Review

Water Sowing and Harvesting (WS&H) for Sustainable Management in Ecuador: A Review

Gricelda Herrera-Franco 1, Fernando Morante-Carballo 2,3,4, Lady Bravo-Montero 2,5,*, Juan Valencia-Robles 5, Maribel Aguilar-Aguilar 2,5,*, Sergio Martos-Rosillo 6 and Paul Carrión-Mero 2,5,*

1 Facultad de Ciencias de la Ingeniería, Universidad Estatal Península de Santa Elena (UPSE), La Libertad 240204, Ecuador; grisherrera@upse.edu.ec
2 Centro de Investigaciones y Proyectos Aplicados a las Ciencias de la Tierra (CIPAT), Campus Gustavo Galindo Km 30.5 Vía Perimetral, ESPOL Polytechnic University, Guayaquil P.O. Box 09-01-5863, Ecuador; fmorante@espol.edu.ec (F.M.-C.); pcarrión@espol.edu.ec (P.C.-M.)
3 Facultad de Ciencias Naturales y Matemáticas (FCNM), Campus Gustavo Galindo Km 30.5 Vía Perimetral, ESPOL Polytechnic University, Guayaquil P.O. Box 09-01-5863, Ecuador
4 Geo-Recursos y Aplicaciones (GIGA), Campus Gustavo Galindo, ESPOL Polytechnic University, Km. 30.5 Vía Perimetral, Guayaquil P.O. Box 09-01-5863, Ecuador
5 Facultad de Ingeniería en Ciencias de la Tierra (FICT), Campus Gustavo Galindo Km 30.5 Vía Perimetral, ESPOL Polytechnic University, Guayaquil P.O. Box 09-01-5863, Ecuador; jivalenc@espol.edu.ec
6 IGME-CSIC, Geological and Mining Institute of Spain-Spanish National Research Council, Urb. Alcázar del Genil, 4-Edif., 18006 Granada, Spain; s.martos@igme.es
* Correspondence: lkbravo@espol.edu.ec (L.B.-M.); maesagui@espol.edu.ec (M.A.-A.); Tel.: +593-95914143 (L.B.-M.); +593-982863190 (M.A.-A.)

Abstract: Water Sowing and Harvesting (WS&H) is an ancestral knowledge widely used as a sustainable technique in water management. This study aims to analyse the importance, promotion, and cultural heritage of WS&H techniques through a literature review in Ecuador, considering applications of ancestral techniques by region (coastal, Andean and insular) with a strengths, opportunities, weaknesses, and threats (SWOTs) analysis and a focus group for a strategy proposal of the water supply. The methodology of this study includes the following: (i) an analysis of the evolution of WS&H studies in Ecuador; (ii) a presentation of WS&H techniques and their applications; and (iii) the contribution of WS&H to the Sustainable Development Goals (SDGs), complemented by a SWOTs analysis. The results show that, in Ecuador, WS&H is a method of Nature-based Solutions (NbSs) applied to the problems of water scarcity and is affordable, ecological, and has high efficiency, improving agricultural productivity and guaranteeing water supply for human consumption. The Manglaralto coastal aquifer, a case study in the coastal region of Ecuador, involves WS&H management and artificial aquifer recharge. WS&H structures became a reference for the sustainable development of rural communities that can be replicated nationally and internationally as a resilient alternative to water scarcity and a global climate emergency, contributing to the SDGs of UNESCO.

Keywords: artificial aquifer recharge; water management; nature-based solutions; rural communities; groundwater heritage; sustainability

1. Introduction

Due to its physical, chemical, and biological properties, water is essential for life on Earth [1]. Furthermore, a water resource is critical to the environment and human well-being (e.g., domestic, industrial, and agricultural use); therefore, it has become an economic resource which conditions the sustainability of a nation [2,3]. In addition, it is considered a right for the world population and is a crucial part of adaptation to climate change, becoming a link between society and the environment [4,5].

Water is a renewable natural resource found on the planet in large quantities, but the vast majority of it is unsuitable for human consumption [6]. Most of the water on Earth is
salty and located in the oceans, representing 97.2% of very little use in the global population; 2.15% of the water corresponds to glaciers and ice caps. The remaining 0.65% comprises surface and groundwater, but the former only represents approximately 136,000 km$^3$ [7–9]. Therefore, less than 1% of water is available for human use in easily accessible freshwater lakes and rivers. However, this percentage varies, because not all freshwater is drinkable and, therefore, can be consumed directly; it needs to be treated [10]. Furthermore, according to Martos-Rosillo [11], the geographical distribution of freshwater at the continental level is uneven, being scarce in desert regions and abundant in tropical jungle areas.

Factors such as population growth, changes in consumption patterns, industrialisation, and increased agricultural production [12] have generated a 1% annual growth in water demand [13], with an increase of 20 to 30% by 2050 [14]. However, the excessive use of water, irregular distribution of rainfall, and effects of climate change make water a scarce commodity, limiting environmental, social, and economic sustainability [15,16]. Water scarcity occurs when water demand exceeds temporal and spatial availability [17,18], a global problem in which two-thirds of the world’s population experiences severe water scarcity conditions at least once a year [19,20].

Water has become the most important geopolitical factor internationally [7], and increased awareness of water in the global population is essential. For example, in Latin America and the Caribbean, 26% of the population requires access to drinking water, and 69% requires better water management with adequate purification systems [21]. Likewise, African countries face water stress due to climate change, mainly in the sub-Saharan zone, which is considered the region of the world in which its inhabitants have less access to water, with 45% of its population without water in good condition and 65% that do not have adequate sanitation [22,23]. Therefore, in the 2030 Sustainable Development Goals (SDGs) Agenda, the sixth objective states guaranteeing access to water and sanitation for all, whose indicator mentions “6.4. By 2030, it will significantly increase the efficient use of water resources in all sectors and ensure the sustainability of freshwater extraction and supply to address water scarcity and significantly reduce the number of people suffering from lack of access to water” [24]. Water scarcity is a great challenge for many countries, including Latin America. Even though in some Latin American countries the percentage of people with access to water has increased, approximately 77 million inhabitants still do not have a water connection in their homes, of which 66% are in rural areas [25]. Therefore, water scarcity requires practical and sustainable management strategies [26,27].

Integrated Water Resource Management (IWRM) is necessary for efficient, equitable, and sustainable water management, guaranteeing human well-being without affecting environmental sustainability [28–30]. Therefore, different water organisations and local authorities have focused on managing water demands through alternative sources, such as reusing grey and wastewater, gross waterboxx technologies, desalination, and Water Harvesting Techniques (WHTs) [16,31,32]. WHTs are artificial systems for collecting and storing water as an alternative for potable (human consumption) and non-potable (irrigation and cleaning) uses [33–35], reducing the problems associated with land degradation due to stormwater runoffs [36]. Owing to its low cost and maintenance, this technique has received considerable attention worldwide [37]. For example, countries like China, Australia, and Jordan encourage rainwater harvesting in new buildings [5,38–40]. It is also important to mention that rainwater collected through “cisterns” is a hydraulic technology and water management practice applied since prehistoric times in places with limited water availability, such as Greece [41–43]. In general, this technique is applied even in countries with a water balance (e.g., the United States, United Kingdom, Italy, Germany, France, and Brazil), whose objective is to increase the water self-sufficiency of cities [44–47].

Among WHTs, rescuing ancestral knowledge has allowed several communities to supply water resources through various collection techniques [48]. According to Fenstand et al. [49], ancestral knowledge is “an accumulated set of knowledge, techniques, practices, and representations maintained and developed by people with a long history of interaction with the natural environment”, allowing for decision making on fundamental
aspects such as hunting, fishing, gathering, agriculture and livestock, water collection and storage, and adaptation to the environment [50-57].

In Latin America and the Iberian Peninsula, rescuing the ancestral knowledge of aquifer recharge through Nature-based Solutions (NbSs) [58] is called Water Sowing and Harvesting (WS&H) [59,60]. According to Martos-Rosillo et al. [11], WS&H is a process through which rainwater is captured through infrastructures based on ancestral knowledge (planting when it rains) and later used through springs, wells, and drainage galleries (harvesting water during droughts). The use of rainwater through collection systems represents a viable alternative (probably the oldest) to solve access to water [61,62]. An example is the artificial recharge of aquifers through infrastructures as an alternative to the construction of water reservoirs. Aquifers are the main store of fresh and thawed water on the planet [63], since they reduce water losses through evaporation and protect water from contamination, among other advantages [64].

Ancestral water management systems have generated social, economic, and environmental benefits and are considered examples of effective and resilient NbSs over time [65]. Among the different WS&H techniques registered globally, some authors have proven their effectiveness. For instance, Martos-Rosillo et al. [62], Oyonarte et al. [51], and Jódar et al. [66] demonstrated that irrigation ditches are techniques that allow natural water infiltration rates to double and recharge aquifers in an ancestral way. The abandonment of this system represents an irreparable cultural and environmental loss, and its potential as a sustainable water management solution based on socio-ecological systems is evident.

A study that fills the knowledge gap in these WS&H techniques that ancestral wisdom brings is essential, as it reflects an environmentally friendly culture and cultural heritage preserved from generation to generation. Exploring water sourcing and harvesting techniques in different geographies, highlighting them, and comparing them with techniques from other places helps configure, order, and promote this vital heritage, and therefore, solve many problems at a low cost [37].

In Ecuador, different WS&H techniques have been applied, mainly in rural areas of the coastal, Andean, and insular regions. In the coastal region, artificial wetlands (qochas or cochas in Quechua, albarradas in Spanish) stand out as do tapes (dykes) [11,60] (e.g., dykes–tapes in the Manglaralto aquifer in the Santa Elena Province [67]). In the Andean region, artificial infiltration ponds known as high-altitude wetlands are used [68] (e.g., the Magdalena lagoon in the Altilllo Lake complex of the Sangay National Park, Chimborazo [69]). Finally, in the insular region or the Galapagos, few water reservoirs come from volcanic cracks and a water supply system (e.g., the water collection points on San Cristóbal Island, such as “Chino Goteras”) [70].

Considering the impact of WS&H techniques on the water supply in Ecuador, this study poses the following research questions: What are the WS&H techniques registered in Ecuador in its different geographies? How can this study contribute to the knowledge of techniques for sustainable water use within a sustainable framework? Therefore, this study aims to define strategies for rescuing the ancestral knowledge of water management in Ecuador through a literature review integrated with a strengths, opportunities, weaknesses, and threats (SWOTs) analysis, with international experts representing the WS&H network in Ibero-America. This allowed us to identify the internal and external aspects of WS&H techniques in the country, their contribution to SDGs, and their replicability at the international level to address problems associated with water scarcity. This study presents a successful case of WS&H in a semi-arid coastal zone of Ecuador, the Manglaralto River–Watershed System (MRWS), due to its effectiveness in the use of dykes that combine ancestral and technical knowledge (academia), as well as a reference of the quintuple helix model of innovation through the synergy between the social, academic, political, economic, and environmental axes to strengthen the artificial recharge of the aquifer and combat the problems of supplying resources in times of low water and beach tourism, which is characteristic of the area as a socioeconomic activity.
2. Materials and Methods

This review of WS&H techniques in Ecuador aims to present a register of WS&H techniques, considering the uses/benefits attributed to different regions of the country. Based on a focus group technique of national and international experts, after a visit to several groundwater heritage field sites with WS&H infrastructures, recommendations and strategies were established to contribute to the SDGs. Thus, they can be replicated at national and international levels as affordable strategies for NbSs in similar hydrogeological regions. Therefore, this study compiled different publications in online databases for the analysis of existing techniques as well as the evolution of research in this field in the country over time. The methodological process included three work phases: (i) an evolutionary analysis of WS&H studies in Ecuador, (ii) WS&H techniques in Ecuador, and (iii) the contribution of WS&H to sustainable development through the SDGs and SWOTs analysis for the formulation of water management strategies (Figure 1).

Figure 1. Methodological framework.

2.1. Stage I: Evolutionary Analysis of WS&H Studies in Ecuador

This review begins by compiling WS&H cases in the country based on information available on the web (e.g., theses, articles, technical reports, and books) and information collected from research projects developed by academic institutions. The inclusion criteria were as follows: (i) all types of documents, (ii) all languages, and (iii) documents up to the present without excluding years. The search criteria used in databases such as Scopus, WoS, and Google Scholar included keywords such as (i) water sowing, (ii) water harvesting, (iii) sustainable management of water, (iv) water recycling, and (v) ancestral knowledge in water management. The review of studies focused on WS&H techniques in the country allowed us to analyse the evolution and impact of research within this area and
its promotion at the national and international levels. The data from the documents were reviewed and processed in Microsoft Excel (2312 version) to identify the different WS&H techniques used in Ecuador for the subsequent processing and analysis in stage two.

2.2. Stage II: WS&H Techniques in Ecuador

Following the techniques reviewed in the compilation of studies in the first phase of this study, they were classified by region (coast, Andean, and insular), exposing the application/use of the technique and the participation of the academic/authorities/companies/community. Once classified by region, techniques were compared based on their usefulness and function. This type of analysis presents the methods used in the country to disseminate them internationally to serve as a replicable model in communities with water scarcity problems. Based on the success stories of water management through WS&H in the country, a case study is presented in the coastal region, specifically in Manglaralto, the province of Santa Elena, an area in which, through an outreach project to the ESPOL society, the integral participation of academia, the community [71,72], governmental entities, and companies have been strengthened in the rescue of ancestral knowledge through technical–artisanal dams for the community management of water resources.

2.3. Stage III: WS&H Contribution with the SDGs and SWOTs Analysis

At this stage, an analysis of the main strengths, opportunities, weaknesses, and threats (SWOTs) [73,74] of the WS&H techniques used in the country is proposed, considering the five subsystems of the quintuple–helix model of innovation [75]. This model is characterized by proposing an interdisciplinary and transdisciplinary framework that integrates the participation of academic/educational, social, environmental/natural, governmental/political, and economic/business systems to promote sustainable development [75,76].

The research tool consisted of a focus group [77] composed of experts in sustainable water management, members of communities that apply WS&H techniques, and the authors of this study. Within the group of experts in water management were the coordinator of the network “Siembra y Cosecha de Agua en Áreas Naturales Protegidas (SyCA)” (WS&H in English) [78] and researchers and coordinators representing Peru, Chile, Colombia, Bolivia, Mexico, Argentina, Spain, and Ecuador (Supplementary Materials, Table S1).

The analysis was developed from the international forum–colloquium “Water Sowing and Harvesting” held from 12 June to 16 June 2023, in Ecuador, in which the existing techniques in the country were presented, as well as the interaction between experts at a demonstration site (Manglaralto, Ecuador) through field visits (Video S1). The different interactions of the WS&H techniques used in Ecuador were carried out under a triple analysis: (i) the contribution and challenges of WS&H in Ecuador in sustainable development, (ii) aspects to consider enhancing the implementation of WS&H techniques and guaranteeing their sustainability in the long term, and (iii) the contribution of WS&H techniques to meet the SDGs. Finally, according to the perspective of experts, the community, and the authors of this work, key themes were defined to establish strategies to rescue the ancestral knowledge of water management that promotes the sustainable development of communities.

3. Results

3.1. Evolution WS&H Studies in Ecuador

Following the inclusion criteria used in the different databases, the results indicate that, in Ecuador, research on WS&H began in 1933 with the study by Sheppard [79], in which albarradas were constructed as artificial wetlands that capture water from rain for later use in times of drought, mainly in the coastal region of Ecuador. Since 1933, there has been progressive growth in the number of documents focused on WS&H studies. Specifically, according to the behaviour of WS&H cases reported per year, it is possible to identify two periods of investigation, Period I (1933–2017) and Period II (2017–2033), of which the second period represents 61.4% of the scientific production (Figure 2).
Figure 2. Behaviour of the scientific production in WS&H in Ecuador over time.

Considering the type of document, the analysed database comprises 70 documents classified by articles, conference papers, books, and degree theses, of which 50.00% correspond to articles. However, reports represented the lowest number of records (4.29%) (Figure 3).

Figure 3. Types of documents about WS&H published in Ecuador during 1933–2023.

3.2. WS&H Techniques in Ecuador

In Ecuador, the application of WS&H considers the coastal, Andean, and insular regions (Figure 4); the techniques vary according to the water storage type and the climatic and geological conditions. Overall, this study documented nine types of ancestral water management techniques: albarradas/cochas/jagüeyes (artificial wetlands in English),
Pishku Chaqui (irrigation system forming an inverted “Y” in English), tajamares (stream dams in English), and tapes (dykes in English).

Figure 4. Locational map of WS&H techniques in Ecuador.

- Tapes (dykes) are an ancestral technique for water care through an artificial recharge that dams the water in certain areas of the riverbed to recover the subsoil water level. The dam or tape consists of a wall of rock and sediment accumulation in preferential sections along the river that allows water to be dammed to meet the population’s needs in times of scarcity [80] (Figure 5a). With the inclusion of the technical knowledge of this type of structure, in the country, there are areas in which the construction of dykes is made of concrete, called a technical–artisanal dyke.

- Waru-Waru/camellones/acequias (complex channel systems) prepare the land (undulations, platforms, and mounds) with earthy materials to grow the ground level and reach an ideal height above the natural surface to improve cultivation conditions and control excess soil water in the winter [81] (Figure 5b). Archaeological studies of the raised fields show that their initial construction is reported since 1000 BC [82].

- Albarradas/cochas/jagüeyes (artificial wetlands) are circular or semicircular structures built for collecting and storing water in areas with scarce water resources or droughts [83]. The system consists of an earth wall that contains the water, constituted by manual or mechanized compaction and foundation; a glass that retains and collects rainwater; a water inlet area that directs the surface water towards the glass; and a vent area that helps release excess water and avoid impact on the wall [84] (Figure 5c). This structure fills with water through the slow accumulation of precipitation or water from nearby elevations. In Ecuador, they constitute a technological, ecological, and cultural heritage of high economic and symbolic value [85]. These hydraulic structures began to be built approximately from 2000 BC [86].

- Pishku Chaqui (an irrigation system forming an inverted “Y” or Pata de pájaro in Spanish) is an artificial water source that forms a bird’s foot through conductors (acequias), which leads to the main conduction, so that the water covers the entire plot, allowing water to be provided to the crops. This technique was adopted by farmers...
who did not have water for irrigation, in which the water is distributed from a higher flow to a lower one, thus covering all the crops with minimal erosion risks (Figure 5d).

- Tajamares (stream dams) consist of joining two approaching slopes through a well-tamped curtain of the terrain to stop rainwater runoffs, forming lagoons. These contain a spillway, a channel that eliminates excess water and that can extract it [87].

- Pilancones (water reservoirs) are reservoirs or ponds arranged on a horizontal surface exposed to meteorological agents, aiming to capture water in small irregularities in rocks. Once the water is retained, chemical weathering begins, in which the anomalies are deeper and wider. In this way, a feedback system is possible, in which the larger the irregularities, the more water retained and the greater chemical weathering. During the winter, the water fills the system (subsoil saturation due to infiltration), taking advantage of it in the dry months (the volume of the springs increases) [88], mainly for agriculture and human consumption.

- Canterones (simple channel systems) are a pre-Hispanic technology related to terraces for agricultural production, used especially on surfaces with less terrain (slopes and valleys), in which it is difficult to ensure the flow of water covers the entire structure. Nevertheless, this system has some advantages, such as the uniformity of irrigation on the ground and the control of the water speed due to the shape that the furrow takes, also avoiding water erosion of the soil [89].

- Reservorio semitechado (semi-roofed reservoir) is a rainwater harvesting technique on flat terrains used in other countries and replicated in Ecuador. It comprises two galvanized sheet roofs supported by wooden supports and located oppositely on a plastic canvas. The roofs have a found drop (30–45° slope) and low height to prevent the evaporation of water from the reservoir. The larger the roof area, the greater the collection of rainwater in a short time [90].

- Pozos de recolección de agua lluvia (rainwater-collection wells) consider the construction of wells to capture rainwater. They are a “green” infiltration infrastructure that allows for the recovery of a non-agricultural area for agriculture, avoiding further soil erosion. These wells are formed particularly by a depth of 10 m and a diameter of 1 m, allowing for their extraction through a geomembrane, which is impermeable material for rainwater collection [91].

Table 1 describes the techniques used by the regions in Ecuador, coastal, Andean, and the Galapagos; their application or use; and the participation of members of the community, academia, companies, and leading authorities. In general, the WS&H techniques reflect a greater variety and concentration in the Andean region, mainly because of their application in optimising water use, improving agricultural productivity, and enhancing groundwater recharge. In the Andean region, WS&H techniques are more preserved and revitalised, as indigenous and local communities lead movements to protect their heritage. Simultaneously, academia, water managers, and decision makers increasingly recognise the traditional value of these practices [92]. In contrast, the coastal region, in addition to using WS&H techniques for agriculture, mainly in semi-arid areas, aims to artificially recharge aquifers to ensure the availability of water resources to control saline intrusion, human consumption, and domestic consumption. The eastern region, or the Ecuadorian Amazon, is the only region that largely disposes of water resources (average rainfall is over 3500 mm per year), without registering cases of WS&H techniques.
Figure 5. Schematic examples of WS&H techniques in Ecuador: (a) tapes (dykes), (b) waru-waru/camellones/acequias (complex channel systems), (c) albarradas (artificial wetlands), and (d) Pishku Chaqui (irrigation system forming an inverted “Y”, named Pata de pájaro in Spanish).

Table 1. WS&H case descriptions in Ecuador classified by region.

<table>
<thead>
<tr>
<th>Region</th>
<th>WS&amp;H Techniques</th>
<th>Applications/Uses</th>
<th>Academic Participation/Authorities/Companies/Community</th>
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<tbody>
<tr>
<td>Coast/ coastal</td>
<td>Albarradas/jagüeyes (artificial wetlands), artisanal dyke (tape), technical-artisanal dyke (tape), and camellones (complex channel systems).</td>
<td>Domestic use, human consumption, agricultural production, and tourism.</td>
<td>CIPAT-ESPOL *, UPSE *, JAAPMAN *, INIAP *, MAGAP *, JRAPO *, and OIEA *.</td>
</tr>
<tr>
<td>Andean/inter-Andean</td>
<td>Cocha/albarrada (artificial wetlands), Pishku Chaqui (irrigation system forming an inverted “Y”), tajamares/pilancoones (water reservoirs), canterones (simple channel systems), reservorio semitechado (semi-roofed reservoir), camellones (complex channel systems), and rainwater-collection wells.</td>
<td>Domestic use, human consumption, irrigation for pastures and crops, and irrigation system for agricultural production.</td>
<td>Junta Parroquial de Limonal, CIPAT-ESPOL, ESPOCHE *, UPS *, USFQ *, IICA *. Universidad Nacional Agraria La Molina, Caja Nacional de Riego and community.</td>
</tr>
<tr>
<td>Insular/the Galapagos</td>
<td>Water reservoirs by volcanic cracks and “Chino Goteras” water supply system (water damming of riverbeds).</td>
<td>Domestic use, human consumption, irrigation and drainage systems, and tourism.</td>
<td>Municipality and community.</td>
</tr>
</tbody>
</table>

* CIPAT-ESPOL: Centro de Investigación y Proyectos Aplicados a las Ciencias de la Tierra-E Escuela Superior Politécnica del Litoral; UPSE: Universidad Península de Santa Elena; JAAPMAN: Junta de Agua Potable de Manglaralto; INIAP: Instituto Nacional de Investigaciones Agropecuarias; MAGAP: Ministerio de Agricultura, Ganadería, Acuacultura y Pesca; JRAPO: Junta Administradora del Sistema Rural de Agua Potable de Olón; OIEA: Organismo Internacional de Energía Atómica; ESPOCHE: Escuela Superior Politécnica de Chimbacorzo; UPS: Universidad Politécnica Salesiana; USFQ: Universidad San Francisco de Quito; IICA: Instituto Interamericano de Cooperación para la Agricultura.
3.2.1. Case Study in Coastal Region: Manglaralto River–Watershed System (MRWS)

The MRWS is located in the northern part of the rural parish of Manglaralto in the Santa Elena Province (Figure 6a). This area belongs to the marine coastal environment of Ecuador and is characterised by an arid–semi-arid megathermal climate. The Manglaralto parish has an area of 497.4 km² [93] and 38,212 inhabitants [94,95]. The Manglaralto River is 19 km long and covers an area of 132 km² (Figure 6b). The hydrographic system integrates the rivers born in the east, in the Chongó-Colonche Mountain range, and flows in a W–SW direction (Figure 6c). The study area comprises the lower part of the MRWS, mainly alluvial deposits composed of gravel and sand, as part of the free-porous coastal aquifer of the Manglaralto River. This aquifer was the primary water source in the MRWS.

3.2.2. WS&H Applications in Manglaralto

Among the different WS&H procedures available [87], the community uses local solutions, the technical–artisanal tape (dyke) of Manglaralto and the albarradas (artificial wetlands), in neighbouring communities of the Santa Elena Province, which were devised by native people as a response to the water deficit in the region. The application of the WS&H technique provides a sustainable solution for the surrounding ecosystem and can be replicated in other coastal sectors. The criteria for the construction of the technical–artisanal tape (dyke) are as follows:

- Consider a channel morphology that favours damming (e.g., riverbanks with slopes and terraces on the flanks), with alluvial material from the river to favour infiltration.
- Large areas allow for excellent water damming and favour the aquifer’s recharge.
- Closed areas for the technical dyke (tape) location, with good river channelling and the optimisation of construction resources.

Figure 7 contains the conceptual scheme of WS&H applications in Manglaralto that consider five axes based on the quintuple–helix model of innovation [75], described as follows:
1. Political axis: The rural communities associated to the MRWS do not have water distribution by the state organisations. Therefore, the Manglaralto Potable Water Management Board (JAAPMAN, an acronym in Spanish) was created, and it is in charge of the water supply system for 90% of the population through the exploitation of 15 water wells (Figure 7b) [97,98].

2. Educational axis: The support of academia through ESPOL University in the evidence of water management through guidance in the generation of the geometric model of the aquifer, monitoring water quality using national norms and the construction of a technical-artisanal tape (dyke), as shown in Figure 7a.

3. Economic axis: This shows the groundwater exploitation, including the water volumes stored and invoiced for services during the JAAPMAN management from 2013 to 2021, indicating an increase in the volume exploited from water wells. However, during 2020–2021, the water volume decreased due to the La Niña climatic phenomenon and COVID-19 restrictions, which did not allow for the correct maintenance of wells and the water distribution network (Figure 7c).

4. Natural axis (cultural and environmental perspective): This includes the construction of dykes (tapes) based on the recovery of ancestral knowledge that favours the artificial recharge of water during the rainy season to maintain surface water for longer (dry season), helping to control saline intrusion and supply the water demand. Additionally, it considers the presence of the Chongón Colonche Protected Forest in the northern area and the recent recognition of the Manglaralto geosite (Figure 7d).

5. Social axis: This highlights women’s inclusion in the sector as members of the JAAPMAN Water Board and stakeholders in water management (Figure 7e and Video S2). Additionally, it highlights the fact that beneficiaries ascend to 20,000 users which are supplied by their own community management.

Figure 7. Conceptual scheme of WS&H application in Manglaralto based on the quintuple-helix innovation model: (a) educational axis; (b) political axis; (c) natural axis, (d) economic axis, and (e) social axis.
3.3. The Contribution of WS&H Techniques with the SDGs

The application of WS&H techniques at the international level as a nature-based solution is a tool to achieve compliance with the SDGs at the local and regional levels. In Ecuador, it is widely used in the coastal and Andean regions, strengthening the sustainable development of mainly rural communities. For example, the semi-arid coastal areas of the country have integrated the application of ancestral knowledge with engineering designs for the artificial recharge of aquifers through “albarradas” or “tapes” that take advantage of the rainy season for damming water and its subsequent infiltration. In the Andean region of the country, WS&H has made possible the use of surfaces for agricultural production, in which the irrigation systems used based on ancestral knowledge have made it possible to adapt land surfaces for agriculture with applications such as “pata de pájaro”, “camellones”, “canterones”, and “pilancones”. Figure 8 summarises the contribution of the WS&H in Ecuador to sustainable development.

![Diagram](image-url)

Figure 8. The contribution of WS&H techniques to the fulfilment of the SDGs.

3.4. SWOTs Analysis

According to the analysis of the internal factors of the WS&H in the country, the strengths identified in Ecuador reflect the importance of ancestral knowledge of water to improve water security with the artificial recharge of aquifers and to increase agricultural production and the recovery of ecosystems with a low-cost implementation. The WS&H weaknesses identified by the focus group highlight the need to integrate community, academic, and government support to strengthen the financing and execution of sustainable water-use projects in different regions of the country, establishing an ecohydrological model of water management that can be replicated (Table 2).
Table 2. Analysis of the internal and external aspects of WS&H in Ecuador.

<table>
<thead>
<tr>
<th>Internal Factors</th>
<th>WS&amp;H Strengths</th>
<th>WS&amp;H Weaknesses</th>
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<tbody>
<tr>
<td>Political system</td>
<td>- Reduce political conflicts over access to water with self-sufficient communities.</td>
<td>- Limited financial resources.</td>
</tr>
<tr>
<td>- They represent sustainable infrastructures during landscape planning by governments.</td>
<td>- Lack of public policy that considers WS&amp;H in the country.</td>
<td></td>
</tr>
<tr>
<td>Educational system</td>
<td>- Techniques with the potential to integrate technical and ancestral knowledge.</td>
<td>- High level of a lack of knowledge of the ancestral techniques in water management.</td>
</tr>
<tr>
<td>- Promote resilience and environmental awareness at the local level.</td>
<td>- Scarce academic and business participation and dissemination of ancestral knowledge.</td>
<td></td>
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<tr>
<td>Economic system</td>
<td>- Economically viable techniques.</td>
<td>- Limited financial resources.</td>
</tr>
<tr>
<td>- WS&amp;H as a strategy to contribute to the challenges of the WEF nexus.</td>
<td>- Some WS&amp;H techniques are temporary, and their design is without technical considerations.</td>
<td></td>
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<tr>
<td>Natural system</td>
<td>- NbSs in problems associated with the scarcity of water.</td>
<td>- Territorial development plans not suitable for the environment in the country.</td>
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<tr>
<td>- Ecosystem regeneration.</td>
<td>- Extreme weather events comprise the function of WS&amp;H techniques.</td>
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<tr>
<td>Social system</td>
<td>- Sustainable water use for agricultural and aquifer recharge.</td>
<td>- Lack of maintenance of existing WS&amp;H techniques.</td>
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<tr>
<td>- Rescue of ancestral knowledge from the community.</td>
<td>- Loss of communities with the ancestral knowledge of WS&amp;H.</td>
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<tr>
<th>External factors</th>
<th>WS&amp;H Opportunities</th>
<th>WS&amp;H Threats</th>
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<tbody>
<tr>
<td>Political system</td>
<td>- Contributed fulfilment of the SDGs.</td>
<td>- Limited land availability to implement WS&amp;H techniques.</td>
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<tr>
<td>- Mitigate water scarcity in rural areas.</td>
<td>- Lack of appreciation and knowledge of WS&amp;H by municipalities and the public.</td>
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<tr>
<td>Educational system</td>
<td>- Design of WS&amp;H systems that integrate ancestral and technical knowledge.</td>
<td>- The loss of communities with the knowledge of WS&amp;H would limit the promotion of these techniques in the educational system.</td>
</tr>
<tr>
<td>- Increase the useful life of the techniques through designs that consider geological and meteorological conditions.</td>
<td>- Although WS&amp;H techniques are cheap, the lack of a budget is a limiting factor.</td>
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<tr>
<td>Economic system</td>
<td>- Circular water economy.</td>
<td>- Infrastructural damage due to rain in the event of the “El Niño” phenomenon.</td>
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<tr>
<td>- Reduce grey infrastructure costs and implement ancestral knowledge.</td>
<td>- Climate change.</td>
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<tr>
<td>Natural system</td>
<td>- Artificial aquifer recharge and rural water supply.</td>
<td>Social system</td>
</tr>
<tr>
<td>- Endemic species reforestation plans.</td>
<td>- Anthropic-work construction.</td>
<td></td>
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<tr>
<td>Social system</td>
<td>- Water use for agricultural irrigation plans.</td>
<td>- Water pollution due to anthropic activities.</td>
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<tr>
<td>- Women’s participation in water management.</td>
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In contrast, the WS&H in Ecuador has demonstrated its contribution in alleviating water stress in arid and semi-arid areas. In this sense, the artificial recharge of aquifers has three benefits: (i) ensuring access to water for domestic and agricultural use, (ii) promoting resilient community empowerment in the face of climate change, and (iii) promoting the development of adaptation policies in the face of water stress. However, natural and anthropogenic factors threaten these systems, such as an increase in the population and the construction of civil works with inadequate territorial development plans (Table 2).
With the external and internal factors presented by WS&H techniques, this study proposed strategies to optimise, promote, and strengthen the ancestral knowledge of water management from social, political, economic, and educational aspects. Table 3 lists the main strategies proposed for the various techniques applied in the country.

**Table 3.** Improvement strategies for WS&H techniques in Ecuador by combining the internal environment (strengths and weaknesses) and the external environment (opportunities and threats) identified by the focus group.

<table>
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<tr>
<th>Strategies: Strengths + Opportunities</th>
<th>Strategies: Weaknesses + Opportunities</th>
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<tbody>
<tr>
<td>- Establish public policies that promote applying WS&amp;H techniques with the participation of the inhabitants.</td>
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<tr>
<td>- Promote awareness campaigns on sustainable water use through WS&amp;H techniques and their benefits for tourism in the region.</td>
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<tr>
<td>- Design circular economy plans for water with the full participation of the community, academia, regional and local government, and companies.</td>
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<tr>
<td>- Implement different WS&amp;H techniques in the artificial recharge of aquifers that guarantee the availability of the resource for consumption and agriculture.</td>
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<td>- Carry out educational plans for all levels that include WS&amp;H techniques as tools in compliance with the SDGs.</td>
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<tr>
<td>- Establish reforms in public policies that include a budget allocation for the maintenance of the different WS&amp;H techniques used for water consumption and irrigation.</td>
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<tr>
<td>- Design training plans by the regional and local government aimed at the participation of women in water care.</td>
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<tr>
<td>- Implement national projects that promote WS&amp;H techniques as a measure of adaptation to climate change and, in addition, as a sustainable employment alternative for communities.</td>
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<tr>
<td>- Execute research or linkage projects through public or private universities with participatory community systems for aquifer recharge with WS&amp;H techniques.</td>
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<tr>
<td>- Integrate technical and the ancestral knowledge of the design and construction of WS&amp;H techniques that guarantee their functionality in the face of extreme weather events.</td>
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<td>- Establish regulations within the country’s construction that guarantee the safety of WS&amp;H techniques in civil works.</td>
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<tr>
<td>- Strengthen the country’s environmental policy, increasing laws of care and monitoring water quality in WS&amp;H practices.</td>
<td></td>
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<tr>
<td>- Carry out awareness workshops and sustainable water management through NbSs.</td>
<td></td>
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<tr>
<td>- Create community participation plans for the maintenance of WS&amp;H infrastructures.</td>
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<tr>
<td>- Carry out studies to assess the impact of climate change in WS&amp;H techniques for the proposal of prevention and mitigation measures.</td>
<td></td>
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<tr>
<td>- Evaluate territorial development plans through technical and environmental criteria that minimize damage to WS&amp;H infrastructures.</td>
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4. Interpretation of Results and Discussion

This study explored the WS&H techniques used in Ecuador, revealing the importance of NbSs in sustainable water management by resuscitating ancestral knowledge. Furthermore, WS&H techniques demonstrate their significance as tools for mitigating the effects of climate change, strengthening ecosystems, and guaranteeing social well-being. In Ecuador, there are two main uses of WS&H: (i) the use of water for human consumption activities, mainly in the coastal region [80,99]; and (ii) the development and strengthening of agricultural production for communities with low economic resources, generally in the Andean region [60]. For different regions, the applied techniques were adapted to the characteristics of the terrain and the needs of the inhabitants.

From an ecological–environmental point of view, this technique allows for mitigating the current water stress in coastal areas, reducing the risk of saline intrusion into aquifers due to the overexploitation of the resource (e.g., technical–artisanal dykes (called in Spanish tapes) and artificial wetlands (called in Spanish albarradas) in the coastal region), as well as the restoration of ecosystems and the preservation of environmental protection zones. On the other hand, the social component of sustainable development through this type of application highlights business, community, and academic participation through high-impact research or outreach projects, in which rural communities rescue and transfer knowledge of WS&H as a key strategy in sustainable water management. Furthermore,
this type of initiative, in which the community is open in decision making to efficiently manage water resources, directly involves the perspective of women, who constitute the largest population that supports water scarcity [100].

In the country, this ancestral heritage, with time, is gaining relevance, since it solves needs or problems with low investments, promotes awareness of water management in different communities, and adds patrimonial and cultural value to the landscape [101,102]. Moreover, from the academic point of view, according to the results obtained in the different databases, an increase in the appreciation of this ancient culture disseminated through scientific publications is evident, which exposes the importance of its application and recognises its benefits to society. However, these ancestral techniques present some barriers–limitations to this application, mainly highlighting the sociopolitical aspect. In Ecuador, the water policy consists of five regulatory axes: (i) the Ecuadorian constitution with specific water considerations [103], (ii) a regulatory law for the use of water and hydrological resources of Ecuador [104], (iii) the Unified Text of the Secondary Legislation of the Ministry of the Environment (TULSMA) [105], (iv) Technical Standards for Drinking Water in Ecuador (NTE INEN 1108) [106], and (v) Associations of Water Users (Water Boards). This type of regulation mainly considers the efficient use of water through technical–environmental criteria.

The Manglaralto case study demonstrates the successful application of tapes (dykes) in the efficient management of water as a WS&H and NbS technique that adopts the quintuple–helix model of innovation, which includes five axes (social, academic, environmental, economic, and political). However, other studies could replicate the use of these techniques in the geographic context of coastal regions, such as north-eastern Ecuador. These peculiarities include a rainy season associated with the Intertropical Convergence Zone (ITCZ), the equatorial front being in its southernmost position and warm, moist air masses bringing significant rainfall and raising the air temperature [107]. The use of dykes (tapes in Spanish) is widespread; for the coastal region and the Galapagos Islands, they are used to retain water; in the Andean region, they have an agricultural use; and in the Amazon, they are used as a flow regulator (see Table 1). From the social point of view, the application of this technique in rural communities reflects the importance of rescuing ancestral heritage in water management, highlighting the participation of women in administrative positions in JAAPMAN (Video S2) and their constant work in raising awareness of the sustainable use of water resources in the community (e.g., [108,109]).

According to the academic axis, the technical–scientific contribution to the development of the geometric model of the aquifer [110]; the continuous monitoring of the physicochemical parameters of water quality; joint work with the community for the construction of the technical–artisanal dyke [80] as a hybrid structure (ancestral knowledge and engineering part) that allows for the recharge of the aquifer, controls saline intrusion, and guarantees the availability of water for human consumption (e.g., [111–113]) are highlighted.

Considering the environmental axis, dykes are structures that favour the restoration of ecosystems in arid zones by improving the quality of the water, air, and soil (e.g., [114,115]). This type of groundwater heritage conservation has been reinforced by the conservation of geological heritage as a geosite and its sustainable use through geotourism [116]. On the other hand, the economic axis in this case study includes water rates and resource distributions to the users of the MRWS. This supply allows for the continuity of tourism, agriculture, and fishing as the main socioeconomic activities of the sector (e.g., [117,118]). Finally, from the political point of view, within this case study, the participation of government entities together with the community and academia in the collection of national and international funds that allow for the optimisation of the water collection and distribution system, as well as the promotion of sustainable agriculture, is highlighted.

This study registered the contribution of WS&H in fulfilling eight SDGs at the local level and focused mainly on the conservation and restoration of ecosystems, the management of water resources, and sustainable economic development in rural communities. Four of the SDGs to which WS&H contributes as NbSs include the following: clean wa-
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ter and sanitation (SDG 6), sustainable cities and communities (SDG 11), climate action (SDG 13), and life on land (SDG 15). These coincide with the SDGs defined by Andrikopoulou et al. [119] in their analysis of NbS projects for fluvial flood risk mitigation and the SDGs proposed by Schmidt et al. [120] in NbSs for the Lahn river landscape. However, although the WS&H techniques used in the country generate positive results, their effectiveness and contribution to the SDGs are conditioned in the long term mainly by the need for dissemination, academic collaboration, and community awareness. That is why, according to Gómez Martín et al. [101], understanding social, economic, and environmental factors is essential for the design and implementation of NbSs.

The SWOTs analysis of the WS&H techniques used in the country reflects three main aspects. The first and most important is that it is directly related to the lack of public policies that guarantee the functionality, maintenance, and applicability of this type of solution in the country. The second aspect corresponds to the integral perception of the community and academy as an alternative based on nature that allows for the sustainable management of water. Finally, the third aspect highlighted by this analysis is the importance of comprehensive participation between the community (e.g., farmers and inhabitants), academia, business (livestock sector and tourism sector), and government (different ministries associated with NGOs) in the rescue and dissemination of ancestral knowledge through economically and environmentally friendly techniques. The SWOTs definition of strategies focused on the management of water resources [121], which considered technical and ancestral knowledge as a fundamental pillar, as well as the current challenges facing the country.

The negative factors of the SWOTs analysis include the threats and weaknesses of the water management techniques used in the country, highlighting the difficulties presented by national and local governments to consider groundwater as an integral part of the system of possibilities of the use of water. These constraints reflect the need to regulate groundwater abstraction for various reasons, including limited water resources that are available, increased demand, and the lack of resolution of competition between different uses and benefits [122]. In addition, water management in the face of climate change and exponential population growth requires policies that integrate social, economic, and environmental aspects, in which NbSs represent essential applications within water governance plans [123]. In various regions of the world, NbSs in water management and climate change mitigation are widely employed and supported through large-scale projects and experimentation (e.g., [124,125]), demonstrating its effectiveness and economic viability in the face of technological solutions [126]. Furthermore, WS&H techniques constitute NbSs as alternatives to strengthen grey infrastructures, mitigating the negative environmental impact at affordable costs and significantly improving biodiversity.

This study recognises, as limitations, the need to be more aware of the advantages of WS&H and its scope. This limiting factor harms isolated rural communities in which the state’s funds do not include pilot project implementations or large-scale WS&H systems. Additionally, the loss of the population with this type of knowledge over time, in addition to the scarce government management of dissemination plans and the low culture of some technicians regarding this ancestral technique, threatens the operation of existing systems and the construction of future designs.

With regards to future research approaches, this study raises three fundamental sociopolitical aspects that the country needs to use in the context of WS&H: (i) include a sixth regulatory axis in the water regulations that considers the design and implementation of WS&H techniques that guarantee social well-being and ecosystem wellness, (ii) implement regulations for the different academic levels that promote the impact of the NbSs and their contribution to sustainable development, and (iii) strengthen funds in research centres and universities, with community participation for the development of projects to integrate technical criteria with ancestral knowledge. Furthermore, this institutional regulation will allow competent authorities to create public awareness, raising concerns for the current legislation regarding water management as a human and autonomous right [127].
5. Conclusions

Addressing the challenge of water scarcity in the face of climate change, population growth, and polluting and degrading anthropogenic activities represents a global problem in which NbSs constitute a promising alternative. This study presents a review of WS&H techniques in Ecuador in all geographies, considering the main positive aspects (i.e., artificial recharge of aquifers, supply to rural areas, and managing saline-intrusion problems) and limitations due to these techniques’ lack of promotion and dissemination to maintain a millenary ancestral knowledge that has gained significant recognition recently (2013–2023) in water stress areas. This study also focuses on academic, social, environmental, economic, and political aspects of water resource management strategies.

The process applied for analysing WS&H techniques and their impact on the sustainable development of communities for the different regions of Ecuador has allowed for the identification of the nine techniques in Ecuador that form a cultural heritage and identify with other regions of Latin America, Asia, Europe, among others. In the coastal region of Ecuador, embankments, ridges, dykes, and technical–artificial tapes are mainly used, and in the Galapagos Islands, through the capture of water by tapes (dykes), the main objective is to store the surface water that would be lost following its course towards the ocean. On the other hand, in the Andean region, albarradas (artificial wetlands), tajamares (stream dams), canterones (simple channel systems), and Pishku Chaqui (irrigation system forming an inverted “Y”) are commonly used to increase agricultural production, mainly in rural communities with a low economic income.

Based on the impact of WS&H in Ecuadorian society, this study demonstrates that the WS&H processes that integrate technical criteria through academic intervention optimise the functioning of the systems used in the country. Furthermore, the NbSs used in the country contribute to the fulfilment of the SDGs through pilot and small-scale projects that demonstrate their effectiveness and the importance of transferring useful, eco-friendly, and economically viable (low-cost) ancestral knowledge. Finally, the findings of the analysis reflect the need to strengthen the legislative framework for water resources, including policies to support and strengthen WS&H techniques, because they are appropriated in areas under water stress that make them an ideal natural laboratory for knowledge transfer.

This study identified two main limitations. The first limitation concerns including multiple unknown and unpublished terms as part of the keywords defined to analyse the techniques used in the country. Therefore, these sites should have a strategy with the scheme of the UNESCO demonstration sites for their promotion and enhancement. The second limitation corresponds to a lack of recognition of the WS&H concept and impact, because even though this study analysed information from several online repositories, reports on WS&H applications still need to be published.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/heritage7070175/s1, Video S1. Forum–colloquium “Water Sowing and Harvesting”, Video S2. Women’s inclusion in Manglaralto, Table S1: Coordinators representing the SyCA network who participated in the forum–colloquium “Water Sowing and Harvesting”.


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Data Availability Statement: The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding authors.

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Conflicts of Interest: The authors declare no conflicts of interest.

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