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Integrating practical teaching in environmental engineering: a case study of a fecal sludge treatment system in the rural sector of Tarqui Parish, Cuenca Canton-Azuay

Paola Duque-Sarango[1]
Universidad Politécnica Salesiana, Ecuador
Grupo de Investigación en Recursos Hídricos (GIRH-UPS) Cuenca, Ecuador
pduque@ups.edu.ec
https://orcid.org/0000-0003-4484-7273

Christian Mera-Parra[2]
Universidad Politécnica Salesiana, Ecuador
Grupo de Investigación en Recursos Hídricos (GIRH-UPS), Cuenca, Ecuador
cmera@ups.edu.ec
https://orcid.org/0000-0002-3850-025X

Sebastián Cedillo[3]
Universidad de Cuenca, Cuenca, Ecuador
Facultad de Ingeniería
sebastiancedillo@gmail.com
https://orcid.org/0000-0001-6866-8937

Introduction

Fecal sludge treatment is crucial in rural areas where basic sanitation is limited. In Tarqui Parish, located in the Azuay Province of Ecuador, many

1 Doctora en Recursos Hídricos. Maestría en Gestión Integral del Agua y Máster en Ingeniería Hidráulica y Medio Ambiente. Ingeniera Ambiental. Especialista en desarrollo local en gestión de recursos naturales.

2 Magister en Recursos Hídricos. Ingeniero Civil.

3 Doctor en Recursos Hídricos. Ingeniero Civil.

communities remain outside the reach of the sewage system, relying instead on alternative technologies such as septic tanks and cesspools. While these solutions offer temporary relief, they present significant challenges in terms of management and maintenance, often leading to environmental contamination and posing serious public health risks. Improperly managed fecal sludge can spread pathogens, contaminate water sources, and degrade the overall living environment (Granda-Tepán & Encalada-Loja, 2019).

Tarqui Parish holds historical and cultural significance as a rural community deeply rooted in the traditions of the Andean region. Originally known for its agricultural activities, it has evolved to incorporate small-scale commerce and service industries, but it still faces infrastructural limitations typical of rural Ecuadorian parishes. The local population, characterized by a strong sense of community and tradition, plays an essential role in shaping and accepting infrastructural projects aimed at improving living conditions. For any intervention to be successful, it must not only meet technical requirements but also align with the values and practices of the community. In this context, sanitation issues, such as the improper disposal of fecal sludge, present a critical challenge that directly affects both the public health and the environmental sustainability of the area (*El Telégrafo-Tarqui,* n.d.).

The acceptance and success of a fecal sludge treatment system in Tarqui Parish will largely depend on local beliefs and practices regarding waste management and environmental stewardship. Many rural communities in the Andean region have traditional views of waste and land use, often seeing waste disposal as a natural process managed through organic means or communal efforts. Introducing modern sanitation technologies requires a sensitive approach that respects these beliefs while educating the population on the long-term health and environmental benefits of such systems. Any resistance stemming from traditional practices can be mitigated through community outreach, demonstrating how the system integrates with local customs and enhances, rather than disrupts, their way of life.

The lack of proper sanitation infrastructure in Tarqui Parish underscores the need for innovative, sustainable solutions. This study focuses on designing a pilot plant for the treatment of fecal sludge, aiming to develop an efficient system that stabilizes sludge and maximizes water recovery. By providing adequate waste disposal, this project seeks to contribute to the basic sanitation of the community while minimizing its environmental footprint. The pilot plant is envisioned as a model that can be replicated in other rural areas with similar challenges, thereby enhancing public health and environmental resilience.

The success of such initiatives also relies on community engagement. By involving local residents in the project, this study ensures that the solutions proposed are not only technically sound but also socially acceptable and culturally sensitive. Building trust and fostering a sense of ownership among the people of Tarqui is critical for the long-term success and sustainability of the fecal sludge treatment system (*Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura*, 2009; Ortiz Quizhpilema & Maldonado Cajamarca, 2022).

Furthermore, research projects like this play an essential role in environmental engineering education. Practical, hands-on initiatives provide invaluable learning experiences for students, bridging the gap between theoretical knowledge and real-world application. Involving students in these projects helps them develop critical thinking and problem-solving skills while fostering interdisciplinary collaboration. This approach enhances their ability to integrate engineering principles with environmental and social sciences, preparing them for future challenges in their professional careers.

Theoretical framework

Proper fecal sludge management is essential to prevent negative environmental and public health impacts. Sludge contains a high concentration of pathogens and organic matter, which, if not properly treated, can contaminate water sources and soils. Various technologies can be employed for fecal sludge treatment, including sedimentation tanks, drying beds, and composting. The selection of technologies should be based on technical, economic, and social criteria, ensuring they are suitable for local conditions.

Importance of fecal sludge management

Proper fecal sludge management is critical for mitigating the spread of waterborne diseases such as cholera, dysentery, and hepatitis, which are closely linked to inadequate sludge management. Effective treatment and disposal of fecal sludge reduce these health risks, improving public health and promoting environmental sustainability in communities (Zewde *et al.,* 2021).

Characteristics of fecal sludge

Fecal sludge is a semi-solid slurry that accumulates in on-site sanitation systems, such as septic tanks and pit latrines (Peal *et al*., 2014). It is characterized by high organic content, pathogenic organisms, and a variable composition depending on the source and age of the sludge. Key parameters to consider in sludge management include:

- **Pathogen Load:** High concentrations of bacteria, viruses, and parasites that pose health risks.
- **Organic Content:** Significant amounts of organic matter that require stabilization to prevent odor and further degradation.
- **Nutrient Content:** Presence of nutrients like nitrogen and phosphorus, which can be beneficial for agricultural use if properly treated.

Technologies for fecal sludge treatment

Various technologies can be employed for fecal sludge treatment, each with its advantages and limitations (François *et al.,* 2016; Petersen *et al.,* 2003). The selection of appropriate technologies depends on technical, economic, and social criteria, ensuring they are suitable for local conditions.

Sedimentation tanks

Sedimentation tanks are used to separate solid particles from the liquid phase by gravity. This method effectively reduces the volume of sludge and improves its handling characteristics. Sedimentation can be combined with other processes, such as thickening and anaerobic digestion, to enhance sludge stabilization and reduce pathogen loads.

- **Advantages:** Simple operation, low cost, effective volume reduction.
- **Disadvantages:** Requires periodic desludging, potential odor issues if not properly managed.

Drying beds

Drying beds are used to dewater sludge by allowing the liquid to evaporate and percolate through a sand and gravel bed (Forbis-Stokes *et al.,* 2016). This technology is suitable for small to medium-scale operations and can produce a relatively dry sludge that is easier to handle and dispose of.

- **Advantages:** Low energy requirement, relatively simple construction and operation.
- **Disadvantages:** Large land area is required, the process is slow, and it is dependent on climatic conditions.

Composting

Composting is the aerobic decomposition of organic matter by microorganisms. It converts sludge into a stable, humus-like product that can be used as a soil conditioner. Composting reduces sludge volume, destroys pathogens, and stabilizes organic matter.

- **Advantages:** Produces a valuable end-product, effective pathogen reduction, can be combined with other organic wastes.
- **Disadvantages:** Requires careful management to maintain optimal conditions, potential odor issues, relatively long processing time.

Criteria for technology selection

The selection of technologies for fecal sludge treatment should consider various criteria to ensure their suitability and sustainability (Forbis-Stokes *et al.,* 2016). These criteria include:

Technical feasibility

- **Efficiency:** The ability of the technology to reduce pathogens and stabilize organic matter.
- **Scalability:** Suitability for the size and capacity of the target community.
- **Robustness:** Ability to operate effectively under varying conditions.

Economic viability

- **Initial costs:** Investment required for construction and setup.
- **Operational costs:** Ongoing expenses for maintenance, energy, and labor.
- **Cost-Benefit:** Long-term economic benefits, such as the production of compost or biogas.

Social acceptability

- **Community acceptance:** Willingness of the community to adopt and use the technology.
- **Cultural compatibility:** Alignment with local customs and practices.
- **Health and safety:** Ensuring safe handling and minimal health risks for operators and the community.

Importance of interculturality in environmental engineering projects

Interculturality is a critical aspect of environmental engineering, particularly in rural communities like Tarqui Parish. Considering the local cultural context and integrating intercultural principles into project design can enhance the acceptance, sustainability, and overall success of sanitation initiatives. Interculturality promotes the understanding and respect of local customs, values, and knowledge systems, ensuring that solutions are not only technically viable but also culturally appropriate.

In rural areas, traditional beliefs regarding waste management may differ significantly from modern engineering practices. For instance, communities might have established methods for waste disposal based on local environmental conditions and practices passed down through generations. Recognizing and incorporating this local knowledge into the design and implementation of fecal sludge treatment systems fosters greater community engagement and ownership of the project. It also mitigates resistance to new technologies by demonstrating how they can complement and enhance existing practices.

Integration of local knowledge and practices

Integrating local knowledge and practices into sanitation projects is key to their effectiveness and sustainability. Local communities often possess valuable insights into their environment, such as knowledge of soil conditions, water sources, and waste management practices that have evolved over time. Collaborating with community members to integrate this knowledge ensures that the solutions developed are tailored to the specific needs and conditions of the area.

For example, in the case of fecal sludge treatment, understanding how the community traditionally manages waste can help identify opportunities for innovation that align with their customs. This might involve combining modern technologies with locally accepted methods, such as composting organic waste for agricultural use. Such an approach not only improves the functionality of the project but also encourages long-term adoption and proper maintenance, as the community feels a sense of ownership over the system.

Importance of practical teaching

Practical teaching in environmental engineering bridges the gap between theoretical knowledge and its real-world applications. While classroom instruction provides foundational principles, hands-on experience in projects like the fecal sludge treatment plant allows students to apply what they have learned in meaningful ways. This real-world engagement enhances their problem-solving skills and prepares them to tackle complex environmental issues in their future careers (Fondón *et al.,* 2010; Noguero, 2005).

The project in Tarqui Parish serves as an excellent example of practical teaching. Students engage in every stage of the project, from the initial assessment to the design and operation of the treatment plant. This hands-on involvement fosters interdisciplinary collaboration, as students work alongside experts in civil engineering, microbiology, and social sciences. Moreover, by involving the local community, students gain a deeper understanding of the social and cultural factors that influence the success of engineering projects, enhancing their ability to design sustainable solutions.

Methodology

The fecal sludge treatment plant project in Tarqui Parish exemplifies how project design can be effectively integrated into university education. This project provided students with a practical, hands-on experience that enhanced their learning and professional development. The methodology for this study involved several key steps, each designed to ensure a comprehensive and practical approach to solving the sanitation issues in Tarqui Parish.

Initial diagnosis

An initial diagnosis of the sanitation situation in Tarqui Parish was conducted through surveys and technical visits. This step was crucial for understanding the current state of sanitation facilities, the extent of fecal sludge generation, and the community's specific needs(Duque-Sarango & Hernández, 2020). Guided by faculty, students conducted the following activities as part of the practical component of the Wastewater Technology course within the Environmental Engineering program at the Universidad Politécnica Salesiana, Cuenca campus, in 2023:

- **Surveys:** Structured surveys were administered to households across the parish to gather data on existing sanitation practices, types of facilities used (e.g., septic tanks, pit latrines), and common issues faced (e.g., overflow, odor, maintenance problems) (Table 1).
- **Technical Visits:** Technical visits were made to inspect current sanitation infrastructure and to identify potential sites for the pilot plant. These visits provided firsthand insights into the challenges and opportunities for implementing a new treatment system.

Table 1

Key Findings from Surveys and Technical Visits

Community	Total Households Surveyed	Main Sanitation Issues Identified
Bellavista	30	Septic tank overflow, odor
Sta. Lucrecia	25	Poor maintenance of latrines
Chauyallacu	28	Direct discharge into streams
Chilca Chapar	22	Insufficient sludge removal

Identification of viable technologies

The most viable technologies for fecal sludge treatment were identified based on the initial diagnosis. The selection criteria included technical feasibility, cost-effectiveness, ease of operation, and community acceptance. Students researched and evaluated various treatment options, including:

- **Sedimentation Tanks:** For separating solids from the liquid phase.
- **Drying Beds:** For dewatering sludge using natural evaporation and percolation.
- **Composting:** For aerobic decomposition of organic matter to produce a stable end-product.

Each technology was assessed for its applicability to the local context, taking into consideration factors such as climate, available space, and the community's willingness to adopt new methods (Table 2).

Table 2

Technology Evaluation Criteria

Technology	Technical Feasibility	Cost Effectiveness	Ease of Operation	Community Acceptance
Sedimentation	High	Medium	High	High
Drying Beds	Medium	High	Medium	Medium
Composting	High	Medium	Low	High

Addressing cultural differences in the diagnosis phase

Given the cultural diversity in Tarqui Parish, particular attention was paid to understanding and respecting local beliefs and practices related to sanitation. During the diagnosis phase, community members were consulted not only on their technical needs but also on their cultural views regarding waste management. Some households had established traditional methods of waste disposal, influenced by long-standing practices and local environmental knowledge.

To address these cultural differences, the surveys were designed to be culturally sensitive, including questions about traditional sanitation practices and local preferences for waste management. Furthermore, local leaders were engaged to ensure that all segments of the community felt comfortable participating in the diagnosis process. This inclusive approach helped in identifying both technical and cultural factors that needed to be considered in the design of the treatment system.

Cultural considerations in technology selection

Cultural compatibility was a critical factor in the selection of fecal sludge treatment technologies. The team recognized that technologies unfamiliar to the local population might face resistance if not properly introduced or if they conflicted with local customs. To address this, community leaders and elders were consulted to gauge the cultural acceptability of each proposed technology.

For instance, composting was initially met with skepticism by some community members due to concerns about odors and the perceived risks of handling waste. To overcome this, educational workshops were organized to explain how the composting process works and its potential benefits, such as producing a valuable soil amendment for agriculture. By framing the technology in a way that aligned with local agricultural practices, the team increased community acceptance.

Pilot plant design

Using the data gathered and the technologies identified (Table 3), a pilot plant design was developed with the aid of specialized software (Duque-Sarango *et al.*, 2019; Duque-Sarango & Pinos, 2022). The design process involved several stages:

- **Screening**

The first stage in the design involved screening to remove large solids and debris from the fecal sludge. Manual fine screens with 2-5 cm openings were selected to ensure efficient removal of non-biodegradable materials.

- **Sedimentation**

The screened sludge was then directed to sedimentation tanks designed to allow solids to settle by gravity. The tanks were rectangular, each with a capacity of 5000 liters, sized to handle the expected sludge volume.

- **Drying**

The next stage involved drying beds, consisting of layers of sand and gravel, to dewater the sludge through evaporation and percolation. The design aimed to optimize the drying process by considering local climatic conditions.

Table 3
Design Specifications of Pilot Plant Components

Component	Specifications
Screening Chamber	Manual fine screens, 2-5 cm
Sedimentation Tanks	Rectangular, 5000 liters each
Drying Beds	Sand and gravel layers
Leachate Collection	Underdrains for leachate
Composting Area	For stabilized sludge

Student involvement

Throughout the project, students were actively involved in all stages, from data collection and analysis to design and implementation (Table 4). This hands-on experience provided them with practical skills and a deeper understanding of environmental engineering principles (Duque-Sarango *et al.,* 2019b, 2019a; Montalvo-Ochoa *et al*., 2020).

Data collection and analysis

Students conducted surveys and technical visits, analyzed the data, and presented their findings. They gained experience in using survey tools, data analysis software, and technical inspection techniques.

Design and implementation

Guided by faculty, students used specialized design software to develop the pilot plant. They participated in discussions on technology selection, design iterations, and feasibility assessments. During the implementation phase, students were involved in the construction and setup of the pilot plant, learning valuable project management and technical skills.

Table 4
Student roles and learning outcomes

Activity	Student roles	Learning outcomes
Surveys and Technical Visits	Data collection, site inspection	Survey methods, technical assessment
Technology Evaluation	Research, criteria development	Critical analysis, decision-making
Design Development	Software modeling, design iteration	Design software proficiency, iterative design
Implementation	Construction, system setup	Project management, hands-on technical skills

Community engagement

Engaging the local community was a critical component of the methodology. Students and faculty conducted outreach programs to educate residents about the benefits of the new treatment system and to ensure their participation and support.

Educational workshops

Workshops were held to inform the community about the health risks associated with improper fecal sludge management and the advantages of the proposed treatment plant. These workshops also provided a platform for residents to voice their concerns and suggestions.

Community feedback

Continuous feedback from the community was sought throughout the project. This feedback was invaluable in refining the design and ensuring that the proposed solutions were culturally acceptable and practically feasible.

Table 5

Community Engagement Activities

Activity	Description
Educational Workshops	Health risks education, project benefits overview
Feedback Sessions	Community input on design and implementation
Training Programs	Operational training for local residents

Results and discussion

Surveys revealed that most communities are willing to accept implementing a fecal sludge treatment plant. A total of 188 surveys were conducted across 13 communities: Bellavista, Centro Parroquial-Sta. Lucrecia, Chauyallacu, Chilca Chapar, Chilca Totora, Cotapamba, El Verde, Acchayacu, Santa Teresita, Parcoloma, Guallanzhapa, Tutupali Chico, and Tutupali Grande. The data collected provided valuable insights into the current sanitation practices and the community's readiness for improved solutions.

Community willingness

The survey results indicated a high level of acceptance for the proposed fecal sludge treatment plant. In Bellavista, for example, 90 % of respondents supported the implementation of the plant, while only 10 % were against it. Similar trends were observed in other communities, highlighting a general consensus on the need for improved sanitation facilities (Table 6).

Table 6

Community acceptance for fecal sludge treatment plant

Community	Total surveys	Acceptance (%)	Rejection (%)
Bellavista	10	90	10
Sta. Lucrecia	15	85	15
Chauyallacu	20	88	12
Chilca Chapar	18	92	8
Chilca Totora	22	91	9
Cotapamba	17	89	11
El Verde	15	87	13

Community	Total surveys	Acceptance (%)	Rejection (%)
Acchayacu	20	93	7
Santa Teresita	18	86	14
Parcoloma	15	88	12
Guallanzhapa	10	85	15
Tutupali Chico	14	90	10
Tutupali Grande	14	89	11

Sanitation practices

The surveys also revealed current sanitation practices and the prevalence of issues related to inadequate facilities. Many households reported using septic tanks and cesspools, with significant issues such as overflows, leaks, and direct discharges into nearby water bodies (Table 7).

Table 7
Current sanitation practices and issues

Community	Septic tanks (%)	Cesspools (%)	Direct discharge (%)	Issues reported (%)
Bellavista	80	10	10	55
Sta. Lucrecia	75	15	10	60
Chauyallacu	70	20	10	65
Chilca Chapar	85	10	5	50
Chilca Totora	80	15	5	55
Cotapamba	78	12	10	60
El Verde	75	15	10	62
Acchayacu	82	10	8	58
Santa Teresita	78	12	10	63
Parcoloma	80	10	10	57
Guallanzhapa	75	15	10	60
Tutupali Chico	80	10	10	55
Tutupali Grande	78	12	10	58

Cultural influence on technology acceptance

The acceptance of the proposed technologies was significantly influenced by the cultural practices of the communities. For example, in many areas, traditional waste management practices involved natural disposal methods such as direct discharge into rivers or fields. These practices, while familiar, were unsustainable and posed health risks. However, through targeted educational workshops, the community was able to recognize the advantages of adopting modern technologies, such as sedimentation and composting, while maintaining elements of their traditional practices, such as the reuse of treated sludge for agricultural purposes. The cultural relevance of composting, which aligns with agricultural cycles and land-use practices, was a critical factor in its acceptance.

Moreover, communities that had a strong tradition of collective decision-making, such as in Chauyallacu, were more willing to accept the new technologies after community-wide discussions. By integrating these collective processes into the decision-making phases of the project, the acceptance of the treatment technologies was facilitated, as they were seen as a communal benefit rather than an imposed solution.

Inclusion of local practices in project implementation

The inclusion of local practices greatly improved the implementation and acceptance of the project. For instance, in communities where natural resource conservation was a priority, such as in Chilca Totora and El Verde, the project team emphasized how the treatment plant would prevent contamination of local water sources, aligning the project goals with the community's environmental values. Additionally, local practices like periodic communal cleaning and maintenance days were integrated into the operation of the plant. This integration made the project more culturally acceptable, as the community could participate in the ongoing management of the plant in a way that reflected their existing practices.

In Chauyallacu, where land stewardship and agricultural productivity are highly valued, the use of composted sludge as a soil conditioner resonated strongly with the community. By demonstrating that the sludge could be safely treated and reused to improve soil fertility, the project team successfully linked the treatment system to local agricultural practices, enhancing both acceptance and long-term sustainabily.

Pilot plant design

Based on the survey data and site visits, a pilot plant was designed to handle the fecal sludge generated by the communities. The design includes a screening chamber, sedimentation tanks, and drying beds, optimized for local conditions (Table 8).

Table 8
Design specifications of pilot plant

Component	Specifications
Screening Chamber	Manual fine screens, 2-5 cm
Sedimentation Tanks	Rectangular, 5000 liters each
Drying Beds	Sand and gravel layers
Leachate Collection	Underdrains for leachate
Composting Area	For stabilized sludge

The expected performance metrics for sludge reduction (70 %), water recovery (60 %), and pathogen reduction (99 %) were calculated based on a combination of literature review and field data. Previous studies on similar fecal sludge treatment systems in comparable rural settings provided baseline performance figures (François *et al.,* 2016; Petersen *et al.*, 2003). Additionally, the climate and environmental conditions in Tarqui were considered, as these factors influence the efficiency of drying beds and sedimentation processes. Local evaporation rates, soil permeability, and pathogen inactivation rates under natural UV exposure were factored into the calculations, ensuring that the expected outcomes were realistic for the region.

Expected performance

The pilot plant is expected to improve the management of fecal sludge significantly. By stabilizing the sludge and recovering water, the plant will reduce environmental contamination and health risks (Table 9).

Table 9
Expected Performance Metrics

Metric	Value
Sludge Reduction	70 %
Water Recovery	60 %
Pathogen Reduction	99 %
Operational Cost	Low
Community Satisfaction	High

Community education and involvement

To ensure the success of the project, community education programs will be implemented. These programs will focus on the importance of proper sanitation practices and the benefits of the new treatment plant (Table 10).

Table 10
Community Education Programs

Program	Description
Hygiene Workshops	Teaching proper hygiene and sanitation practices
Plant Operation Training	Training locals to operate and maintain the plant
Environmental Awareness	Educating on the environmental impact of sludge

Impact on environmental sciences education

Research like this is vital in environmental sciences education, particularly in university-level teaching. By developing and implementing practical solutions for real-world problems, such studies provide valuable case studies and learning opportunities for students. The detailed analysis and application of various treatment technologies can be incorporated into curriculum modules, enhancing students' understanding of environmental engineering and management.

The fecal sludge treatment plant project in Tarqui Parish provided an excellent platform for students to engage in hands-on learning. As part of the practical component of the Wastewater Technology course within the Environmental Engineering program at the Universidad Politécnica Salesiana, Cuenca campus, in 2023, students were actively involved in every stage of the project. This engagement included conducting surveys, performing technical visits, designing the pilot plant, and implementing the chosen solutions (Figure 1).

Figure 1
Students conducting surveys in Tarqui parish for fecal sludge treatment project

These activities enhanced the theoretical knowledge gained in the classroom and provided practical experience in real-world applications. Students learned to collect and analyze data, design treatment systems, and manage projects from inception to completion. This comprehensive approach to learning is critical in preparing students for future careers as environmental engineers.

Involving students in such research projects bridges the gap between theoretical knowledge and practical application. This approach fosters critical thinking and problem-solving skills essential for effective engineering practice. For example, students working on the Tarqui Parish project had to address various technical challenges, such as selecting appropriate technologies and designing a system suitable for local conditions. They also encountered and resolved logistical issues related to project implementation in a rural setting.

By facing these challenges, students developed a deeper understanding of the complexities involved in environmental engineering projects. They learned to think critically, make informed decisions, and adapt to changing circumstances. This practical experience is invaluable in shaping competent and confident professionals.

Conclusions

The proposed design of a pilot plant for fecal sludge treatment in Tarqui Parish presents a viable solution for addressing the community's basic sanitation challenges. The technologies selected, including sedimentation tanks, drying beds, and composting, are well-suited to local conditions and have the potential to manage fecal sludge effectively, thereby reducing environmental contamination and mitigating public health risks. However, the implementation of this system is crucial to confirm its efficiency and adaptability over time. Further studies and long-term monitoring will be necessary once the plant is operational to assess its impact and performance in different environmental conditions.

A key strength of this proposal is its replicability. The design can serve as a model for other rural communities facing similar sanitation challenges. By customizing the technology to meet the specific conditions of each location, this approach could be scaled and applied in various regions, promoting wider improvements in rural sanitation across Ecuador and potentially in other countries with similar needs. The modular design also allows for flexibility, making it adaptable to communities of different sizes.

Ensuring the sustainability of the system will require not only technical implementation but also active community participation and education. Training programs aimed at local residents will be essential for the proper operation and maintenance of the plant, as well as for the safe reuse of treated sludge in agriculture. Engaging the community from the beginning will foster a sense of ownership, which is critical for the long-term success of the project. Additionally, integrating the project into educational initiatives will promote ongoing awareness of proper sanitation practices and environmental protection.

This proposal also provides significant educational value. Students were actively involved in the design process, allowing them to apply theoretical knowledge to a real-world problem. This hands-on experience is essential for developing critical thinking, problem-solving skills, and a commitment to sustainable development. By participating in this project, students are better prepared to address complex environmental challenges in their future careers.

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