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NATURAL SWIMMING POOLS: AN NBS APPLICATION FOR WATER SAVING IN ECOTOURISM CENTERS IN JALCOMULCO, VERACRUZ, MÉXICO

PISCINAS NATURAIS: UMA APLICAÇÃO DE SOLUÇÕES BASEADAS NA NATUREZA (SBN) PARA A ECONOMIA DE ÁGUA EM CENTROS ECOTURÍSTICOS EM JALCOMULCO, VERACRUZ, MÉXICO

PISCINAS NATURALES: UNA APLICACIÓN DE SBN PARA EL AHORRO DE AGUA EN CENTROS ECOTURÍSTICOS EN JALCOMULCO, VERACRUZ, MÉXICO

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ABSTRACT
Ecotourism is a practice that suggests responsible travel in natural areas, improving the well-being of local populations; However, little is discussed about the water needs of the sector. It is estimated that a tourist uses 300 liters by day (Gössling et al., 2012); for optimize the use of water resources, in Jalcomulco, Veracruz; four hotels and four ecotourism centers were characterized, estimating the water consumption of the infrastructure, especially the swimming pools. Finally, a natural swimming pool was designed and built with NbS at the La Aldea Ecotourism Center located in the town; where the treatment of water quality is based on biochemical processes carried out by aquatic plants, swamps and the microorganisms associated with them. This is one of the few works on the implementation of natural pools in Veracruz, providing useful information for future research.

Keywords: Natural Swimming Pools. Treatment. Quality.

RESUMO
O ecoturismo é uma prática que propõe viagens responsáveis a áreas naturais, promovendo o bem-estar das populações locais; entretanto, pouco se discute sobre as necessidades hídricas do setor. Estima-se que um turista utilize 300 litros por dia (Gössling et al., 2012). Para otimizar o uso dos recursos hídricos, em Jalcomulco, Veracruz, quatro hotéis e quatro centros ecoturísticos foram caracterizados, estimando-se o consumo de água da infraestrutura, especialmente das piscinas. Por fim, uma piscina natural foi projetada e construída com SbN no Centro Ecoturístico La Aldea, localizado na comunidade, onde o tratamento da qualidade da água baseia-se em processos bioquímicos realizados por plantas aquáticas, brejos e pelos microrganismos a eles associados. Este é um dos poucos trabalhos sobre a implementação de piscinas naturais em Veracruz, fornecendo informações úteis para pesquisas futuras.

Palavras-chave: Piscinas Naturais. Tratamento. Qualidade.

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RESUMEN
El ecoturismo es una práctica que sugiere el viaje responsable en zonas naturales, mejorando el bienestar de las poblaciones locales; sin embargo, poco se discute de las necesidades hídricas del sector. Se estima que un turista utiliza 300 litros por día (Gössling et al., 2012); Para optimizar el uso de recursos hídricos, en Jalcomulco, Veracruz; se caracterizaron cuatro hoteles y cuatro centros ecoturísticos, estimando el consumo de agua de la infraestructura, especialmente las albercas. Finalmente, se diseñó y construyó una biopiscina con SbN en el Centro Ecoturístico La Aldea ubicado en la localidad; en donde el tratamiento de la calidad del agua parte de procesos bioquímicos realizados por plantas acuáticas, palustres y los microorganismos asociados a ellas. Este es uno de los pocos trabajos sobre la implementación de albercas naturales en Veracruz, proporcionando información útil para futuras investigaciones.

Palabras clave: Piscinas Naturales. Tratamiento. Calidad.

1 INTRODUCTION

The practice of ecotourism represents an innovative way of enjoying nature that seeks to balance social recreation with the preservation of the environment and the well-being of local communities, as defined by Drumm and Moore (2005). This approach requires the creation of spaces that offer outdoor activities, comfort and, above all, a direct connection with nature. However, tourism is a phenomenon that involves people moving to places other than their usual environment and has a significant impact on the consumption of water resources at the local, regional, and global levels (Creative Destinations, 2023).

In this sense, tourists use water in various ways, from showering to watering gardens and golf courses, filling swimming pools or washing bedding. The tourism industry is highly dependent on the availability of water, so any scarcity can have detrimental effects on its development (Gabarda et al., 2015). It is estimated that the water consumption by an average tourist reaches 300 liters per day and swimming pools represent 15% of the total water consumption in a hotel (Gössling et al., 2012). Therefore, while ecotourism generates significant economic benefits, it can also lead to water imbalances that negatively affect the environment and, ultimately, the communities linked to this activity.

This work aims to link the amount of water destined for resting sites in order to promote the optimal use of water resources in ecotourism development. In addition, it seeks to promote the implementation and construction of nature-based solutions in the town of Jalcomulco, Veracruz.

Biopools as a nature-based solution for the treatment of water quality and its rational consumption

When we think of a swimming pool, many of us imagine a place of recreation where chlorine is an essential component. We have become accustomed to swimming in water with a characteristic smell. However, chlorine, like any chemical, can have adverse effects on our health. Its presence in water can cause eye irritation, nasal congestion, sore throat and other symptoms associated with prolonged contact with this element.

Natural pools or also called biopools, arise from the need to implement filtration and natural treatment systems to maintain optimal water quality where recreational activities are carried out, without effects due to being in direct contact with chlorine, as well as clarifying chemical compounds and pH regulation. among others, which are discharged into the water, prior to use.

Although research on natural pools is grouped in little bibliography, in 2007 Charles Durrant made a proposal for the Olympic pool of the University of Seville, where the main objective was to design a functional pool with low financing and operating costs. The design of the natural pool contemplated four heights, sand filters and two copper and silver ionization units to maintain excellent water quality in the pool, the energy from the photovoltaic solar panels was used to heat the water to about 25°C.

In 2013, the IX National Congress of Excellence in Management was held in Rio de Janeiro, where these systems are proposed to improve environmental and economic impact (Brotherhood, 2013).

In June of the same year, the event of the 7th Encontro de Educação Ambiental, Divulgação de práticas e partilha de experiências was held, where sustainable alternatives were mentioned: in the case of biological pools, they explain that the operation of these infrastructures depends on purification through vegetation in which biological processes of aquatic plants and microorganisms associated with them are carried out. these systems are an imitation of natural ecosystems, so it excludes the use of chemicals used in conventional pools (Mafra et al., 2017).

According to HCMA Architecture + Design (2016), there are more than 20,000 private and public infrastructures in Europe, more than 100 in Germany and one in Canada. The first infrastructure with these characteristics in North America was opened in Minneapolis, Minnesota in July 2015 and another in Edmonton, Alberta in 2016.

Based on the above, the operation of a natural pool consists of purifying and cleaning the water without chemical products. There are three areas: the main pool or swimming area, then the water arrives by gravity through filters that collect large particles to the regeneration area where it is filtered through layers of substrate, it is here where the bacteria decompose and function as nutrients for plant growth. Once the water is purified, it goes to the pumping area and returns to the swimming area.

Dr. Wolfram Kircher made a proposal of four designs for the construction of Biopools, analyzing the movement of water, the filtration technique, division and the type of construction in the bathing area. Filtration consists of a hydrobotanical system, where the principles of the operation of a wetland are recovered, implementing layers of substrate where the water flows slowly, or in its case a system of pipes where the water is conducted to a storage where a rapid flow filter is placed. As for the regeneration (filtration) zones, it proposes three designs, the Ein-Kammer system (one chamber), zwei-Kammer-System (two chambers) and the

Mehr-Kammer System (multi-chamber). As for the construction principles to delimit the bathing area, there is the option of building it without walls, or with the construction of boundaries with low walls. (Kircher et al., 2016).

On the other hand, Quintero et al., (2017), evaluated in the laboratory the use of vertical wetlands as a phytoremediation system, obtaining water quality values below the permitted limits. Later, Karczmarczyk (2019) studied the possibility of using three parallel mineral filters for the removal of phosphate from water in biopools. In that same year, Cedeño proposed the use of vertical flow wetlands, obtaining values below the maximum values allowed in terms of water quality (Ávila, 2022). Finally, biopools were proposed as an alternative to chlorinated pools to eliminate the need for chemical treatment and expenses in mechanical and electrical processes, minimizing pumping requirements, and reducing possible harmful health effects (Sánchez et al., 2020).

1.1 NATURE GARTEN-BADETEICH NATURAL POOLS

During the 1980s, the landscaping industry in Germany experienced an overuse of exotic plants from Asia. In response to this trend, Thöle met Martin Mikulitsch, who in 1987 designed and built the world's first natural swimming pool in the Nature Garten-Badeteich style (Biopiscinas Ameyalli, n.d.). In 1992 Robert Thöle founded the company Nature Garten-BadeTEICH, with the aim of creating gardens in harmony with nature, using local materials and endemic plants. In 1999 the Naturgarten NPO association patented the certificate "Fachbetrieb für Naturnahes Grün", which accredits a company with the reproduction and use of endemic plants to guarantee the quality of gardening services in Europe (Biopiscinas Ameyalli, n.d.).

Thus, in 1999 the first natural pool was built in Germany, implementing the Nature Garten-Badeteich style, which triggered hundreds of similar projects throughout Europe. The company joined the continent's international society of natural pools, responsible for the standardization, planning and construction of these pools. In 2009, Bioland recognized it as one of the two most important organizations in Europe in the supervision of organic producers. Bioland is a company that brings together and controls organic producers, and is one of the two most important labels in Europe for organic and biological products.

As a consequence, this concept was appropriated in 2013 in the city of Amatlán de Quetzalcoatl, Cuernavaca, with the emergence of the company Biopiscinas Ameyalli, directed by the German landscape architect Robert Thöle and Sofía Cadena Noria, who has dedicated her life to the care, propagation and protection of aquatic plants (Biopiscinas Ameyalli, n.d.).

This idea aims to implement nature-friendly construction processes, taking into account the importance of water and the decrease in anthropic consumption in the filling of pools in the area, in addition to focusing efforts on cultivating and propagating the endemic plants of the region, since Mexican aquatic plants are mostly considered threatened species by the modifications. deterioration and disappearance of the habitats where they develop.

1.2 THE UNIT OF ANALYSIS: JALCOMULCO, VERACRUZ

One of the most representative adventure destinations in the state of Veracruz is presented as a case study. Located between parallels 19° 16' and 19° 24' north latitude and meridians 96° 41' and 96° 50' west longitude, it is located between 200 and 800 meters above sea level. The municipality of Jalcomulco is located 41.4 km from the capital of Veracruz, a journey of approximately 51 minutes. This municipality is bordered to the north by Emiliano Zapata and Apazapan; to the east by Apazapan and Tlaltetela; to the south by Tlaltetela; and to the west by Tlaltetela and Coatepec. The geographical area of Jalcomulco is 72.72 km², representing 0.1% of the state territory (SIEGVER, 2020).

The predominant climate is warm sub-humid with rainfall in summer, with average humidity (99%), and warm sub-humid with rainfall in summer and higher humidity (1%). The average temperature varies between 20°C and 26°C, while annual rainfall ranges between 1100 and 1300 mm (SIEGVER, 2020).

According to the INEGI 2020 Census, Jalcomulco has 5054 inhabitants and represents 0.06% of the state population. It has four localities, three in rural areas, Santa María Tatetla with 1707 inhabitants, Tacotalpan with 153 inhabitants and Rivera del Río with 44 inhabitants, while the municipal seat houses 3,150 inhabitants.

Ricalde (2016) comments that the most important adventure tourism destinations in Veracruz correspond to Jalcomulco and the Filobobos Natural Protected Area and its surroundings. This confirms the importance that persists in the visitor to get closer to the region. In addition to the climate, within the geoforms that are housed in the territory we can find mountain, valley, low elevations, hills and cumulative ramp, these characteristics detonate an attractive biodiversity in the region, since it is this site where the offer of services of one of the business groups in the ecotourism sector in the State of Veracruz is structured. This data is crucial since it introduces an absolutely determining variable in the configuration of the value chain: nature, and specifically the river, a distinctive feature of this tourism segment. It is around the river that the learning capacities of the companies of the Jalcomulco cluster are built (Saldaña et al., 2012).

The hydrography that surrounds the territory belongs to the fluvial system of hydrological region No. 28, being decisive the basin of the Papaloapan river and secondarily the Actopan, La Antigua and Jamapa rivers; it occupies 41.11% of the total state territorial area (28,636 km, being 39.32% of the total of the regions), as well as the largest discharge of fresh water (44,829 million cubic meters per year, which represents 42.28% for the state); on the other hand, the La Antigua river basin covers an area of 2,827 km2 (Pereyra et al., 2010); and it is made up of 27 municipalities, 22 of them belong to the State of Veracruz and 5 to the State of Puebla, partially or totally (PAMIC, 2017).

The La Antigua River rises in the Sierra Madre Oriental, with the name of Resumidero River, at an altitude of 3,350 m, east of the town of González Ortega in the state of Puebla. It flows southeast in mountainous terrain and, at the height of Rancho Calixitla, it changes its course to the ENE until the confluence with the Barranca Grande River 3 km north of the hill of the same name; at this site the general collector changes its name to Los Pescados River. It follows its southeast course and on the limits of the states of Puebla and Veracruz it changes it to the northeast; downstream from this point it receives the Cozolapa River on the left bank. At this confluence, the general collector changes its name to La Antigua River; it continues its southeast course passing through the town of Jalcomulco, Ver (Pereyra et al., 2010).

The entire territory of Jalcomulco (72.72 km2), which is located in the basin of the La Antigua River, is home to two perennial water streams: Los Pescados and Santa María; and intermittent currents of the Cascajal, Hediondo, Moyuapan and Tenexapa rivers (INEGI, 2010). It is part of the segmentation of the sub-basin identified with the code Ant24, which receives only surface water, which leads to its identification as a receiving area with a low water supply; the Los Pescados River has a Horton-Strahler order of 7, an area of 359,230 km2, 16.51 km of the main river and represents 3.34 % of the total territory of the basin (PAMIC, 2017).

Of the above, in terms of tourism development, the territory of Jalcomulco has been ideal for the construction of various hotels and ecotourism centers; according to the Royal Spanish Academy, a hotel is an establishment for an inn capable of comfortably accommodating guests or travelers; on the other hand, ecotourism centers show a close relationship with ecotourism activity, which according to the World Conservation Union, defines it as: That environmentally responsible tourism modality consisting of traveling or visiting natural areas in order to enjoy and appreciate nature (as well as any cultural manifestation of the present and the past), which promotes conservation, has a low visitation impact and fosters an active and socioeconomically beneficial involvement of local populations (Drumm et al., 2005).

In this sense, it can be said that adventure tourism companies in Jalcomulco depend on the river, and in this sense they are, if we may use the expression, dependent rivers (a play on words built from the notion of path dependence, well known to evolutionary economists) (Saldaña et al., 2012).

This study identifies a hotel offer of 25 hotels located exclusively in the urban locality. Most of these establishments are semi-open and surrounded by green areas. In addition, they have common spaces that include chlorinated water pools, with up to four facilities of this type in various sizes.

2 METHODOLOGY

To gather information about the tourist offer of Jalcomulco, tours were carried out in the community to identify lodging spaces and establish communication with the personnel who work in them, this activity involved four hotels and four ecotourism centers that provided information, since it was a voluntary decision to be part of the development of the reception work in progress. To this end, a database was designed that collected information regarding the demand for accommodation during the year 2022, as well as quantifying the amount of hydrosanitary furniture, the presence of water tanks or cisterns for water storage, and detailed measurements of the pools present in the rest sites, in order to determine the amount of water necessary for their filling; the typology of the infrastructure was also characterized, considering two variants in the analysis, in the case of hotels, those places of lodging where contact with nature is not related to the infrastructure were identified as those places of lodging where contact with nature has no relation to the infrastructure and as ecotourism centers (E.C.), those spaces where recreational practices merge with the presence of natural resources.

Subsequently, three fundamental steps were established to model water consumption in the eight tourist destinations, based on the concepts obtained from studies such as "Water

Consumption in Hotel Establishments in Mexico" by Santacruz De León et al. (2020). Listed below are the three steps to follow:

1. The first step in modelling a chain's consumption is to segment its hotels into similar groups according to their typical consumption (Escalera et al., 2014).
2. The second step consisted of detecting the water consumption that is required to meet the needs of a guest.
3. The third step consisted of calculating an estimate of water consumption derived from the hydraulic infrastructure of each hotel or ecotourism center, including the volume of water required by the pools. Consumption per use was also quantified according to site occupancy. Finally, the results were graphed.

Once we had bibliographic references and qualitative and quantitative data from the aforementioned database, comprehensive information was generated that made it possible to raise awareness and know the consumption of water in ecotourism centers and hotels, specifically the consumption of water for filling swimming pools.

During the tour of the eight tourist sites for the collection of information, the owners and managers were mentioned the purpose of investing in the construction of a natural pool, so they were invited to a talk focused on nature-based solutions for the treatment of water quality in swimming pools, which was carried out in the multipurpose room of the ejido house.

This call was attended only by the manager of the La Aldea Ecotourism Center with the possibility of making an investment, after knowing in detail the components, operation and advantages of the biopools, a visit to the facilities was formalized to make a reconnaissance of the site and to be able to choose the best location for the construction of the biopool. Once the site was defined, a topographic survey was carried out, to obtain the representation of the terrain, the information obtained from the terrain was processed in computer-aided drawing programs (AutoCAD and CivilCAD).

Two technical economic proposals were worked on and presented to the investors of the La Aldea ecotourism center. A prototype with a square shape of six meters per side was chosen. Once the design was concluded, the construction process was carried out with the necessary materials, which was documented.

The prototype was put into operation to the public. To do this, it was necessary to design an infographic with the regulations for its use, as well as an infographic that briefly explains the definition of biopools and their main elements.

As a result, in-depth research was carried out, which concluded in the design and construction of an infrastructure compatible with the three areas of Sustainable Development, economic, social and environmental. The following chapter presents the results obtained from this project.

3 RESULTS

3.1 CHARACTERIZATION OF THE HOSTING INFRASTRUCTURE

The construction of the hotels in the town of Jalcomulco includes modern buildings, as well as infrastructure with alternative sustainable materials such as bamboo, bahareque and adobe.

In relation to characterization, no lodging site has biofilters, wetlands for water treatment or dry toilets. Most have fewer than 10 rooms, a single pool, and green areas. There is a homogeneity in the construction materials in the four ecotourism centers, since they all use wood and bamboo. In the case of ecotourism center two, they also use bahareque (compacted earth walls). Only one of the hotels uses these materials; the other three are built with masonry walls and concrete slabs. A single ecotourism center has sunlight (photocell) and a system to capture rainwater. Two have a septic tank and three have a biodigester. Table 1 shows the participating sites, which provide hosting services with some of their general characteristics.

Table 1

Characterization of hotels and ecotourism centers in Jalcomulco, Ver.

Type (C.E./ Hotel)	C.E. 1	C.E 2	C.E. 3	E.C. 4	Hotel 1	Hotel 2	Hotel 3	Hotel 4
Type of building	Horizontal	Vertical	Horizontal	Horizontal	Horizontal	Vertical	Horizontal	Horizontal
Number of rooms	6	6	71	34	5	7	8	13
Total capacity	30	26	272	112	30	20	30	40
Total pools	1	3	1	1	1	1	1	1
Green Areas	Yes	Yes	Yes	Yes	Yes	No	No	No
Materials	Wood	Bamboo, wood,	Wood, adobe	Adobe, palm, canvas.	Wood, bamboo,	Concrete and	Concrete and	Concrete and

		bahareque, canvas.	walls, bamboo		masonry walls.	masonry walls,	masonry walls,	masonry walls.
Sunlight	No	Yes	No	No	No	No	No	No
Septic tank	No	No	No	Yes	Yes	No	No	No
Biodigester	Yes	Yes	Yes	No	No	No	No	No
Eco-techniques for water care								
Rainwater catchment	No	Yes	No	No	No	No	No	No
Dry toilets	No	No	No	No	No	No	No	No
Biofilters	No	No	No	No	No	No	No	No
Treatment Wetlands	No	No	No	No	No	No	No	No
Chemical Treatment	No	No	Yes	No	No	No	No	No

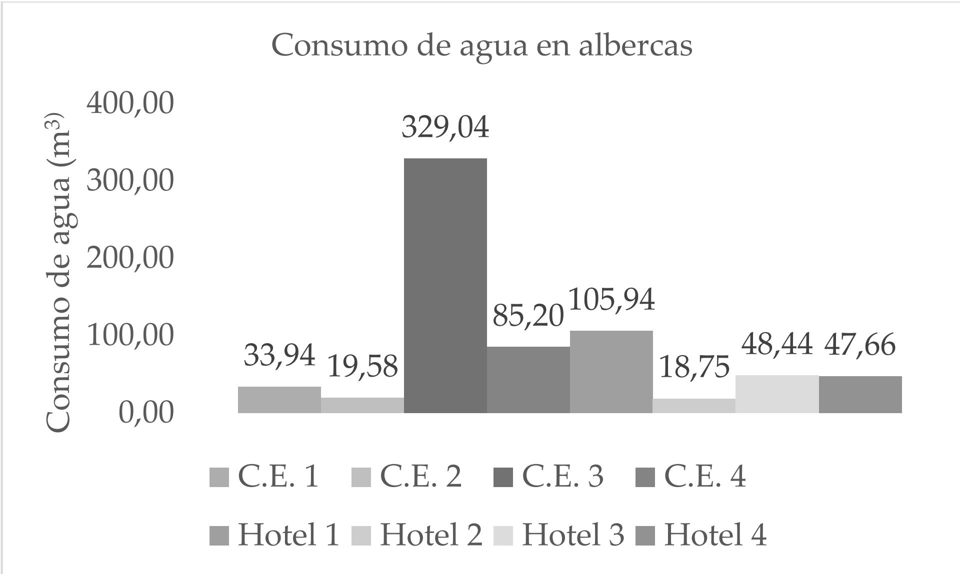
3.2 ANALYSIS AND DISCUSSION OF THE RESULTS OF WATER CONSUMPTION FOR THE FILLING OF SWIMMING POOLS IN HOTELS AND ECOTOURISM CENTERS IN JALCOMULCO

Although ecotourism centers are those spaces that are linked to natural areas, they require greater amounts of water to meet the needs of guests. In all cases, it was detected that the highest consumption corresponds to the filling of pools, since they are infrastructures that, due to their characteristics, require a permanent volume of the natural resource for their filling.

The highest consumption is reflected in Ecotourism Center 3 with 329.04 m3 of water that must be covered 365 days a year (figure 1), which seems to be related to the lodging capacity.

Figure 1

Demand for water volume in swimming pools



Source: Authors' elaboration based on the analysis of results.

As an integral part, issues related to water resource management were addressed.

In the case of Ecotourism Center 1, there is a stream from the spring that supplies drinking water to the entire community. However, from 7 am to 4 pm, the spring supplies producers directly and it is forbidden by the ejido organization to use the water for other purposes. For this reason, this Ecotourism Center begins to fill its tank and cistern during the afternoon and part of the night.

This same stream passes through Hotel 1, so it also makes use of the resource to fill its drinking water storage infrastructure, as well as the filling of the pool, in the same way, when cleaning is required, the water is discharged into the same body of water.

Ecotourism Center 2 obtains water directly from the river by pumping, in turn supplying water to other establishments. A remarkable fact about this space is that the water used to fill the pool does not use chemicals.

In the case of Ecotourism Center 3, they have a concession title from CONAGUA, so the water they extract comes from a well located within their facilities. However, the water table has decreased over time, and on some occasions they have chosen to buy water in pipes to be able to supply users. In this accommodation, they carry out a chemical treatment with a plant of minimal dimensions and, therefore, reuse the resource.

In Ecotourism Center 4, water is extracted from the river to supply the entire hydraulic infrastructure, including the swimming pool. In the case of Hotels 2, 3 and 4, being located in the center of the town, they have the supply of drinking water from the municipal line, also the discharges are poured into the sanitary drain, however, this drainage converges to the river downstream.

As for filling the pools, in general, the water is changed every third day if there has been a lot of tourist influx. The emptied water is used to irrigate the gardens or for cleaning.

As a brief discussion, of the characterization of hotel sites, it was possible to identify the construction of ecotechniques for the care and integral management of water, such is the case of the rainwater catchment and a sedimentation plant for sewage treatment in the Ecotourism Center 3; however, those in charge of the tourist sites showed interest in training to implement actions to have water reservoirs, especially in the dry season.

Regarding the infrastructure of hotel demand, it was detected that there are lodging sites in Jalcomulco that exceed their maximum capacity by up to 300%, of the above, Gössling (2012), documented that the highest water consumption rates are found in hotels with spas and swimming pools; so it was found that the pools measured in this intervention, have 18,000 liters to 329,000 liters of water and the larger the establishment, the greater the size of the water demand, however the problem of this use does not end there, because it is water that must be renewed at least every third day, depending on its use and its emptying, it affects ecosystems by disposing of contaminated water in water veins that connect populations during its journey.

Design, construction, operation and maintenance of the Biopiscina at the La Aldea Ecotourism Center

A topographic survey was carried out to determine the unevenness of the terrain. Once the information was processed, a square area of 6 x 6 meters was allocated for the biopool. To do this, it was necessary to calculate and build a stone perimeter wall to give stability to the infrastructure. It is worth mentioning that the composition of the soil allowed the reuse of the site's material, optimizing costs and resources. Of the two technical-economic proposals raised, the one whose investment was $170,000.00 M.N. was chosen. The area destined for planting corresponds to approximately 50% of the surface, while the remaining percentage is the swimming pool.

The design of the biopool considered three areas:

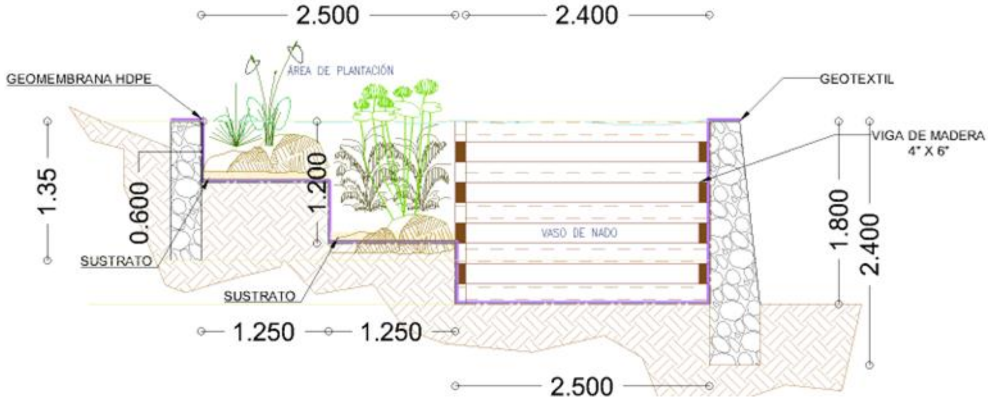
1.- Swimming pool: this area includes only the area available for swimming. Delimited by a length of 5.20 m, a width of 2.50 and a depth of 1.80 m, to receive 23.4 m3 of water.

2.- Submerged plant area: In this space of 1.25 x 5.20 m and a depth of 1.20 m, two types of plants are proposed, Potamogeton coloratus (fully submerged) and Nymphaea colorata (floating submerged rooted), and the area will receive 7.80 m3 of water.

3.- Area of emergent plants: In this space 1.25 x 5.20 m and a depth of 0.60 m are located emergent plants such as taro, horsetails, colocasias and papyrus, as shown in figure 2, this area requires 3.90 m3 of water.

Figure 2

Cross-sectional view



Source: Authored by the authors.

The planting area in a biopool should represent between 50 and 75 percent of the total area of the system. In this case, the total area intended for construction is 48 m², with a swimming area of 15 m² and a planting area of 33 m², approximately 75% of the total area, thus meeting the requirement.

The materials used for the construction included 200 gr/m² geotextile, Firestone EPDM geomembrane, pine wood beams, zeolite, earth, wooden dowels, vegetation and water.

The plants selected for the natural pool are classified as:

- Fully submerged: Potamogeton coloratus
- Fully Submerged Rooted Float: Nymphaea colorata
- Lemnaceae (free floaters): Salvinia minima and Pistia stratiotes
- Rooted submerged (edible): Colocasia esculenta
- Emergent rooted submerged: Colocasia esculenta, var. "Black Magic"; Cyperus papyrus; and Equisetum arvense.

For the construction phase, the area was delimited with the support of the total station, this topographic instrument locates georeferenced points with arbitrary coordinates; In this case, the vertices of the area destined for the perimeter wall were located and placed in order to orient the infrastructure. Once marked, the excavation with mechanical means and the construction of the stepped stone walls began, respecting the depths of the design for the planting areas. This wall has a width of 50 cm and a height ranging from 1.35 to 2.40 meters.

Once the work that delimits the biopool area was completed, the geotextile was placed, a permeable and flexible fabric made of polypropylene or polyester, whose main function is to separate different layers of materials. Subsequently, the EPDM geomembrane was placed, whose main function is to provide the system with an impermeable layer.

Next, the swimming pool area was delimited, with wooden beams of 10 x 20 cm high and wide and a length of 5.20 m in the long direction and 2.50 m in the short direction.

For the planting area, another layer of geotextile was placed, to receive the substrate, which resulted from the combination of black soil from the site and granulated zeolite. This mineral, a product of sedimentary rocks, is used in water quality treatment systems. Being highly hydrophilic, it facilitates the absorption of nutrients by plants, since these are taken up by the roots dissolved in water (Chica Toro et al., 2006).

Simultaneously with the planting, the biopool began to be filled. Additionally, stones were placed over the area to fix roots and as ornamental elements. Once filled, the ecosystem stabilization stage was carried out (Figure 3).

After filling, the stabilization phase began that lasted from November 6 to December 18, 2023, during these six weeks, the natural pool was not used for recreational purposes, with the aim of allowing the ecosystem to adapt and begin the process of reproduction of the plants. In the case of water lilies (Nymphaea colorata), the growth of the petioles began from the second week, as well as the reproduction of their leaves and the first flower bud took place during the third week of May 2024.

Figure 3

Biopool finished

Source: Photograph of the authors.

In the case of papyri and reeds, emergent stems were observed. Colocasia var. Black Magic showed an increase in the size of its leaves and their reproduction. However, it took until the third week for the Potamogeton species to start breeding. During this time, it was necessary to clean up the bottom of the planting area due to the proliferation of algae, which hindered leaf growth. Once the cleaning was complete, the reproduction of the Potamogeton leaves continued steadily. As for the fauna of the ecosystem, dragonflies were observed in the larval and adult stages, as well as snails, ladybugs and bees. Water turbidity was also monitored to prevent eutrophication in the ecosystem.

After the weeks of stabilization, a maintenance session was held to train the personnel who work in the ecotourism center. During this activity, the team carried out various tasks such as cleaning and removing leaf litter from the bottom, untangling petioles in the water lily area, and removing dead vegetation. Finally, the infrastructure was opened to the public during the month of March 2024.

Figure 4

General view of the biopool

Source: Photograph of the authors.

To improve the landscape and protect the geomembrane in place, planters were built using leftover materials and recycled wooden pallets. These planters were placed around the planting area to collect leaf litter and organic matter derived from the pruning of the plants responsible for phytoremediation. In addition, various species of ornamental plants were planted and a wooden corridor was built to walk through the swimming area and bamboo railings were placed to improve the safety of visitors (figure 4).

In this same sense, and in order to inform tourists about the operation of natural pools and the regulations to make use of these infrastructures, the design of two infographics was carried out, which are shown below in Figure 5. It should be noted that the QR codes attached to them link information that was collected during the execution of the reception work.

Figure 5

Supporting infographics

Source: Authored by the authors.

4 CONCLUSION

Based on the results obtained, it is concluded that the design, construction, operation and maintenance of the natural biopool has been a meticulous, carefully planned and comprehensive process. From the beginning with the topographic survey to determine the unevenness of the terrain, to the selection and efficient use of materials such as EPDM geomembrane and geotextile, each step has been key to ensure the stability and functionality of the system. The stabilization phase has been fundamental, allowing the natural ecosystem to adapt and begin to thrive, evidenced by the growth and reproduction of various plant species, as well as the presence of a variety of aquatic fauna.

In addition, post-stabilization maintenance and improvement measures, such as the construction of planters with recycled materials, the planting of ornamental plants, and the installation of safe infrastructure for visitors, have contributed not only to the protection of the landscape, but also to the continued well-being of the ecosystem. The integration of sustainable practices and the reuse of resources have been fundamental pillars throughout the process, highlighting a commitment to environmental conservation and efficiency in the use of natural resources.

This project stands out for effectively addressing local water management through innovative solutions such as natural pools, also serving as a model of collaboration between various social actors. The active participation of the tourism business sector and the local community have been instrumental in its success, underscoring a shared commitment to environmental conservation and sustainable development.

The La Aldea Ecotourism Center has played a central role in investing in innovative infrastructure and promoting sustainable practices within its tourist destination. This has not only added economic and environmental value to the place, but has also contributed to strengthening the identity of Jalcomulco as a destination committed to the care of its natural resources.

Overall, the biopool not only meets the expected technical and aesthetic standards, but also stands as an example of how ecotourism can coexist harmoniously with environmental conservation, offering visitors a unique and educational experience in a restored and cared for natural environment.

In addition, the dissemination of this project has the potential to positively influence the adoption of similar solutions in other localities and sectors. By promoting eco-techniques and integrated water management, a culture of environmental responsibility is fostered that can be replicated in future academic and business initiatives.

It is essential to continue sharing knowledge and raising awareness about the importance of taking care of water resources. This study lays the groundwork for future research and improvements in ecotourism biopools, as well as advocating for the integration of nature-based solutions as an effective response to global water stress.

In summary, the natural biopool in Jalcomulco represents a remarkable example of how innovation, collaboration, and community engagement can converge to promote sustainable and resilient practices in the face of current environmental challenges.

REFERENCES

Ávila, V. 2022. Biopools, a sustainable alternative. Bachelor's Thesis in Technical Architecture. Higher Polytechnic School. University of Alicante. San Vicente del Raspeig, Spain. 144 p.

Ameyalli Biopools. (n.d). https://www.biopiscinas.com.mx/biopiscinastepoztlan/ [Accessed July 10, 2024].

Brotherhood, M. E. 2013. The viabilitye of the implantation of biological pools in Brazil. IX National Congress of Management Excellence. Rio de Janeiro.

Committee of Statistical and Geographic Information of the State of Veracruz (CEIEG). 2020. Statistical and Geographic Information System of the State of Veracruz de Ignacio de la Llave (SIEGVER). Municipal Booklets 2020. Jalcomulco. 11 p.

Drumm, A., Moore, A. 2005. A Handbook for Conservation Practitioners, Volume 1. Arlington, Virginia, USA: The Nature Conservancy. 102 p.

Dupuis, A. 2023. Exploring what tourism is. Creative Destinations https://www.destinoscreativos.com/que-es-el-turismo/ [Accessed July 10, 2024].

Durrant, C., Correia, E., Golding, G., & Bola, S. 2007. Natural Swimming Pool Design. In W. D. Medhat Moussa, Proceedings of the ENGG 3100: Design III Projects, 2007. Guelph: University of Guelph. 81-82.

Gabarda M. A., Ribas P. A. and Daunis-i-E. J. 2015. Tourism development and efficient water management. An opportunity for sustainable tourism on the Costa Brava (Girona). Tourism Research. 9:50–69.

Gössling, S., Peeters, P., Hall, C. M., Ceron, J. P., & Dubois, G. 2012. "Tourism and water use: Supply, demand, and security. An international review". Tourism Management. 33(1):1-15.

HCMA Architecture + Design. 2016. Natural Swimming Pools. The future of public swimming without chlorine. 33 p.

INEGI. 2010. Compendium of Municipal Geographic Information 2010 Jalcomulco Veracruz de Ignacio de la Llave. https://www.inegi.org.mx/app/biblioteca/ficha.html?upc=702825293192 [Accessed July 1, 2022].

INEGI. 2020. Population and Housing Census 2020. https://www.inegi.org.mx/app/scitel/Default?ev=9 [Accessed July 1, 2022].

Karczmarczyk, A., Bus A., and Baryla A. 2019. Influence of operation time, hydraulic load and drying on phosphate retention capacity of mineral filters treating natural swimming pool water. Ecological Engineering. 130:176-183.

Kircher, W., & Thon, A. 2016. How to Build a Natural Swimming Pool. London: Filbert Press. 328 p.

Mafra, P., Rodrigues, M. J., Martins, M. C., Gonçalves, A. (Coords.). 2017. 7th Environmental Education Meeting: Book of Ties. Bragança: Polytechnic Institute of Bragança, Escola Superior de Educação. 92 p.

Pereyra, D. D., Pérez, S. J. A., Salas, O. M. R. 2010. Hydrology. Atlas of the natural, historical and cultural heritage of Veracruz; Enrique Florescano, Juan Ortíz Escamilla, coordinators. Mexico: Government of the State of Veracruz: Commission of the State of Veracruz for the Commemoration of National Independence and the Mexican Revolution: Universidad Veracruzana, 2010. v. 1, p. 85-122.

Coastal Watershed Conservation Program in the Context of Climate Change C6. 2017. Integrated Management Action Plan (PAMIC) Antigua River Basin. 108 p.

Quintero, F., Guardia-Puebla, Y. and Rodríguez-Pérez, S. 2017. Phytoremediation for the treatment of swimming pool water. Hydraulic and Environmental Engineering. 38(3):101-113.

Ricalde, G. S. 2016. Analysis of the impact of adventure tourism Through the system of sustainability indicators for tourism in Jalcomulco, Veracruz, Mexico. Master's thesis. University of Costa Rica. San José, Costa Rica. 195 p.

Saldaña, A., Cardoso C.J. and León, K. 2012. The Business Group of Jalcomulco, Veracruz: The Institutionalization of a Business Model in Adventure Tourism in Mexico. Administrative Science. 2:25-36.

Sánchez, C., Trejo, M., Sánchez L., & Sánchez, M., 2020. Implementation of natural pools: an alternative to improve the effects on the respiratory tract due to exposure to chlorinated pools. Pneumology and Thoracic Surgery. 79(3):71-84.

Santacruz De León, E. E., and Santacruz De León, G. 2020. Water consumption in hotel establishments in Mexico. Studies and Perspectives in Tourism, 29(1):120-136.