Current status of wastewater treatment through large-scale treatment wetlands in the State of Veracruz, Mexico

Karina Elizabeth Martínez-Aguilar [1], José Luis Marín-Muñiz [2,*], Luis Manuel Álvarez-Hernández [1], Elizabeth Delfín Portela [3], and Sergio A. Zamora-Castro [4]

[1] Doctorado en Desarrollo Regional Sustentable, El Colegio de Veracruz, Xalapa, Veracruz, México.
[2] Academia de Desarrollo Regional Sustentable, El Colegio de Veracruz, Xalapa, Veracruz, México.
[3] Tecnológico Nacional de México / ITS de Misantla, Misantla, Veracruz, México.
[4] Facultad de ingeniería construcción y hábitat. Universidad Veracruzana. Bocal del Río, Veracruz, México.
* Corresponding author: jmarin@colver.info; Tel.: +52 2281079457

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Abstract: The use of treatment wetlands has increased globally in the last twenty years. In the State of Veracruz, Mexico, CONAGUA has only registered six wetland-based treatment plants. However, recent research has revealed the existence of additional wetland treatment systems in operation that were not listed in the CONAGUA inventory. The main objective of this study is to diagnose the current situation of wastewater treatment in the State of Veracruz, Mexico, and identify the large-scale treatment wetlands that exist in the region. The study will focus on the design and implementation characteristics of these wetlands. The research is qualitative and descriptive, based on publications between 2000 and 2023 from Google Scholar and databases published by CONAGUA. The information review process used a content analysis technique to identify the geographical location of the wetlands, their installation area, the type of wetland, the type and volume of treated water, the vegetation used, and the year of installation. The results identified 12 large-scale treatment wetlands currently in operation in the State of Veracruz, Mexico, which have different design characteristics. The main variations are in the type of plants used. Some of these wetlands have been in operation for periods ranging from 1 to 17 years, but there is no updated information regarding their current functioning. Thus, future research is suggested to focus on the situational diagnosis of these systems years after their installation.

Keywords: treatment wetlands; design; ecotechnologies; sewage; Veracruz.

Introduction

Water plays a crucial role in various aspects of the society's social and economic life. It significantly affects the quality of life of the people. Therefore, it is everyone's responsibility to preserve its quantity and quality as it is of vital importance (CONAGUA, 2022).

Wastewater treatment is an effective solution to mitigate water quality issues by minimizing the presence of pollutants in discharged water bodies. Unfortunately, Mexico is currently facing serious water management problems due to the neglect of wastewater treatment. As a result, ensuring water quality and providing effective wastewater sanitation services in the country have become crucial challenges (García-García *et al*., 2016).

In 2015, the United Nations (UN) approved the 2030 Agenda for Sustainable Development which contains 17 Sustainable Development Goals (SDGs). These goals are a worldwide appeal to end poverty, safeguard the planet, and enhance people's lives and prospects globally (UN, 2015). SDG No. 6 specifically focuses on granting access to adequate and fair sanitation, enhancing water quality, and protecting and restoring water-related ecosystems (ECLAC, 2018). Unfortunately, 80% of wastewater globally is estimated to return to nature without proper treatment, posing significant environmental and public health risks (Cross *et al*., 2023).

Over the past few decades, governments and water management agencies have made wastewater treatment a top priority and a central strategy to enhance the quality of life, safeguard public health, and promote sustainable development. Despite these efforts, achieving these goals remains a challenge, as noted by Rivera *et al*. (2018).

Based on the 2020 Population and Housing Census by INEGI, there were 2,872 functioning municipal Wastewater Treatment Plants (WWTP) across 2,469 municipalities by the close of 2021. As per the National Water Commission (CONAGUA), the country's total installed treatment capacity amounts to 198,603.55 liters per second, with a treated flow of 145,341.0 liters per second. This corresponds to 67.5% of the wastewater generated and collected in the municipal sewage systems nationwide, as of 2022.

Similarly, while the establishment of plant infrastructure may receive support from the state or federal entities, it is the responsibility of municipalities to bear the expenses of operating and maintaining treatment systems. Unfortunately, a significant number of municipalities lack the financial means to prioritize the management of their plants, according to a study by Rivera *et al*. (2018). To address this challenge, it is crucial to examine the availability of public programs and policies that can offer economic resources, enabling municipalities to cover these costs.

Various factors contribute to WWTPs being out of operation, including limited economic resources of the operating organizations to cover expenses, insufficiently trained personnel, outdated infrastructure, flaws in the design and construction, lack of support from local authorities, and inadequate or absent sanitary sewage supply (Pedrozo, 2021).

The lack of eco-friendly technologies that are affordable and energy-efficient has caused significant environmental pollution in various regions of the country, including smaller businesses and under-resourced areas that lack proper wastewater treatment. This impact is felt on both large and small scales, especially in tropical and subtropical regions and subregions of Mexico, as noted by Puente *et al*. in 2017.

While there are numerous wastewater treatment systems available, many of them come with exorbitant installation and operational costs, rendering them impractical in certain cases. However, sustainable sanitation practices that prioritize the preservation of ecosystems can still be achieved through the use of innovative technologies, such as nature-based solutions (NBS) such as treatment wetlands (Cross *et al*., 2023).

Palma-Cabrera *et al*. (2022) note that wetlands have been utilized for water sanitation since the 1950s in various regions across the globe. Since then, treatment wetlands (also referred to as constructed wetlands, constructed wetlands, or bioengineered wetlands) have emerged as a dependable technology for treating diverse forms of wastewater (Vymazal, 2010). Treatment wetlands engineered to treat wastewater have been deployed on all continents, with records of 138 treatment wetlands in 38 nations worldwide exhibiting promising outcomes about improving water quality (Vymazal, 2014; Sandoval-Herazo *et al*., 2018).

According to the Mexican Institute of Water Technology (IMTA), the use of treatment wetlands has increased globally over the last two decades due to their economical treatment, ease of maintenance, simplicity of operation, and environmental friendliness (Rivas, 2021).

Switzerland, Denmark, North America, and Australia are leading the way in using treatment wetlands to conserve natural resources. Sydney, Australia is also exploring the aesthetic benefits of these wetlands, creating a visually pleasing landscape (Palma-Cabrera *et al*., 2022). In Mexico, treatment wetlands have become a popular, cost-effective option for treating wastewater in recent years, boasting zero energy costs and high contaminant removal rates (Sandoval-Herazo *et al*., 2018; Marín-Muñiz *et al*., 2023).

Similar to natural wetlands, treatment wetlands provide an important group of services to the ecosystem and to humans, including: improvement of water quality, supply of biomass, recreation, regulation of gases (carbon sequestration), regulation of microclimate, regulation of water flows (groundwater recharge), habitat for diverse species (microorganisms, plants and animals), aesthetics, conservation of ecological and genetic biodiversity, energy production, and scientific and educational values (Dumax and Rozan 2021; Masi *et al*. 2018; Mitsch *et al*. 2014; Yang *et al*. 2018). Some authors consider that it may take 5 to 15 years for a constructed wetland to provide the same ecosystem services as natural ones (Jiang and Chui 2022).

The social participation of local communities is a critical factor in the success of constructed wetlands as ecotechnology for wastewater treatment. According to recent research by Zitácuaro (2021), involving social actors in the operation and maintenance of these systems enhances their sustainability. Therefore, it is essential to examine the social perception of residents in the areas where these wetlands are situated.

In recent times, addressing wastewater treatment management from an unconventional perspective has become essential. Combining hydrological, environmental, and social aspects, constructed wetlands have emerged as an innovative, efficient, and sustainable alternative for treating wastewater (Pérez *et al*., 2022). The treated water obtained from these systems has an acceptable quality, which encourages the implementation of the circular economy.

It provides the possibility of reusing the treated water, promoting water circularity by forming loop systems, and even closed systems to reuse water resources (Cruz *et al*., 2018). By closing the cycles of matter, water, and energy, this "different" economy enables growth while reducing extractions from the natural environment (Frérot, 2014). Transitioning to a circular economy, where resources are conserved, and waste generation is minimized, is crucial to achieving sustainability in the economy (García, 2016).

In the State of Veracruz, CONAGUA's inventory currently lists only six wetland-based treatment plants. However, recent studies (Marín-Muñiz *et al*., 2023; Rivera *et al*., 2023; Sandoval *et al*., 2023) have identified additional wetland treatment systems that are currently operational but not included in the CONAGUA inventory.

Presently, there exists a substantial body of scientific literature that highlights an increasing number of studies centered on the design, creation, and efficacy of various treatment wetlands (Sandoval-Herazo *et al*., 2020; Marín-Muñiz *et al*., 2023). Nonetheless, these publications are predominantly focused on disseminating preliminary outcomes stemming from the adoption and functionality of the treatment system, with scant attention paid to the social, economic, and environmental facets of the system in the years following its implementation.

As the treatment wetlands is a recent technology, further studies are required to explore various alternatives that may exist. These alternatives include the use of alternative substrates, implementation of external microorganisms, innovative cell designs, and their use for waste treatment for different types of water. Additionally, it is important to study the various plants that can be planted in these wetlands. Studies conducted by Hernández *et al*. (2016), Sandoval-Herazo *et al*. (2016), Casierra *et al*. (2016), and Marín-Muñíz *et al*. (2017) provide valuable insights on the subject.

This study is premised on the notion that with the many options and permutations available for configuring wastewater treatment systems, and the growing popularity of treatment wetlands in recent years, the State of Veracruz, Mexico likely boasts an array of treatment wetland-based systems spread throughout the region, constructed with diverse design specifications that suit the unique needs and circumstances of the area.

The primary aim of this endeavor is to conduct a comprehensive assessment of the present state of wastewater treatment in the Mexican State of Veracruz. Additionally, the objective is to recognize the prominent large-scale treatment wetlands in the same region and delineate their key features, including their design and execution.

Materials and Methods

This study employs a qualitative methodology and entails a descriptive research design. The research draws on data obtained from Google Scholar (https://scholar.google.es/schhp?hl=es) and Dimensions (https://app.dimensions.ai/discover/publication), where the search terms "constructed", "wetlands", "México", and "Veracruz" were used to limit the results to publications ranging from 2000 to 2023. Furthermore, the study also examines the databases made available by CONAGUA via the National Water Information System portal (https://sinav30.conagua.gob.mx:8080/).

The review process involved a content analysis technique that first assessed the current wastewater treatment situation in Veracruz. Afterward, we identified the treatment wetlands in the state, including their location and installation area. Our objective was to identify large-scale wetlands in Veracruz, and we referred to the classification by Marín-Muñiz *et al*. (2023). This classification defines experiments that are developed at the site where wastewater is generated and where at least part of the tributary water is treated as "large scale". Additionally, the wetland's extension must be at least 20 m^2.

Subsequently, the key attributes comprising these treatment systems were discerned, including the wetland type, treated water type, treated water volume, vegetation employed, and year of installation. This data was collected and analyzed following the methodologies of Rodríguez-Domínguez *et al*. (2020) and Marín-Muñiz *et al*. (2023), enabling a systematic identification of the primary design and implementation features of the sizeable treatment wetlands presently in operation within Veracruz, Mexico.

Results and Discussion

Current situation of wastewater treatment in the State of Veracruz

Veracruz is located in the eastern region of Mexico and spans an area of 72,410 square kilometers. This makes up 3.7% of the country's landmass. Its coastline along the Gulf of Mexico stretches for approximately 745 kilometers. This accounts for 29% of the Mexican coast along the Gulf of Mexico and 4% of the entire Gulf of Mexico basin, as reported by CONABIO in 2021. The State of Veracruz de Ignacio de la Llave is divided into 212 municipalities and has a population of 8,062,579 individuals residing in 9 metropolitan areas, according to INEGI's most recent data from 2020.

According to estimates, about 30% of the national runoff passes through the State of Veracruz. This highlights the significant contributions of the Coatzacoalcos and Papaloapan regions, accounting for almost 14% and 13%, respectively. Additionally, the state has 18 aquifers with an average annual recharge of 4,080 hm3, renewable recharge of 52,990 hm^3/year, and per capita availability of 6,572 m^3/inhabitant/year. The pressure degree is considered "High" at 11.4%. In terms of access to drinking water coverage, the urban area has 96.37% coverage, while the rural area has 83.09%. Drainage is also well-covered, with 98.19% in the urban area and 78.02% in the rural area (CONAGUA, 2021).

Throughout the 20th century, Veracruz became a thriving regional hub due to its abundant water resources, strategic geographic location, and significant hydrocarbon deposits. This allowed for the growth of vital productive industries, unfortunately resulting in the contamination of the region's bodies of water. The majority of these waterways receive wastewater discharges from various sources, such as urban centers, oil and chemical industries, thermoelectric industries, sugar mills, coffee mills, and livestock farms. Sadly, this has led to severe environmental degradation in the Pánuco, Papaloapan, and Coatzacoalcos rivers, primarily due to pollution from pesticides and hydrocarbons (CONABIO, 2021).

According to official government data from Mexico in 2022, the State of Veracruz produced an annual volume of wastewater totaling 7,409,720,865 m3. To manage this, there are 106 treatment plants dedicated to municipal wastewater treatment in Veracruz, with a combined installed capacity of 7,036.3 l/s and a treated flow of 4,372.6 l/s, as reported by CONAGUA in 2021.

According to the latest data from CONAGUA's National Inventory of Municipal Purification and Treatment Plants, activated sludge processes account for 37% of the wastewater treatment methods utilized in Veracruz, while Upflow Anaerobic Sludge Blanket (UASB) make up 20% (as shown in Figure 1).

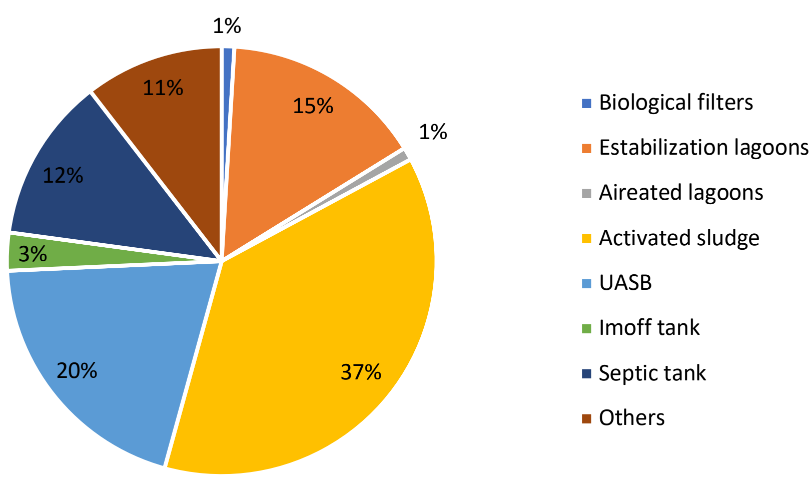

Figure 1. Main wastewater treatment processes in the State of Veracruz. Source: Data from CONAGUA (2022).

It is worth noting that according to the annual chronological review reported by CONAGUA, the number of treatment plants installed in the State of Veracruz has increased (Figure 2). However, it is unknown how effectively these facilities operate, as CONAGUA only provides location data (municipality and town), the plant's name, process, installed capacity, treated flow, receiving body, and the person responsible for operating the plant. There is no information available about the operation of the facility or the quality parameters of the treated water.

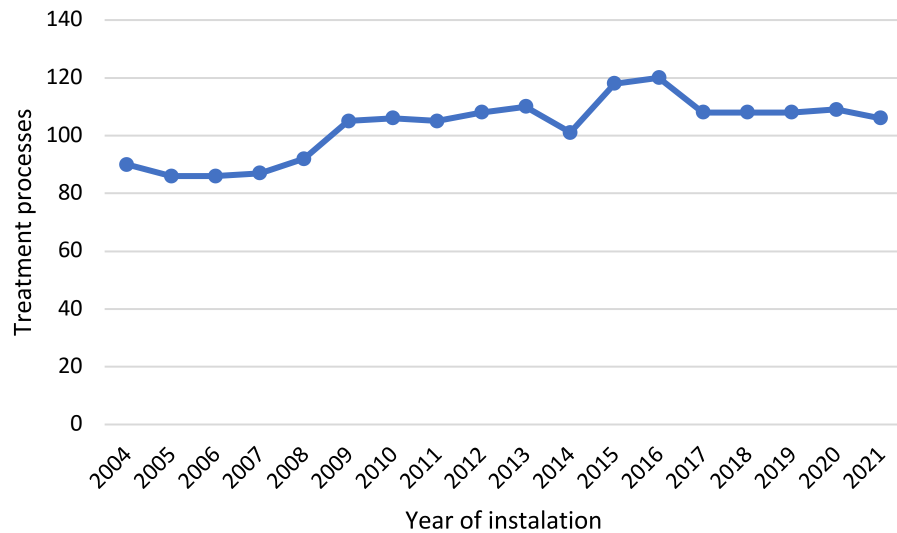

Figure 2. Main wastewater treatment processes in the State of Veracruz. Source: Data from CONAGUA (2004-2022).

While there has been a slight increase in the installation of wastewater treatment plants in Veracruz, this has not resulted in significant benefits. The reasons for some of these facilities ceasing operations are unclear. However, it is commonly known that conventional treatment systems face financial and resource challenges for successful operation and maintenance, including the need for human and material resources (Medrano *et al*., 2020).

Moreover, various scholars (Pedrozo, 2021; Rivas, 2021; Rollano, 2021) have highlighted that there are multiple reasons why wastewater treatment plants (WWTPs) may remain non-operational. A significant factor is the insufficient economic capacity of the operating organizations to cover the costs of necessary inputs. Other factors include a shortage of trained personnel, outdated infrastructure, design and construction flaws, a lack of interest from local authorities, and inadequate sewage supply, amongst other challenges.

It is important to recognize that local operating organizations bear the responsibility for the operation and upkeep of WWTPs (CONAGUA, 2021). These organizations face a range of challenges, including financial, technical, administrative, and regulatory hurdles (Gómez, 2021). In the absence of such organizations, municipal governments may manage these treatment systems, yet they often lack the requisite resources and prioritization to do so effectively.

Despite the drawbacks that traditional wastewater treatment methods present, treatment wetlands offer an attractive solution. Not only do they have lower treatment costs compared to electromechanical systems, which require electrical energy to function, but they are also highly effective in purifying wastewater. Additionally, their simplicity of operation and maintenance makes them an economical choice, as they do not require specialized labor or input expenses. Treatment wetlands also provide beautiful natural spaces, as the careful selection of plants can lead to productive processes such as the cultivation and sale of ornamental flowers or plant species that can be used for crafting by the community. Furthermore, they encourage the recycling of elements in nature (Rivas, 2021).

Identification of treatment wetlands in the State of Veracruz

A comprehensive analysis was conducted on 105 publications along with the CONAGUA database, which led to the discovery of 12 fully operational large-scale treatment wetlands in the State of Veracruz, Mexico. Figure 3 provides a clear view of the municipalities and localities where these systems are situated, while Table 1 outlines their key design features.

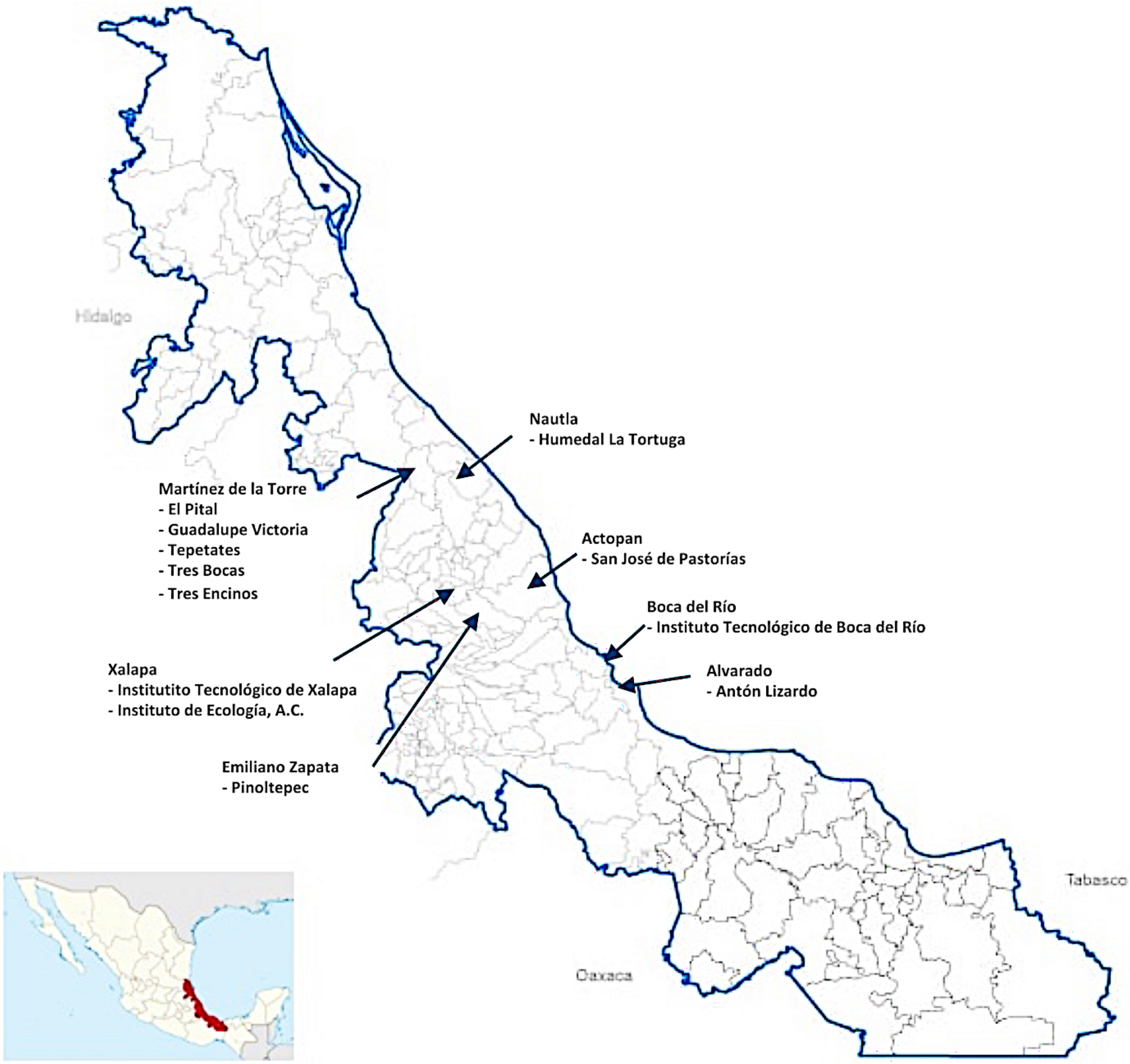

Figure 3. Location of large-scale treatment wetlands in the State of Veracruz, Mexico.

The search results reveal that there are only a handful of wetland-based treatment systems (12) identified in the State of Veracruz, with the majority located in central municipalities such as Xalapa (3), Boca del Río (1), Alvarado (1), Nautla (1), Martínez de la Torre (4), Emiliano Zapata (1), and Actopan (1). Notably, a quarter of these systems have been established by educational institutions, including the Higher Technological Institutes of Xalapa and Boca del Río, as well as the A.C. Institute of Ecology. Treatment volumes vary from 0.23 to 5.9 liters per second, with the municipal wetlands listed in the CONAGUA database (2022) showing higher treatment rates.

It is worth mentioning that ornamental plant varieties, including *Canna hybrids, Alpinia purpurata, Cyperus papyrus*, and *Heliconia sp.*, are frequently employed as phytoremediators. This aligns with the findings of other research conducted on treatment wetlands in Mexico (Marín-Muñiz *et al*., 2023). This may be attributed to the outstanding results achieved in pollutant removal by these species, with *Typha sp. and Canna hybrids* exhibiting removal rates of approximately 92.5% for Dissolved Oxygen, 80.5% for Ammonium, 80% for Total Suspended Solids, and 85% for Phosphorus (Boyás *et al*., 2022).

Table 1. Characteristics of large-scale treatment wetlands in the State of Veracruz, Mexico.

Location	Type of system	Type of treated water	Treated water volume (l.p.s.)	Vegetation used	Surface (m^2)	Year of installation	Pollutant Removal (%)	Reference
Antón Lizardo, Alvarado*	UASB + Wetland	Municipal wastewater	3.0	N.S.	N.S.	2006	N.S.	Comisión Nacional del Agua (2022)
El Pital, Martínez de la Torre*	UASB + Wetland	Municipal wastewater	5.9	N.S.	N.S.	2009	N.S.	Comisión Nacional del Agua (2022)
Guadalupe Victoria, Martínez de la Torre*	UASB + Wetland	Municipal wastewater	2.0	N.S.	N.S.	2009	N.S.	Comisión Nacional del Agua (2022)
Tepetates, Martínez de la Torre*	UASB + Wetland	Municipal wastewater	1.8	N.S.	N.S.	2009	N.S.	Comisión Nacional del Agua (2022)
Tres Bocas, Martínez de la Torre*	UASB + Wetland	Municipal wastewater	1.0	N.S.	N.S.	2009	N.S.	Comisión Nacional del Agua (2022)
Tres Encinos, Martínez de la Torre*	UASB + Wetland	Municipal wastewater	0.8	N.S.	N.S.	2009	N.S.	Comisión Nacional del Agua (2022)
Pinoltepec, Emiliano Zapata**	HSSFW	Community System	0.23	*Typha sp., Zantedeschia aethiopica., Hedychium coronarium. Cyperus papyrus*	60	2013	TN: 47 TP 33 COD: 67 TSS: 34	Hernández (2016)
Instituto de Ecología, A.C. Xalapa**	HSSFW	Private system	N.S.	*Hedychium coronarium, Strelitzia reginae, Zantedeschia aethiopica, Lilium sp., Cyperus papyrus, Heliconia sp.*	48	2016	NH_4^+-N: 68-70 and 97-98 PO_4-P 58-62 $SO_4^{-2:}$ 82 BOD_5: 70-80	Hernández y Lagunes (2018)
San José Pastorías, Actopan**	HSSFW	Community System	0.21	*Typha sp., Canna hybrids*	50	2018	COD : 86.95 BOD_5: 81.3 TSS : 64.6 TP : 85.2 TN : 52	López (2022) Marín-Muñiz (2022) Sandoval (2023)
Instituto Tecnológico de Boca del Río, Boca del Río**	N.S.	Educational institution	0.36	*Alpinia purpurata., Ruellia brottoniana., Canna hybrids., Cyperus papyrus., Heliconia pisittacorum., Pennisetum setaceumy and others ND.*	157	2019	BOD_5: 15 COD : 15 N : 70 P : 70	Lango (2021)
Instituto Tecnológico de Xalapa, Xalapa**	UASB + VSSFW	Educational institution	N.S.	*Cyperrus papyrus, Heliconia sp.*	196	2021	N.S.	Humedales ITSX
Humedal La Tortuga, Nautla	HSSFW	Municipal wastewater	15	*Canna hybrids, Alpinia purpurata, Cyperus papyrus*	2500	2022	COD: 80–90	Crónica Veracruz.com

* Source: Made with data from CONAGUA (2022).

**University research project. l.p.s. (liters per second). N.S.=Not Specified. UASB=Upflow Anaerobic Sludge Blanket. HSSFW=Horizontal subsurface flow constructed wetland. VSSFW=Vertical subsurface flow constructed wetland.

TN=Total Nitrogen, TP=Total phosphorus, COD= Chemical oxygen demand, BOD= Biochemical oxygen demand, PO_4-P=phosphate, SO_4^{-2}= Sulfates, NH_4^+-N = ammonium

Table 1 displays treatment wetlands that have been in operation for over 17 years, including the wetland situated in Antón Lizardo town, Alvarado municipality, and others. Additionally, some systems have been functioning for over 14 years, like the treatment wetlands in Martínez de la Torre municipality. These are all part of the CONAGUA inventory of municipal wastewater treatment plants. Though the inventory lists these systems, it does not provide removal values or percentages achieved by them.

The remaining treatment wetlands described here are relatively new and have been extensively studied with detailed information available on their design and operation characteristics. Many of these systems were developed as part of educational or research projects, resulting in the generation of theses, dissemination articles, and book chapters to share the findings. Notable sources include Hernández in 2016 and Palma-Cabrera *et al*. in 2022.

In the analysis conducted, it was found that in the State of Veracruz, other treatment wetland systems have been implemented and studied by various researchers. These systems have been designed for different scales such as microcosms, mesocosms, and pilot scales, and have been used to treat various types of wastewater, including industrial, swine, and agricultural wastewater. Researchers have reported positive results in the removal of contaminants (Mateo *et al*., 2019; Solano *et al*., 2020; García *et al*., 2021; Delfín-Portela *et al*., 2022; Martínez-Aguilar, 2022; González-Rivadeneyra *et al*., 2023; Marín-Muñiz *et al*., 2024a; Marín-Muñiz *et al*., 2024b). These findings validate the effectiveness of treatment wetlands as efficient systems for wastewater treatment.

Although the cost of implementing of these eco-technologies is an important factor for their replication in other sites, this data is rarely reported. It is worth mentioning that for the case of the system implemented at the Technological Institute of Xalapa, an approximate investment of 1.6 million Mexican pesos has been published (Humedales ITSX). For the case of the Pastorías wetland, a total version of approximately 300 thousand Mexican pesos was allocated (SEDEMA, 2023). Meanwhile, the Emiliano Zapata system had an expenditure of less than 200 thousand Mexican pesos (Hernández, 2016).

It's worth noting that a wetland that treats the town of Díaz Mirón in the municipality of Misantla, Ver. has been identified, in addition to the wetlands previously mentioned (RTV, 2023). This system is capable of treating wastewater and is beneficial to 1,200 community members. Similarly, a wetland for wastewater treatment with whey water has been reported in the town of Miahuatlán, in the municipality of Naolinco (Pilatos, 2024). However, these systems were not included in the research results due to the lack of technical information required to categorize their implementation and design data.

Furthermore, as part of the "Projects for Environmental Promotion 2023" initiative, the Environment Secretariat of the Government of the State of Veracruz has been actively promoting the establishment of new wetlands in various communities, including San Marcos Atexquilapan in the municipality of Naolinco, rural communities in the municipality of Martínez de la Torre, Zacatianguis in the municipality of Platón Sánchez, and Palmas de Abajo in the municipality of Actopan (SEDEMA, 2023). These wetland systems are presently undergoing construction and are expected to commence operation in the first quarter of 2024.

Even though the advantages of implementing and operating treatment systems are clear, conventional systems remain the most widely used in the state. Furthermore, the promotion of replicable systems by municipal authorities has only recently begun.

Furthermore, for treatment wetlands to thrive, it is crucial to promote the benefits and advantages of these systems, including the value that may be derived from utilizing plant life (Zitácuaro-Contreras *et al*., 2021). Additionally, these sites can serve as green spaces (Brix *et al*., 2010), and as experimental grounds for academic research, commonly referred to as "social laboratories" (Cid, 2003). This collaboration between academia, government, and society is essential for progress.

A pesar de conocer la funcionalidad de los HC y de los beneficios que estos tienen al ser implementados, existen situaciones que han impedido que esta ecotecnología sea replicada, como son el desconocimiento general de estos, la falta de manuales y la falta de inclusión de la población en los proyectos de investigación para que estas ecotecnologías sean adoptadas y apropiadas (Portillo-Peralta, *et al*. 2022).

Conclusions

The proper treatment of wastewater to meet environmental regulations is a significant challenge for governments. In the State of Veracruz, Mexico, there has been notable progress in implementing treatment plants to sanitize wastewater. Despite this progress, conventional treatment systems have drawbacks that hinder their sustainability. As a result, treatment wetlands have emerged as a promising alternative that is both innovative and efficient, while also being sustainable.

Currently, 12 large-scale wetland treatment systems are in operation in the State of Veracruz. These systems have varying design characteristics, primarily in the type of plants used. Some of these have been operational for several years, ranging from 17 to 1 year, and have reported their results mainly during the first years of operation.

Unfortunately, there is a lack of current information regarding the functioning of these treatment wetlands. Therefore, it is recommended that future research focus on conducting situational assessments of these systems years after their installation. This will enable researchers to gain insights into the current operational status of each wetland, analyze its effectiveness, and identify any technical, economic, or socio-environmental factors that can enhance the implementation of treatment wetlands in other areas.

In addition, addressing the issue of untreated wastewater discharge is a pressing global challenge that demands collective and immediate action from all stakeholders. It is imperative to undertake a comprehensive examination of treatment wetlands from a global perspective, encompassing their legal and regulatory framework, as well as the socio-environmental attitudes towards their implementation.

By utilizing the aforementioned information, we can address the current challenges at hand and develop a durable plan for incorporating treatment wetlands. This solution can be replicated in various municipalities of Veracruz, as well as other regions of Mexico and the world, to enhance the access and sustainability of water for everyone.

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