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Integrated Wastewater Management for Environmental Protection and Sustainable Ecotourism in an Andean Paramo Community

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Abstract: The rural Andean community of Yacubiana, Ecuador, currently lacks an adequate sanitation infrastructure, with domestic wastewater managed through individual septic tanks. These decentralized systems have exhibited significant infiltration issues, resulting in groundwater contamination, degradation of sensitive páramo ecosystems, and adverse public health outcomes. Furthermore, this environmental degradation has impeded the community's potential for ecotourism-based development. To address these challenges, an integrated wastewater management strategy was developed, grounded in sanitary engineering principles and aligned with conservation priorities. The proposed framework encompassed four sequential phases: (i) a comprehensive analysis of existing data on water and wastewater practices within the community; (ii) a systematic evaluation of sanitation alternatives tailored to the community's socio-environmental context and the ecological fragility of Andean paramos; (iii) the design of a selected sanitation solution in accordance with national and international technical standards; and (iv) a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis conducted with both technical experts in water resource management and local community representatives. This participatory evaluation aimed to identify strategic pathways for enhancing environmental stewardship, promoting circular water economies, and enabling sustainable tourism. The recommended intervention consists of a simplified, decentralized sewage collection system linked to a trickling filter-based treatment plant, designed for a hydraulic load of 2.79 L/s. The SWOT analysis revealed substantial institutional and infrastructural constraints, primarily due to limited governmental support; however, it also identified considerable ecotourism potential grounded in the area's geological, ecological, and cultural assets. When implemented within a conservation-based framework, the proposed system is expected to support compliance with Sustainable Development Goals (SDGs) 3 (Good Health and Well-being), 6 (Clean Water and Sanitation), and 11 (Sustainable Cities and Communities). The methodological approach developed herein offers a replicable model for integrated wastewater management in rural, environmentally sensitive regions, providing a viable foundation for community-led, sustainable socio-economic development.

Keywords: Sanitary system; Wastewater treatment; Trickling filter; Rural communities; Sustainability tourism development

1. Introduction

Water is an essential natural resource for life on the planet, as it is interconnected with ecological, social and productive systems; therefore, any alteration in its availability and quality can put its survival at risk (UNESCO World Water Assessment Programme, 2020). Developing activities at the domestic, economic, agricultural and industrial levels strongly depends on water resources. Unfortunately, these activities involve physical, chemical and biological contamination processes that generate large amounts of wastewater, negatively impacting the environment (Rout et al., 2021). The contaminants present in these waters are removed or reduced by a wastewater treatment system (WTS), which can be centralized (CWTS) or decentralized (DWTS).

CWTS is designed to collect and transport wastewater from an entire city or community from the source to a wastewater treatment plant (WTP) through an extensive network of underground pipes (sanitary sewer) (Muya, 2024). WTPs seek to remove contaminants from water for safe return to the environment or reuse (Yin et al., 2019). In general, contaminant removal is carried out in four treatment stages: preliminary (separation of visible solids), primary (removal of coarse and sedimentable material), secondary (removal of organic matter), and tertiary (removal of nutrients and microorganisms) (Metcalf & Eddy, 1995).

CWTS have more excellent coverage in urban areas with high population density, while DWTS is used in low-density population centres, commonly in small cities, peri-urban areas and rural communities in developing countries (Nanninga et al., 2012; Singh et al., 2015). DWTS focus primarily on treating and removing pollutants at or near the source so that the sanitary sewer application is significantly reduced or obviated (Capodaglio et al., 2017). It is worth mentioning that the success of its implementation depends mainly on regular inspection and maintenance work (Massoud et al., 2009). Otherwise, there is a risk of wastewater seeping into the subsoil, degrading the surrounding soils and contaminating underground water bodies.

Rural communities often have precarious or, in some cases, non-existent sanitation systems, so the use of DWTS based on septic tanks or cesspools is every day (Abioye & Perera, 2019; Dudley & May, 2007). Although they have been considered acceptable solutions for wastewater disposal, there is increasing evidence that they represent a potential risk for surface and underground sources (Lasagna & De Luca, 2019; Shirazi et al., 2015; Singh et al., 2020). The problem worsens when communities settle in sensitive ecosystems important for water conservation, such as the paramos.

The paramos are high mountain ecosystems found in an elevation range between 3,000 and 5,000 m.a.s.l. and are characterized by a humid and cold climate, with low temperatures throughout the year (Sevillano-Ríos et al., 2020). They constitute essential freshwater sources since they act as natural sponges that supply multiple hydrographic basins, providing water resources to rural and urban communities (Mosquera et al., 2023). Another fundamental aspect is that they are ecosystems that host a great diversity of endemic flora and fauna typical of high-altitude ecosystems (Christmann & Oliveras, 2020). This condition makes them attractive sites for ecotourism, which represents a source of income widely applied in Andean communities, focusing on conservation and environmental protection (García et al., 2019; Ross, 2020). Andean communities in the paramos often have a close relationship with this environment through ancestral practices in agriculture, livestock, and natural resource management (Brück et al., 2023; Buytaert et al., 2006). Factors such as accessibility, lack of infrastructure, technological resource scarcity, and low temperatures represent challenges that require adaptive approaches in decision-making for ecosystem conservation, which also influences wastewater management (Zhang et al., 2025).

According to the reviewed literature, there are few studies related to wastewater management in rural communities settled in sensitive ecosystems and its impact on socio-economic development. Studies such as Ali et al. (2021) evaluated the impacts generated by wastewater on biodiversity loss in a protected area of Dena in southwest Iran. On the other hand, Bakir (2001) proposed a management model in communities in the Middle East and North Africa to preserve the area's scarce water resources. In both cases, adequate wastewater management's importance is reflected in protecting the environment and public health. In developing countries, it is crucial to protect aquatic ecosystems to guarantee ecosystem services, where community participation plays a fundamental role (Carroll et al., 2019; Fonseca et al., 2024; Vollmer et al., 2022). According to Mosquera et al. (2023), there is a need to develop studies related to water management in communities located in the paramos. In the systematic literature review carried out by these authors, scientific progress related to biotic, abiotic, and sociopolitical aspects of water resources in paramos is evident, highlighting that Ecuador is the country that leads this type of research. However, in Ecuador and the Andean region in general, no study has yet been conducted on wastewater management in rural communities located in paramos to mitigate environmental problems and ecosystem conservation.

In Ecuador, according to data from the National Institute of Statistics and the 2022 Census, 68% of the population lives in urban areas and 32% lives in rural areas. In urban areas, 16% of households are not connected to a sewerage system; in rural areas, the figure increases to 76%. In general, 24% of households that do not have access to a sewerage system dump their wastewater into a septic tank, 4.2% into a cesspool, 1.2% into a latrine, and 3.5% do not have a sanitary facility (Instituto Nacional de Estadística y Censo, 2022). Paramos located in the central highlands of Ecuador have been characterised by more significant impacts due to their accessibility and the diverse presence of communities (Ramón, 2002). According to Torres et al. (2023a), the different communities located in "Salinas de Guaranda" are the object of study because of their socioeconomic development due to agricultural and livestock activities that threaten the conservation objectives of the paramos. The effects of climate change due to droughts registered in the country added to the decrease in water capture and storage due to excessive soil compaction related mainly to livestock farming and continuous burning for agriculture (Naranjo Borja et al., 2018). Although the communities of Salinas de Guaranda, from an economic point of view, depend exclusively on existing cheese factories, it has been shown that this activity is not aligned with the conservation objectives of paramos. This indicates the need to rethink local socioeconomic activities with environmental conservation strategies that arise from the needs of communities (Torres et al., 2023b). An alternative to mitigating the impact of agricultural and livestock activities on communities located in paramos is ecotourism development as a convivial conservation activity (Amador-Jimenez & Millner, 2024; Chávez-Velásquez, 2022), which protects sensitive ecosystems while simultaneously promoting the socioeconomic development of the population.

This research analyzes the case of the Yacubiana rural commune, located in the Guaranda canton, Ecuador, approximately 23 km from the Chimborazo volcano, with an average elevation of 3,589 m.a.s.l. and an average temperature of 9-10°C (Figure 1). Its economy depends on livestock, agricultural activities and a community cheese factory, its primary source of income being the commercialization of field products (Alava Zuñiga & Vallejo Palomeque, 2021). Currently, the community has 65% water service coverage, provided through a piped water system to supply domestic use and consumption needs, with access 24 hours a day. However, it lacks a wastewater collection and purification system, so the community's inhabitants have opted to use septic tanks, which have no internal lining, representing a risk to the protection of the moor and health.

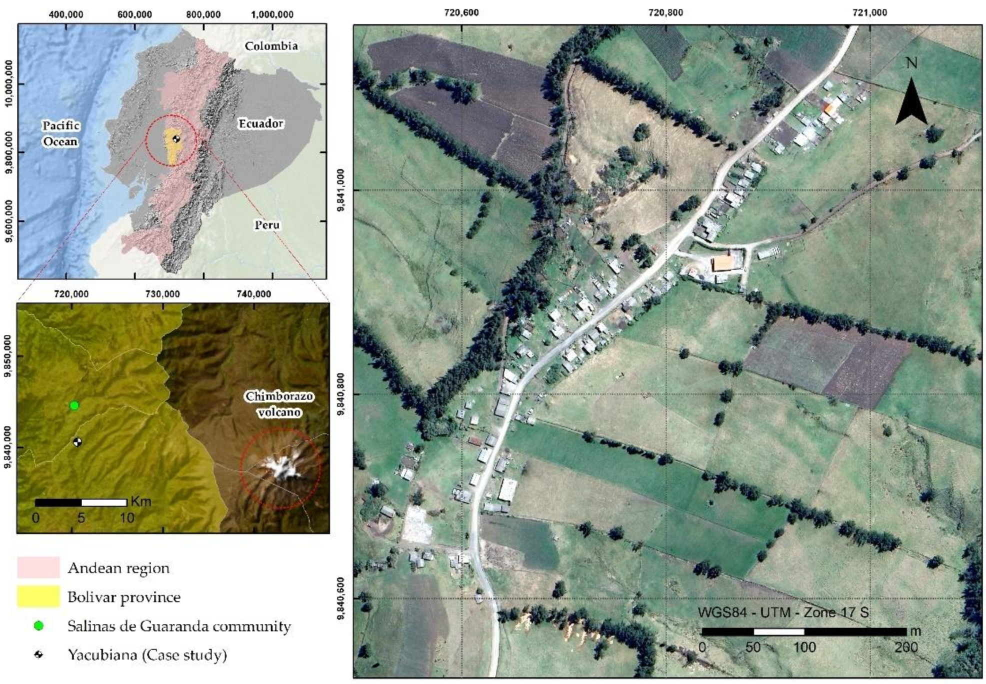

Figure 1. Location of the Yacubiana rural community

On the other hand, Yacubiana also seeks to integrate into the local economy through tourism development, similar to the Salinas de Guaranda community, located 4 km away, where 28 community micro-enterprises operate that generate different artisanal products offered in the national market and exported to other countries, making it a benchmark for community tourism in Ecuador (AME, 2021). However, the lack of adequate infrastructure for wastewater management limits the tourism development of Yacubiana, where the future construction of a community hotel, houses and cafes is contemplated, taking advantage of the area's natural, geological and cultural attractions.

Based on the above, the following research question arises: How can socioeconomic development be achieved without causing significant impacts on the paramo by improving wastewater management? Therefore, this study seeks to propose a wastewater treatment system that meets two essential goals following sanitary engineering principles: i) mitigate the degradation of paramos caused by economic activities associated with livestock farming and human activity in general, through a wastewater transport, collection, and treatment system; and ii) propose ecotourism as a socioeconomic activity that adapts to the conservation objectives of paramos and addresses the economic needs of the community, from the perspective of different key stakeholders. The research findings will lay the foundations for the community to migrate to a community tourism model that ensures sustainable social development and environmental protection in the long term.

2. Methodology

The study methodology combines the sanitation system design and qualitative analysis of the rural community tourist potential through three phases: The methodology consists of four phases: i) existing information analysis, ii) evaluation of alternatives for the sanitation system, iii) selected alternative design under current national and international technical standards, iv) Analysis of Strengths, Opportunities, Weaknesses and Threats (SWOT) to define strategies that promote environmental care, the circular economy of water, as well as the tourist development of the area (Figure 2).

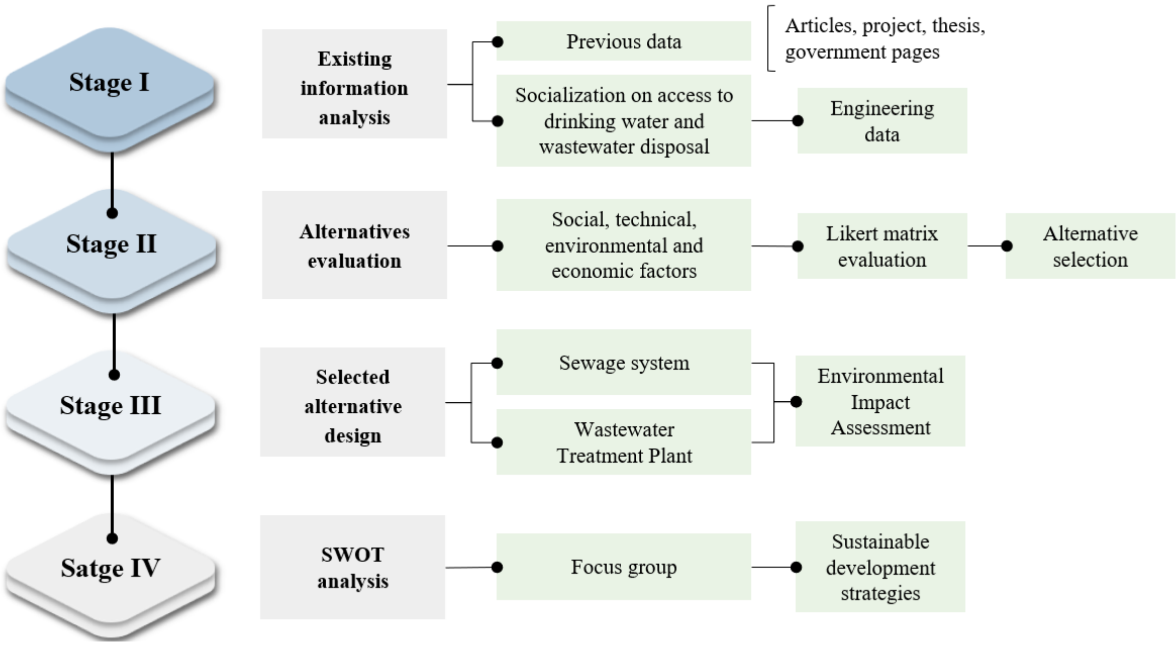

Figure 2. Methodological scheme

2.1 Stage I: Existing Information Analysis

The existing information analysis and field trips allowed us to determine the social and cultural conditions of the population, the current sanitation system state, consumption habits, basic services coverage and expansion plans that the community has projected in a minimum period of five years. Additionally, the topographic survey of the study area was carried out to determine the level curves and slopes through the ArcGIS program.

The study estimated a) the projected Yacubiana population and b) the number of population equivalents to the wastewater input generated by the communal cheese factory (Boiocchi & Bertanza, 2022). This allowed for identifying the applicable sanitation system type according to local regulations, which also serves as a design parameter for the wastewater transport and disposal system.

The population projection for Yacubiana used information from previous censuses as starting data, considering the influence of the changing population according to expansion plans (INEC, 2022). Local regulations described in the Ecuadorian Code of Practice CPE-INEN:5:9:2 (Instituto Ecuatoriano de Normalización, 1992) recommend using three population projection methods to estimate the future population at the end of the design period, so the study considered the arithmetic, geometric and exponential methods (Hinde, 2014; Raymondo, 1992). The selected approach was the one that obtained the Pearson "R^2" coefficient closest to one (Schober et al., 2018).

The number of people equivalent to the cheese factory's production was determined by the relationship between the cheese factory's pollutant load (CC) and the contributing load per person (CC_p). Since there is no official figure for CC_p in Ecuador, a reference value was taken from the available bibliography (Huertas & Marcos, 2012). On the other hand, CC was estimated as the product of the Biochemical Oxygen Demand concentration and the cheese factory's discharge flow rate, obtained by the volumetric method (Instituto Privado de Investigación sobre Cambio Climático, 2017).

It is worth mentioning that the study considered the water characterization of the cheese factory located in Salinas de Guaranda as an expected range of contamination due to the following conditions:

- Yacubiana does not have the resources to carry out this monitoring, so they have no composition record of the cheese factory's wastewater.
- Both cheese factories share similar raw materials, production processes, and product type characteristics.

- Similar climatic conditions (both locations are approximately 3.5 km apart).

The water provision for the commune is based on the considerations of the CPE-INEN 5:9:2 and was corrected based on the current demand because the socioeconomic conditions of the area will change for this; the study considered an increase of 1 l/hab/day for each year of the design period.

2.2 Stage II: Alternatives Evaluation using Likert Scale

Since the population uses septic tanks for wastewater disposal from the domestic sector and the cheese industry, an alternative was sought that would allow for a solution considering the community's economic, geographic and cultural limitations.

The study proposed three proposals to select the most convenient collection and treatment system, choosing the best alternative using the Likert scale, which rates the alternatives from 1 to 5, with 1 being the most unfavourable condition and 5 the most favourable condition (Table 1) (Likert, 1932). For the application of the Likert scale, a series of conditions were considered that would imply a restriction to the proposed alternative application (Table 2).

Table 1. Wastewater management alternatives

Component	Alternative 1	Alternative 2	Alternative 3
Wastewater collection	Conventional sewerage	Simplified sewerage (Non conventional)	Dry toilets
Wastewater treatment	Trickling filter	Rotatory Biological Contactors (RBC)	Peat filter

Table 2. Restrictions criteria for sanitation system components

Wastewater Collection System			
Social	**Technical**	**Environmental**	**Economic**
1) Bad odors formations 2) Presence of insects/pests 3) Pedestrian accidents risk 4) Community participation 5) Vehicular traffic interruption	6) Standardization, regulations 7) Qualified personnel	8) Flora and fauna destruction 9) Risk of aquifers alteration 10) Dust generation	11) Construction 12) Equipment/ machinery 13) Implementation 14) Operation/maintenance

Wastewater Treatment System				
Economic	**Environmental**	**Sludge Management**	**Biophysical Conditions**	**Change in Flow/ Pollutant Load**
1) Implementation 2) Operation 3) Maintenance 4) Energy consumption	5) Bad odours 6) Noise 7) Landscape integration	8) Quantity generated 9) Removal frequency	10) Surface 11) Low temperature	12) Heavy ollution 13) Change flow adaption

2.3 Stage III: Alternative Technical Design

2.3.1 Flows calculation and sewerage system design

The average flow (Q_m) was calculated in Eq. (1), which is a function of the domestic (Q_{dom}) in Eq. (2), institutional (Q_{ins}), industrial (Q_{ind}) and commercial (Q_{com}) flows.

$$Q_m = Q_{dom} + Q_{ins} + Q_{ind} + Q_{com} \quad [l/s] \tag{1}$$

$$Q_{dom} = \frac{P * D}{86400} * Cr \qquad [l/s] \tag{2}$$

Cr: Return coefficient (between 0.7 and 0.85, depending on the complexity of the system)
D: Endowment of drinking water (L/hab/day)
Q: Population (hab)

Additionally, it is necessary to estimate the infiltration flow (Q_{INF}) and the flow due to illegal connections (Q_{ILI}), as well as the maximum hourly flow (Q_{MH}), which is an average flow function. The design flow calculation (Q_{des}) is given by Eq. (3) and follows the considerations of the sewerage system design standard as established in (Empresa metropolitana de alcantarillado y agua potable de Quito, 2009).

$$Q_{des} = Q_{MH} + Q_{INF} + Q_{ILI} \tag{3}$$

The new sewerage network design must be governed by compliance with the minimum requirements for slopes, diameters and speeds to ensure the correct hydraulic operation of the system and that it works by gravity (Instituto Ecuatoriano de Normalización, 1992). For the design, it is important to verify, through hydraulic relations, that the system works with a partially full pipe and under pressure Eq. (4).

$$\frac{Design\ flow}{Full\ pipe\ flow} \leq 0.85 \tag{4}$$

For the treatment system design, the study considered the implementation of a pretreatment system (sand remover), a primary treatment system (Imhoff tank) and a secondary treatment system (trickling filter or bacterial bed). The study considered a horizontal flow range, whose sizing depends on the cross-sectional area and deposit length, which considers the maximum hourly flow and horizontal velocity. Therefore, it is necessary to analyse the particle size because the horizontal velocity values arise from this parameter. The desander allows the separation of heavy solids in suspension so as not to affect the performance of subsequent treatments. The design conforms to the guidelines and equations established in (Hernández Muñoz et al., 2004).

The Imhoff tank design follows the criteria established in the "Guide for the Design of Septic Tanks, Imhoff Tanks and Stabilization Ponds" (Organización Panamericana de la Salud & Centro Panamericano de Ingeniería Sanitaria y Ciencias del Ambiente, 2005), which contemplates a sedimentation and digestion zone. For sludge treatment, the study considered the implementation of drying beds. This section does not include detailed design details because the guide is practical and has a logical design sequence.

The Trickling Filter (TF) design follows the steps recommended in (Metcalf & Eddy, 1995), where, depending on the depth, the ambient temperature, the recirculation rate, the BOD_5 concentration at the inlet and outlet of the system, and a treatability constant, which allow determining the necessary surface of the TF, and later the diameter. The distributor's arm's rotation speed is also estimated based on the hydraulic load and the dosing flow.

At the output, the values must be less than or equal to the Maximum Permissible Limit (LMP) following the Unified Text of Secondary Legislation of Ecuador's Ministry of the Environment (TULSMA) (Ministerio del Ambiente Agua y Transición Ecológica del Ecuador, 2015).

Finally, an environmental impact matrix was developed to assess the potential effects that would be generated by the activities associated with implementing the sanitation system during the construction and maintenance stage. Table 3 shows the activities related to implementing the selected proposals. The Environmental Impact Assessment (EIA) was carried out using the Integrated Relevant Criteria (CRI) that uses indicators based on the intensity, extent, duration, reversibility and incidence of the impacts (Buroz Castillo, 1998; Neuberger-Cywiak, 2001). The indicators are quantitatively assessed according to the scale shown in Table 4.

Table 3. Activities in the construction and operation stage

Construction Stage	Operation Stage
(i) Site Cleaning and Clearing.	
(ii) Construction camp installation.	(i) Manhole maintenance.
(iii) Loan material explotation.	(ii) System treatment process control.
(iv) Loan material transportation.	(iii) Maintenance of system treatment processes.
(v) Excavation and removal of material.	(iv) Residual sludge collection.
(vi) PVC pipes and plastic fillers transport.	(v) Activated sludge drying.
(vii) Concrete elements casting.	(vi) Residual sludge disposal.
(viii) Signage.	

Table 4. Evaluation scale for environmental impact indicators

Indicator	Criteria	Value
Intensity	-	1-10
	Long (>5 years)	10
Duration	Medium (2-5 years)	5
	Short (1-2 years)	2
	Generalized	10
Extent	Local	5
	Punctual	2
	Irreversible	10
Reversibility	Partially reversible	5
	Reversible	2
	High (> 50 %)	10
Incidence	Medium (10-50%)	5
	Low (1-10%)	2

According to the CRI method, Eq. (5) determines the impact magnitude (M) of the activities planned for the construction and operation stages. Finally, Eq. (6) allowed us to estimate the Environmental Index Value (EIV) of each activity corresponding to the construction and operation stage, and to identify those that generate impacts on a Low (0-3), Medium (4-7) and High (8-10) scale.

$$M = 0.40 * I + 0.40 * E + 0.20 * D \quad (5)$$

$$EIV = R^{0.22} \cdot G^{0.17} \cdot |M|^{0.61} \quad (6)$$

2.4 Stage IV: SWOT Analysis

Finally, the study included the SWOT analysis (Leigh, 2010), which considered two main aspects: i) the current socioeconomic reality of the study area and its impact on the conservation of the paramo, ii) the technical proposal of this study to address the health problems of the community, and iii) the need to rethink community socioeconomic development activities through participatory approaches that promote migration to ecotourism as an alternative that meets the economic needs of the community and promotes compliance in the conservation of this type of sensitive ecosystem. For the analysis, the main tool was a focus group (Kitzinger, 1994) composed of experts in water management and the sustainable use of resources, community members, and representatives of the community cheese factory. In total, eight people participated and were selected based on their experience in resource management from a community and academic research perspective, as well as the openness received by the population and their interest in participating in the study. The analysis made it possible to define strategies to promote tourism development by considering four key aspects: i) location, ii) community characteristics, iii) sustainable development, and iv) experiences.

3. Results

3.1 General Information and Population Analysis

The Yacubiana commune is between 3,555 and 3,614 meters above sea level, where low temperatures predominate. Residents point out that the name Yacubiana comes from the Kichwa language: yacu (water) and ubiana (drink); thus, Yacubiana means "drink water." Regarding the landscape, the commune has natural elevations allowing excursions and panoramic views of Chimborazo Volcano and the surrounding ecosystem. At higher altitudes, flora species are abundant (Yagual, Fan Palm, Fern, Guayusa, Guayacán, Cane Guadua, Romerillo, Mint, Chamomile, Laurel, among others). Similarly, the fauna has migrated to other areas due to human activity and is characterized mainly by rabbits, wolves, quinde, deer, armadillos, squirrels, owls, and curiquingues (a bird characteristic of the Andes). From a geological perspective, the study area primarily comprises the Pisayambo Volcanic Formation, which includes, within its lithology, andesites, agglomerates, lava flows, tuffs, and pyroclastic deposits. Natural and cultivated pastures are abundant, so the presence of sheep, pigs, and cattle is familiar. The community cheese factory uses part of the milk obtained from cattle, which produces 260 kilos of cheese per day, which is sold in different parts of the country. Agriculture is also the primary income source, with the predominant crops being potatoes, corn, beans, oca, legumes, wheat, barley, and other crops (Figure 3).

Figure 3. Natural, geological and cultural wealth of Yacubiana

The surveys conducted on the inhabitants offer information on the conditions of the service and coverage of water in the community, as well as the current sanitation system (Figure 4). In general, water for human consumption comes from springs and does not receive prior treatment, whereas wastewater ends up in unlined septic tanks, which causes contamination in the subsoil.

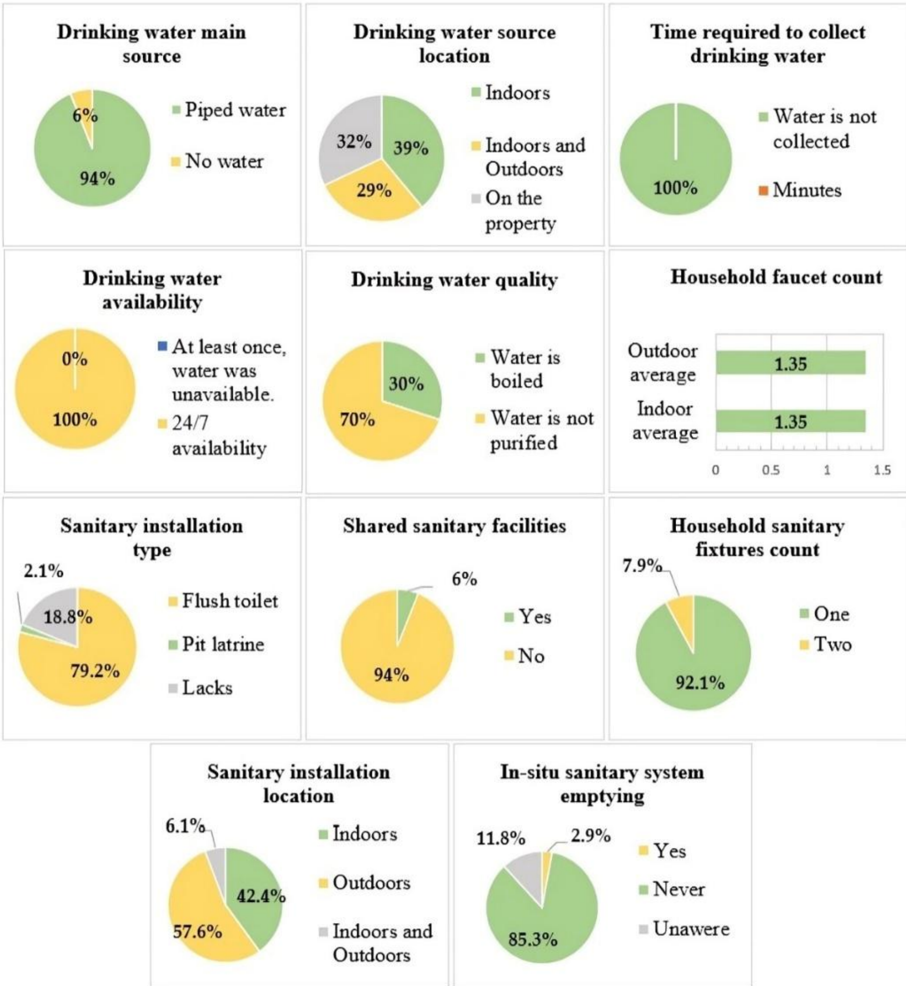

Figure 4. Results of surveys on water supply for human consumption and wastewater disposal

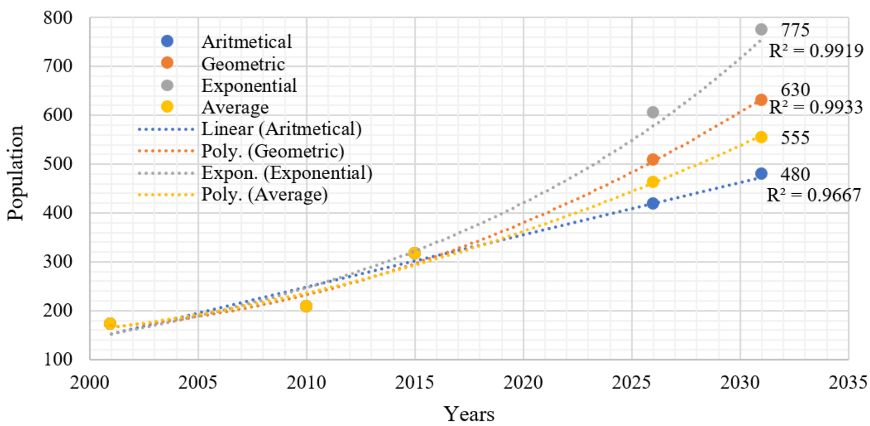

Figure 5. Yacubiana population projection

As part of the operational plan for Yacubiana's economic development, local authorities plan to invest in tourism infrastructure that will accommodate an average of 55 people (floating population) and offer tourist packages to promote the city's natural and geological wealth. For a 10-year design period, the study carried out the population projection using the arithmetic, geometric and exponential approaches. The geometric method shows a better fit concerning the natural population growth, according to Pearson's R^2 coefficient (Figure 5); however, since this is a rural community, arithmetic method values were averaged so that by 2031 the design population will be 555 inhabitants. Considering the commune's expansion plans, the floating population will increase by 55 inhabitants, resulting in a final design population of 610.

The analysis determined that the community cheese factory input is equivalent to 1950 inhabitants by applying the criterion of population equivalent to estimate the industry contribution based on the pollutant load (CC) (Table 5).

Table 5. Equivalent population generated by the industry

Q [l/s]	BOD_5 [mg/l]	CC [kg/day]	CC_p [kg/day*hab]	Population Equivalent
0.62	2179	117	0.06	1950

The number of equivalent population, added to the 610 inhabitants obtained from the population projection, represents 2560 inhabitants. Therefore, according to local regulations, the community requires a Type IIb excreta disposal service level, which involves implementing a sanitary sewerage system. Additionally, for small communities located in a predominantly cold climate (less than 10°), regulations recommend a supply of 62 [l/hab/day]. However, considering that the endowment grows by 1 [l/hab/day] for each year of the design period, the final endowment was equal to 72 [l/hab/day].

3.2 Proposals for a Sanitation System and Likert Evaluation

According to the results obtained from evaluating alternatives with the Likert scale, considering the respective restrictions, the proposal for an unconventional sewerage system scored 51. In contrast, for the treatment system, the trickling filter had a score of 29, which implies that both proposals are the most appropriate (Tables 6 and 7).

Table 6. Wastewater collection system evaluation

Restrictions Criteria		Conventional Sewerage	Simplified Sewerage	Dry Toilets
Social	Bad odors formations	5	5	1
	Presence of insects/pests	5	5	1
	Pedestrian accident risks	3	2	4
	Community participation	5	3	1
Technical	Interruptions of vehicle traffic	1	4	5
	Standardization, Regulations	5	3	1
	Qualified personnel	5	3	4
Environmental	Flora and fauna destruction	4	5	3
	Risks of aquifers alterations	4	3	2
	Dust generation	2	3	4
Economic	Construction costs	2	5	4
	Equipment and machinery costs	1	4	5
	Implementation costs	1	3	5
	Operation and maintenance costs	1	3	2
Total		44	51	42

Table 7. Wastewater treatment system evaluation

Restrictions Criteria		Trickling Filter	RBC	Peat Filter
Economic	Implementation	2	1	3
	Operation	2	1	2
	Maintenance	2	1	2
	Energy consumption	2	1	3
Eenvironmental	Potential for bad odors	2	2	2
	Potential for noise	2	1	3
	Landscape integration degree	1	1	3
Sludge management	Sludge generation	2	2	2
	Sludge removal frequency	2	1	2
Biophysical conditions	Surface	3	3	1
	Low temperature	3	2	2
Change in flow/ pollutant load	Heavy pollution	3	3	1
	Change Flow adaption	3	3	1
Total		29	22	27

3.3 Sanitation System Components

According to the calculated design flow rates, the proposed sewer system requires pipes of Ø200 to Ø300 mm for minimum and maximum flow rates of 1.60 to 2.79 l/s. The design allows flow velocities between 0.45 and 2.5 m/s to avoid problems associated with sedimentation and pipe erosion. Additionally, the velocities obtained meet the traction force criterion greater than 0.12 kg/cm^2 for self-cleaning the pipe. Figure 6 shows the sewer system location, with a total length of 916.83 m, which connects to the treatment system at the lowest point of the topography, according to the contour lines.

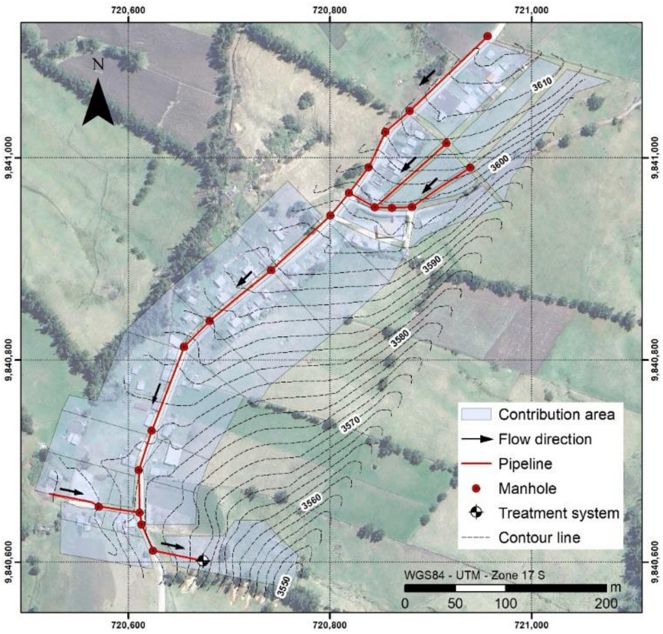

Figure 6. Wastewater collection system implementation

3.4 Wastewater Treatment System Design

The system comprises a screening channel/grit chamber, an Imhoff tank, a drying bed, and a trickling filter (Figure 7). Efforts were made to locate the treatment system in a low area so that the sewage system would work by gravity. The design flows for the sand remover and the TF correspond to the maximum hourly flow (4.12 l/s), while for the Imhoff tank, full daily use was used (8.29 m^3/h).

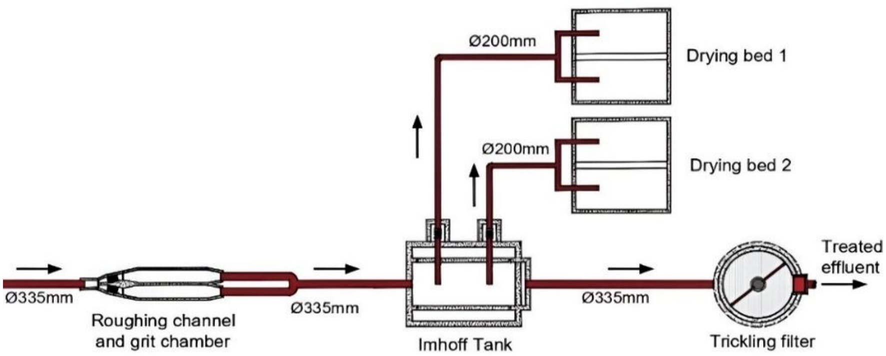

Figure 7. Scheme of proposed treatment system

3.4.1 Screening channel and grit chamber

The screening channel requires a screen to remove and extract coarse solids and prevent obstructions in the system. The grit chamber design considered a particle size of 0.005 cm to estimate its dimensions. With these dimensions, the hydraulic retention time in the system was equal to 2.18 minutes. The transition angle at the inlet and outlet of the desander was 12.5° (Figure 8).

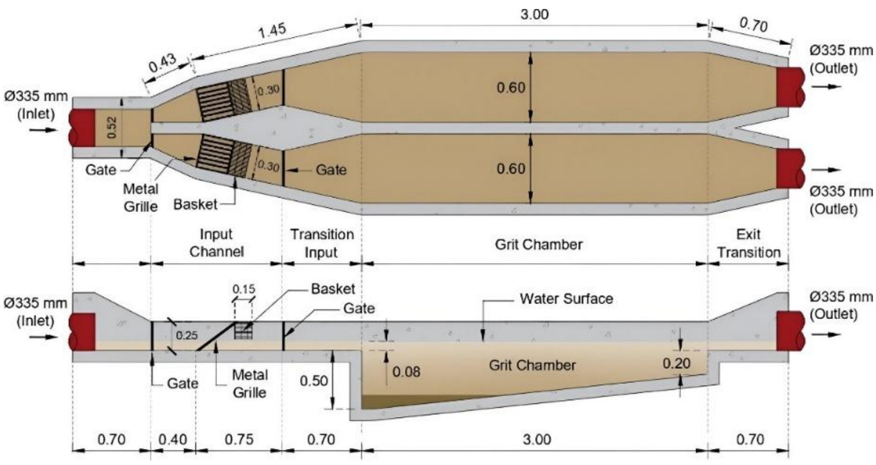

Figure 8. Screening channel and grit chamber dimensions

3.4.2. Primary treatment system: Imhoff tank and drying bed

The tank dimensions were obtained using maximum daily flow (QMD), including a sedimentation and digester zone (Figure 9). The total tank height was equal to 7.30 m, with a length of 4.50 m and a width of 3.40 m. Table 8 shows the removal percentages obtained from Total Suspended Solids (TSS) and Biochemical Oxygen Demand (BOD_5), reaching removal percentages of 47% and 28%, respectively.

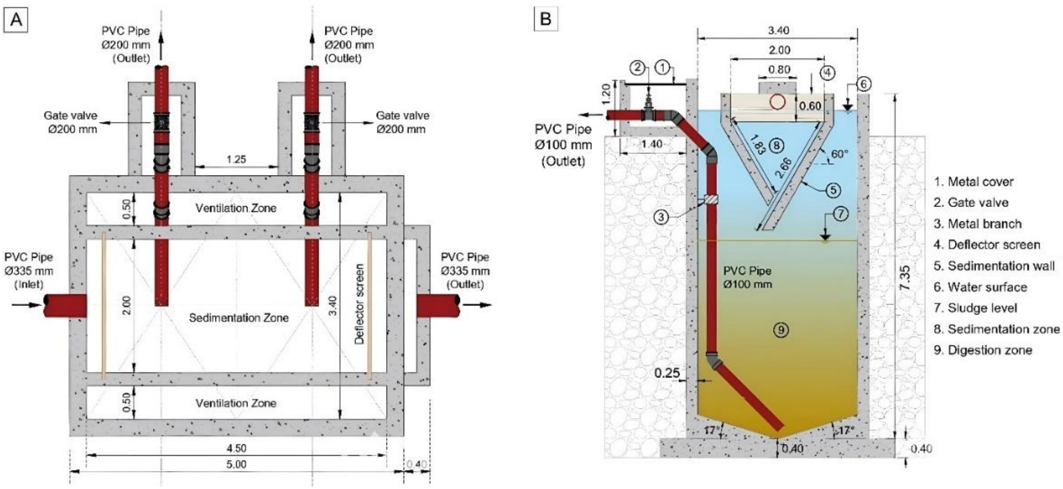

Figure 9. (A) Plan view of the Imhoff tank. (B) Transversal view of the Imhoff tank

Table 8. Percentage of removal obtained

Pollutant	Inflow	Outflow	Removal
TSS [mg/l]	198	104.94	47%
BOD_5 [mg/l]	237.5	171	28%

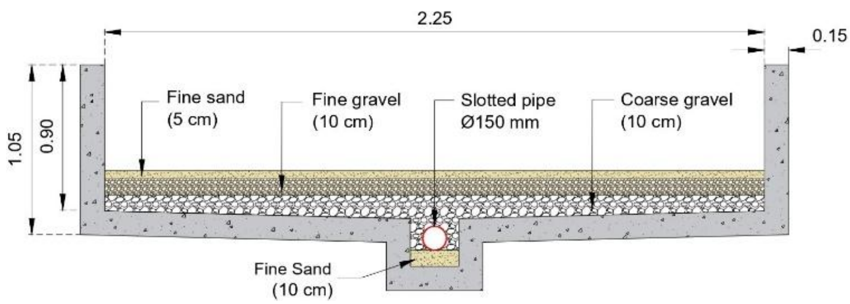

Figure 10. Sectional view of the drying bed

According to the calculations, the drying beds obtain a digested sludge daily volume of 171.53 l/day. In contrast, the sludge volume that must be extracted is 13.04 l/day. The system requires an implantation area of 16.30 m^2, so the drying bed dimensions are 4.0 × 4.1 m. The drying bed bottom contains a geotextile that rests on a filter medium made up of coarse sand and another gravel layer of 0.15 cm each (Figure 10).

3.4.3. Secondary treatment system—Trickling filter

Depending on the contaminant load and the filter medium (plastic rosettes to increase the contact surface), the analysis considered a recirculation rate (RC) equal to four, which reduces the BOD_5 concentration to a value of 98.27 mg/l. Additionally, with a treatability constant (k) of 0.17 and an expected BOD_5 concentration of 80 mg/l at the system outlet, the circular TF had a diameter of 3.10 m and an arm rotation speed of 2.36 revolutions per minute. Figure 11 shows treatment system details and its dimensions, respectively. Upon entering the trickling filter system, the flow from the Imhoff tank reduced BOD_5 concentration by 53% (Table 9). Finally, the proposed system achieved an expected removal of 52% and 68% of the TSS and BOD_5, respectively (Table 10).

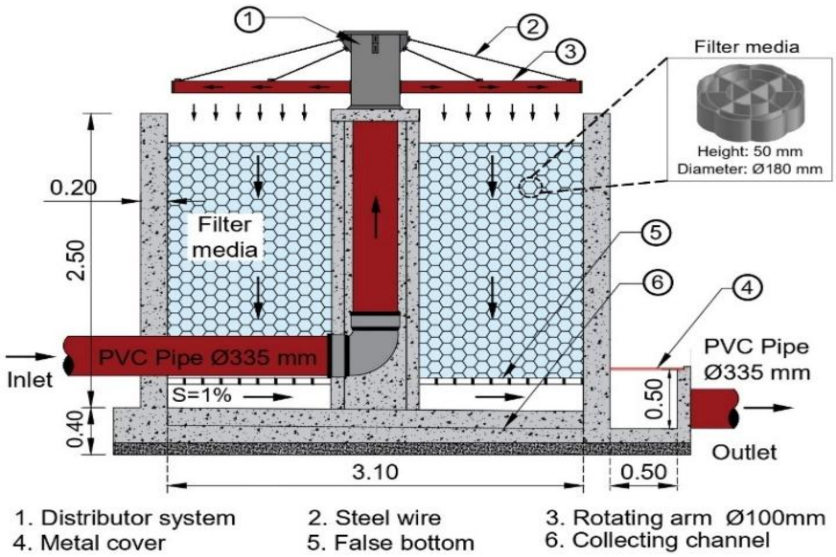

Figure 11. View of the trickling filter system

Table 9. Trickling filter removal percentage

Pollutant	Inflow	Outflow	Removal
TSS [mg/l]	104.94	104.94	-
BOD_5 [mg/l]	171	80	53%

Table 10. Efficiency of the entire treatment system proposed

Pollutant	Inflow	Outflow	Removal	Regulation	Comply
TSS [mg/l]	220	104.94	52.3%	130	ok
BOD_5 [mg/l]	250	80	68%	100	ok

3.4.4 Environmental impact assessment

The environmental study considered a series of factors that could alter the air, soil, water, and biota properties, as well as the socio-economic conditions of the commune during the construction and operation stages. The factors directly or indirectly affected are detailed below:

- Soil (S): Quality (1) erosion (2) and waste generation (3).
- Air (A): Dust levels (4) and noise levels (5).
- Water (W): Surface drainage system (6) and surface and groundwater quality (7).
- Biotic (B): Terrestrial biota (8).
- Socioeconomic (SE): Occupational health (9), public health (10), economic activity (11) and landscape degradation (12).

During the construction phase, the EIV identified that clearing, excavation and removal of materials would cause medium-level impacts in the study area. However, when analyzing it by factors, it can be seen that: a) air is the most affected environmental component, b) in the socioeconomic part, measures should be sought for public and occupational health care, and c) soil quality would also be affected in this phase (Table 11). On the other hand, the operation and maintenance phase would impact the environment mainly with the collection and sludge disposal activities, affecting primarily the soil, water and socioeconomic aspects (Table 12).

Table 11. EIV-construction stage

Construction Stage Activities	S			A		W		B		SE			Average
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	
Site Cleaning and Clearing.	8	6	3	7	7	2	0	4	8	4	0	3	4
Construction camp installation	5	2	5	0	0	2	0	2	6	0	6	4	3
Loan material explotation	9	7	0	8	7	0	1	5	6	0	0	0	4
Loan material transportation	0	0	5	8	7	0	0	0	2	0	5	0	2
Excavation and removal of material	6	4	2	8	8	3	3	4	8	3	5	0	5
PVC pipes and plastic fillers transport	0	0	0	7	7	0	0	0	0	0	0	0	1
Concrete elements casting	0	0	6	5	3	0	0	4	0	0	7	0	2
Sinage	0	0	0	0	0	0	0	0	6	7	0	0	1
Average	4	2	3	5	5	1	1	2	5	2	3	1	

Table 12. EIV-operation stage

Operation Stage Activities	S			A		W		B		SE			Average
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	
Manhole maintenance	5	0	5	0	5	0	4	0	6	5	2	2	3
System treatment process control	0	3	6	0	0	0	4	5	6	0	4	0	2
Maintenance of system treatment	0	3	7	0	4	0	8	5	6	5	4	1	4
Residual sludge collection	3	3	8	1	4	0	5	6	9	0	5	3	4
Activated sludge drying	0	0	7	0	2	0	6	0	3	0	0	3	2
Residual sludge disposal	8	2	6	0	2	2	6	8	6	6	5	7	5
Average	3	2	7	0	3	0	6	4	6	3	3	3	

3.5 SWOT Analysis

Through the SWOT analysis, the study identified the rural commune's main SWOT. In general, the analysis of internal aspects reflects that the community has a representative natural and geological wealth of the area, with economic activities represented by agriculture, livestock, and artisan cheese production. However, the problems associated with the basic infrastructure (roads, accommodation, and health centres) and the existing sanitation system affect the well-being of the population and the conservation of ecosystems.

On the other hand, the external aspects analysis allows us to identify the potential of a community to achieve sustainable community development using natural and geological wealth, which is strengthened by the sanitation system implementation that serves as an example at the national, local, regional, and international levels to promote a circular water economy. However, government support is a conditioning factor threatening a community's potential.

- **Strengths**
  - Sites of geological and natural interest for geotourism.
  - National and international scope for artisanal cheese production.
  - Agricultural development.
  - Natural value for its diversity in flora and fauna.
- **Weaknesses**
  - Limited basic services.
  - Limited financial resources.
  - Inadequate sanitation system.
  - Contaminate water sources due to wastewater and livestock.
- **Opportunities**
  - Acquisition of international funds to implement a sanitation system.
  - Treated wastewater reuse for circular economy and protection of Andean paramo.
  - Development of infrastructure to promote community tourism.
  - Conservation of cultural identity.
- **Threats**
  - Tourism competitiveness of nearby areas.
  - Lack of municipal support.
  - Climate emergency will influence the water resources availability.
  - Migration of young population.

This analysis proposes strategies to promote tourism development based on four key axes: location, sustainable development, community characteristics, and experience (Table 13). Specifically, the proposals of this study focus on the tourist infrastructure adequacy, the conditioning of natural and geological interest sites, sustainable management of residual water, and the community-academy interaction for the development of projects that allow solving the different problems from the environmental, social, educational, economic, and political viewpoints.

Table 13. Strategies for sustainable community development

Axes	Strategies
Sustainable Development	1. Implement the proposed sanitation system to properly manage wastewater. 2. Implement alternative economic activities that include ecotourism and geotourism. 3. Conduct the survey and evaluation of sites of geological interest with potential for geosites. 4. Implement a tertiary purification system for effective water reuse.
Location	5. Carry out a project to adapt road and tourist infrastructure (community hotel, restaurant, health center). 6. Propose tourist routes complemented by peripheral sites with geological, cultural or natural wealth. 7. Create plans to disseminate natural and geological wealth through social networks and academia.
Experiences	8. Implement guides for different points of community and tourist interest. 9. Install interpretive panels with historical, cultural, natural and geological data. 10. Promote social networks to develop forums that allow people to learn about the culture of the community. 11. Train staff for technical visits to community wastewater management.
Community features	12. Promote projects to attract national and international funds to improve tourist sites. 13. Promote community participation in environmental education programs and sustainable water management. 14. Improve access to education with an emphasis on the conservation of cultural and natural resources. 15. Strengthen local governance through community inclusion in decision-making.

4. Discussion

The proposed methodological approach addresses the problems associated with wastewater management in rural communities located in sensitive ecosystems, where the search for solutions must have a comprehensive approach within the framework of the SDGs. The Yacubiana case reflects the reality of many rural communities that lack an adequate disposal system for the final liquid waste. According to the surveys carried out in the community (Figure 3), there is a low level of environmental awareness and action regarding wastewater management. Of the 81% of the population with a sanitary installation corresponding to septic tanks, only 3% have performed maintenance on the system at least once, representing a potential risk to people's health and the conservation of the natural environment in rural communities. This health problem highlights the need to improve sanitation conditions in vulnerable communities (Nasim et al., 2022).

The study evaluated three alternatives for wastewater transport (Table 7). The unconventional simplified sewerage system is better adapted to the terrain conditions, requiring fewer deep excavations and using fewer pipes compared to a conventional system (Yap et al., 2023). This reduces the costs associated with its implementation, making it more convenient in areas with low population density (Bakalian et al., 1994; Hawkins et al., 2013). The non-conventional simplified sewerage system covers a length of 917 m, with pipes of Ø200 to Ø300 mm diameter and a capacity of 2.90 l/s. Although sewerage systems are not commonly used in rural areas due to their low population density (Novotný et al., 2018; Xie et al., 2022), the initial cheese industry contribution in the study area, in terms of equivalent population (1950 inhabitants), makes its implementation feasible. However, it is essential to highlight that the designed system requires periodic cleaning to avoid obstructions when there is not enough water for washing.

The wastewater treatment system for the study area considered three alternatives (Table 8), of which the rotating biological contactors were discarded because they experience a decrease in their performance when operating in environments with low temperatures, and the energy consumption is high (Waqas et al., 2023). Regarding peat filters, it is required that the water table be deep enough to avoid leaks into water bodies and contamination (Kennedy & Geel, 2000); however, the paramos usually have a water table close to the surface, which restricts their application.

Therefore, the optimal alternative for the conditions analyzed corresponds to a trickling filter, which, according to the proposed design, is complemented by a sand trap and an Imhoff tank. This system removes 47% of TSS and 68% of BOD_5, complying with the quality standards of local regulations (Ministerio del Ambiente Agua y Transición Ecológica, 2015). This type of wastewater treatment systems promotes the inhabitant's well-being and environmental protection, as reported by other studies (Rehman et al., 2021; Sehar & Naz, 2016). However, monitoring the treated water quality is necessary to ensure that the treated effluent does not represent a potential risk to water sources.

The resulting effluent can be used in reforestation and crop irrigation programs in controlled areas, which would reduce water extraction and improve agricultural productivity without the need for additional fertilizers (e.g., Carballo et al., 2019; Morante-Carballo et al., 2024). The literature review presented by Singh (2021) shows the potential contribution of fertilizers to the soil with different treated wastewater amounts. For example, an irrigation application of 4000 m^3/ha, with a wastewater concentration of 18–60 mg/L, would contribute an equivalent of 64–248 kg/ha of nitrogen. Similarly, a concentration of 4–66 mg/L would represent 276 kg/ha of potassium to the soil, and a concentration of 6–23 mg/L would be equivalent to up to 96 kg/ha of phosphorus. Another helpful element is the sludge generated in the process, which is stabilized in drying beds and could later be used as fertilizer for agricultural activities (Aleisa et al., 2021). This approach promotes the circular economy by converting waste into valuable resources and optimizing the use of water and nutrients.

Addressing the sanitation problem in a rural community located in an area of natural importance and vulnerable to anthropic activity represents an indicator of SDG fulfilment, improving people's well-being and quality of life with a focus on environmental care (Molina et al., 2018). According to Obaideen et al. (2022), implementing sanitation systems leads to the fulfilment of SDG 6, which has a transversal impact on achieving the other SDGs. The internal and external aspects of the evaluation of the community (SWOT analysis) allowed us to define a set of strategies for sustainable community development with an ecotourism and conservation approach, of which three essential aspects are highlighted:

- Financial and technical support from local governments for implementing infrastructure allows for more excellent basic services coverage (Schmidt et al., 2019). The need for national and international alliances with non-profit organizations (NPOs) to finance community projects related to the circular economy of water and sustainable tourism is highlighted.
- Community solidarity habits can be critical objectives to achieve economic and social development through a model based on community tourism (Đurkin & Perić, 2017; Ruiz-Ballesteros, 2011). These types of practices can include i) artisanal cheese production, an activity replicated by peripheral communities (Salinas de Guaranda); ii) implementing tourist routes that integrate natural, cultural and geological value; and iii) projects for effective water reuse in reforestation plans.
- Community-academia interaction to develop studies that address the environmental, social and economic needs of the community. This allows for proposing solutions that promote equity and sustainability and promote a greater understanding of local priorities and needs to obtain adequate solutions (Carrión-Mero et al., 2021).

The proposal can be replicated in other low-density localities where the area's geomorphology limits space availability. Larger populations may require more complex sewage and wastewater treatment systems, with higher investment, operation, and training costs. Other treatment alternatives using wetlands may be more common in rural areas because they are economically and environmentally friendly; however, they require considerable land area, relatively flat topography, and impermeable soil (Agunwamba, 2001; Mahapatra et al., 2022). Protecting water sources through a sanitation system promotes the development of ecotourism, which is a viable option for developing small communities and preserving their culture. However, some communities may be reluctant to change their usual practices due to a lack of knowledge. In this context, academic support becomes essential, as their participation through extension projects can provide them with tools to make the proposal sustainable (Mancini et al., 2022; Wong et al., 2025).

Regarding the study limitations, trickling filters allow for adequate wastewater treatment; however, at low temperatures, additional measures must be implemented to prevent the freezing of the filter media, as this delays the organic matter degradation by bacteria, thereby increasing the clogging probability (Scholz, 2016). Another limitation is that the proposed design considers wastewater characterization based on typical values, which do not necessarily reflect the actual conditions in Yacubiana. To implement this sanitation project in the community, it is recommended that wastewater characterization studies be conducted for the community and the cheese factory to adjust the proposed design and implement tertiary treatment systems that achieve greater removal (Mosquera et al., 2023; Tortajada, 2020).

Finally, future research could include identifying and evaluating sites of geological interest that can be developed as geosites. This represents a path for the development of guided tours, adding tourist and scientific value to the area, as suggested by Carrión-Mero et al. (2020). Furthermore, due to the dependence on agricultural activities, it is necessary to investigate sustainable practices that promote soil conservation and the efficient use of water resources. Dialogue between stakeholders is essential to avoid conflicts and design an action plan for the transition to innovative systems (Ramírez-Gómez et al., 2025; Robineau et al., 2010).

5. Conclusions

Protecting water in sensitive areas such as the Andean paramo is a national and regional priority to conserve water resources and promote proper management. This research proposes strategies for protecting Andean moors in a rural commune in Ecuador by implementing a sanitary system that integrates simplified sewerage and a wastewater treatment system through a trickling filter. The proposed solution is replacing the existing sanitation system consisting of septic tanks, which represent a risk to ecosystem conservation, as well as impacts on local health and the tourism development deterioration of the sector.

The designed system guarantees the adequate collection and transport of wastewater with a pipe network with a capacity of 2.8 l/s according to the population density and the study area conditions. The designed purification system would achieve total removals of 47% of TSS and 68% of BOD_5, allowing a safe discharge into the environment. However, its proper functioning depends mainly on periodic maintenance work (sludge removal and filter washing).

This health management type provides a favourable environment for the sector's socio-economic development, especially tourism, with future tourist infrastructure implementation and improved accessibility. In this context, the SWOT analysis mainly highlights the community's strategic location near other international tourist reference points and the geological, natural and cultural wealth as the main tourist attraction. However, it is essential to highlight the need to strengthen government support, financing and community participation.

The methodological approach used in this study is a replicable tool for Andean paramo communities to address problems or needs related to sanitation management for ecosystem conservation, local development, and compliance with SDGs 6 and 11. The originality and contribution of this research lie in its focus on wastewater management and the promotion of ecotourism as a sustainable alternative for socioeconomic development. The practical recommendations presented here are aligned with paramo conservation objectives and are expected to contribute to decision-makers in the management of the Andean territory, a vital ecosystem for water regulation and biodiversity in the region. Future research could explore the system's solid waste management and implementation of tertiary purification systems that guarantee safe water reuse.

Author Contributions

Conceptualization, B.M.-S., F.M.-C., S.S.-Z., and M.A.-A.; methodology, B.M.-S., F.M.-C., S.S.-Z., M.A.-A., B.Á.-Z. and F.V.-P.; software, S.S.-Z., M.A.-A., B.Á.-Z. and F.V.-P.; validation, B.M.-S. and F.M.-C.; formal analysis, B.M.-S., F.M.-C., S.S.-Z., and M.A.-A.; investigation, B.M.-S., F.M.-C., S.S.-Z., M.A.-A., B.Á.-Z. and F.V.-P.; resources, B.M.-S. and F.M.-C.; data curation, S.S.-Z., M.A.-A., B.Á.-Z. and F.V.-P.; writing—original draft preparation, S.S.-Z., M.A.-A., B.Á.-Z. and F.V.-P.; writing—review and editing, S.S.-Z., M.A.-A., B.Á.-Z. and F.V.-P.; visualization, B.M.-S. and F.M.-C.; supervision, B.M.-S. and F.M.-C.; project administration, B.M.-S. and F.M.-C.; funding acquisition, B.M.-S. and F.M.-C.. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare no conflict of interest.

References

Abioye, S. O. & Perera, E. D. P. (2019). Public health effects due to insufficient groundwater quality monitoring in Igando and Agbowo regions in Nigeria: A review. *Sustain. Water Resour. Manage.*, *5*(4), 1711–1721. https://doi.org/10.1007/s40899-019-00330-5.

Agunwamba, J. C. (2001). Effect of tapering on the performance of waste stabilization ponds. *Water Res.*, *35*(5), 1191–1200. https://doi.org/10.1016/S0043-1354(00)00391-2.

Alava Zuñiga, B. M. & Vallejo Palomeque, F. A. (2021). *Estudio y diseños para el alcantarillado sanitario y planta depuradora de aguas residuales de la comunidad Yacubiana, parroquia Salinas, cantón Guaranda* Escuela Superior Politécnica del Litoral. https://www.dspace.espol.edu.ec/handle/123456789/52181

Aleisa, E., Alsulaili, A., & Almuzaini, Y. (2021). Recirculating treated sewage sludge for agricultural use: Life cycle assessment for a circular economy. *Waste Manage.*, *135*, 79–89. https://doi.org/10.1016/j.wasman.2021.08.035.

Ali, M. R. S., Zare, A., & Pournouri, M. (2021). Investigating and identifying the effects of rural wastewater in Dena protected area and presenting an environmental management pattern. *Anthropog. Pollut.*, *5*(1). https://doi.org/10.22034/ap.2021.1914771.1084.

Amador-Jimenez, M. & Millner, N. (2024). Being paramuno : Peasant world-making practices in the paramos [high moorlands] of the Colombian Andes. *Soc. Nat. Resour.*, *37*(5), 733–751. https://doi.org/10.1080/08941920.2023.2258346.

AME. (2021). *Salinas de Guaranda es conocido como el lugar del queso y el chocolate*. Asociación de Municipalidades Ecuatorianas. https://ame.gob.ec/2021/04/01/salinas-de-guaranda-es-conocido-como-el-lugar-del-queso-y-el-chocolate/

Bakalian, A., Wright, A., Otis, R., & Azevedo Netto, J. (1994). *Simplified Sewerage: Design Guideline*. International Bank for Reconstruction and Development. https://documents1.worldbank.org/curated/ar/676741468227353807/pdf/multi-page.pdf

Bakir, H. A. (2001). Sustainable wastewater management for small communities in the Middle East and North Africa. *J.Environ. Manage.*, *61*(4), 319–328. https://doi.org/10.1006/jema.2000.0414.

Boiocchi, R. & Bertanza, G. (2022). Interpreting per capita loads of organic matter and nutrients in municipal wastewater: A study on 168 Italian agglomerations. *Sci. Total Environ.*, *819*. https://doi.org/10.1016/j.scitotenv.2022.153236.

Brück, S. A., Torres, B. D. M., & de Moraes Polizeli, M. de L. T. (2023). The Ecuadorian paramo in danger: What we know and what might be learned from northern wetlands. *Global Ecol. Conserv.*, *47*, e02639. https://doi.org/10.1016/j.gecco.2023.e02639.

Buroz Castillo, E. (1998). *La gestión Ambiental: Marco de Referencia Para Las Evaluaciones de Impacto Ambiental*. Fundación Polar.

Buytaert, W., Célleri, R., De Bièvre, B., Cisneros, F., Wyseure, G., Deckers, J., & Hofstede, R. (2006). Human impact on the hydrology of the Andean páramos. *Earth Sci. Rev.*, *79*(1–2), 53–72. https://doi.org/10.1016/j.earscirev.2006.06.002.

Capodaglio, A. G., Callegari, A., Cecconet, D., & Molognoni, D. (2017). Sustainability of decentralized wastewater treatment technologies. *Water Pract. Technol.*, *12*(2), 463–477. https://doi.org/10.2166/wpt.2017.055.

Carballo, F. M., Brito, L. M., Mero, P. C., Aguilar, M. A., & Ramírez, J. T. (2019). Urban wastewater treatment through a system of green filters in the Montañita commune, Santa Elena, Ecuador. In *WIT Transactions on Ecology and the Environment*, WIT Press, pp. 233–249. https://doi.org/10.2495/WS190211.

Carrión-Mero, P., Ayala-Granda, A., Serrano-Ayala, S., Morante-Carballo, F., Aguilar-Aguilar, M., Gurumendi-Noriega, M., Paz-Salas, N., Herrera-Franco, G., & Berrezueta, E. (2020). Assessment of geomorphosites for geotourism in the northern part of the “ruta escondida” (Quito, ecuador). *Sustainability*, *12*(20), 8468. https://doi.org/10.3390/su12208468.

Carrión-Mero, P., Morante-Carballo, F., Herrera-Franco, G., Jaya-Montalvo, M., Rodríguez, D., Loor, C., & Berrezueta, E. (2021). Community-university partnership in water education and linkage process. Study case: Manglaralto, Santa Elena, Ecuador. *Water*, *13*(15), 25. https://doi.org/10.3390/w13151998.

Carroll, J. M., Beck, J., Boyer, E. W., Dhanorkar, S., & Gupta, S. (2019). Empowering community water data stakeholders. *Interact. Comput.*, *31*(5), 492–506. https://doi.org/10.1093/iwcomp/iwz032.

Chávez-Velásquez, R. (2022). Mountain protected areas and ecotourism for sustainable development: A case study of Ecuador, In *Montology Palimpsest*, Springer, Cham, pp. 375–396. https://doi.org/10.1007/978-3-031-13298-8_21.

Christmann, T. & Oliveras, I. (2020). Nature of alpine ecosystems in tropical mountains of south america. In *Encyclopedia of the World's Biomes*, Elsevier, pp. 282–291. https://doi.org/10.1016/B978-0-12-409548-9.12481-9.

Dudley, B. & May, L. (2007). *Estimating the phosphorus load to waterbodies from septic tanks*. https://nora.nerc.ac.uk/id/eprint/2531/2/DudleySepticTanksRep.pdf

Đurkin, J. & Perić, M. (2017). Organising for community-based tourism: Comparing attitudes of local residents and local tourism entrepreneurs in Ravna Gora, Croatia. *Local Econ. J. Local Econo. Policy Unit*, *32*(7), 678–691. https://doi.org/10.1177/0269094217734811.

Empresa metropolitana de alcantarillado y agua potable de Quito. (2009). *Norma de diseño de sistemas de* *alcantarillado para la empresa metropolitana de alcantarillado y agua potable de Quito*. https://www.aguaquito.gob.ec/Alojamientos/PROYECTO%20LA%20MERCED/ANEXO%202%20NORMAS_ALCANTARILLADO_EMAAP.pdf

Fonseca, K., Espitia-Sarmiento, E. F., Ilbay-Yupa, M., & Breuer, L. (2024). Integrating community knowledge into nature-based solutions for the sustainability of water ecosystem services: Insight from local communities in Ecuador. *Front. Sustain.*, *5*. https://doi.org/10.3389/frsus.2024.1491776.

García, V. J., Márquez, C. O., Isenhart, T. M., Rodríguez, M., Crespo, S. D., & Cifuentes, A. G. (2019). Evaluating the conservation state of the páramo ecosystem: An object-based image analysis and CART algorithm approach for central Ecuador. *Heliyon*, *5*(10), e02701. https://doi.org/10.1016/j.heliyon.2019.e02701.

Hawkins, P., Blackett, I., & Heymans, C. (2013). *Poor Inclusive Urban Sanitation : An Overview*. World Bank Group. https://openknowledge.worldbank.org/handle/10986/17385

Hernández Muñoz, A., Hernández Lehmann, A., & Galán Matínez, P. (2004). *Manual de Depuración Uralita : Sistemas Para Depuración de Aguas Residuales en Núcleos de Hasta 20.000 Habitantes*. Ediciones Paraninfo.

Hinde, A. (2014). *Demographic Methods*. Taylor & Francis.

Huertas, R. & Marcos, C. (2012). *GUÍA PRÁCTICA para la depuración de aguas residuales en pequeñas poblaciones*. https://www.diputaciondepalencia.es/system/files/generico/archivos/20190709/guiapractica-depuracionaguas-chd.pdf

INEC. (2022). *Población y Demografía*. Insitituto Nacional de Estadística y Censo. https://www.ecuadorencifras.gob.ec/censo-de-poblacion-y-vivienda/

Instituto Ecuatoriano de Normalización. (1992). Código de practica para el diseño de sistemas de abastecimiento de agua potable, disposición de excretas y residuos líquidos en el área rural. https://inmobiliariadja.wordpress.com/wp-content/uploads/2016/09/normas_disec3b1o_cpe_inen_5_parte_9-2_1997-menos-de-1000-hab.pdf

Instituto Nacional de Estadística y Censo. (2022). *Boletín Técnico Nacional*. https://www.censoecuador.gob.ec/public/Boletin_Nacional.htm#6_VIVIENDAS5

Instituto Privado de Investigación sobre Cambio Climático. (2017). *Manual de Medición de Caudales*. https://icc.org.gt/wp-content/uploads/2023/03/064.pdf

Kennedy, P. & Geel, P. J. V. A. N. (2000). Hydraulics of peat filters treating septic tank effluent. *Transp. Porous Media*, 47–60. https://doi.org/10.1023/A:1006796827147.

Kitzinger, J. (1994). The methodology of focus groups: The importance of interaction between research participants. *Sociol. Health Illness*, *16*(1), 103–121. https://doi.org/10.1111/1467-9566.ep11347023.

Lasagna, M. & De Luca, D. A. (2019). Evaluation of sources and fate of nitrates in the western Po plain groundwater (Italy) using nitrogen and boron isotopes. *Environ. Sci. Pollut. Res.*, *26*(3), 2089–2104. https://doi.org/10.1007/s11356-017-0792-6.

Leigh, D. (2010). SWOT analysis. In *Handbook of Improving Performance in the Workplace: Volumes 1-3*, John Wiley & Sons, pp. 115–140. https://doi.org/10.1002/9780470592663.ch24,

Likert, R. (1932). A technique for the measurement of attitudes. *Arch. Psycol.*, *22*(140), 55. https://psycnet.apa.org/record/1933-01885-001.

Mahapatra, S., Samal, K., & Dash, R. R. (2022). Waste Stabilization Pond (WSP) for wastewater treatment: A review on factors, modelling and cost analysis. *J. Environ. Manage.*, *308*, 114668. https://doi.org/10.1016/j.jenvman.2022.114668.

Mancini, M. C., Arfini, F., & Guareschi, M. (2022). When higher education meets sustainable development of rural areas: Lessons learned from a community–University partnership. *Soc. Sci.*, *11*(8), 338. https://doi.org/10.3390/socsci11080338.

Massoud, M. A., Tarhini, A., & Nasr, J. A. (2009). Decentralized approaches to wastewater treatment and management: Applicability in developing countries. *J. Environ. Manage.*, *90*(1), 652–659. https://doi.org/10.1016/j.jenvman.2008.07.001.

Metcalf & Eddy. (1995). *Ingeniería de Aguas Residuales: Tratamiento, Vertido y Reutilización, 3rd ed.* McGraw-Hill.

Ministerio del Ambiente Agua y Transición Ecológica del Ecuador. (2015). *Revisión del anexo 1 del libro vi del Texto Unificado de Legislación Secundaria del Ministerio del Ambiente: Norma de calidad ambiental y descarga de efluentes al recurso agua.* https://www.cip.org.ec/attachments/article/1579/PROPUESTA%20ANEXO%201.pdf

Molina, A., Pozo, M., & Serrano, J. C. (2018). *Agua, saneamiento e higiene: medición de los ODS en Ecuador*. https://www.ecuadorencifras.gob.ec/documentos/web-inec/Bibliotecas/Libros/AGUA,_SANEAMIENTO_e_HIGIENE.pdf

Morante-Carballo, F., Parrales-Gómez, M., Pozo-Ramos, E., & Dueñas-Tovar, J. (2024). Wastewater treatment using green filters systems in a small urban area for a reforestation pilot plan. In *Sustainable Development with Renewable Energy*, Springer, Cham, pp. 345–358. https://doi.org/10.1007/978-3-031-54394-4_27.

Mosquera, G. M., Hofstede, R., Bremer, L. L., Asbjornsen, H., Carabajo-Hidalgo, A., Célleri, R., Crespo, P., Esquivel-Hernández, G., Feyen, J., Manosalvas, R., et al. (2023). Frontiers in páramo water resources research: A multidisciplinary assessment. *Sci. Total Environ.*, *892*, 164373. https://doi.org/10.1016/j.scitotenv.2023.164373.

Muya, A. (2024). *Centralized Wastewater Treatment: How it Works?* Express Drainage Solutions Limited. https://www.expresswatersolutions.com/waste-management/centralized-wastewater-treatment-how-it-works/

Nanninga, T. A., Bisschops, I., López, E., Martínez-Ruiz, J. L., Murillo, D., Essl, L., & Starkl, M. (2012). Discussion on sustainable water technologies for peri-urban areas of mexico city: balancing urbanization and environmental conservation. *Water*, *4*(3), 739–758. https://doi.org/10.3390/w4030739.

Naranjo Borja, E., Abad Merchán, A., & Ramos, V. (2018). Factores culturales de logro del sistema de producción comunitaria de la parroquia salinas en la provincia de Bolívar, Ecuador. *Chakiñan, Revista De Ciencias Sociales Y Humanidades*, *6*, 136–148. https://doi.org/10.37135/chk.002.06.09.

Nasim, N., El-Zein, A., & Thomas, J. (2022). A review of rural and peri-urban sanitation infrastructure in South-East Asia and the Western Pacific: Highlighting regional inequalities and limited data. *Int. J. Hyg. Environ. Health*, *244*, 113992. https://doi.org/10.1016/j.ijheh.2022.113992.

Neuberger-Cywiak, L. (2001). Diferentes Métodos utilizados en la Evaluación de Impacto Ambiental (EIA). *Doctum*, *4*(2), 90–107.

Novotný, J., Hasman, J., & Lepič, M. (2018). Contextual factors and motivations affecting rural community sanitation in low- and middle-income countries: A systematic review. *Int. J. Hyg. Environ. Health*, *221*(2), 121–133. https://doi.org/10.1016/j.ijheh.2017.10.018.

Obaideen, K., Shehata, N., Sayed, E. T., Abdelkareem, M. A., Mahmoud, M. S., & Olabi, A. G. (2022). The role of wastewater treatment in achieving sustainable development goals (SDGs) and sustainability guideline. *Energy Nexus*, *7*, 100112. https://doi.org/10.1016/j.nexus.2022.100112.

Organización Panamericana de la Salud & Centro Panamericano de Ingeniería Sanitaria y Ciencias del Ambiente. (2005). *Guía para el diseño de tanques sépticos, tanques Imhoff y lagunas de estabilización*. https://sswm.info/sites/default/files/reference_attachments/OPS%202005.%20Gu%C3%ADa%20para%20el%20dise%C3%B1o%20de%20tanques%20s%C3%A9pticos.pdf

Ramírez-Gómez, C. J., García-Cuervo, A., & Rodriguez-Espinosa, H. (2025). The adoption of sustainable practices in livestock production systems in tropical Andean Páramos. *Front. Sustain. Food Syst.*, *8*. https://doi.org/10.3389/fsufs.2024.1461713.

Ramón, G. (2002). *Visiones, Usos e Intervenciones en los Páramos del Ecuador* (GTP/Abya-Y). GTP/Abya-Yala.

Raymondo, J. (1992). *Population Estimation and Projection Methods for Marketing, Demographic, and Planning Personnel*. Bloomsbury Academic.

Rehman, A., Anees, M., Sehar, S., Alhewairini, S. S., Saroj, D. P., & Ahmed, S. (2021). Simulated modelling, design, and performance evaluation of a pilot-scale trickling filter system for removal of carbonaceous pollutants from domestic wastewater. *Water*, *13*(22), 3210. https://doi.org/10.3390/w13223210.

Robineau, O., Châtelet, M., Soulard, C.-T., Michel-Dounias, I., & Posner, J. (2010). Integrating farming and páramo conservation: A case study from Colombia. *Mountain Res. Dev.*, *30*(3), 212–221. https://doi.org/10.1659/MRD-JOURNAL-D-10-00048.1.

Ross, S. (2020). Sightseeing the Anthropocene: tourism, moorland management, and the hound of the baskervilles. *Nineteenth Century Contexts*, *42*(4), 449–465. https://doi.org/10.1080/08905495.2020.1782018.

Rout, P. R., Zhang, T. C., Bhunia, P., & Surampalli, R. Y. (2021). Treatment technologies for emerging contaminants in wastewater treatment plants: A review. *Sci. Total Environ.*, *753*, 141990. https://doi.org/10.1016/j.scitotenv.2020.141990.

Ruiz-Ballesteros, E. (2011). Social-ecological resilience and community-based tourism. *Tour. Manage.*, *32*(3), 655–666. https://doi.org/10.1016/j.tourman.2010.05.021.

Schmidt, I. B., Urzedo, D. I., Piña-Rodrigues, F. C. M., Vieira, D. L. M., Rezende, G. M., Sampaio, A. B., & Junqueira, R. G. P. (2019). Community-based native seed production for restoration in Brazil—The role of science and policy. *Plant Biol.*, *21*(3), 389–397. https://doi.org/10.1111/plb.12842.

Schober, P., Boer, C., & Schwarte, L. A. (2018). Correlation Coefficients. *Anesthesia Analgesia*, *126*(5), 1763–1768. https://doi.org/10.1213/ANE.0000000000002864.

Scholz, M. (2016). Biological filtration. In *Wetlands for Water Pollution Control*, Elsevier, pp. 81–85. https://doi.org/10.1016/B978-0-444-63607-2.00013-7.

Sehar, S. & Naz, I. (2016). Role of the biofilms in wastewater treatment. In *Microbial Biofilms - Importance and Applications*. InTech. https://doi.org/10.5772/63499.

Sevillano-Ríos, C. S., Rodewald, A. D., & Morales, L. V. (2020). Alpine birds of south America. In *Encyclopedia of the World's Biomes*, Elsevier, pp. 492–504. https://doi.org/10.1016/B978-0-12-409548-9.11806-8.

Shirazi, S. M., Adham, M. I., Zardari, N. H., Ismail, Z., Imran, H. M., & Mangrio, M. A. (2015). Groundwater quality and hydrogeological characteristics of Malacca state in Malaysia. *J. Water Land Dev.*, *24*(1), 11–19.

https://doi.org/10.1515/jwld-2015-0002.
Singh, A. (2021). A review of wastewater irrigation: Environmental implications. *Resour. Conserv. Recycl.*, *168*, 105454. https://doi.org/10.1016/j.resconrec.2021.105454.
Singh, N. K., Kazmi, A. A., & Starkl, M. (2015). A review on full-scale decentralized wastewater treatment systems: Techno-economical approach. *Water Sci. Technol.*, *71*(4), 468–478. https://doi.org/10.2166/wst.2014.413.
Singh, S., Hariteja, N., Renuka Prasad, T. J., Raju, N. J., & Ramakrishna, C. (2020). Impact assessment of faecal sludge on groundwater and river water quality in Lucknow environs, Uttar Pradesh, India. *Groundwater Sustain. Dev.*, *11*, 100461. https://doi.org/10.1016/j.gsd.2020.100461.
Torres, M. C., Naranjo, E., & Fierro, V. (2023a). Challenges facing andean communities in the protection of the páramo in the central highlands of Ecuador. *Sustainability*, *15*(15), 11980. https://doi.org/10.3390/su151511980.
Torres, M. C., Naranjo, E., Fierro, V., & Carchipulla-Morales, D. (2023b). Social technology for the protection of the páramo in the Central Andes of Ecuador. *Mountain Res. Dev.*, *43*(4). https://doi.org/10.1659/mrd.2022.00022.
Tortajada, C. (2020). Contributions of recycled wastewater to clean water and sanitation Sustainable Development Goals. *Npj Clean Water*, *3*(1), 22. https://doi.org/10.1038/s41545-020-0069-3.
UNESCO World Water Assessment Programme. (2020). *Informe Mundial de las Naciones Unidas sobre el Desarrollo de los Recursos Hídricos 2020: Agua y Cambio Climático*. https://unesdoc.unesco.org/ark:/48223/pf0000373611.locale=es
Vollmer, D., Burkhard, K., Adem Esmail, B., Guerrero, P., & Nagabhatla, N. (2022). Incorporating ecosystem services into water resources management—Tools, policies, promising pathways. *Environ. Manage.*, *69*(4), 627–635. https://doi.org/10.1007/s00267-022-01640-9.
Waqas, S., Harun, N. Y., Sambudi, N. S., Bilad, M. R., Abioye, K. J., Ali, A., & Abdulrahman, A. (2023). A review of rotating biological contactors for wastewater treatment. *Water*, *15*(10), 1–19. https://doi.org/10.3390/w15101913.
Wong, L. T., Mui, K. W., & Zhang, D. (2025). International service-learning projects on water sustainable management in higher education: A case study on improving water quality in a needy community. *Int. J. Sustaina. Higher Educ.*. https://doi.org/10.1108/IJSHE-03-2024-0186.
Xie, Y. D., Zhang, Q. H., Li, Y., Jin, P. K., Dzakpasu, M., & Wang, X. C. (2022). A new paradigm of sewage collection in rural areas. *Environ. Sci. Pollut. Res.*, *30*(11), 28609–28620. https://doi.org/10.1007/s11356-022-24014-4.
Yap, C., Mcfarlane, C., Ndezi, T., & Makoba, F. D. (2023). Sanitation challenges in Dar es Salaam: The potential of simplified sewerage systems. *Environ. Urban.*, *35*(1), 12–29. https://doi.org/10.1177/09562478221146722.
Yin, H., Xie, M., Zhang, L., Huang, J., Xu, Z., Li, H., Jiang, R., Wang, R., & Zeng, X. (2019). Identification of sewage markers to indicate sources of contamination: Low cost options for misconnected non-stormwater source tracking in stormwater systems. *Sci. Total Environ.*, *648*, 125–134. https://doi.org/10.1016/j.scitotenv.2018.07.448.
Zhang, R., Wang, Z., Cao, Z., Rousseau, D. P. L., & Hulle, S. Van. (2025). Addressing the rural wastewater treatment dilemma: A techno-environmental-economic analysis. *Chem. Eng. J.*, *504*, 158905. https://doi.org/10.1016/j.cej.2024.158905.

Nomenclature

SWOT	Strengths, Opportunities, Weaknesses and Threats
CC	Pollutant load, kg/day
CC_p	Contributing load per person, kg/day*hab
BOD_5	Biochemical Oxygen Demand, mg/l
TSS	Total Suspended Solids, mg/l
CRI	Integrated Relevant Criteria
EIA	Environmental Impact Assessment
TF	Trickling filter
EIV	Environmental Index Value
Ø	Pipe diameter