Assessment of the Tourist Carrying Capacity in the Manglaralto River–Aquifer System, Santa Elena (Ecuador): A UNESCO Ecohydrology Demonstration Site

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Abstract

The UNESCO-sponsored ecohydrology demonstration sites function as natural spaces designed for water purification and nutrient reduction, promoting sustainable management based on both technical and ancestral ecological processes. The unique characteristics of these sites have attracted the interest of visitors, researchers, and students interested in ecotourism, environmental education, and conservation. Assessing tourism carrying capacity plays a key role in ensuring the ecological, social, and cultural sustainability of such sites. This study aims to determine the tourist carrying capacity of the Manglaralto River-Aquifer System, identifying interactions between visitors and water resources using analytical tools, to promote sustainable and responsible management of the water resources. The methodology involved applying a cause-and-effect matrix, which allowed for the visualisation of six negative components, with magnitudes ranging from -3.5 to -9, that affect the interaction between environmental quality and tourism performance. This assessment allowed for the definition of management strategies, such as reforestation, signage, and community participation. The approach of these measures integrates ecohydrological practices as an educational tourism element, promoting environmental awareness and positioning Manglaralto as a replicable model for marine coastal systems sensitive to anthropogenic activity.

Keywords

Geosites, Ecology, Aquifers, Sustainability

1. Introduction

For decades, people have taken advantage of places with singular natural landscapes to engage in tourism, causing significant modifications to the ecosystem. The development of tourism is usually supported using land for the construction of infrastructure, the creation of regulations related to over-accommodation and construction, and the promotion of historical, cultural, and natural attractions [1]. Marine-coastal tourism is growing daily and is key to the economic reports of each sector [2]. Mark [3], defined marine tourism as recreational activities carried out on a trip that involve the marine environment. On many occasions, tourists are unaware of the conservation of marine coastal fauna and associated ecosystems, such as beaches, plains, tidal flats, dunes, and estuaries [4, 5].

One way to mitigate visitor damage in tourist areas is through carrying capacity, a definition first introduced in 1921 [6, 7], and described as the most significant capacity of an environment to resist environmental changes. Carrying capacity was mainly used in the field of ecology to determine the number of animals or plants in a specific area [8]. Later, it was modified and conceptualised as the assumption of the area available for tourism and the number of visitors that the place can accommodate without altering its ecosystem, considering the physical, biological, environmental

ICAIW 2025: Workshops at the 8th International Conference on Applied Informatics 2025, October 8–11, 2025, Ben Guerir, Morocco
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factors and characteristics of the place [9, 10]. There are two approaches to tourism carrying capacity: the first covers the destination's willingness to accommodate tourists before damage is caused to the ecosystem, and the second is based on the negative experience of the tourist's perception of the poor conditions of the environment, making the place less satisfactory and attractive [11].

In recent years, the need to preserve coastal tourism sites has led to tourism development plans being adjusted to include broader environmental and sociocultural concerns [12, 13]. Since 2011, the United Nations Educational, Scientific and Cultural Organisation (UNESCO) through the International Hydrological Programme (IHP) has promoted the creation of demonstration sites in various parts of the world, implementing ecohydrological solutions in watersheds at different scales [14]. The demonstration sites aim to showcase ecohydrology as a transdisciplinary science. In 2001, the IHP supported initiatives that achieved scientific progress and fostered transparency of knowledge, promoting education. To this end, criteria have been defined to identify places where innovative and sustainable water management is implemented [15].

The concept of ecohydrology is represented by the approach to the restoration and sustainability of water resources, serving as an additional tool to control the ecological degradation of water and surface processes [5]. Within the framework of water sustainability, ecohydrology relates hydrology to environmental and biotic processes [16]. This approach seeks to understand and take advantage of the functions of these processes to achieve a correct balance in ecosystems, especially those that have been disturbed by humans [17]. In coastal areas, ecohydrology is key to the sustainability of the ecosystem, as the process of interaction between freshwater and saltwater mitigates the impacts of coastal erosion and saline pollution [18].

Coastal ecohydrology focuses on the restoration of the carrying capacity of estuarine and coastal areas, allowing the concept of management, harmonisation, and solutions to problems in basins [17]. An example of coastal ecohydrology is the case of the Guadiana River estuary (Portugal), declared an Ecohydrology Demonstration Site (EDS) by UNESCO in 2006 [19], where a dam was built to reduce dependence on water from Spain and the irrigation of 22.3% in the agricultural area [16, 19]. Another example is the Lacar Lake EDS project (Argentina), recognised in 2005, representing Latin America and the Caribbean, by exhibiting the application of ecohydrological approaches in a basin [15]. In Ecuador there are three EDS located in the Andean, coastal and island regions, being Palta Catacocha, Loja (2018) the first EDS in Ecuador, considered as an artificial reservoir where rain and runoff water are used to recharge the associated aquifer [16], Pelican Bay, Galapagos (2019) stands out for its ecological importance, and the management of water resources on Santa Cruz Island [15] and the most recent Manglaralto, Santa Elena (2025) which is characterised by the river-aquifer system and its role in supplying rural coastal communities [20].

The province of Santa Elena (SEP) is a semi-arid area, whose freshwater distribution resources are differentiated according to geographical location and resources. For example, the southern zone of the SEP is based on the Chongo-Colonche and Azúcar reservoirs of the Daule-Guayas River transfer and the administration of the public company [21, 22]. The northern zone depends on coastal aquifers and the management of community water organisations [23]. Manglaralto is north of the SEP and has two types of climates characterised by the season of intense rains (February-April) and moderate rains, "garuas" (July-December) [24, 25], with temperatures that fluctuate between 22 °C and 26 °C. This commune is made up of an impermeable lithology favouring the accumulation of water, while the permeable layer is composed of Quaternary alluvial deposits, where the inhabitants have taken advantage of underground water resources through artisanal wells [20].

The Manglaralto River-Aquifer System is a project declared as an EDS in March 2025, which stands out for the influence of the "tape" (technical-artisanal dam) in the biota-hydrology processes of the Manglaralto River sub-basin [20]. This hydraulic structure allows the retention of rainwater flows in the seasonal riverbed, allowing infiltration into the soil and recharging the aquifer (sowing process), to be later used through wells built by the community organisation Junta Administradora de Agua Potable Regional Manglaralto (JAAPMAN) for controlled extraction in times of drought (harvesting process) [24]. In this context, it is necessary to evaluate the tourist carrying capacity at demonstration sites, such as the Manglaralto River-Aquifer System, to establish strategies according to sustainability trends and water resource management. Coastal areas are places of connection between land and ocean, where beach tourism is carried out to improve socioeconomic conditions. This anthropic activity poses particular challenges in the degradation and loss of the marine-coastal ecosystem [26, 27]. Faced with this problem, the following research questions are posed: What is the tourist carrying capacity of the Manglaralto River-Aquifer System? What strategies are proposed to contribute to the ecohydrological, hydrogeological and socioeconomic sustainability of the UNESCO ecohydrology demonstration site? The study aims to evaluate the tourist carrying capacity in the Manglaralto River-Aquifer System, through physical, ecological, and social indicators and the cause-effect methodology, to obtain the minimum number of tourists necessary for the definition of sustainability strategies for water resources.

2. Material and methods

This study evaluates quantitative and qualitative techniques for analysing tourism carrying capacity within the Manglaralto River-Aquifer system using environmental and social criteria. The process involves three research phases: i) data collection and analysis, ii) assessment of tourism carrying capacity, and iii) formulation of sustainability strategies (Figure 1).

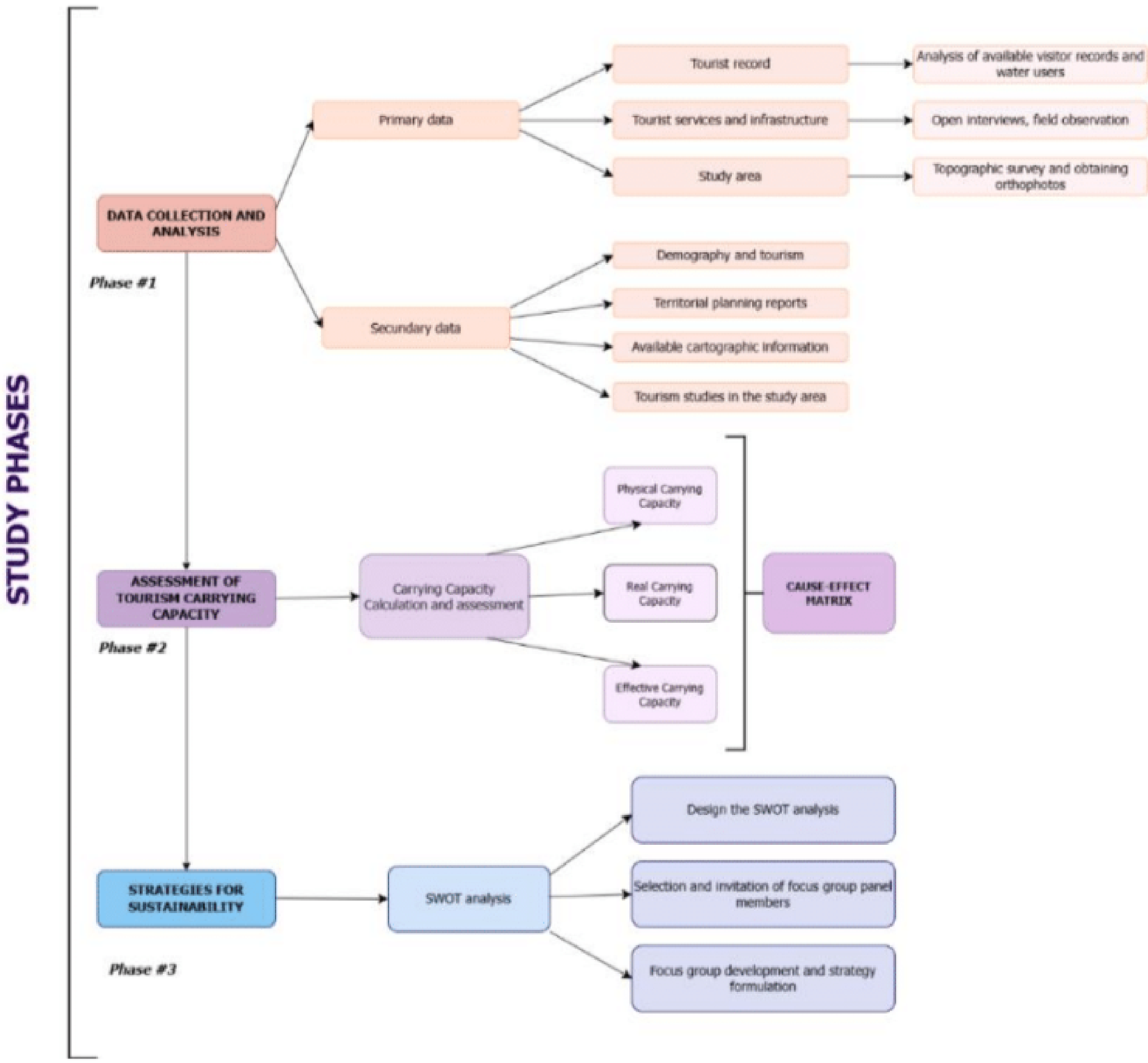

Figure 1: Methodology applied for the evaluation of the tourism carrying capacity of the Ecohydrology Demonstration Site in Manglaralto.

2.1. Phase I: Data collection and analysis

The first phase consisted of the collection of primary and secondary information using various tools for documentary and spatial analysis, field observations, and open interviews. Data on the number of inhabitants were obtained by analysing population information from official sources, such as the census conducted by the National Institute of Statistics and Census (INEC) [28]. Meanwhile, available visitor records were provided by JAAPMAN, and the type of tourist, duration, and main activities carried out during their stay were evaluated.

Additionally, during this stage, accessibility, services, and tourism infrastructure were evaluated through observation, field visits, open-ended interviews with the water board president and operators, and the use of georeferenced tracking mobile devices (Geo Tracker version 5.4.1.4346). This application allowed us to determine the distance and duration of the trip. The study area was delimited by a topographic survey using differential GPS (EGM 1996) and a drone (DJI Mavic Pro-2). The images obtained were processed using Agisoft Metashape (version 1.8.4) and QGIS software to obtain Digital Elevation Models and orthomosaics. This spatial information provided information on the area and physical characteristics of the site.

2.2. Phase II: Assessment of tourism carrying capacity

Phase II evaluated tourist carrying capacity following the method proposed by Cifuentes [29], which is used to estimate the maximum number of visitors a site can accommodate based on physical, social, environmental, and administrative conditions [30, 31]. Three components were considered [32]:

- Physical Carrying Capacity (PCC): This is the limit of tourists that a site can receive in a specific time and space.
- Carrying Capacity (RCC): This is composed of correction factors that directly and indirectly affect the site.
- Effective Carrying Capacity (ECC): This is the management or administrative capacity of the site.

Physical carrying capacity (PCC)

To calculate the physical carrying capacity of the SDE, the following parameters were determined: the total area of the site, the number of daily hours it is open to the public, the average duration of a tourist visit, and, in the case of the trail, the estimated time it takes for a visitor to complete the route. These elements formed the basis for evaluating the physical carrying capacity of the site, without considering additional factors such as vegetation, infrastructure, or ecological fragility. Physical carrying capacity represents the maximum number of visitors a site can accommodate simultaneously under ideal conditions without generating immediate negative impacts. This value was calculated using the following equation 1, proposed by Cifuentes [29]:

$$CCP = \frac{A}{ap}.NV \tag{1}$$

Where: CCP =Physical Carrying Capacity, A = total area of the site, ap = area occupied by a person, NV = number of times the site can be visited.

Real carrying capacity

To determine the real capacity, it was necessary to decide on the correction factors according to Cifuentes [29]. In this study, the factors were social (how many people enter), erodibility (the eroded area of the site), rainfall per year, solar radiation per year, limiting days per year (for maintenance or nesting), vegetation, and accessibility [29]. Subsequently, the actual load capacity of the site was calculated according to Cifuentes' equation 2:

$$RCC = PCC * CFX * CFY * ...CFZ \tag{2}$$

Where: RCC = Real Carrying capacity, PCC = Physical Carrying capacity, $CFX, Y...Z$ = correction factors.

Effective Carrying Capacity (ECC)

Additionally, the ECC was determined by the product between the RCC and the handling capacity (HC), which is presented in equation 3:

$$ECC = RCC * HC \tag{3}$$

Where: ECC = Carrying capacity, RCC = Real Carrying Capacity, HC = Handling capacity represented by the equation 4:

$$HC = \frac{equip + infra + pers}{3} \tag{4}$$

Cause-and-effect matrix

The cause-effect matrix is a tool to identify the effect based on a set of qualitative characteristics to measure the environmental impact [33, 34]. In this case, eight tourist activities were considered, and the affected component, based on the magnitude, was observed. The characteristics to be considered are listed in Table 1:

Table 1
Characteristics of the cause-effect matrix for qualitative and quantitative evaluation.

Characteristics	Description	Characteristics	Description
Nature	Beneficial = 1 Adverse = -1	**Reversibility**	Short Term = 1 Long term= 2
Probability	Unlikely =0,1 Probable = 0,5 Certain=1	**Intensity**	Low=1 Medium=2 High=3
Duration	Temporary=1 Permanent=2	**Exclusivity**	Puntual =1 Local = 2 Regional =3

The magnitude of the environmental impact was obtained according to the characteristics of the impact using the following equation 5:

$$Magnitude = Nat * Pro * (Dur + Rev + Int + Exc) \tag{5}$$

Where: Nat = Nature, Pro = Probability, Dur = Duration, Rev = Revesibility, Int = Intensity, Exc = Exclusivity.

Table 2 establishes the qualitative and quantitative ranges used to evaluate the impact of tourism activities. The evaluation considers criteria such as the magnitude range of the impact, which ranges from -9 to +7, and the interpretation of the impact, ranging from high negative to high positive [34].

2.3. Phase III: Strategies for sustainability

To ensure effective and participatory planning, the creation of a multidisciplinary panel for the formulation of an environmental strategy was proposed. The panel comprised 13 members selected based on rigorous criteria, such as technical experience in hydrology, ecology, geology, and tourism, as well as community leadership, institutional representation, and local cultural knowledge from the six communities benefiting from the JAAPMAN service. The composition of the panel included the

Table 2
Impact classification according to magnitude range.

Magnitude Impact Range	Impact Assessment	Magnitude Impact Range	Impact Assessment
$\leq$ -9	High Negative Impact	**+1 a +3**	Low Positive Impact
-6 a -8	Medium Negative Impact	**+4 a +6**	Medium Positive Impact
-3 a -5	Low Negative Impact	**$\geq$+7**	High Positive Impact
0	No Impact		

president of the water board, two technical operators of the system, four geological engineers and researchers related to the geosciences, an environmental engineer, a tourism graduate, a civil engineer, and three members of the financial administration of JAAPMAN. The panel was held in person through the workshop 'Main Challenges in the Management of the Demonstrative Ecohydrology Site', held on January 1, 2025, where three rounds were sequentially developed, aimed at creating environmental strategies for the site:

1. **Conceptualization stage:** Where the concept of a 'Demonstration Site' was defined, integrating ecological, technical, and community impacts.
2. **Participatory diagnosis stage:** Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis tools [21] were applied to evaluate the Demonstration Site project to inform sustainable decision-making. This analysis indicates the strengths, opportunities, weaknesses, and threats of the site from the perspective of the representatives of each expert panel. They contributed ideas based on their local experience and shared their vision regarding the challenges and potential opportunities to enhance the site.
3. **Stage of strategy planning and socialization:** Strategies were implemented to manage sustainable tourism, aimed at reducing the impact on the ecosystem and improving the tourist experience in the DSE. These strategies were shared among specialists and community representatives. And it was carried out by applying the crossing of the aspects established in the SWOT analysis.

3. Results and discussion

3.1. Baseline diagnosis and spatial characterization of the demonstration site of the Manglaralto-Aquifer River

The DSE has an area of 1891.55 m2, of which 809 m2 is enabled for tourism activities (figure 2), while the remaining area is covered by vegetation. The walking tour of the site takes approximately 20 minutes, starting at the pumping station, where an introduction to the local water catchment system is provided. Next, the visit proceeds to Well 1, where historical and technical information about the construction of the well is provided, highlighting the role of international cooperation projects between ESPOL and the International Atomic Energy Agency (IAEA). At this point, monthly monitoring of physicochemical analyses and static/dynamic water levels (Figure 3a) is regularly conducted, allowing for the assessment of its quality and hydrogeological characteristics. Well 2 serves the purpose of monitoring the static level of the aquifer, providing essential information for understanding the behaviour of the underground system and the state of the water table at different times of the year.

Continuing with the tour, we reached the halfway point of the journey, where the upstream environment of the Manglaralto River can be observed (Figure 3b). In front, there is an observation area for the endemic species of the region (Figures 4a and 4b), which enhances the ecological experience of the trail. Moving along the route, the journey concluded at the 'tape' dam, a place used by residents for artisanal shrimp fishing and as a water recreation area. On warm afternoons, this site becomes a gathering place where dozens of families enjoy the natural scenery and the freshwater of the Manglaralto River (Figure 4c) for almost three hours. Furthermore, the 'tape' is used like a didactic example of the technique for sowing and harvesting water that facilitates the recharge of the coastal aquifer.

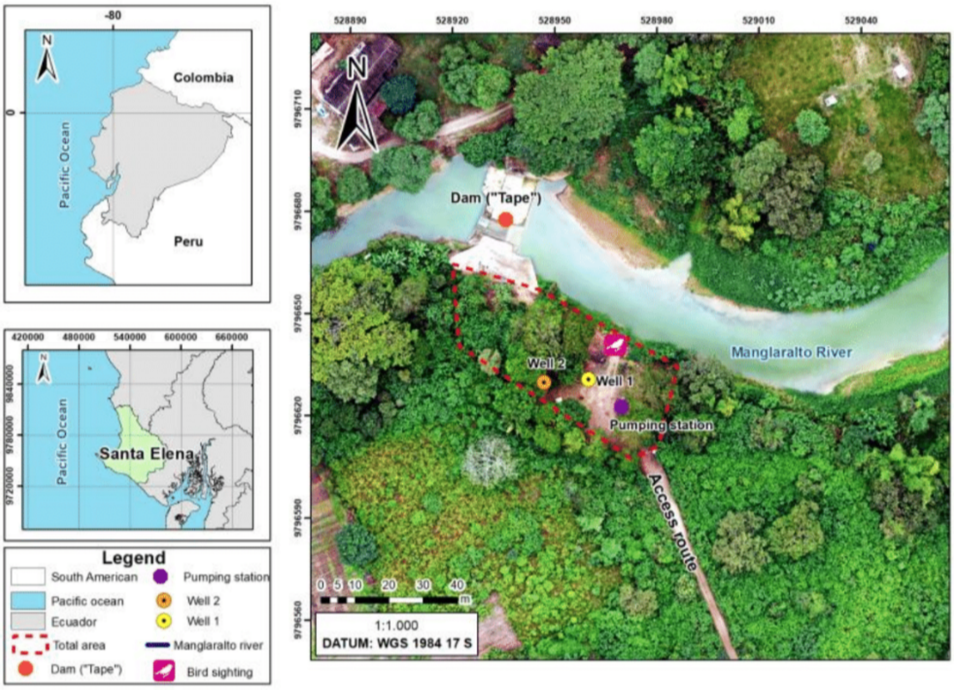

Figure 2: Location map and delimitation of the area corresponding to the Manglaralto River-Aquifer System.

(a) Monitoring activity of levels and physicochemical parameters of wells.

(b) View of the upper part of the Manglaralto River.

Figure 3: Community wells and Manglaralto River upstream

Regarding the site's basic infrastructure, it is enclosed by fencing but lacks essential amenities such as signage, paved pathways, sanitary facilities, food courts, information kiosks, and waste disposal services. From an environmental management perspective, the only existing measure is a warning sign indicating deep waters, which is poorly visible due to surrounding vegetation. From a tourist service perspective, there are no designated guides available during visiting hours to monitor visitor numbers or to tour the characteristics of the Manglaralto River–Aquifer System.

3.2. Assessment of environmental impacts and tourism carrying capacity of the site

The FCC of the DSE is 2523 visitors per day, considering the entire site area. To obtain the RCC, correction factors were considered, and a total of 698 visitors per day was obtained. In the ECC, a 0.33%

(a) Golden-toed Heron (Egretta thula)

(b) Blue Heron (Ardea herodias).

(c) Panoramic view of the ’tape’ dam

Figure 4: Ecological and hydrological features

was obtained considering the handling capacity at the site, with a daily tourist load capacity of 24 people without causing ecological collapse. A similar case study is the Complejo Educativo Ambiental Naciente Arriaz (CEANA) in Costa Rica, which encompasses 4.31 hectares of forest protecting a spring that is used for supplying drinking water to the communities of “Taras”, “La Lima”, and part of “La Fátima”, where ecotourism activities are conducted. At CEANA, it was established that the three trails should be used by an average of 26 people per day to maintain the ecological balance of the site in relation to the spring season. However, before 2019, this spring was affected by vandalism and pollution, which led to the creation of a fence around it to ensure the sustainability of the site [35]. Even in UNESCO World Heritage sites like Angkor, it has been shown that a 6% increase in annual visits can cause impacts on the unique elements of this type of site, including temples and heritage monuments, as well as generating impacts on freshwater sources due to excessive tourism, such as the extraction of more than 27,900 m^3 of groundwater [36]. According to scientific literature [37, 38] sustained tourist pressure on ecosystems can lead to gradual degradation of their natural and cultural attributes, ultimately rendering the site unsuitable for visitation. In the context of UNESCO demonstration sites, where the dual objective is to promote sustainable use while conserving ecological integrity, calculating the tourist carrying capacity becomes a key management tool.

For the analysis of the cause-effect matrix, tourist activity (cause) and the affected component (effect) were considered. Recreational activities, such as walking on unpaved trails, bird watching, artisanal fishing, excessive use of the dam, presence of garbage in the dam, and vehicle frequency, were found to have negative impacts, with magnitudes between -9 and -3.5 (Table 3). Meanwhile, activities that integrate socio-educational values had positive impacts with magnitudes of +4 and +5.

Table 3
Environmental impact assessment, through the cause-effect matrix.

Tourist Activity	Affected Component	Nat	Pro	Dur	Rev	Int	Ext	Mag	Observation
Hike with unpaved trail	Soil compaction and erosion	-1	0.5	2	2	2	2	-4	Average negative impact, it is recommended to properly pave the path.
Birdwatching	Endemic fauna (noise stress)	-1	0.5	1	2	2	2	-3.5	Low negative impact
Recreational artisanal fishing	Aquatic ecological balance	-1	0.5	2	2	2	2	-4	Medium negative impact, alteration of shrimp population.
Excessive use of the dam	Recreation and water quality	-1	1	2	2	3	2	-9	High impact, if not controlled.
Presence of garbage in the green area	Vegetation	-1	0.5	2	2	2	2	-4	Average negative impact, ecological pollution.
Proper signage	Landscaping	+1	1	2	1	1	1	+5	Average positive impact, if the design is adequate.
Educational workshop for visitors	Knowledge of the local environment	+1	1	1	1	1	1	+4	Positive impact.
Vehicle frequency	Noise pollution and smoke emission.	-1	0.5	1	1	2	2	-3	Low negative impact

3.3. Strategic guidelines for sustainable tourism in a Manglaralto River-Aquifer demonstration site

Table 4 presents the SWOT analysis of the participatory workshop held in Manglaralto, where the main internal and external factors are displayed, which allowed the establishment of priority strategies for the development of sustainable tourism in the Manglaralto River-Aquifer system, summarized as follows:

- **Basic infrastructure and tourism use planning:**(strategies derived from WO+WA): This includes the development of minimum services (bathrooms, signage, resting areas), site zoning, control of tourist carrying capacity, and implementation of a tourism management and monitoring plan.
- **Environmental education and strengthening the scientific value of the site:** (strategies derived from SO+WO): designing an eco-hydrological and geotourism interpretive trail, generating workshops, guided tours, informational panels, and training local guides. In addition to promoting technical, scientific, and educational tourism at the local level.
- **Conservation of biodiversity and ecological restoration:** (strategies derived from OT+WO): implementation of riparian vegetation restoration programs, control of invasive species and habitat recovery, development of a biological inventory program, and participatory monitoring of flora and fauna in partnership with academia-research.
- **Participatory management and institutional articulation:** (strategies derived from SO+WT+OT): consolidation of a local management unit of the site (JAAPMAN+allies), strengthening of alliances with universities, tourism stakeholders, and cooperation agencies, and development of promotional campaigns for the site in networks of geosites and protected areas at the national and international levels.

4. Conclusions

The study established a tourist load of a minimum of 24 tourists per day, keeping the negative impacts of tourism under control. Through the cause-effect matrix, the most sensitive environmental components were identified. For example, excessive use of the dam for recreational activities could generate significant wear, classified as a high negative impact with a magnitude of -9. In contrast, the implementation of proper signage would contribute to the appreciation of the landscape, classified as a medium positive impact with a magnitude of +5.

Table 4
SWOT analysis conducted in the participatory workshop.

Internal Factors	**Strengths (S)**	**Weaknesses (W)**
External Factors	**S1:** Coastal ecosystem with interaction between water, flora, and fauna, ideal for educational interpretation. **S2:** Site declared by UNESCO as a demonstrative site for ecohydrology in 2025. **S3:** Nature-based solution (NbS) that promotes groundwater recharge and safe water supply to coastal communities. **S4:** Attractive setting for community-based tourism and technical-educational tourism. **S5:** Presence of native riparian vegetation that supports local biodiversity.	**W1:** Lack of tourist services (bathrooms, parking, guides, signage, visitor management system). **W2:** Need for an updated inventory of flora and fauna. **W3:** Risk of erosion of the banks upstream of the dam. **W4:**Limited educational outreach about the ecohydrological role of the site in surrounding communities.
Opportunities (O)	**Strategies S + O**	**Strategies W+O**
O1: Development of an interpretive trail for the promotion of tourism. **O2:** Replicable eco-hydrological model in other sub-basins. **O3:** Design of interpretive stations that explain the hydrological cycle and the importance of the site to visitors. **O4:** Space for coastal geological education and participatory monitoring. **O5:** Potential to carry out other activities such as birdwatching and community workshops on ecological education.	**S1.S2.S4.O1:** Design of the ecohydrological and geotourism interpretive trail. **S2.O2:** Replication of the model in other coastal communities. **S3.S5.O4.O5:** Creation of a community center for environmental education and technical tourism.	**W1.O1.O3:** Generation of proposals for fundraising or partnerships for investment in basic tourism infrastructure and signage. **W2.O5:** Development of the site's biodiversity inventory. **W3.O2:** Strengthening hydrological and geotechnical models through nature-based solutions strategies to prevent riverbank erosion. **W4.O4.O5:** Creation of community training workshops in environmental guiding and participatory monitoring.
Threats (T)	**Strategies: S + T**	**Strategies: W + T**
T1: Erosion of alluvial terraces. **T2:** Urban expansion upstream that could modify the hydrological regime by increasing flows and sediments. **T4:** Uncontrolled deforestation and agricultural expansion could lead to loss of cover and fragmentation of the landscape. **T5:** Introduction of invasive species, disturbances from noise or unregulated human presence. **T6:** Disorganized tourism deteriorates the environment and may interfere with ecohydrological function.	**S2.T3.T6:** Tourist management plan with zoning and flow control for the promotion of responsible tourism with a UNESCO–SbN approach. **S4.T1:** Implementation of ecological restoration practices and control of exotic species. **S1.S3.T2.T5:** Implementation of ecological restoration practices and control of exotic species. **S2.T4:** Integration of the site into the corridor of geosites or local protected areas.	**W1.T6:** Creation of a local management unit for the demonstration site. **W3.T1:** Application of natural physical barriers and erosion control on vulnerable slopes. **W4.T3.T4.T5:** Creation of "Guardians SyCA" campaigns and community regulations for responsible and sustainable use of the site.

Strategies were proposed in the structural area, such as the design of a geotouristic interpretative trail, development of minimum services (bathrooms, signage, resting areas), site zoning, and implementation of a tourism management and monitoring plan. From an educational perspective, the creation of a community centre for environmental education and technical tourism, as well as workshops for community training in environmental guidance and participatory monitoring, was proposed. This study used quantitative approaches based on physical, social, environmental, and administrative conditions, as well as the perceptions of key stakeholders and experts. State space model studies are necessary to quantify carrying capacity from the perspective of ecological efficiency for sustainable and dynamic management of carrying capacity at sites of coastal ecohydrological importance, such as the case study.

Acknowledgements

The authors are grateful for the support provided through the research project "Registry of Geological Sites of Interest in Ecuador for Sustainable Development Strategies" (CIPAT-004-2024), which strengthened the tourism, ecological, and hydrogeological components of this case study. They also acknowledge the support of the community engagement project "Sowing Harvesting and Reusing Water for Sustainability (Phase II)" (PG13-PY25-07) and JAAPMAN, whose key stakeholders actively participated in the various stages of the research process.

Declaration on Generative AI

The authors have not employed any Generative AI tools.

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