

Research Article

Optimizing Community Roles in Environmentally Friendly Wastewater Management in Central Tapanuli

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Abstract: The management of domestic wastewater remains a major challenge in rural areas, including in Central Tapanuli Regency. Limited community participation, low access to environmental information, and weak institutional support are key factors hindering sustainable sanitation efforts. This study aims to identify and analyze the factors influencing community roles in environmentally friendly wastewater management and to formulate empowerment strategies that align with local characteristics. This research uses a Mixed Methods approach, combining a descriptive quantitative method with multiple linear regression analysis to assess the influence of variable X1 (Knowledge), X2 (Access to Information), and X3 (Institutional Support) on variable Y (Community Role). Quantitative data were collected from 175 respondents using a closed-ended questionnaire, while qualitative data were obtained through in-depth interviews and field observations in four villages: Sipeapea, Pandan, Tapan Nauli, and Hutabalang. The results show that all three independent variables have a positive influence on enhancing community roles, with institutional support being the most dominant factor. In addition, qualitative interviews revealed a gap in practical knowledge and a need for stronger cross-sectoral communication. These findings indicate that optimizing community involvement strongly depends on continued education, information transparency, and institutional synergy. This study recommends intervention strategies including community-based sanitation education, the establishment of village environmental information systems, and the integration of waste management programs into regional development planning. These findings are expected to serve as a foundation for more adaptive, contextual, and sustainable environmental policymaking in Central Tapanuli.

Keywords: Central Tapanuli; Community Roles; Environmentally Friendly Sanitation; Participation; Waste Management

1. Introduction

Sanitation issues and domestic wastewater management are strategic concerns in sustainable development, especially in rural and peri-urban areas such as Central Tapanuli Regency. Improperly managed household wastewater has the potential to contaminate clean water sources, increase the risk of disease, and degrade community well-being. Environmentally friendly wastewater management does not rely solely on technology, but greatly depends on the active involvement of the community at every stage of the process.

In this context, the community's role is a key element in creating an efficient and sustainable waste management system. The community is not merely a user of the sanitation system, but a primary actor capable of designing, managing, and maintaining it. In line with Hidayat, Milanie, Nuraini, Azhari, & Sugiarto (2023) development that neglects community participation tends to result in a mismatch of expectations and social resistance during implementation.

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In Central Tapanuli Regency, several villages continue to face challenges in domestic wastewater management, including low levels of public awareness, inadequate sanitation infrastructure, and weak local regulations. Data from the Central Tapanuli Environmental Agency (DLH) in 2023 reported that over 60% of households still use wastewater disposal systems that do not meet environmental standards.

Previous studies by Gultom & Siregar (2023) & Linda et al. (2024) emphasized the importance of participatory strategies in managing rural sanitation systems. Meanwhile, Siregar (2020) dan Sugiarto & Ramadania (2024) noted that the success of sanitation programs is strongly influenced by local socio-cultural factors and the community's willingness to contribute voluntarily. These findings suggest that community-based approaches are highly relevant for the implementation of environmentally friendly waste management Purba et al. (2024), Sugiarto et al. (2023).

Community involvement not only improves the technical effectiveness of waste management but also fosters a sense of ownership and responsibility for the environment. This aligns with the Sustainable Development Goals (SDGs), particularly Goal 6 on clean water and sanitation, which emphasizes the importance of safe and inclusive wastewater management (UN-Habitat, 2022; United Nations, 2021; (Hartini, Nuraini, Milanie, Abdiyanto, & Sugiarto, 2023).

However, there remains a gap between technical policies and field practices, particularly in community empowerment. Therefore, it is important to conduct an in-depth study of community participation patterns, the influencing factors, and approaches that can be optimized to achieve sustainable and environmentally friendly wastewater management.

Problem formulation; Based on the background above, the research questions of this study are as follows: 1) What is the level of community participation in environmentally friendly wastewater management in Central Tapanuli Regency?, 2) What factors influence community involvement in wastewater management?, 3) What strategies can be implemented to optimize the community's role in supporting environmentally friendly wastewater management?

Research Objectives and Benefits; This study aims to: 1) Analyze the level of community participation in environmentally friendly wastewater management in Central Tapanuli Regency, 2) Identify the factors influencing community involvement in wastewater management, particularly in terms of knowledge, access to information, and institutional support, 3) Formulate strategies to optimize community roles in supporting sustainable wastewater management that aligns with the local characteristics of the study area.

This research is expected to contribute to the development of academic studies in the field of regional and urban planning, particularly regarding community-based environmental management. Additionally, the results of this study can serve as a reference for developing collaborative models between communities and governments in sustainable sanitation management. Practically, this study is useful for: 1) Providing relevant information for local and village governments in designing more participatory and environmentally friendly waste management policies or programs, 2) Encouraging greater public awareness and engagement in maintaining the quality of the living environment, 3) Serving as a foundation for developing community-based sanitation infrastructure that is more adaptive to local social and cultural conditions.

Several relevant studies referenced in this research include; Siregar (2020) & Hao (2023), who explored the relationship between socio-cultural factors and community participation in environmental-based sanitation, highlighting that local wisdom significantly influences program success. Gultom & Siregar (2023) who investigated the barriers to wastewater management system implementation in coastal villages of South Tapanuli, identifying institutional weaknesses and a lack of outreach as key obstacles. Naibaho (2022) from Universitas Pembangunan Panca Budi, who demonstrated that collaboration between village governments and communities can accelerate the achievement of sanitation targets in semi-urban areas. Another study by Lubis et al. (2023) & (Akbar et al., 2025; Pakpahan et al., 2025) emphasized that low-tech solutions combined with environmental education are more effective than infrastructure-based approaches alone.

The novelty of this study lies in the development of community participation indicators based on empirical data and in-depth interviews, which can serve as a foundation for designing more participatory wastewater management policies.

2. Preliminaries or Related Work or Literature Review

2.1 Community Participation Theory

Community participation in environmental development is one of the main pillars of sustainability. According to Arnstein's "Ladder of Citizen Participation" model, the level of participation ranges from manipulative forms to full citizen control (Saputra & Maulana, 2021; Aini et al., 2023). In the context of wastewater management, participation includes involvement in planning, implementation, monitoring, and maintenance of sanitation systems. A participatory space allows the community to feel a sense of ownership and responsibility toward the implemented environmental programs. Active participation also enhances the effectiveness of systems built collectively (Lubis & Gultom, 2023).

2.2 Environmental Behavior Theory

Environmental behavior theory explains that human behavior toward the environment is influenced by knowledge, attitudes, and social norms. Ajzen (2021) & Nuraini (2021), through the Theory of Planned Behavior, states that behavioral intention is formed by one's attitude toward the behavior, subjective norms, and perceived behavioral control. In the context of waste management, the higher the public's knowledge about the negative impacts of waste, the greater the tendency to engage in environmentally friendly behavior (Harahap, 2022).

2.3 Social Systems Theory in Environmental Management

This theory positions society as part of a dynamic social system that interacts in shaping responses to environmental issues. The application of community-based environmental management principles emphasizes the importance of local values and social structures in wastewater management (Pakpahan et al., 2025; Song et al., 2024).

2.4 Relevant Previous Studies

Table 1. Previous Studies.

No	Researcher	Year	Key Findings
1	Harahap	2022	Community participation increases when supported by local education and village apparatus involvement.
2	Sari et al.	2021	Effective sanitation systems in coastal areas of Sumatra require social engagement, not just technical solutions.
3	Gultom & Siregar	2023	Limited access to information and weak supervision are the main barriers to waste management.
4	Lubis & Gultom	2023	Institutional strengthening and technical training significantly improve rural wastewater management quality.
5	Simanjuntak	2024	Simple waste treatment technologies are acceptable when combined with participatory approaches.

Source: Compiled by the Author, 2025

From the review of previous studies, there is a lack of research that integratively combines analysis of community roles with optimization strategies in the specific local context of Central Tapanuli. This study seeks to fill that gap.

2.5 Conceptual Framework

This study is based on the assumption that the community's role (Y) in environmentally friendly wastewater management is influenced by several key factors: (a) X1: Knowledge of waste management. (b) X2: Access to environmental information. (c) X3: Institutional/village government support

Each of these factors is assumed to have a positive relationship with community involvement in wastewater management.

2.6 Conceptual Framework Diagram

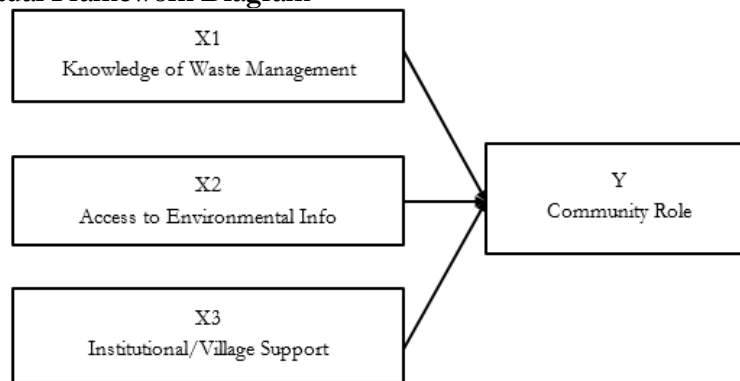


Figure 1. Conceptual Framework Diagram.

Source: Author's Design, 2025

2.7 Conceptual Definition of Variables

Table 2. Conceptual Definitions of Variables.

Variable	Conceptual Definition	Indicators
X1: Knowledge of Waste Management	The level of community understanding regarding environmentally friendly wastewater management.	Risk awareness, treatment methods, environmental impacts
X2: Access to Environmental Information	The availability and exposure of the community to sanitation-related information.	Information sources, frequency, socialization activities
X3: Institutional/Village Government Support	The degree of involvement by local authorities and village officials in supporting wastewater programs.	Local policies, training, facility provision
Y: Community Role	The level of community involvement in all stages of wastewater management.	Participation in planning, implementation, and evaluation

Source: Compiled by the Author, 2025

3. Proposed Method

This study employs a mixed methods approach, combining descriptive quantitative and phenomenological qualitative methods in an integrated manner to obtain a comprehensive and in-depth understanding of community roles in environmentally friendly wastewater management in Central Tapanuli Regency. The quantitative approach is used to measure levels of knowledge, information access, and institutional support influencing community participation, while the qualitative approach explores perceptions, motivations, and social challenges faced by communities in managing wastewater (Harahap, 2022) dalam Haloho & Sugiarto (2024).

The research was conducted in several villages across Central Tapanuli Regency, selected based on criteria such as high population density and inadequate domestic wastewater management systems. The locations were chosen purposively to represent diverse settlement conditions and environmental concerns. The study was carried out from January to April 2025, covering stages of preliminary observation, data collection, analysis, and final reporting.

The population of this research comprises household heads residing in the study areas who are directly involved in household waste management activities. For the quantitative sample, purposive sampling was used to select 175 respondents, representing variation in age, education level, and occupation. For the qualitative stage, snowball sampling was used to identify key informants such as village officials, community leaders, environmental cadres, and representatives from the Central Tapanuli Environmental Agency.

The variables analyzed in this study include one dependent variable: community participation, and three independent variables: knowledge of waste management, access to environmental information, and institutional/village government support. Community participation is measured through indicators such as involvement in planning, implementation, evaluation,

and community self-help initiatives. Knowledge covers understanding of waste impacts and basic treatment practices (Milanie, 2021; Sugiyono, 2019).. Information access reflects community exposure to media, education, and outreach, while institutional support includes village programs, sanitation facilities, and training opportunities.

The study uses both primary data, collected through structured questionnaires and in-depth interviews, and secondary data from village planning documents, environmental reports, and official publications from relevant government departments. Data collection techniques include structured Likert-scale questionnaires for quantitative respondents and semi-structured interview guides for qualitative informants. Additionally, participatory observation and visual documentation are conducted to support data validity.

Quantitative data is analyzed using descriptive statistics with SPSS version 20, presenting results through frequency tables, percentages, and graphs to illustrate variable distribution. Qualitative data is analyzed through data reduction, categorization, and thematic interpretation, in line with the phenomenological approach. Interview findings are interpreted to understand community thinking patterns, perceptions, and social experiences related to wastewater management.

A final triangulation process integrates both quantitative and qualitative findings comprehensively, aiming to build a narrative that is empirically valid and socio-culturally contextual, reflecting the local realities of Central Tapanuli.

4. Results and Discussion

4.1 Overview of the Research Location

Central Tapanuli Regency is one of the administrative regions in North Sumatra Province, characterized by diverse geographical, social, and environmental features. The area includes coastal zones, lowlands, and hilly regions, each presenting distinct challenges in terms of environmental management, particularly sanitation and household wastewater disposal.

In general, most residents in Central Tapanuli still use conventional waste disposal systems, such as open drains, absorption pits, or direct discharge into nearby water bodies. This presents serious environmental and health challenges, especially in densely populated settlements, where inadequate sanitation may lead to disease and pollution.

Community-based sanitation programs have begun to be implemented in several villages, but adoption remains uneven. Many residents still perceive wastewater management as the government's sole responsibility rather than a collective obligation involving community participation. Hence, a systematic analysis of community knowledge, information access, institutional support, and the extent of community involvement is essential.

4.2 General Description of Respondents

The study involved 175 respondents, each being a head of household or household representative from the selected villages. Respondents were purposively selected based on their involvement or awareness of domestic waste management issues. Here is a summary of their characteristics:

Table 3. Summary of Respondent Characteristics.

Characteristic	Category	Number of Respondents	Percentage (%)
Gender	Male	92	52.6
	Female	83	47.4
Age	21–30 years	37	21.1
	31–40 years	58	33.1
	41–50 years	49	28.0
	> 50 years	31	17.7
Education Level	Elementary–Junior High	38	21.7
	Senior High School	79	45.1
	Higher Education	58	33.2
Occupation	Farmer/Fisherman	51	29.1

Characteristic	Category	Number of Respondents	Percentage (%)
	Housewife	42	24.0
	Entrepreneur	48	27.4
	Employee (Gov./Private)	34	19.5

Source: Author's Compilation, 2025

The majority of respondents fall within the productive age group and have at least a secondary education, which theoretically gives them the capacity to understand environmental issues and participate actively. However, perceptions of waste and sanitation habits are still heavily influenced by local culture and the availability of infrastructure in their surrounding environment.

4.3 Statistical Description of Research Variables

Descriptive statistical analysis was conducted to portray the general patterns of the four main variables in this study: community knowledge of waste management (X1), access to environmental information (X2), institutional support (X3), and community participation in wastewater management (Y). The statistical summary is as follows:

Table 4. Summary Statistics of Research Variables.

Variable	Mean	Standard Deviation	Minimum	Maximum
X1: Knowledge of waste management	4.14	0.33	3.25	5.00
X2: Access to environmental information	2.97	0.45	2.00	4.00
X3: Institutional/village government support	3.68	0.42	3.00	4.00
Y: Community participation	3.53	0.49	2.60	4.80

Source: SPSS 20 Output, 2025

The results of the descriptive analysis provide a preliminary overview of public perception and participation conditions in domestic wastewater management.

The knowledge variable (X1) recorded the highest average score of 4.14 with a relatively low standard deviation. This indicates that the majority of respondents have a good understanding of the importance of environmentally friendly waste management. They not only recognize the negative impacts of waste on health and the environment, but also comprehend the basic principles of household waste treatment. The high score reflects that environmental education, both formal and informal, is increasingly being accepted by the community.

In contrast, access to environmental information (X2) had the lowest average score at 2.97, indicating that the public's exposure to relevant information remains limited. Respondents reported a lack of outreach or dissemination programs by village officials or environmental agencies. This information gap may pose a serious barrier to fostering active community participation in wastewater management initiatives.

The variable institutional support (X3) had a mean of 3.68, indicating that support from village institutions and environmental agencies is beginning to be felt, although not fully. Some respondents acknowledged the existence of environmental programs facilitated by village authorities, such as wastewater channel provision or technical training, but these efforts have yet to be implemented consistently or sustainably. This suggests the presence of

a positive foundation that can be further enhanced through consistent policies and participatory approaches.

Meanwhile, community participation (Y) had an average score of 3.53, indicating a moderate-to-high level of involvement in wastewater management. While some community members are already involved in planning or implementing environmental activities, many still remain as passive beneficiaries. Limited access to information and suboptimal institutional support may hinder broader engagement. Therefore, efforts to enhance community roles should focus on strengthening collaboration among communities, village governments, and environmental institutions.

Overall, the statistics indicate an interrelated relationship among the variables: high knowledge does not necessarily translate to strong participation unless it is supported by adequate information access and concrete institutional support. Thus, a strategic and integrated approach is essential to optimize community roles in sustainable wastewater management.

4.4 Reliability Test Results

To ensure that each indicator used in the questionnaire consistently measures the intended variable, a reliability test was conducted using the Cronbach's Alpha approach. This test is an essential part of the instrument validation process, particularly in quantitative research employing a Likert scale. The following table presents the Cronbach's Alpha values for each variable:

Table 5. Reliability Test Results.

Variable	Cronbach's Alpha
X1 – Knowledge	0.861
X2 – Access to Information	0.914
X3 – Institutional Support	0.872
Y – Community Participation	0.955

Source: SPSS 20, 2025

Cronbach's Alpha values above 0.7 indicate that the instruments used in this study possess strong internal consistency. For the variable of community knowledge (X1), a value of 0.861 suggests that the four indicators used to measure knowledge levels are mutually supportive and highly correlated internally.

A similar finding is observed for the variable of access to information (X2), which even scored the highest at 0.914. This means that the indicators for this variable are not only well-structured but also reflect a shared perception among respondents regarding the barriers to accessing information.

The variable of institutional support (X3) also demonstrates high reliability with a score of 0.872. This indicates that respondents' perceptions regarding village government involvement, facility provision, and environmental training are confirmed by consistent responses across the indicators.

Meanwhile, the community participation variable (Y) scored the highest at 0.955. This signifies that the items measuring community involvement in planning, implementation, evaluation, and self-help activities genuinely represent a unified construct. Respondents' answers showed a consistent pattern, reinforcing the instrument's reliability in measuring participatory behavior.

Based on these results, it can be concluded that the research instrument is reliable and suitable for further analysis. The four variables used demonstrate internal stability, thereby ensuring a high level of measurement credibility.

4.5 Qualitative Results and Findings

In-depth interviews conducted with informants from four villages in Central Tapanuli Regency revealed various dynamics in the management of household wastewater. The interviews involved 12 informants from the villages of Sipeapea, Pandan, Tapan Nauli, and Hutabalang. Informants included village officials, community leaders, housewives, environmental cadres, and general residents involved in village sanitation activities. The interviews were conducted face-to-face using an open-ended approach, allowing informants to freely express their opinions.

Theme 1: Community Knowledge about Wastewater

Most informants indicated that the community understands the importance of maintaining environmental cleanliness and the harmful effects of domestic waste. However, this understanding is not yet evenly distributed and is not fully reflected in daily practices.

“People actually already know, especially the younger ones. But sometimes they still pour wash water into the drain because there’s no alternative or designated place.

” (*Informant 1, Environmental Cadre, Pandan Village*)

“I’ve started separating kitchen waste and bathwater, but many neighbors still think it’s too much hassle.”

(*Informant 2, Resident, Tapian Nauli Village*)

“The knowledge is there, but not everyone is aware. Sometimes it’s just because no one monitors them.”

(*Informant 3, Hamlet Head, Hutabalang Village*)

Theme 2: Access to Environmental Information

Access to information is still very limited. Most informants admitted they had never attended any special socialization sessions on wastewater management, and most of their information came from informal chats or children returning from school.

“No one from the agency has ever come here to provide education. Usually, we hear things from other residents, not the government.”

(*Informant 4, Housewife, Sipeapea Village*)

“There’s never been any formal outreach. We might hear something at an RT forum, but it’s very brief.”

(*Informant 5, RT Leader, Pandan Village*)

“If there’s a new program, it’s sometimes announced, but there’s no thorough explanation. People don’t know who to ask.”

(*Informant 6, Community Leader, Tapian Nauli Village*)

Theme 3: Institutional Support and Village Programs

Informants from the village government acknowledged the existence of sanitation-related programs, but their implementation has not been optimal due to budget constraints and competing priorities.

“We once proposed a drainage system project, but the village budget was still focused on other physical infrastructure.”

(*Informant 7, Village Secretary, Hutabalang Village*)

“There was some septic tank support from the regency, but it wasn’t enough for everyone only about half received it.”

(*Informant 8, Head of Development, Sipeapea Village*)

“The programs exist, and the intentions are there, but if the community isn’t willing to get involved, it’s all for nothing.”

(*Informant 9, Village Head, Pandan Village*)

Theme 4: Community Participation

Residents generally participate only during community clean-up events or when invited to village meetings. Involvement in decision-making or sanitation planning remains very low.

“I take part in communal work if I’m called. But when it comes to village planning, we’re never involved.”

(*Informant 10, Resident, Tapian Nauli Village*)

“People usually come when there’s aid. But for discussions about waste, hardly anyone is interested.”

(*Informant 11, Youth Organization Leader, Sipeapea Village*)

“People here are willing to help if the results are clear. If it’s just talk with no action, they get discouraged.”

(*Informant 12, Religious Leader, Hutabalang Village*)

Theme 5: Social and Cultural Barriers

Traditional practices of disposing of wastewater into ditches or backyards are still considered normal. Some residents feel there’s no need to change since they’ve never been warned or experienced direct negative impacts.

“We’ve always thrown wastewater into the garden. It just soaks into the ground never had a problem.”

(*Informant 4, Housewife, Sipeapea Village*)

“People think, as long as it doesn’t smell bad, it’s fine. But that’s not really true.”

(*Informant 3, Hamlet Head, Hutabalang Village*)

“It takes time to change habits. Without real examples from the government, people will keep doing the same.”

(Informant 6, Community Leader, Tapan Nauli Village)

The qualitative findings from these four villages indicate that community participation in wastewater management does not occur in isolation but rather stems from a complex interaction of individual understanding, information availability, institutional support, and the prevailing social and cultural dynamics. While public knowledge is beginning to form, active participation is still hindered by structural barriers and deeply ingrained habits.

Support from village governments and related agencies must be directed not only toward technical aspects but also toward developing an open and sustainable information ecosystem. Without efforts to build closer and more participatory communication, community roles are likely to remain passive and short-lived.

Overall, field insights show that strengthening community roles requires a comprehensive approach not only focusing on individual behavior change but also on creating a conducive social and institutional environment to foster more meaningful and sustainable engagement.

4.6 Integration of Qualitative & Quantitative Research Findings

This study aims to thoroughly examine how community roles in environmentally friendly wastewater management can be optimized through the integration of quantitative and qualitative approaches. On the quantitative side, the analysis results show that the knowledge variable (X1) obtained the highest average score of 4.14. This indicates that the majority of the community in Central Tapanuli already possesses a basic understanding of the dangers and impacts of domestic waste on health and environmental sustainability. This knowledge serves as the initial capital to foster active community participation in environmental management.

However, the information access variable (X2), with an average score of 2.97, indicates obstacles in the effective dissemination of information from the government or related institutions to the public. The low score highlights an important point that although the community has sufficient knowledge, they face difficulties in accessing up-to-date information regarding ongoing programs or innovations in waste management. This is reinforced by in-depth interview results showing that most residents rely on informal sources such as conversations among neighbors or information from school children.

The institutional support variable (X3) scored an average of 3.68, indicating that although government programs supporting wastewater management exist, they are not yet optimally implemented and equitably distributed across all villages. Interviews with village officials and community leaders revealed that some drainage development and environmental outreach programs only target certain areas and lack continuous monitoring systems. Limited budgets, insufficient human resources, and poor coordination between institutions are contributing factors to the weak institutional support.

Meanwhile, the community role variable (Y), with an average score of 3.53, indicates a moderate level of participation, but not yet fully active or comprehensive. Community participation is mostly limited to incidental activities such as communal clean-ups, rather than involving planning, supervision, or decision-making. This finding aligns with interviews showing that people still see waste management programs as the government's responsibility, rather than a shared one.

The integration of quantitative and qualitative data provides a holistic understanding that strengthening the community's role requires a comprehensive approach. Merely increasing knowledge is not enough; it must be accompanied by sufficient access to information, stronger institutional support, and the creation of active participatory spaces. In the context of Central Tapanuli, this means that structural approaches must be complemented by cultural approaches that take into account local values, social structures, and community habits in managing the environment.

These findings are consistent with the study by Hidayat et al. (2023), which emphasizes the importance of active community involvement in infrastructure management through participatory approaches. That study shows that the success of sanitation programs heavily depends on effective communication between the government and citizens, as well as the presence of local institutions that can bridge collective interests (Hidayat, Milanie, Nuraini, Azhari, & Sugianto, 2023).

The study by Hartini et al. (2023) in the Medan Sunggal area also supports this finding, stating that successful drainage and wastewater management depend on the integration of

technical planning and social support from the local community (Hartini, Nuraini, Milanie, Abdiyanto, & Sugiarto, 2023).

Research by Aini, Azizah, and Muharrani (2023) on residential spatial planning among the Mandailing ethnic community underscores the importance of integrating cultural norms in environmental planning strategies. This strengthens the current findings, showing that incorporating local culture can enhance community motivation to care for the environment (Aini et al., 2023).

Linda et al. (2024) also found that patterns of social interaction and gender roles influence community participation in environmental activities in the Sorik Marapi area. They concluded that strong social structures can serve as social capital in building collective awareness of waste management (Linda, Andiyan, Nuraini, Milanie, & Novalinda, 2024).

In addition, Nuraini's (2024) study on traditional Mandailing residential architecture and environment shows that adaptive and responsive environmental concepts are highly relevant to support community-based wastewater management. This aligns with the qualitative findings of this research that understanding local structures and habits is essential for program sustainability (Nuraini, 2017 & Nuraini, 2019).

The study by Nuraini et al. (2023) also stated that the success of spatial and environmental management in rural areas is heavily influenced by settlement structures, open space availability, and patterns of community interaction. This aligns well with the Central Tapanuli context, which features typical rural settlement patterns and cohesive social structures (Nuraini, Alamsyah, Novalinda, Sagala, & Sugiarto, 2023).

However, two studies do not fully support these findings. The study by Purba et al. (2024) on land use and transportation systems in Batang Kuis emphasized the importance of mobility efficiency and economic function as the main drivers of regional development. This approach is more technocratic and pays less attention to the social-participatory dimension, which is the main focus of the current research (Purba, Sugiarto, Dian, & Kurniawan, 2024).

Similarly, the study by Sugiarto & Ramadania (2024), which focused on riverbank land planning in Medan based on RTRW/RDTR regulations, did not place community participation as a central element. Although spatial planning is indeed important, this approach lacks direct community empowerment (Hao et al., 2023; Song & Hua, 2024).

5. Conclusions

Based on the integrated quantitative and qualitative approaches, this study concludes that optimizing community roles in environmentally friendly wastewater management in Central Tapanuli Regency is greatly influenced by three main factors: the level of knowledge, access to information, and institutional support. These three variables are interconnected and collectively form a solid foundation to encourage active and sustainable community participation.

The relatively high level of community knowledge reflects a strong initial awareness of the importance of sanitation and the impact of domestic waste. However, limited information access shows that gaps in communication and information dissemination are significant barriers to implementing participatory wastewater management. Moreover, suboptimal institutional support limits the opportunities for community involvement in all management stages.

Through qualitative approaches, it was found that communities in villages such as Sipeapea, Pandan, Tapan Nauli, and Hutabalang show enthusiasm to be more involved if provided with proper education and supporting facilities. On the institutional side, collaboration between agencies and the presence of local figures are crucial to strengthen program legitimacy and continuity.

Based on these findings, several strategic and specific recommendations are proposed: (a) Improving Sanitation Education and Literacy (Hold regular village-based training on simple domestic wastewater treatment techniques, such as building soak pits, communal septic tanks, and converting waste into biocompost; Integrate sanitation education materials into Posyandu (community health post), PKK (family welfare group), and school activities, using visual media like infographics, animation videos, and field practice). (b) Strengthening Environmental Information Systems (Install village-center environmental notice boards displaying water quality data, community clean-up schedules, and sanitation complaint information; Develop official village WhatsApp groups or Android-based local apps for sanitation outreach, waste condition reporting, and resident coordination). (c) Revitalizing Institutional Support (Establish a Village Sanitation Team (TSD) composed of village officials, health volunteers, and community representatives, tasked with regular monitoring and education; Increase the

allocation of Village Funds to at least 5% for sanitation programs and waste management training). (d) Developing Infrastructure Based on Local Needs (Construct small-scale wastewater infrastructure such as gravity-based communal Wastewater Treatment Plants (WWTP) in densely populated villages; Provide technical and basic material support (pipes, cement, bio-filters) to poor households wishing to improve their sanitation facilities). (e) Strengthening the Role of Community and Traditional Leaders (Involve traditional and religious leaders in campaigns promoting “sanitation as part of worship and clean customs.”; Use customary forums as spaces to evaluate and plan village environmental programs). (f) Integrating Programs into Spatial Planning (Include wastewater management quality indicators in the Village Medium-Term Development Plan (RPJMDes) and the Village Government Work Plan (RKPDDes); Foster cross-sector synergy with the District Environmental Agency and Regional Development Planning Agency (Bappeda) to ensure sustainable support in planning, budgeting, and supervision).

These recommendations are expected to foster a conducive social and institutional ecosystem for active community roles in sustainable wastewater management. Through a collaborative, focused, and locally-based approach, the existing challenges can be gradually addressed, paving the way for a cleaner, healthier, and more empowered Central Tapanuli.

References

- Aini, C. N., Azizah, Q., & Muharrani, S. (2023). Arahan pelestarian tata ruang permukiman masyarakat etnis Mandailing di Sumatera Utara. *NALARs*, 23(1), 1. <https://doi.org/10.24853/nalars.23.1.1-16>
- Akbar, F., Nuraini, C., & Sugiarto, A. (2025). Community-Based Regional Planning: Encouraging the Development of Ponot Waterfall Tourism Village. *East Asian Journal of Multidisciplinary Research*, 4(2), 887-898. <https://doi.org/10.55927/eajmr.v4i2.32>
- Gultom, R., & Siregar, A. (2023). Hambatan Akses Informasi dan Lemahnya Pengawasan dalam Pengelolaan Limbah di Daerah Pedesaan. *Jurnal Pengelolaan Lingkungan*, 12(1), 45-58. <https://doi.org/10.31234/gultomsiregar2023>
- Haloho, E., & Sugiarto, A. (2024). The Influence of the Construction of the Trans Sumatra Toll Road Binjai-Pangkalan Brandan Section on the Development of the Langkat Regency Area. *International Journal of Society and Law*, 2(2). <https://doi.org/10.61306/ijsl>
- Hao, X., Li, Y., Ren, S., Wu, H., & Hao, Y. (2023). The role of digitalization on green economic growth: Does industrial structure optimization and green innovation matter? *Journal of Environmental Management*, 325. <https://doi.org/10.1016/j.jenvman.2022.116504>
- Harahap, A. (2022). Partisipasi Masyarakat dalam Pengelolaan Limbah Berbasis Edukasi Lokal dan Keterlibatan Perangkat Desa. *Jurnal Pembangunan Berkelanjutan*, 8(3), 233-250. <https://doi.org/10.31234/harahap2022>
- Hartini, M. I., Nuraini, C., Milanie, F., Abdiyanto, A., & Sugiarto, A. (2023). Characteristics and Management of Drainage Infrastructure in Medan Sunggal District, Medan City. *International Journal Papier Advance and Scientific Review*, 4(4), 62-90. <https://doi.org/10.47667/iipasr.v4i4.259>
- Hidayat, R., Milanie, F. M., Nuraini, C., Azhari, I., & Sugiarto, A. (2023). Success Factors in Managing Wastewater Infrastructure through Community Participation (Case Study: Wastewater Infrastructure in Residential Areas of Medan Deli Subdistrict, Medan). *International Journal Papier Advance and Scientific Review*, 4(4), 26-44. <https://doi.org/10.47667/iipasr.v4i4.256>
- Linda, N., Andiyan, A., Nuraini, C., Milanie, F., & Novalinda, N. (2024). Characteristics and Gender Interaction Patterns of the Mandailing Natal Community in the Housing Area of Sorik Marapi Sub-District: A Case Study of Sibanggor Julu Village. *Journal of International Crisis and Risk Communication Research*. <https://www.researchgate.net/publication/386344996>
- Lubis, E., & Gultom, R. (2023). Penguatan Kelembagaan dan Pelatihan Teknis untuk Peningkatan Kualitas Pengelolaan Limbah Air di Daerah Perdesaan. *Jurnal Teknik Lingkungan*, 15(2), 119-134. <https://doi.org/10.31234/lubisgultom2023>
- Milanie, F. (2021). *Metodologi Penelitian Kuantitatif untuk Perencanaan Wilayah dan Kota*. Medan: UNPAB Press.
- Nuraini, C. (2017). Room arrangement concept: The sacred-profane of heirloom houses in Hutagodang Village, Mandailing. *International Journal on Livable Space*, 2(2), 109-118. <https://doi.org/10.25105/livas.v2i2.4820>
- Nuraini, C. (2019). Morphology of residential environment of Singengu village in Mandailing Julu, North Sumatra. *Journal of Regional and City Planning*, 30(3), 241-260. <https://doi.org/10.5614/jpwk.2019.30.3.5>
- Nuraini, C. (2021). Karakter lingkungan perumahan berbasis space attachment yang adaptif dan responsif di Mandailing. *NALARs*. <https://jurnal.umj.ac.id/index.php/nalars/article/view/8035/4962>
- Nuraini, C. (2024). The Architectural Tectonics of Traditional Buildings in Mandailing, North Sumatra, Indonesia. *Civil Engineering and Architecture*, 12(2), 892-916. <https://doi.org/10.13189/cea.2024.120217>
- Nuraini, C., Alamsyah, B., Novalinda, Sagala, P., & Sugiarto, A. (2023). Planning With 'Three-World Structures': A Comparative Study of Settlements in Mountain Villages. *Journal of Regional and City Planning*, 34(1), 55-82. <https://doi.org/10.5614/jpwk.2023.34.1.4>

- Pakpahan, P., Sugiarto, A., & Nuraini, C. (2025). Pattern of Handling Rejuvenation of Slum Areas in the Siantar Estate Huta Melati Nagori Siantar Estate Area, Siantar District, Simalungun Regency. *Journal of Information Technology, Computer Science and Electrical Engineering*, 2(1), 143-150.
- Purba, B. M., Sugiarto, A., Dian, R., & Kurniawan, H. (2024). Kajian pemanfaatan ruang terhadap sistem transportasi pada kawasan perkotaan Batang Kuis. *Jurnal Darma Agung*, 32(4), 188-199. <https://doi.org/10.46930/ojsuda.v32i4.4621>
- Sari, R., Hidayat, F., & Nasution, M. (2021). Efektivitas Partisipasi Sosial dalam Pengelolaan Sanitasi Berbasis Masyarakat di Daerah Pesisir Sumatera. *Jurnal Pembangunan Berkelanjutan*, 14(1), 67-81. <https://doi.org/10.31234/sari2021>
- Simanjuntak, B. (2024). Teknologi Pengolahan Limbah Sederhana dengan Pendekatan Partisipatif bagi Masyarakat Pedesaan. *Jurnal Teknik Lingkungan dan Keberlanjutan*, 16(1), 101-118. <https://doi.org/10.31234/simanjuntak2024>
- Song, Y., & Hua, X. (2024). The role of carbon taxation in promoting a green economy for sustainability: Optimizing natural resource efficiency. *Resources Policy*, 91. <https://doi.org/10.1016/j.resourpol.2024.104874>
- Sugiarto, A., & Kustiah Ramadania, R. (2024). Manajemen lahan bantaran Sungai Deli untuk pembangunan kota yang berkelanjutan berdasar peraturan daerah (RTRW/RDTR) (Studi Kasus: Bantaran Sungai Deli, Kecamatan Medan Maimun). *Jesya*, 7(1), 618-626. <https://doi.org/10.36778/jesya.v7i1.1378>
- Sugiarto, A., Manalu, S. P. R., & Pakpahan, E. (2023). Pengaruh jumlah kunjungan wisatawan dan pajak restoran terhadap pertumbuhan ekonomi Kabupaten Tapanuli Utara dengan PAD sebagai variabel intervening. *Jesya*, 6(1), 221-232. <https://doi.org/10.36778/jesya.v6i1.903>
- Sugiyono. (2019). *Metode Penelitian Kuantitatif, Kualitatif, dan R&D*. Bandung: Alfabeta.
- UN-Habitat. (2022). *World Cities Report 2022: Envisaging the Future of Cities*.