., Amin, Rasminto, & Syamsu, F. D. (2021): Analysis of Sustainable Waste Management in Urban Areas in Indonesia. Bina Gogik, 8(1): 1–12.

Samsuri, & Maulana, L. H. (2019): URBAN WASTE MANAGEMENT MODEL (Survey on Waste Management in Bogor City). Journal of Vision, 5(2): 54–61.

Sekarninngrum, B., Suprayogi S, Y., & Yunita, D. (2020): Application Of The Waste Management Model "POJOK KANGPISMAN." Chemistry, 3(3): 548–560.

Subqi, I., & Albab, U. (2019): Waste Management Model in the Wonosobo Kalibeber Waste Care Association Group. Journal of Community Empowerment: Media of Development Thought and Da'wah, 3(2): 451–476.

Swarjana, I. K. (2022): Populasi-sampel, teknik sampling & bias dalam penelitian. Penerbit Andi.

Tini, D. L. R., & Yuliastina, R. (2021): Training and Assistance in Bumdes Administration Management in Ellak Daya Village, Lenteng District. Journal of Community Service and Quality Improvement (JANAYU), 2(1): 66–76.

Zhang, L., & Ma, Y. (2023): A study of the impact of project-based learning on student learning effects: A meta-analysis study. Frontiers in psychology, 14, 1202728