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Human centered governance for sustainable campus canteen wastewater management using design thinking and 5ME

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Abstract
Canteen wastewater management in higher education institutions exemplifies the intersection of environmental, social, and institutional sustainability. This study applies a human-centered governance approach integrating Design Thinking (DT) and the 5M + E framework (Man, Machine, Method, Material, Money, Environment) to co-develop and evaluate a low-cost, participatory wastewater treatment model at Telkom University, Bandung, Indonesia. Using a Process–Management–Governance (PMG) perspective, DT guided iterative problem-solving (Empathize–Define–Ideate–Prototype–Test), while the 5M + E model structured the assessment of operational and sustainability factors. University commitment acted as the governance layer ensuring accountability and long-term viability. The resulting two-stage natural filtration system—comprising banana stems, coconut fiber, red brick, charcoal, and split stone—was collaboratively designed under limited resources. Sentinel indicators showed qualitative improvements: pH shifted from alkaline to neutral, water clarity and odor improved, aquatic biota reappeared, indicating preliminary visually evidence of ecological recovery, along with increased stakeholder acceptance. Although COD, BOD_5, TSS, and FOG were not yet measured at this pilot stage, compliance with Indonesian discharge standards will be verified in subsequent studies. These findings are based on qualitative and sentinel indicators and should not be interpreted as a formal regulatory compliance assessment. The 5M + E analysis identified Environment, Material, and Man as the primary sustainability drivers. Findings suggest that long-term success depends less on filtration technology than on the governance architecture that institutionalizes learning, participation, and legitimacy. The study's novelty lies in reframing wastewater treatment as a governance-driven sustainability process by operationalizing human-centered design and managerial frameworks within a real institutional context in a developing country, thereby extending the literature on sustainability governance and design thinking for management, and supporting progress toward UN SDGs 6 and 12.

Keywords Campus canteen wastewater, Environmentally-friendly, Human-based solutions, Design thinking, 5M + E

1 Introduction

Water is a crucial resource for sustaining life, yet it faces growing risks from pollution arising from human activities [1]. This issue is particularly relevant in academic environments, where campus operations such as cafeteria services, laboratories, and dormitories generate wastewater that can threaten local ecosystems [2]. In Indonesia, universities are increasingly expected to act as catalysts for sustainability transformation by integrating environmental management into their daily operations and curricula [3].

Several Indonesian universities have implemented innovative and community-based initiatives to address wastewater and environmental challenges. Abidin et al. [4] developed a Masaro-based Integrated Waste Processing (IWP) system at ITB Jatinangor, integrating technology, community participation, and education to achieve zero waste and environmental sustainability. Kristanto et al. [5] reported that Universitas Indonesia's Faculty of Engineering applied an integrated approach to solid waste management (3R—Reduce, Reuse, Recycle), sustainable water and wastewater treatment, and energy-efficient smart buildings, reinforcing its position as a global green campus leader through the UI GreenMetric ranking. Similarly, Kusumawanto and Setyowati [6] found that Universitas Gadjah Mada implemented the 12 principles of green engineering in its campus waste system, while Universitas Sebelas Maret (UNS) and Institut Pertanian Bogor (IPB) advanced sustainable water management practices [7, 8]. These efforts reflect growing institutional commitment to sustainability, though challenges remain in maintenance, funding, and stakeholder engagement [3].

Against this national backdrop, Telkom University, a leading private university in Indonesia, has committed to reducing its environmental footprint through sustainability initiatives that harness internal capabilities and align with broader Sustainable Development Goals (SDGs). At its Dayeuh Kolot campus in Bandung Regency, Telkom University has introduced various environmental and social programs; however, canteen wastewater management remains a pressing challenge. Wastewater from the seven campus canteens contains oil, grease, and suspended solids, with effluent from the Telkom University Landmark Tower (TULT) canteen posing the greatest concern. This wastewater flows directly into campus drainage systems, creating polluted ditches devoid of aquatic life.

Figures 1 and 2 illustrate the condition of canteen wash water and the resulting polluted ditch prior to intervention. Preliminary interviews and observations conducted in February 2023 further indicated that wastewater from the TULT canteen contaminated irrigation ditches supplying nearby rice fields, whereas wastewater from other canteens was only partially treated before discharge. These findings highlight the urgent need for an effective and sustainable treatment system.

Developing a wastewater treatment solution at Telkom University offers an opportunity for higher education institutions to lead environmental conservation through innovation. Beyond the technical challenge, the sustainability of such programs also depends on organizational and social factors. Interviews with team members and management emphasized the importance of identifying key drivers of program success to ensure long-term impact. This study responds to these challenges by developing and evaluating a two-stage natural media filtration system that uses locally available and environmentally friendly materials—banana stems, coconut husks, red bricks, and charcoal. Banana stems have been proven effective as natural adsorbents for removing heavy metals and

Fig. 1 Canteen wastewater (*Source*: Authors Documentation, 2023)

organic pollutants in wastewater due to their high lignocellulosic content and porous structure [9, 10]. The research adopts a design thinking approach, combining water quality testing, observations, interviews, and focus group discussions (FGDs) with campus stakeholders to ensure human-centered and practical outcomes.

To further strengthen the sustainability dimension, the study incorporates the 5M + E framework (People, Machines, Methods, Materials, Money, and Environment) as a secondary analytical lens. The initiative is designed to generate sustainable, human-centered solutions that respond to the multifaceted challenges of wastewater management [11, 12]. While previous studies have primarily focused on engineering-based interventions such as grease traps, alum coagulation, constructed wetlands, or centralized wastewater treatment systems, these methods often require higher costs, skilled labor, and regular maintenance, factors that constrain adoption in many Indonesian universities.

This research develops, implements, and evaluates a two-stage natural media filtration system co-designed with campus stakeholders. The filtration system uses locally available, environmentally friendly materials—banana stems, coconut fiber, red brick, charcoal, and split stone—to treat canteen wastewater. The study combines qualitative methods (observation, interviews, and focus group discussions) with sentinel water quality indicators (pH, clarity, odor, and aquatic biota) to evaluate both environmental and governance outcomes.

While the pilot stage prioritizes sentinel indicators to assess feasibility and human-centered acceptance, comprehensive compliance testing for COD, BOD_5, TSS, FOG, nutrients, and E. coli will be conducted in follow-up research using SNI/APHA/ISO procedures and benchmarked against the Indonesian domestic wastewater standard (Permen LHK No. P.68/2016).

By reframing campus wastewater management as a governance-driven sustainability process—integrating DT's participatory process approach with the 5M + E management framework—this study fills a documented research gap in Indonesian higher education and contributes a replicable model for low-cost, human-centered environmental innovation.

Fig. 2 Pre-program ditch condition (*Source*: Authors Documentation, 2023)

To address the research problem, this study is guided by the following research questions:

RQ1 How can a canteen wastewater treatment system be developed using a Design Thinking approach in a resource-constrained higher education context?

RQ2 What are the environmental and social outcomes of the implemented wastewater treatment system, as assessed through sentinel indicators and stakeholder responses?

RQ3 What Critical Success Factors (CSFs) in managerial and governance dimensions influence the success and sustainability of the wastewater treatment program, as identified through a 5M + E analytical framework using thematic analysis of qualitative data?

While prior studies have explored engineering-based approaches such as grease traps, constructed wetlands, and centralized wastewater systems, comparatively little attention has been given to governance-oriented, rapid, and low-cost implementation approaches in Indonesian universities. This research addresses that gap by integrating natural filtration technologies with human-centered design and sustainability analysis, thereby contributing to the evolving discourse on sustainability governance in higher education. The governance perspective in this study aligns with Koliba et al. [13, 14], who describe governance networks as institutional architectures linking processes, people, and management systems to achieve collective sustainability outcomes [13, 14]. The study's novelty lies not in the filtration media itself but in the governance-oriented process model that operationalizes design thinking and management coordination under real-world resource and skill constraints.

2 Literature review

2.1 Design thinking (DT)

The theoretical concept that will be used to solve campus canteen wastewater treatment is design thinking (DT). This concept is a generic tool based on humans: it is iterative, flexible, collaborative, interdisciplinary, creative, and innovative. This theory focuses on human needs. Humans are direct users, solution providers, internal members of the organization, the surrounding community, and other related humans.

Design thinking is a process that provides solutions for existing problems. In this process, we understand the users, question the assumptions used, and redefine problems to identify alternative strategies and solutions that may not be immediately visible to our initial level of understanding. Design thinking is a human-centered design concept in which all stakeholders are essential in finding solutions to problems. Many studies, including [15–18] provide insight into the importance of involving various stakeholders, including employees or members of the organization, in the human-centered design process.

Design thinking is a mindset that:

1. Human-centered. Design thinking begins with deep empathy and understanding of people's needs and motivations.
2. Collaborative. Several great minds are always more substantial than just one when solving a challenge from multiple perspectives.
3. Optimism is the fundamental belief that we can all create change, regardless of how big a problem or constraint is. Designing is an enjoyable process.
4. Experimental design permits you to fail and learn from your mistakes, generate new ideas, receive feedback, and then iterate.

Design thinking is about learning by doing; it is the belief that new, better things are possible, and that we can make them happen. A human-centered design must answer three questions:

- Desirability: Is the solution that will be built desired by the users?
- Feasibility: Can the solution be built within our resource constraints?
- Viability: Can the solution we built sustain itself by generating money or support?

Figure 3 shows the five stages of the DT: Empathy, Design, Ideate, Prototype, and Test.

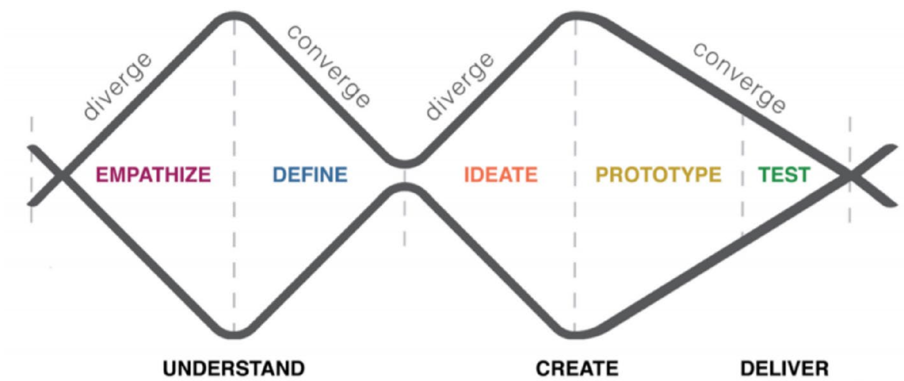


Fig. 3 Stages of design thinking [5]

The stages of design thinking include:

1. Empathize. Work you do to understand people. Here is divergent thinking (open to all inputs).
2. Define. All about bringing clarity and focus to the problem space. Here is convergent thinking (formulating, focusing on the problem).
3. Ideate. Concentration of idea generation. Here again is divergent thinking (exploring various alternative solutions).
4. Prototype. The iterative generation of artifacts is intended to answer questions that help approach the final solution. Here, think convergently (focus again on determining solution options and continuing to create prototypes).
5. Test. This process solicits user feedback about the created prototypes and offers another opportunity to gain empathy for people for design purposes.

Design thinkers are expected to be open-minded, creative, and innovative during the DT process, especially during the empathizing and ideating stages. Iteration is fundamental to producing a good design during the DT process, cycling through the entire process multiple times and within each step. Creating numerous prototypes or trying variations in brainstorming topics with various stakeholders [18].

2.2 5M + E concept

This pilot wastewater treatment program was implemented as a first-stage/ initial solution and requires iterative improvement to identify and reinforce success factors and to correct weaknesses in order to maintain its sustainability.

The theoretical concepts of Critical Success Factors (CSF), Key Success Factors (KSF), and production factors/operational process man, methods, machines, materials, money, and environment (5M + E) are three concepts that can be used to analyze the success factors of a program/project/process. The CSF from Rockart [19] is a concept used at the strategic level, and the user must first define these factors. The concept of KSF is an essential aspect that must exist or be performed well to ensure the success of an entity.

They are key to achieving competitive advantage and long-term success. The concept of "5M" (Man, Machine, Methods, Money, Material) is often used in management and production to identify and manage the main factors that affect the work process. Of the three concepts, the concept is considered to fit the research object, and its problem is the 5M concept. Although the 5M concept has been widely used, only some sources or individuals are explicitly recognized as creators of this concept. However, this idea comes from a systematic production and quality management approach developed mainly in the mid-twentieth century. Many associate it with the development of scientific management by Frederick Winslow Taylor in the early twentieth century, and then reinforced by other management theories, such as Total Quality Management (TQM) and Six Sigma [20]. The 5M concept has developed and evolved. This concept has been expanded and adapted in various ways according to the needs and developments in technology and modern management methodologies. A critical evolution of the 5M concept is the addition of an environmental factor that includes aspects of the natural environment and humans (society) that can affect operations. This concept follows Elkington's [21] triple bottom-line concept. In addition, companies, in this case organizations, that are smart can use environmental strategies to innovate, create value, and build competitive advantage [22].

This study acknowledges distinctions among process, management, and governance approaches. Process approaches focus on workflows and iterative improvement cycles [23], management approaches emphasize planning, organizing, and controlling daily operations [24], and governance approaches highlight institutional arrangements, accountability, and stakeholder roles that ensure sustainability [25]. Recent works reinforce these distinctions in sustainability contexts [26–30].

Design Thinking (DT) provides an iterative, human-centered methodology for co-designing solutions in collaboration with stakeholders [15, 16]. The 5M + Environment framework (5M + E) complements DT by offering a structured lens to analyze the operational factors that influence program success. Prior engineering research has demonstrated the adsorption and coagulation potential of natural materials such as banana stem/pith and coconut coir [31, 32], supporting their experimental use as low-cost filtration media in pilot studies.

Despite these technical insights, limited scholarship has explored the integration of DT and 5M + E to generate governance lessons for campus-scale wastewater management in developing-country contexts. This study addresses that gap by combining DT with the 5M + E framework to design, implement, and evaluate a canteen wastewater treatment system at Telkom University. Through this integration, the research not only assesses technical effectiveness but more importantly, it identifies critical success factors necessary for ensuring long-term program sustainability. Process, Management and Governance (PMG).

In addition to DT and the 5M + E framework, this study also draws upon distinctions among governance, management, and process approaches. Governance refers to institutional arrangements, rules, and accountability structures that sustain programs beyond immediate operations [26]. Management emphasizes tactical and operational implementation such as planning, organizing, and controlling daily activities [24]. Process approaches focus on workflow and iterative cycles to improve efficiency and quality [23]. These distinctions help situate our study in the broader literature on organizational and sustainability approaches.

Process approaches focus on workflows, iterative cycles, and operational improvement. Management approaches emphasize planning, organizing, and controlling daily activities to ensure tactical efficiency and from 5M + E factors. Governance approaches concern institutional structures, rules, and accountability systems that ensure legitimacy and long-term sustainability. Table 1 synthesizes these perspectives across three decision levels—operational, tactical, and strategic—drawing upon Braganza and Lambert [33] for process–governance integration and Anthony [34] for hierarchical decision levels. Koliba et al. [13, 14] further extend this logic by demonstrating that governance mechanisms must function across all levels to achieve sustainability transitions, consistent with the concept of governance architecture [12, 13, 33, 34].

In this study, the process layer captures iterative workflows through DT; the management layer represents resource coordination and staff execution guided by the 5M + E framework; and the governance layer encompasses institutional policies, accountability, and long-term sustainability alignment. Expected outcomes vary by level—workflow efficiency (operational), implementation effectiveness (tactical), and institutional legitimacy (strategic). Governance is conceptualized as an institutional layer that ensures alignment, accountability, and long-term sustainability of the program. Drawing on governance literature [13, 14, 26] governance encompasses key elements including leadership commitment, policy and institutional alignment, stakeholder coordination, accountability, and adaptive learning mechanisms. These elements operate across strategic, tactical, and operational levels, but primarily function to secure institutional legitimacy and sustainability beyond short-term implementation.

This PMG synthesis provides a conceptual foundation for interpreting the empirical findings presented later in the study. It also situates the intervention within the broader literature on organizational sustainability and governance. The PMG framework thus integrates iterative design processes, managerial coordination, and institutional accountability into a unified model of sustainable program governance.

The framework developed for this study is illustrated in Fig. 4.

Table 1 Process–management–governance (PMG) conceptual synthesis (*Source*: Authors' compilation)

Level/aspect	Process approach (workflow)	Management approach (execution and control)	Governance approach (institutional and sustainability)	References
Focus	Workflow, innovation cycle	Planning, organizing, actuating, controlling resources for day-to-day effectiveness	Institutional rules, accountability, stakeholder roles, sustainability monitoring	[12, 13, 33]
Level	Operational—daily implementation of processes	Tactical—mid-level planning, resource allocation, monitoring staff	Strategic/institutional—long-term direction, policies, legitimacy, sustainability	[34]
Unit of analysis	Workflow and activities	Resource and staff assignment	Institutional governance	[33]
Main outcomes	Efficiency of workflow (smooth process, reduced errors, measurable iterations)	Effectiveness of execution (goal achievement, cost/resource balance)	Sustainability and legitimacy (long-term viability, stakeholder trust)	[13, 14]; Governance literature
Implication	Provides how processes run efficiently	Ensures resources and people execute plans properly	Ensures alignment with mission, accountability, and stakeholder legitimacy	Synthesis from multi-level governance theories

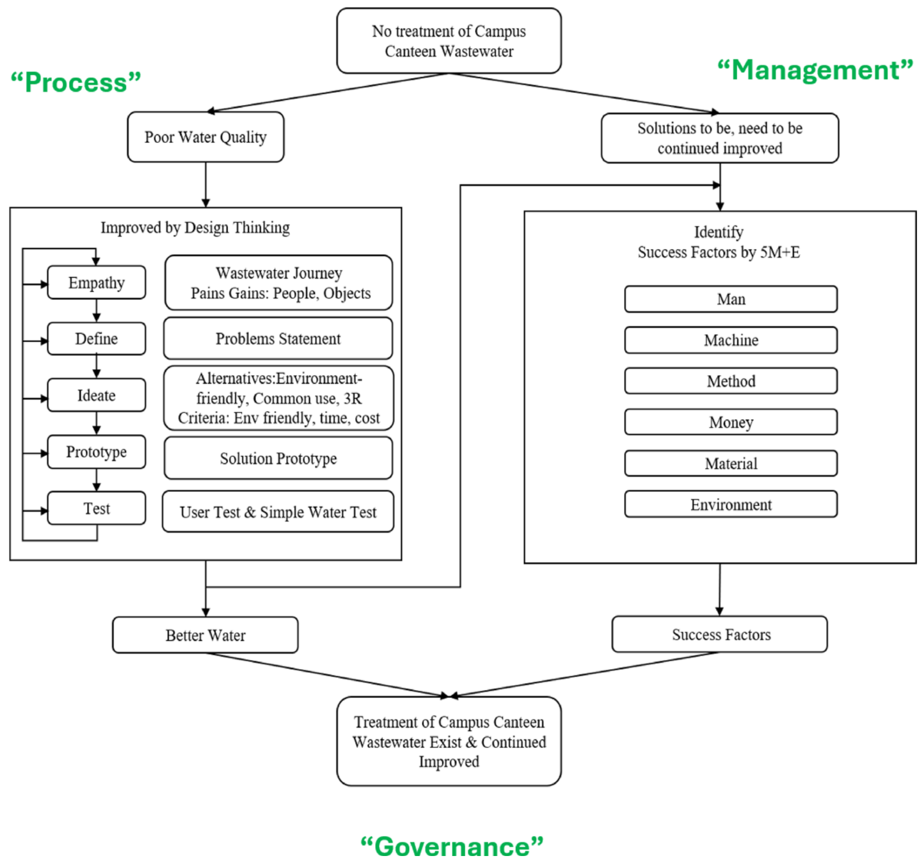


Fig. 4 Research framework (*Source*: Authors Figure, 2023)

3 Methods

3.1 Research design

This study adopted a qualitative research design supplemented by sentinel indicators—including pH measurements, direct field observations, and a short questionnaire—to capture both human-centered and environmental dimensions of the pilot program. The methodological flow followed the Design Thinking (DT) stages, integrated with water quality testing and the 5M + E analysis. A management-centered pilot was conducted using the DT stages (Empathize, Define, Ideate, Prototype, and Test), supported by 5M + E evaluation to identify sustainability enablers.

3.1.1 Study site, sampling design, and data collection

The pilot was conducted at the TULT canteen in Bandung, Indonesia, which discharges approximately 2.3 m^3 of wastewater per day into irrigation ditches connected to nearby rice fields.

A purposive sampling was applied to select both informants and observed units, representing stakeholders directly engaged with or affected by canteen wastewater management. The sample included canteen managers, facilities staff, students, local farmers, and campus water supervisors. A total of 14 informants participated, including two who also served as members of the research team. One informant (TA1) acted in multiple roles—user, proposer, and builder of the wastewater treatment system—across EDIPT stages. To maintain objectivity, TA1 did not participate in the questionnaire and focus group discussion (FGD) related to the 5M + E assessment. Another author (KB1) contributed as an informant in the 5M + E FGD because of his strategic management position.

Sentinel water quality indicators were assessed using pH, color, and odor, measured at both the inlet (before filtration) and outlet (after filtration) of the treatment system. pH was measured using a pH meter, while color and odor were evaluated through structured visual and sensory observations. Given that ecological recovery requires time, other sentinel indicators— ditch condition and aquatic biota presence—were observed prior to program implementation (March 2023) and 1 year after implementation (April 2024).

The observation units and research stages are summarized in Table 2.

Subsequently, the final stage of the research involved an empirical analysis of governance mechanisms, conducted through focus group discussions (FGDs) and a review of institutional governance documents to identify leadership commitment, policy alignment, and stakeholder coordination mechanisms.

3.1.2 Measured parameters

This pilot study intentionally focused on sentinel indicators—pH, color, odor, and aquatic biota—to evaluate both environmental improvement and governance feasibility under real-world resource constraints (see Table 15 in the Appendix). These indicators were selected to reflect immediate, observable changes that are meaningful for stakeholders and suitable for rapid, human-centered implementation.

The use of sentinel indicators is consistent with the exploratory nature of this study, which prioritizes institutional readiness, stakeholder participation, and iterative learning (see Table 16 in the Appendix). Comprehensive physicochemical analysis—including COD, BOD_5, TSS, FOG, nutrients, and microbiological parameters—will be conducted in a subsequent engineering phase using standardized methods (SNI/APHA/ISO) and benchmarked against Indonesian domestic wastewater standards (Permen LHK No. P.68/2016). This study does not include laboratory-based measurements of COD, BOD_5, TSS, or other physicochemical parameters, as it is positioned as a pilot-scale, governance-oriented study.

To ensure systematic and transparent data collection, the study applied a structured framework that linked research questions with corresponding variables, dimensions, data collection techniques, instruments, sources, and expected results. This framework, summarized in Table 3, provided an integrated overview of how field data were gathered and analyzed in alignment with the study's objectives.

Subsequently, the DT and 5M + E results were interpreted within a governance perspective as an integrating mechanism across organizational levels. This dimension was empirically examined through FGDs and institutional document analysis.

3.1.3 System design and engineering parameters

The filtration system comprised two stages:

- Stage 1 (Pre-treatment): chopped banana pseudo-stems (30–50 cm layer) for coarse solids retention and natural coagulation.
- Stage 2 (Polishing): sequential layers of coconut fiber (25 cm), crushed red brick (25 cm), and charcoal (25 cm) for particle filtration and adsorption.

The horizontal tank measured 4.15 m × 1.0 m × 1.2 m (L × W × H) with an effective volume of ~ 4 m^3. The average influent flow rate was 0.10–0.15 L/s, corresponding to a hydraulic retention time (HRT) of 15–60 min, depending on inflow variability. Clogging thresholds were monitored via weekly flow-rate checks and head loss observations; material replacement was scheduled every 6–9 months based on visual degradation of the banana stems.

Table 4 resumes the above key operational parameters, environmental friendly filtering material, construction cost and annual cost.

3.2 Ethical compliance

Telkom University currently does not have a dedicated division for managing research ethics approvals, all permits and approvals for research are overseen by the Directorate of Research and Community Service (Clinical trial number: not applicable). The interviews were conducted with the informants' consent, ensuring the confidentiality of their data. Additionally, informants were granted the freedom to withdraw from the interview at any time if they felt uncomfortable. All recordings of the interviews were made with the informants' consent.

3.3 Data analysis

Data analysis in this study employed a triangulation strategy integrating both quantitative and qualitative approaches to enhance analytical rigor and contextual validity. The analysis combined: (i) quantitative and qualitative assessment of sentinel water quality indicators (pH, color, and odor), (ii) qualitative insights from semi-structured interviews and focus group discussions (FGDs), and (iii) field observations of aquatic biotic indicators. This mixed-method approach enabled cross-verification of findings and a holistic understanding of the technical, social, and ecological dimensions of the wastewater treatment intervention.

The interpretation of results primarily focuses on observed changes in sentinel indicators, particularly pH, color, and odor, as well as visually observed environmental conditions. The observed pH values fall within the general neutral range [6–9]; however, this should be interpreted only as a qualitative reference rather than a formal compliance assessment.

The inclusion of diverse stakeholder groups—canteen staff, facilities officers, students, and local farmers—was intended to minimize bias and enrich data interpretation through multiple perspectives. In addition, independent verification of pH measurements and field observations was conducted by the School of Applied Sciences, Telkom University, to enhance data reliability.

Governance elements were identified through thematic analysis of focus group discussions (FGDs) and institutional documentation. These governance elements were analytically categorized into five dimensions: leadership commitment, policy and institutional alignment, stakeholder coordination, accountability, and adaptive learning mechanisms, that support long-term program sustainability, which guided the interpretation of governance outcomes in this study.

Given the pilot-scale nature of this study, the analysis was intentionally limited to sentinel indicators and short-term observations to assess feasibility, stakeholder acceptance, and governance readiness. The absence of a time-series design and comprehensive

Table 2 Informants and objects of research (DT, water tests, 5M + E) (*Source*: Research Processing (2023, 2024))

No	Informants position/ role or objects to be researched	Selection criteria roles in research	Code	E	D	I	P	T	Water pH	Water color odor	Ditch condition	Aqua biota	5M + E factors
				Int, Obs	FGD	FGD	FGD	Int	pH meter	Obs	Obs	Obs	Ques & FGD
Informants													
1	Field farmers/surrounding community	Users of campus water ditches outlet	PS1	√				√					
		Provides condition before and after astewater treatment developed	PS2	√				√					
2	Local water supervisor	Local water supervisor Provides info environmental impact	PA1	√				√					
3	Canteen staff	Source of wastewater	PK1	√	√	√		√					√
		Provides info regarding wastewater process	PK2	√	√	√		√					√
4	Civitas academia	Users (direct and indirect) of campus water and water ditchage	SA1	√	√	√	√	√					√
		Provides info: wastewater process	SA2	√	√	√	√	√					√
5	Canteen wastewater treatment team	Direct Task in wastewater mgt Provides info: campus ditches system, wastewater problem, solution ideas, selection, prototype implementation	TA1 & TA4*	√	√	√	√	√					√
			TA2	√	√	√	√	√					√
			TA3	√	√	√	√	√					√
6	General support	Peer-related task in mgt	GS1										√
		Explains ditches system and encountered issues	GS2										√
7	Upper management	Represent strategic management Provides information on campus facility policies and management	KB1										√
Objects to be researched													
8	Canteen wastewater before treatment	Simple measurement water quality Provides before treatment measured pH result							√	√			
9	Canteen wastewater after treatment	Simple measurement water quality Provides after treatment measured pH result							√	√			

Table 2 (continued)

No	Informants position/ role or objects to be researched	Selection criteria roles in research	Code	E	D	I	P	T	Water pH	Water color odor	Ditch condition	Aqua biota	5M + E factors
				Int, Obs	FGD	FGD	FGD	Int	pH meter	Obs	Obs	Obs	Ques & FGD
10	Water and ditch before treatment	Research observed physical objects Provides before observed results									√	√	
11	Water and ditch after treatment	Research observed physical objects Provides after observed results									√	√	

Int, Interview; FGD, Focus group discussion; Obs, Observation; Ques, Questionnaire

*TA1: E, D, I, P and TA4: 5M + E

Table 3 Research instrument mapping (*Source*: Researcher Processing (2023, 2024))

No	Variables DT/5M + E	Expected results	Data gathering technique	Questions/topics/items	Informants/objects	Timeline
RQ1. How can a canteen wastewater treatment system be developed using a Design Thinking approach in a resource-constrained higher education context?						
1	Empathy	Impact of campus wastewater (Pains & Gains) Journey Wastewater and the affected people/objects	Interview	Questions: What are your pains? What are your gains?	Field Farmers/ Community Water Supervisor Canteen Staff Civitas Academia Canteen Wastewater Treatment Team	Feb 2023
			Observation	Observed items: Journey of canteen wastewater Impact on people and related objects	Journey/wastewater process flow Affected people Affected objects	Feb 2023
2	Define	Problem formulation	Focus group discussion (FGD)	Topics to be discussed (previous results from the Empathy stage): Problems and evident data Canteen Wastewater impacts on people the environment The program should be sustained and continuously improved Problem formulation: Need a wastewater treatment system and knowing what are the success factors of the program and its sustainability in the future	Canteen Staff Civitas Academia Canteen Wastewater Treatment Team	16 Mar 2023
3	Ideate	Alternative solutions Selection criteria Prototype of the selected solution	FGD	Topics to be discussed (Continuing the results Define) Gathering ideas for alternative solutions: What do you suggest to solve this problem? Selection Criteria: Resources are limited, so criteria are needed Selected alternatives: Which solution is chosen based on the criteria	Canteen Staff Civitas Academia Canteen Wastewater Treatment Team	16 Mar 2023
4	Prototype	Prototype	FGD & execution: design, prototype building	Items to be discussed to be done: Designing the Prototype Building the Prototype (including the iteration process when needed)	Civitas Academia Canteen Wastewater Treatment Team	Mar–Apr 2023

Table 3 (continued)

No	Variables DT/5M + E	Expected results	Data gathering technique	Questions/topics/items	Informants/objects	Timeline
5	Test	Benefits of canteen wastewater treatment	Interview	Question (to User): Benefits of wastewater treatment Test Technique: Comparison of benefits before and after treatment filter developed	Field Farmers/ Community Water Supervisor Canteen Staff Civitas Academia	Mar 2023 and Apr 2024
		Water physical condition	Observation	Physical condition of water (color and odor of water) Test Technique: comparison before and after filter developed *General reference: transparent color, odorless*	Water ditches before and after the filter tank operates after the maintenance period ends (initially set at 1 year), March 2023 (before program), and April 2024 (after program)	Mar 2023 and Apr 2024
		Water ditches physical condition	Observation	Water ditches physical condition Test technique: comparison before and after filter developed *General reference: reduced turbidity and absence of foul odor*	Water ditches before and after the filter tank operates after the maintenance period ends (initially set at 1 year), March 2023 (before program), and April 2024 (after program)	Mar 2023 and Apr 2024
		Aquatic Biota Condition (Conclusive Condition)	Observation	Aquatic Biota Life Test technique: Comparison before and after filter development *General reference: presence of living biota*	Biota in the ditches before and after the filter tank operates after the maintenance period ends (initially set at 1 year), March 2023 (before program), and April 2024 (after program)	Mar 2023 and Apr 2024
		Water Acidity Level (simple additional test)	Water chemistry test, water acidity level Simple pH meter test	Water Acidity Level (pH) Test Technique: Comparison before (inlet) and after treatment (outlet) *General reference: neutral pH range (6–9)*	Wastewater before treatment (inlet filter) and after treatment (outlet filter), 3 times test	3 times in Apr 2024
RQ2. What are the environmental and social outcomes of the implemented wastewater treatment system, as assessed through sentinel indicators and stakeholder responses?						
	Outcome evaluation (DT—Test stage)	Environmental and social outcomes	Triangulation (interviews, observation, pH test)	Sentinel indicators (pH, color, odor, ditch condition, aquatic biota); before–after developed comparison	Stakeholders	March 2023 versus April 2024
RQ3. What managerial and governance factors influence the success and sustainability of the wastewater treatment program, based on the 5M + E framework?						

Table 3 (continued)

No	Variables DT/5M + E	Expected results	Data gathering technique	Questions/topics/items	Informants/objects	Timeline
1	RQ3 (5M + E)	1. 3 Factors that are the most influential in the success of the implemented program; 2. 3 Factors estimated that are the most influential in the success of the sustainability program in the future	Closed questionnaire Answer options = Scale 1 to 10; Scale 1 = Least influential in the success of the program; Scale 10 = Most influential in the success	Questionnaire Questions: 1. In your opinion, which factor is the most influential in the SUCCESS of the Canteen Wastewater Treatment Program that is already running? (same question for each factor) 2. In your opinion, which factor is the most influential in the SUSTAINABILITY of the Canteen Wastewater Treatment Program in the future? (same question for each factor)	Canteen Staff Civitas Academia Canteen Wastewater Treatment Team General Support Upper Management	26 Mar 2024
		Top-3 5M + E factors verification	FGD	Verification of the factors ranking. The discussion is based on the results of the questionnaire calculation	Canteen Staff Civitas Academia Canteen Wastewater Treatment Team General Support Upper Management	Apr 2024
2	RQ3 (Governance dimension): How governance mechanisms support program sustainability	Verification of FGD results regarding Governance	Institutional document analysis	Empirical evidence of governance mechanisms	Institutional Documents	Up to Mar 2024
		Governance findings; Conclusions and Recommendations		FGD Topics: Governance findings What insights/conclusions are obtained	Canteen Staff Civitas Academia Canteen Wastewater Treatment Team General Support Upper Management	Apr 2024

Table 4 Key operational parameters of the pilot system

No	Parameter	Value	Type
1	Design flow	~ 2.3 m^3/day	Estimated
2	Average influent flow	0.10–0.15 L/s	Measured
3	Hydraulic retention time (HRT)	15–60 min	Calculated
4	Tank dimensions	4.15 × 1.0 × 1.2 m	Measured
5	Media configuration	Banana stem, coconut fiber, red brick, charcoal, split stone	Design
6	Media replacement interval	6–9 months	Observed
7	Construction cost	~ IDR 10,000,000	Estimated
8	Annual O&M cost	Low (included in existing maintenance)	Estimated

Source: Researcher Processing (2024)

physicochemical parameters may limit generalizability. However, this approach is consistent with the study's objective of evaluating a human-centered governance model under real-world constraints.

A follow-up engineering phase is planned to incorporate comprehensive laboratory parameters—including COD, BOD_5, TSS, FOG, TN, TP, and *E. coli*—along with continuous monitoring and controlled comparisons. These future enhancements are expected

Table 5 Canteen wastewater acidity level (no/before treatment) (*Sources*: Field survey by the authors (2024))

No	Canteen	pH meter
1	Asri	8.93
2	Public Lecture Building	8.84
3	Bandung Techno Park	8.21
4	School of Communication and Business	8.39
5	School of Applied Sciences	8.93
6	Engineering	9.89
7	TULT	10.03

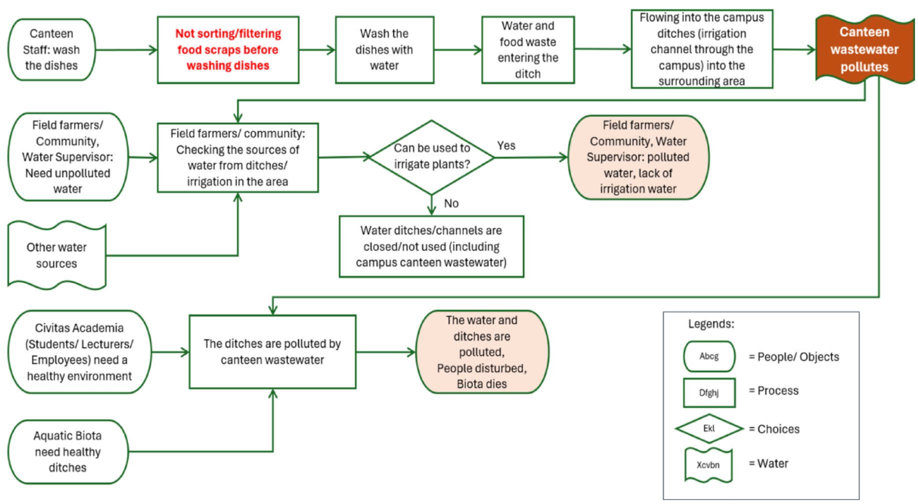


Fig. 5 Canteen wastewater flow and impacted stakeholders (Authors Figure, 2023)

to enable stronger statistical inference, improved reproducibility, and a more robust evaluation of long-term system performance.

4 Result

4.1 Design thinking (process)

The results are structured according to the five stages of the Design Thinking (DT) process: Empathize, Define, Ideate, Prototype, and Test.

4.1.1 Empathize

Field observations and interviews with the wastewater management team revealed that Telkom University's Dayeuhkolot campus (approximately 50 ha) is surrounded by rice fields, residential areas, and local shops, with drainage channels directly connected to nearby irrigation systems. Among seven campus canteen areas, the Telkom University Landmark Tower (TULT) canteen posed the greatest concern because its effluent flowed directly into external irrigation ditches without prior treatment, degrading local water quality and ecosystem health.

Measurements of canteen wastewater (Table 5) showed alkaline pH levels across all sites, with the TULT canteen recording the highest (pH = 10.03). Based on these findings, the team prioritized the TULT canteen for immediate intervention. Figure 5 maps the wastewater flow and affected stakeholders, showing that farmers experienced decreased irrigation water quality, water supervisors urged immediate mitigation, and academics noted the complete absence of aquatic biota.

4.1.2 Define

The first Focus Group Discussion (FGD), conducted in March 2023, identified the main problem: the absence of any structured initiative for managing canteen wastewater. Stakeholders emphasized that untreated wastewater from the TULT canteen had long polluted nearby ditches, reducing water usability for irrigation and producing foul odors.

The FGD established both short- and long-term objectives. The short-term goal was to develop a pilot-scale treatment system within 3 months using local materials and minimal resources. The long-term goal was to design an integrated, centrally monitored system applicable across all canteens.

Five indicators of success were defined as selection criteria for solution design:

1. Use of environmentally friendly materials that generate no secondary pollution.
2. Observable improvement in water conditions through sentinel indicators.
3. Rapid implementation (≤ 3 months).
4. Minimal additional resources/ budget, given the absence of a dedicated environmental engineering unit and this program is not budgeted
5. Limited workforce/ resources, simple maintenance, initially set at once per year.

These indicators guided the ideation and selection of feasible solutions.

4.1.3 Ideate

The Ideate FGD generated three potential solutions (Table 6):

- Alternative 1: Filtration using natural media (banana stems, coconut fiber, red bricks, charcoal, split stone).
- Alternative 2: Chemical treatment using alum and chlorine.
- Alternative 3: Source reduction—requiring canteen operators to pre-filter or reduce waste before washing.

After multi-criteria comparison, Alternative 1 was selected for prototyping because it met all five criteria, combining environmental compatibility, low cost, rapid installation,

Table 6 Summary of FGD ideate results (*Source*: FGD Results, Authors Document (2023))

Criterias (sorted)	**Alternatives**		
	Alternative 1: Filtration using natural media	**Alternative 2: Filtration using chemical**	**Alternative 3: Reduce waste before washing-Implement by canteen**
1. Use green materials	(√)	(x)	1. A different approach solution, Reducing waste from its source
2. Improvement water sentinel indicators	(√)	(x)	2. No installation/processing system costs
3. Rapid implementation (≤ 3mo)	(√)	(x)	3. Additional cost for Canteen side
4. Minimal add resources/budget	(√)	(x)	4. Need time to set the system including control
5. Simple maintenance (initial set 1x/year)	(√)	(√)	
Description: (√) = meets the criteria, (x) = not meet the criteria			A different solution: Complementary, medium-term
Sum of criterias meet	5 of 5	1 of 5	
Decision	Selected	Not Selected	

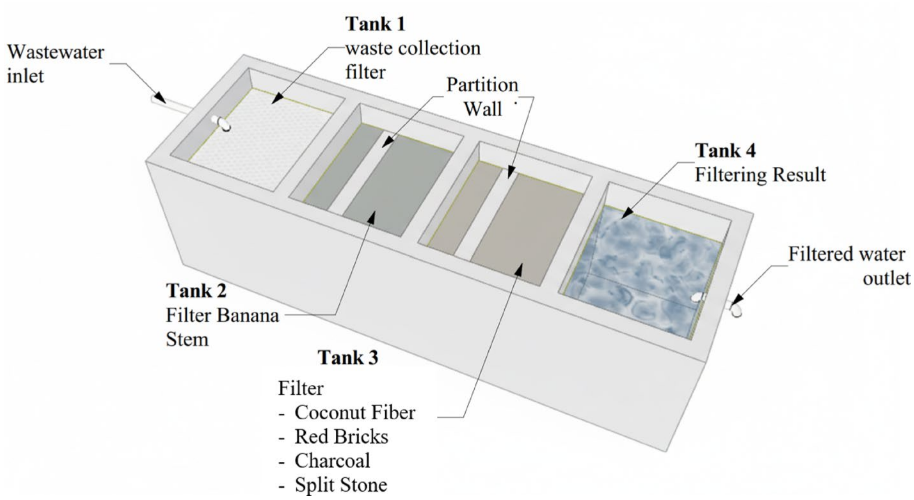


Fig. 6 Two-stage wastewater filtration tank installed at the Telkom University Landmark Tower outfall Stage 1 consists of a chopped banana stem layer. Stage 2 comprises sequential layers of split stone, charcoal, coconut fiber, and red brick. (Source: Authors Figure)

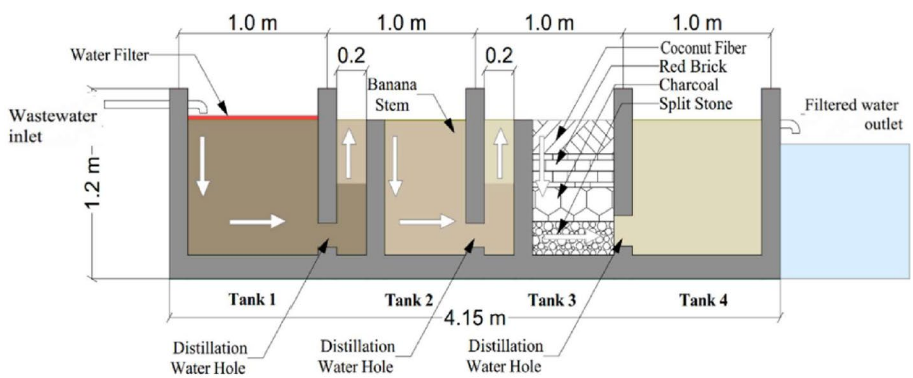


Fig. 7 Cross-sectional schematic of the two-stage filtration tank showing flow path and media layering. Inlet positioned at the upper left; outlet at the lower right. Media thickness: banana stems (~ 50 cm), coconut fiber (~ 25 cm), red brick (~ 25 cm), charcoal (~ 25 cm), split stone (~ 25 cm) (*Source*: Authors Figure)

and minimal maintenance. Alternative 3 was recognized as a complementary medium-term measure focusing on behavior change at the source.

4.1.4 Prototype

Considering the large campus area (~ 50 ha) and dispersed canteen locations, the team selected the TULT canteen as the pilot site to minimize risk and facilitate learning. The filtration tank was designed as a two-stage natural filtration system (Figs. 6, 7).

The two stages are:

1. Stage 1: Coarse filtration using chopped banana stems to capture solids and adsorb oils and grease.
2. Stage 2: Polishing filtration using split stone, charcoal, red brick, layered palm/ coconut fiber (base filter, particle removal, color reduction, and odor control).

The horizontally oriented tank (4.15 m × 1.0 m × 1.2 m) had a total capacity of ~ 4 m^3/day, with a hydraulic retention time of 15–60 min depending on flow rate. Construction was

Fig. 8 Developed prototype filtration system in operation and maintenance. The main maintenance activity involves monitoring the filtration performance of the banana stem layer, which is replaced when its color turns dark. Based on initial iteration evaluation, a 9-month replacement interval was established. (Source: Authors Documentation)

Table 7 Resume of informants interviews (before and after filter developed) (*Source*: Interview Minutes, Authors' results (2023, 2024))

Informants code	Interview resume (Before)—March 2023	Interview resume (After)—April 2024
1. PS1-Field Farmer 2. PS2-Community Member 3. PA-Water Supervisor 4. PK1 & PK2-Canteen Staffs 5. SA1 & SA2-Civitas Academia (Campus members)	1. Canteen Wastewater pollutes the environment and the ditch water cannot be used for rice field irrigation 2. Not all stakeholders are aware of this harmful condition	1. The ditch water can be used to irrigate rice fields and plants 2. Canteen wastewater no longer harms the areas 3. Appreciation to Tel-U

Table 8 Resume of water sentinel indicators (pH, color, odor) (*Source*: Authors Results (2024))

Sentinel indicators (measurement method)	Before	After
1. Water acidity pH (quantitative: pH meter)		
Resume (3 measurement)	9.64 ± 0.48 (alkaline)	6.82 ± 0.53 (neutral)
2. Color (qualitative: observation, human vision)		
Resume 3 observers (SA1, SA2, TA2)	Oily, brownish, murky	No oily; much clearer
3. Water odor (qualitative: observation, human smell)		
Resume 3 observers (SA1, SA2, TA2)	Fishy smell	Odorless (no fishy smell)

completed within 1 month using campus-sourced materials, including banana stems and locally made charcoal from the university's green program.

An iteration was conducted to optimize water flow between partitions. Maintenance evaluation after 1 year revealed that banana stems darkened, indicating decreased filtration capacity; therefore, the replacement interval was adjusted from 12 months to 6–9 months depending on media condition (Fig. 8).

4.1.5 Test

The Test phase assessed both environmental performance and stakeholder acceptance through interviews, direct observations, and sentinel pH measurements (the interview results before and after filtering can be seen in the Table 14 in the Appendix). Informants included local farmers, canteen workers, students, lecturers, and water supervisors.

Interviews indicated improved perception and usability of ditch water for irrigation (Table 7).

The post-treatment pH value of 6.82 ± 0.53 in Table 8 indicates a shift from alkaline toward neutral conditions. This range falls within the commonly referenced neutral interval [6–9]; however, it should be interpreted as an indicative result rather than evidence of regulatory compliance, given the absence of comprehensive physicochemical testing. Human observations found that water became clearer and odorless, and oily residues disappeared.

Observations of aquatic life (Table 9) recorded the reappearance of plants, fish, snails, and crabs, signaling ecological recovery.

Overall, this initial DT cycle improved water conditions and restored visible environmental quality through a low-cost, human-centered approach.

4.2 5M + E (management)

The 5M + E framework was applied to systematically identify Critical Success Factors (CSFs) influencing program success and long-term sustainability, while also serving as the basis for constructing the governance architecture examined in this study. Data were collected from ten internal informants representing different organizational levels through a two-stage process. First, informants completed a structured questionnaire in which they rated the importance of each factor—Man, Machine, Method, Material, Money, and Environment—on a 1–10 scale under two conditions: (1) current program success and (2) future program sustainability. Second, a verification Focus Group Discussion (FGD) was conducted to validate the scoring results and to further explore the governance mechanisms, institutional roles, and coordination processes underlying each factor.

The governance architecture was derived through an integrative analysis combining the quantitative ratings with qualitative insights from the FGD. In particular, the "Man" dimension was disaggregated into three levels to capture the multi-layered governance structure, namely Man1 (top management: Rector, Vice Rectors, and Directors), Man2 (middle management: program leaders and managers responsible for assets and sustainability), and Man3 (operational level: program implementation team). Strong management commitment was identified based on consistently high importance ratings (scores of 8–10) and supported by qualitative evidence indicating active leadership involvement in strategic decision-making, resource allocation, and policy enforcement. Meanwhile, the formulation and implementation of governance instruments—such as policies, standard operating procedures, and sustainability programs—were identified primarily through the "Method" and "Environment" dimensions, supported by FGD discussions and document review that confirmed their existence, application, and monitoring. Accordingly, the unit of analysis in this study is defined as the multi-level governance structure of the wastewater treatment program, encompassing strategic, managerial,

Table 9 Resume of ditch sentinel indicators (physical & biota existence) (*Source*: Authors Results (2023 and 2024))

Ditch and biotas (method)	Before treatment (March 2023)	After 1-year treatment (April 2024)
1. Ditch physical (observation)		
Resume	Dark, turbid, polluted; not visible ditch bottom; very fishy smell	Clear ditch color, visible ditch bottom; not fishy smell
2. Aquatic biota existence (observation)		
Resume	No biota life	Plants, Fish, Snail, Crabs exist, reappearance biotas in the ditch and surrounding

Table 10 Resume of factors rank of implemented program (*Source*: Authors' results (2024))

No	5M + E factors	Total score	Mean	SD	Rank
1	Material	91	9.1	0.88	Top-3
2	Environment	89	8.9	0.74	
3	Man 2	88	8.8	0.63	
4	Man 3	86	8.6	1.26	
5	Method	84	8.4	0.97	
6	Money	72	7.2	2.44	
7	Machine	68	6.8	3.19	
8	Man 1	63	6.3	2.54	

Table 11 Resume of factors rank in the sustainability of future programs (*Source*: Authors' results (2024))

No	5M + E factors	Total score	Mean	SD	Remarks
1	Environment	93	9.3	0.82	Top-3
2	Material	92	9.2	0.92	
3	Man 2	90	9.0	0.67	
4	Method	86	8.6	0.97	
5	Man 3	82	8.2	1.14	
6	Money	77	7.7	1.49	
7	Machine	73	7.3	2.87	
8	Man 1	63	6.3	2.54	

and operational levels, which together shape the effectiveness and sustainability of the program.

Tables 10 and 11 summarize factor rankings. Both assessments identified the same top three factors—Environment, Material, and Man—though in different order. In the ongoing program, *Material* ranked highest because the use of natural, locally available filtration media was crucial for implementation success. For future sustainability, *Environment* rose to first rank, reflecting growing awareness of ecological responsibility and institutional commitment among campus stakeholders.

In Table 10 and 11, scores are based on a 1–10 scale from ten respondents, standard deviation was calculated using the sample formula ($n - 1$); lower values indicate a higher level of agreement among respondents, whereas higher values indicate greater dispersion in responses.

The "Man" factor is divided into three levels representing top (Man 1), middle (Man 2), and operational management (Man 3).

The relatively lower ranking of Machine and Money further indicates that the proposed approach is suitable for resource-constrained environments, where governance and stakeholder engagement play a more decisive role than capital-intensive technologies.

The results indicate that Material, Environment, and Man2 consistently emerge as the top three factors influencing both current program implementation and future sustainability. This finding suggests that the success of the pilot is not primarily driven by technological sophistication (Machine) or financial investment (Money), but rather by the availability of locally appropriate materials, environmental awareness, and human commitment.

Specifically, the prominence of the Material factor reflects the critical role of low-cost, locally sourced filtration media in enabling rapid implementation under resource constraints. This aligns with the study's human-centered design approach, where feasibility and accessibility are prioritized over technical complexity.

The high ranking of the Environment factor highlights the increasing institutional awareness and cultural orientation toward sustainability, indicating that environmental values are becoming embedded within campus practices. Meanwhile, the Man2 factor which represents the middle management level responsible for leading program implementation, underscores the importance of leadership, competencies, and stakeholder engagement in driving program implementation and continuity.

From a governance perspective, these findings demonstrate that sustainability outcomes are shaped not only by operational factors but by the alignment between human capacity, environmental commitment, and resource accessibility. This reinforces the role of governance as an integrative mechanism that connects managerial factors (5M + E) with institutional sustainability objectives.

While the 5M + E analysis provides valuable insights into the factors influencing program success and sustainability, the results should be interpreted as exploratory insights rather than statistically generalizable findings, given the small sample size, purposive sampling approach, and absence of formal validity and reliability testing.

FGD verification produced three key insights:

1. Environmental factor: Maintain and leverage campus-wide awareness and engagement to support continuous environmental improvement.
2. Material factor: Consistently utilize and innovate environmentally friendly filtration materials.
3. Man factor: Institutionalize leadership competencies and environmental values through structured cadre development.

These Top-3 factors are concluded as main drivers to sustain the future program.

4.3 Governance

The governance dimension of this study was analyzed to understand how institutional arrangements support the sustainability and scalability of the wastewater treatment program. These governance elements were identified through thematic analysis of FGD data and triangulated with institutional document analysis.

Drawing on thematic analysis of focus group discussions (FGDs) and institutional documents, several key governance elements were identified, including leadership commitment, policy alignment, stakeholder coordination, accountability, and adaptive learning mechanisms. These findings are structured around five key governance elements, which together form the governance architecture supporting program sustainability.

First, strong leadership commitment emerged as a central enabler. This was reflected in formal institutional support, including Rector-level decrees related to sustainability initiatives, the establishment of a dedicated Green Campus team, and the integration of environmental programs into university priorities. These structures provided legitimacy and direction for the implementation of the wastewater treatment program.

Second, policy alignment and strategic orientation were reinforced through the university's participation in sustainability benchmarking initiatives such as UI GreenMetric, where water management constitutes a key performance indicator. This external benchmarking encouraged internal alignment of policies, roadmaps, and operational procedures related to environmental sustainability.

Third, stakeholder coordination played a critical role in ensuring program effectiveness. The collaboration among canteen operators, facilities management, academic staff, students, and surrounding communities enabled shared ownership of the program and facilitated the integration of technical and social considerations.

Fourth, accountability mechanisms were reflected in the assignment of roles and responsibilities among stakeholders involved in the program. The establishment of dedicated teams, clear task distribution, and oversight from university management contributed to transparency and ensured that program implementation remained aligned with institutional objectives. This accountability structure supports program continuity and reinforces stakeholder trust.

Fifth, adaptive learning mechanisms were evident through iterative evaluation, feedback collection, and continuous improvement practices embedded in the program. The use of Design Thinking cycles, periodic maintenance assessments, and stakeholder feedback through FGDs enabled the program to evolve over time. These learning processes are critical for refining both technical and managerial aspects of the system under real-world conditions.

In addition, FGD participants emphasized the importance of systematic documentation, transparent communication, and periodic evaluation to support governance continuity and iterative learning. These mechanisms are essential to institutionalize the program beyond the pilot phase and to ensure its long-term sustainability.

To strengthen the FGD findings, a review of institutional documents and governance mechanisms was conducted to substantiate the implementation of the identified governance elements. The results are presented in Table 12. The institutional document and governance mechanism analysis provides formal evidence that the identified governance elements are not only perceived by stakeholders but are also institutionally embedded within the university's governance system.

Overall, the findings indicate that the success of the wastewater treatment initiative is not determined solely by technical design, but by the presence of a governance architecture that aligns institutional commitment, stakeholder engagement, and adaptive learning processes. These governance elements collectively demonstrate how institutional structures, rather than technological sophistication alone, determine the sustainability and scalability of the intervention. The findings reinforce the role of governance as an integrative layer that connects process (Design Thinking) and management (5M + E) into a coherent sustainability framework.

5 Discussion

In addressing the complex challenge of canteen wastewater management at Telkom University, the application of Design Thinking (DT) provides a structured yet flexible framework for developing and implementing an effective solution. The process began with the crucial empathy stage, in which the needs and perspectives of stakeholders were thoroughly explored. This stage laid the foundation for identifying key opportunities for

Table 12 Empirical Evidence of Governance Mechanisms (FGD and Institutional Document Analysis) (*Source*: Authors Results)

No	Governance element	Evidence (institutional documents analysis)	Identified findings (FGD)
1	Leadership commitment	Rector Decree No. KR.175/HKM5/SPS/2019 on Sustainable Campus Policy Telkom University Leaders Gathering (TULG) as a periodic leadership forum Quarterly RAPIM 2023, 2024 decisions establishing priority programs, including wastewater management	Embedded in the university's vision and mission aligned with the Sustainable Development Goals (SDGs), supported by formal institutional commitment, program prioritization, and periodic evaluation by top management
2	Policy alignment	Rector Decree No. KR.0086/SDM9/LOG-BLA/2021 on Green & Sustainability Program Team Rector-level policies supporting sustainability integration; roadmap alignment across indicators (waste, water, etc.) Structured KPIs, alignment with UI GreenMetric indicators Aligned with the "Tridharma Perguruan Tinggi" (Tridharma of Higher Education), which integrates education, research, and community service as core institutional responsibilities Annual resource allocation, university budgeting system/RKA 2023, 2024 by Rector Decree	Sustainability is institutionalized through formal structures, participation in the UI GreenMetric program*, shared performance indicators, and resource prioritization across organizational units *UI GreenMetric World University Rankings is a global university ranking system focused on sustainability, developed by the University of Indonesia (UI) in 2010
3	Stakeholder coordination	Internal coordination mechanisms (e.g., TULG and cross-unit collaboration forums, UIGM forums, cross-functionals) involvement of students and surrounding communities; strengthening of SDGs functions to facilitate external stakeholder coordination	Strong and continuous coordination among internal and external stakeholders, embedded in cross-unit collaboration practices and sustainability programs, including student and community engagement
4	Accountability	Governance structure under Vice Rector II oversight; formal role assignment within Green Campus and UI GreenMetric teams (including sub-teams for water and waste indicators); documented reporting and evaluation mechanisms annually Embedded within the "Tridharma of Higher Education", which encompasses the core responsibilities of the academic community (civitas academica—academic community)	Clearly defined governance structure with assigned roles and responsibilities across organizational levels, ensuring supervision, alignment, and implementation consistency
5	Adaptive learning mechanisms	Adaptive Implementation of Green Campus programs, including wastewater initiatives DT process implementation for adaptive problem-solving in resource-constrained contexts e.g. this wastewater treatment program	Institutionalized through iterative learning processes, continuous evaluation, and integration of sustainability programs across indicators

improvement, such as the necessity for canteen staff to sort and reduce solid waste better before initiating the washing process. By leveraging journey tools and flow diagrams, the empathy phase not only highlighted critical insights but also demonstrated the power of user-centered approaches in shaping the subsequent stages of problem solving.

The Define stage (problem formulation) is critical, as it establishes the foundation for subsequent solution development. However, in practice, multiple competing problems may arise. Nevertheless, there must be specific interests and objectives and limited available resources. Therefore, it is crucial to prioritize these issues. At this stage, the opposite mindset of the empathy stage must be divergent, open-minded, and creative in finding ideas for solutions; the thought process at the defining stage is convergent. Here, one must be able to think narrowly to determine which alternative will be chosen. Based on these considerations, it is important to determine the criteria for selecting alternative solutions at this stage (priority).

During the ideation phase, the three alternatives generated by the team were discussed in an FGD. Alternative ideas use the daily experiences of team members, because water is a fundamental human necessity. However, all of these experiences have a theoretical basis. The first alternative was in line with the research of Natanael and Yuliyati [35] based on chemistry science, who showed that banana stems with tea dregs could improve the quality of canteen wastewater. This study also aligns with the research based on physics and chemistry theories from Kakoi et al. [36], in which banana pith was used as a natural coagulant for polluted river water. The second alternative is widely used by the community using alum and chlorine, which are widely sold in the market as water cleaning agents. Alum and chlorine are chemicals that have been academically proven to be used to purify water [37, 38]. Unlike the previous two alternatives, which directly solve the canteen wastewater problem, the third alternative is an idea that arose after analyzing the wastewater process flow diagram, where the process before washing was considered necessary to reduce solid waste entering the washing process. This process is included in Reduce, which is included in the 3R concept (Reduce, Reuse, Recycle) or 5R (Refuse, Reduce, Reuse, Recycle, Rot), which is widely used by academics in waste management [39–41]. FGD determined alternative one as the alternative to be prototyped with the criteria of natural materials, improving flow quality, being fast to build, inexpensive, and having less maintenance because of limited human power.

The prototype was built by a team based on team competency, especially by the Team Leader, who personally has passion and extensive experience in environmental programs. This competence is evident from the many campus environmental programs built by the person concerned and his team, such as campus waste management from initially paying to generating income/monetization [42]. Experience-based solutions complemented by an academic basis complement these programmes. Many academic studies have supported the gradual filtering system of this program with natural materials. The wastewater filtration stage begins with the filtration of big chunks of banana stems, followed by the filtration of smaller particles by coconut fiber and red bricks, and the final stage using charcoal as an odor reducer [43, 44]. Another critical part of the prototype is the filtering tank, which, with the availability of land and materials, is made horizontal rather than vertical. The vertical tank configuration does not require a dividing wall because it is sufficient to use automatic gravity and wastewater falls from top to bottom. The filter tank is not built directly from a detailed plan because no team member understands the details of the tank construction calculations, especially on the right side of the dividing wall. Therefore, the water pressure is appropriate so that the water flows down and up to be filtered by the next tank with the water pressure itself without using a pump. In this stage, an iterative process, which is one of the characteristics of design thinking, is used. Considering the small scale of the prototype, the risk is small;

therefore, it supports the team in iterating because the resources used are manageable. In only one iteration, the optimal filtering tank was obtained.

The test conducted in this study adopted the last stage of design thinking, namely, the user test. This user test was conducted by re-interviewing users who were affected by the prototype that had been created. Furthermore, observations were made in the affected environment to increase the credibility of the test results, and simple water quality tests were performed. These three methods fulfill technical triangulation so that the results of this test are credible [45].

Regarding the simple water tests, it was tested by sentinel indicators and the results showed qualitative improvements: pH shifted from alkaline to neutral, water clarity and odor improved, and aquatic biota reappeared. Despite stakeholders' acceptance, this ecological recovery is preliminary, visual, and not yet supported by quantitative biodiversity metrics. These observations are indicative and qualitative in nature and should not be interpreted as a comprehensive ecological or regulatory performance assessment.

In addition to improving water quality, this research has enriched the results by identifying the success factors of the developing solution process that will be used to improve the program continuously. Luca [46], in his research on the R&D project, used the same basic concept as this research, namely 5M, but with the addition of three factors: politics, social, and economic. In this study, environmental factors were considered. Each added factor was adjusted for the objective of the research. In addition, these research results show that the wastewater problem solution and program success factors can be solved and found human-centered and predominantly based on social sciences.

The outcomes of this research not only show improvements in water quality but also contribute to the broader goal of achieving Sustainable Development Goal (SDG) 6—Clean Water and Sanitation and 12—Responsible Consumption and Production. This study aligns with national environmental priorities, as outlined in Government Regulation No. 22 of 2021 on wastewater disposal in Indonesia. Specifically, the governance architecture supports SDG 6.3 by enabling decentralized and participatory improvements in wastewater quality. At the same time, the low-cost (with an estimated construction cost of approximately IDR 10 million) and resource-efficient nature of the system contributes to SDG 12 by promoting responsible resource utilization and sustainable production practices within the campus environment.

To further clarify the conceptual positioning of this study, Table 13 presents a structured comparison of process, management, and governance approaches within the Process–Management–Governance (PMG) framework. The analytical dimensions used in the table—focus, level, unit of analysis, main outcomes, and implications—are synthesized from prior literature on organizational processes, management functions, and governance systems [13, 33, 34]. This synthesis builds on established theoretical foundations. The "level" dimension follows hierarchical decision-making frameworks distinguishing operational, tactical, and strategic layers [34]. The "focus" and "implication" dimensions reflect process–governance integration perspectives that emphasize the linkage between workflows and institutional arrangements [33]. The governance dimension further draws on governance network theory, highlighting institutional elements such as accountability and coordination [13]. Meanwhile, the dimensions of unit

Table 13 PMG (process–management–governance) map

Level/aspect	P Process approach (workflow)	M Management approach (execution and control)	G Governance approach (institutional and sustainability)	References
Focus	Workflow, innovation cycle	Planning, organizing, actuating, controlling resources for day-to-day effectiveness	Institutional governance architecture that ensures sustainability through *leadership commitment, policy and institutional alignment, stakeholder coordination, accountability mechanisms,* and *adaptive learning processes*	[12, 13, 26, 33]
Level	Operational—daily implementation of processes	Tactical—mid-level planning, resource allocation, monitoring staff	Primarily strategic–institutional, with cascading influence across tactical and operational levels through formal policies, coordination mechanisms, and governance structures	[34]
Unit of analysis in this study	DT (E-D-I-P–T) Natural filter (two-stage natural filtration system): Pilot program with human-centered assessment (stakeholders acceptance) and sentinel indicators (resources constraints and DT nature: start simple then improved)	5M + E Resource and staff assignment: Short term 3-key factor (Environment-strong awareness, Material-green material, Man-cadre programs) 6-mo filter media replacement Documenting processes and results, effective communication, ongoing evaluation	University-level governance system operationalized through: rector-level policies and sustainability commitments; Green Campus programs; alignment with UI GreenMetric indicators; cross-unit stakeholder coordination mechanisms (faculties, directorates, students, and external communities); formal assignment of roles and responsibilities (e.g., Vice Rector II oversight); and iterative evaluation and feedback processes	[33]
Main outcomes	Efficiency of workflow: Green materials, Fast development, low cost and available resources	Effectiveness of execution: goal achievement, cost/resource balance	Sustainability and institutional legitimacy, reflected in long-term program viability, improved environmental outcomes, stakeholder trust and acceptance, and the institutionalization of wastewater management practices within campus governance structures	[13, 14]; Governance literature
Implication	Processes run efficiently	Resources and people/Man execute plans effectively/properly	Ensures alignment between sustainability initiatives and institutional mission (Green Campus), strengthens accountability across top–middle–operational levels, facilitates coordinated stakeholder engagement, and enables continuous improvement through *adaptive learning mechanisms*	Synthesis from multi-level governance theories

Source: Authors Results

of analysis and main outcomes are grounded in general management and operations literature, where analytical clarity is achieved by specifying what is being analyzed and the expected results.

This synthesis enables a consistent and comparative interpretation across the three analytical layers. In this study, the process dimension is operationalized through Design Thinking (DT), the management dimension through the 5M + E framework, and the governance dimension through empirically identified institutional mechanisms. This structured comparison highlights how governance functions as an integrative layer that connects iterative processes and managerial execution into a coherent sustainability framework.

The governance dimension presented in Table 13 can be further understood through its analytical components across focus, level, unit of analysis, outcomes, and implications. Unlike process and management perspectives, which primarily emphasize execution and resource coordination, governance operates at the institutional level to ensure sustainability and legitimacy. Its focus lies in establishing a governance architecture composed of leadership commitment, policy alignment, stakeholder coordination, accountability, and adaptive learning mechanisms, as empirically identified in this study.

At the level dimension, governance is anchored at the strategic–institutional layer but extends across tactical and operational levels through structured policies, coordination mechanisms, and organizational roles. The unit of analysis reflects the university governance system, operationalized through formal policies, sustainability programs, and cross-unit collaboration mechanisms. These arrangements enable governance to produce outcomes that go beyond efficiency and effectiveness, namely institutional legitimacy, stakeholder trust, and long-term program viability.

The implications of this governance structure highlight its role as an integrative mechanism that aligns iterative processes (Design Thinking) and managerial execution (5M + E) within a coherent sustainability framework. This confirms that the sustainability of wastewater management initiatives in higher education is not primarily determined by technological sophistication, but by the strength of institutional governance that enables continuity, scalability, and adaptive learning.

On the other hand, this pilot demonstrates that a DT and 5M + E governance approach can rapidly mobilize campus stakeholders and implement a low-cost filtration prototype that yields early signs of environmental improvement. The primary contribution of this study lies in demonstrating a governance-driven sustainability model that integrates process (Design Thinking) and management (5M + E) into an institutional framework applicable to resource-constrained higher education settings. We caution that sentinel results must be validated by an engineering-grade follow-up to confirm treatment efficacy against regulatory thresholds.

From a sustainability perspective, the findings of this study can be explicitly linked to the United Nations Sustainable Development Goals (SDGs), particularly SDG 6 and SDG 12. The governance architecture developed in this study—encompassing leadership commitment, policy alignment, stakeholder coordination, accountability, and adaptive learning—directly supports SDG 6.3, which aims to improve water quality by reducing pollution and enhancing wastewater treatment. Although the present study is based on sentinel indicators, the observed improvements in pH, clarity, and odor, along with the reappearance of aquatic biota, indicate early progress toward this goal within a resource-constrained institutional context.

Furthermore, the low-cost, participatory model developed through Design Thinking and the 5M + E framework aligns with SDG 12 on responsible consumption and production. The use of locally sourced, environmentally friendly materials, combined with stakeholder engagement and behavioral awareness, reflects a shift toward more sustainable resource utilization and waste management practices. This demonstrates that sustainability transitions in higher education can be effectively driven by governance mechanisms that integrate human-centered design, resource efficiency, and institutional commitment.

6 Conclusion

This study demonstrates that integrating Design Thinking (DT) with the 5M + E governance framework provides an effective and replicable model for managing campus canteen wastewater in resource-constrained environments. The combination of human-centered design, participatory governance, and low-cost natural filtration media (banana stems, coconut fiber, red brick, charcoal, and split stone) produced observable improvements in both environmental and social outcomes. Sentinel indicators—including pH, color, odor, and aquatic biota—showed observable improvement: the effluent pH improved from 9.64 ± 0.48 (alkaline) to 6.82 ± 0.53 (neutral), approaching the commonly accepted neutral range (pH 6–9), based on sentinel measurement.

Qualitative observations further confirmed the reappearance of aquatic life and increased stakeholder acceptance. These outcomes affirm that sustainability innovation in higher education depends not only on technology, but also on the governance architecture that institutionalizes iterative learning, shared accountability, and environmental stewardship.

From a managerial perspective, the study highlights that the key drivers of sustainability—identified through the 5M + E framework—are Environment, Material, and Man. Strong management commitment, structured stakeholder engagement, and consistent use of environmentally friendly materials underpin both operational success and long-term program legitimacy. The research contributes to the broader literature by reframing wastewater management not merely as an engineering task, but as a human-centered governance process that bridges the domains of process (DT), management (5M + E), and governance (institutional alignment). This Process–Management–Governance (PMG) integration ensures that sustainability transitions in universities evolve through adaptive, participatory, and accountable mechanisms.

Nevertheless, this pilot study is limited by its reliance on sentinel indicators rather than comprehensive laboratory datasets. Future research should validate the treatment performance through full-parameter analyses—including COD, BOD_5, TSS, FOG, TN, TP, and E. coli—in accordance with SNI 6989 (Uji Kualitas Air dan Air Limbah) and APHA/ISO methods, benchmarked against the Indonesian Regulation on Domestic Wastewater Discharge Standards (Permen LHK No. P.68/2016). Expanding replication to other institutional and urban contexts, supported by quantitative cost–benefit, ecological, and governance evaluations, will enhance generalizability. Future work should also explore how human-centered governance frameworks can be scaled across campus sustainability programs—spanning waste, water, and energy—to accelerate progress toward UN SDGs 6 and 12.

Appendix

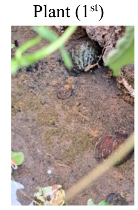
Table 14 Results of informants interviews: before versus after filter developed—March 2023 versus April 2024

No	Informants code	Interview resume—before March 2023	Interview resume—after April 2024
1	PS1 Field farmer	The campus's ditch water is polluted, so it is closed Previously, it could be used to irrigate rice fields	After the program, the water from the campus ditch can be used to irrigate rice fields
2	PS2 Community member	Polluting the environment	After the program, the water from the campus ditch can be used for watery plants and other uses
3	PA Water supervisor	Polluting the environment	After the program, the water can be used to irrigate rice fields and plants Thank you for TelU's efforts
4	PK1 and PK2 Canteen staff	Initially, they were not aware the impact of canteen waste on the environment	After the program, it was realized that canteen waste was polluting the environment Grateful because canteen wastewater no longer pollutes the environment Will support the program more
5	SA1 and SA2 Civitas Academia (campus members)	The ditch and the surrounding biotas were harmed by the canteen wastewater	Grateful because it is starting to lessen the environmental harms
Validation process		All responses: similar (valid)	All Responses: similar (valid)
Conclusion		Before: Canteen Wastewater pollutes the environment and the ditch water cannot be used for rice field irrigation Not all stakeholders are aware of this harmful condition	After: The ditch water can be used to irrigate rice fields and plants Canteen wastewater no longer harms the areas People thanks Tel-U

Table 15 Water test results—sentinel indicators: before (inlet) vs after treatment (outlet)—April 2024 (*Source*: Research Results, 2024)

No	Water test	Before/inlet	After/outlet
Simple water chemical test: acidity level (pH meter)			
1	1st test pH	9.11	6.22
2	2nd test pH	10.03	7.23
3	3rd test pH	9.78	7.01
pH range (rounded)		9–10	6–7
Conclusion		Water is alkaline	Water is neutral
Water physical test: color observation			
By human eye (vision)			
1	1st Obs (SA1)	Oily, murky, dull	Not oily, much clearer
2	2nd Obs (SA2)	Brownish, murky	clearer
3	3rd Obs (TA2)	Oily, very murky	Not oily, much clearer
Conclusion		Oily, brownish, murky	It is not oily; much clearer
Water physical test: odor observation			
By human nose (sense of smell)		Water Odor	Water Odor
1	1st Obs (SA1)	Very fishy smell	Not fishy smell
2	2nd Obs (SA2)	Fishy smell	Odorless
3	3rd Obs (TA2)	Fishy smell	Less fishy smell
Conclusion		Fishy smell	Not fishy smell

Table 16 Ditch sentinel indicators (physical condition and aquatic biota existence): before vs after filter developed—March 2023 versus April 2024 (*Source*: Research Results, (2023 and 2024))

No	Ditch observation	Before filter developed (March 2023)	After filter developed (a year afterwards, April 2024)
1. Ditch physical condition			
	Physical condition	 (March 2023)	 (April 2024)
	Ditch color (1st obs)	Dark, turbid, and polluted	Ditch water color clearer
	Ditch bottom (2nd obs)	Bottom not visible	Bottom visible
	Ditch smell (3rd obs)	Very fishy smell	Not fishy smell
	Conclusion	The water was dark, turbid, and polluted, with the ditch bottom obscured and accompanied by a strong foul odor	Clear and visible ditch bottom Not fishy smell
2. Aquatic biota existence			
	Aquatic biota existence in ditch	No aquatic life (March 2023) 	Existence of Diverse Aquatic biota (April 2024)  Plant (1st)  Small fish (2nd)  Snail (3rd)  Crab (4th)
	Conclusion	No aquatic life	The ditch ecosystem improved, and various aquatic biota life exists

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Author contributions
Rina Djunita Pasaribu: Conceptualize, Formal Analysis, Methodology, Validation, Visualization, Writing—Original Draft; Deni Wahyu Dewanata: Data Curation, Funding Acquisition, Investigation, Project Administration, Resources, Supervision; Mohammad Riza Sutjipto: Conceptualize, Formal Analysis, Methodology, Validation; Taufan Umbara: Funding Acquisition; Aris Hartaman: Funding Acquisition; Darmawan: Data Curation, Investigation, Resources; Erna Sri Sugesti: Resources; Anton Abulbasah Kamil: Data Curation; Grisna Anggadwita: Validation, Visualization, Writing—Review and Editing.

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Data availability
The data that support the findings of this study are available from the first and second authors, (rinadjunita@telkomuniversity.ac.id and deniwahyu@telkomuniversity.ac.id), upon reasonable request.

Declarations

Ethics approval and consent to participate
The research reported in this manuscript was conducted in accordance with recognized ethical standards and institutional guidelines. Ethical review and approval were conducted by the Directorate of Research and Community Services, Telkom University. We hereby confirm that all participants involved in this study provided their informed consent prior to participation. The consent process adhered to ethical standards for human subject research, including voluntary participation, the right to withdraw, and assurance of confidentiality. Signed consent forms from all participants are attached as supporting documentation and are available for review upon request.

Consent for publication
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Competing interests
The authors declare that they have no competing interests.

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