

Legal feasibility of using constructed wetlands for wastewater treatment in social housing units in Xalapa, Veracruz, Mexico

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Abstract: Constructed Wetlands (CWs) are a type of nature-based solution that uses ecological engineering to treat wastewater. The legal feasibility of implementing CWs as a treatment system in urban residential areas has been researched in various Latin American countries, including Chile, Peru, Colombia, Panama, and Guatemala. However, research regarding the legal feasibility of implementing CWs in urban areas, particularly in Multifamily Housing Units of Social Interest (MHUSI) in Mexico, was not found. Thus, this research aims to analyze the legal feasibility of CWs as wastewater treatment systems in the MHUSI of Xalapa, Veracruz, Mexico. To achieve this objective, a qualitative exploratory study was conducted. The study involved a documentary investigation to gather information about the background of the research, as well as content analysis to scrutinize legal documents such as laws, regulations, decrees, and Mexican Official Standards. The documental research focused on the search for regulatory documents, such as laws, regulations, decrees and standards, both at the federal level and at the state and municipal level. The content analysis focused on identifying the subsections, fractions and articles of the regulations found on water and sanitation, environmental impact and urban development applicable to the wastewater treatment systems of the MHUSI of Xalapa, Veracruz, Mexico. The research revealed that in Mexico, regulations mandate MHUSI to have a treatment plant in situations where it is not feasible to connect to the municipal sewage network. However, the use of CWs on a large scale to mitigate pollution from discharges has not been identified as a solution. After careful analysis, it has been determined that installing CWs wastewater treatment systems in MHUSI is legally feasible. In Veracruz, in terms of environmental impact, wastewater treatment systems no require an Environmental Impact Statement, which simplifies the procedures for this type of systems. In terms of urban development, MHUSI must incorporate a wastewater treatment system into their infrastructure. Regarding water and sanitation, no restrictions were found beyond guaranteeing compliance with the maximum permissible limits of contaminants established in Mexican standards. Finally, it was found that CWs are a method accepted by CONAGUA for the treatment of wastewater; in addition, this entity has a published manual and an inventory that includes them as a recognized process. However, it is crucial to ensure that the operation of these systems adheres to the regulations governing environmental impact and the permissible levels of contaminants in wastewater discharges to municipal sewage networks. This study is the first in Mexico to examine the legal viability of CWs as wastewater treatment systems in urban environments, specifically in MHUSI, providing a background that can contribute to the development of policies and regulations in this field. It is recommended to carry out technical, structural and financial feasibility studies to implement CWs in MHUSI in Xalapa, Veracruz, Mexico., aspects that were not addressed in this research.

Keywords: legal feasibility; sustainable urban development; constructed wetland; housing units; environmental impact.

Introduction

Urbanization or population growth in cities is steadily increasing worldwide. According to Gu *et al.* (2023), more than half of the world's population currently resides in urban areas, and it is expected that by the year 2050 this figure could exceed 60%. This trend is resulting in a world that is becoming increasingly urban, while rural areas are being reduced in size due to the growth of cities (Martin, 2015). This growth is bringing with it socio-environmental and economic challenges, as well as an increased demand for natural resources (Sun *et al.*, 2022). The concept of Sustainable Urban Development (SUD) was introduced to tackle the challenges of rapid and massive growth of urbanization. The formalization of this concept started with its inclusion in Agenda 21, which was the result of the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992. The seventh chapter of this agenda deals with the institutionalization of SUD and its significance in solving the challenges related to sustainable development in cities (United Nations Organization [UN], 1992). In the words of Ceballos Pérez (2020), SUD is a development model that promotes the harmonious coexistence of both natural and human ecosystems.

According to Müller *et al.* (2018), for the first time in history, the SUD has been classified as a significant goal for the growth and planning of cities. This acknowledgment recognizes the importance of the SUD in improving the quality of

life of the population and preserving the environment. The Sustainable Development Goal (SDG) number 11, named "Sustainable Cities and Communities," addresses a range of goals related to cities and human settlements (UN, 2015). These goals cover aspects such as urbanization, housing, environment, and transportation. Koch and Ahmad (2018) suggest that SDG 11 can be interpreted as a global guide to the minimum standards that a city must meet in terms of human settlements and housing units, regardless of their location.

Multifamily housing units of social interest (MHUSI) are residential complexes with several apartments in the same building. Although they share services and common areas, each home maintains its individual privacy (Zendejas Santín, 2023). This study examines the legal feasibility of implementing CWS in UHMIS for the following reasons: According to the Ministry of Social Development (2021), this type of housing is institutional in nature and must comply with current regulations on housing and sustainable urban development such as what is established in Law 241 of Urban Development, Territorial Planning and Housing (LDUOTV) and its regulations. On the other hand, these buildings generate a specific discharge of wastewater, which allows it to be channeled to the treatment system. Finally, in these groups there is already an established and delimited population in urban terms, which creates a favorable context for the implementation of CWS.

According to the Secretaría de Desarrollo Social (2021), this type of housing is institutional in nature and must comply with current regulations on housing and urban development on sustainable housing. In the state of Veracruz, Mexico, MHUSI must follow the provisions of the Law 241 of Urban Development, Territorial Planning, and Housing (LDUOTV) and its regulations on issues of density, subdivision, land use, destinations, uses, roads, equipment, and urban infrastructure.

The New Urban Agenda (NUA), also known as UN HABITAT III, was created to promote and facilitate the achievement of Sustainable Development Goal 11. The NUA is a guide that helps cities face challenges and take advantage of urban development opportunities. Its objective is to promote cities that are safe to live in, capable of adapting to climate change, and where all people have the same opportunities in an increasingly urbanized world. In October 2016, the United Nations Conference on Housing and Sustainable Urban Development adopted NUA in Quito, Ecuador (UN, 2016).

In Mexico, they have taken steps to fulfill this commitment by promulgating the General Law of Human Settlements, Territorial Planning and Urban Development (LGAHOTDU) in 2016. The purpose of this law is to establish the standards and tools necessary for planning the use of the territory and the organization of human settlements in the country. In general terms, LGAHOTDU lays the foundations for orderly, equitable, and sustainable urban development.

Nature-based solutions (NBS) have been developed under the new perspectives offered by the NUA, which include urban and human development, resilience, and citizen participation. CWs, which are now also called treatment wetlands, are a NBS that emulates natural wetlands processes (physical, chemical, and biological) in order to optimize and treat different types of wastewaters (Marín-Muñiz, 2018). CWs consist of shallow cells or channels with an impermeable layer and structures to control the water level, flow direction, and hydraulic retention time. Substrate, microorganisms, and plants are the principal components of CWs. Such technology has been created to treat wastewater from urban areas. These solutions aim to take advantage of wastewater reuse, as highlighted by Buitrago Coca (2022) and Marín-Muñiz *et al.* (2023). The primary purpose of these CWs is to purify different types of wastewaters (Zitácuaro and Marín, 2020). CWs are characterized by their easy operation, maintenance and low construction cost. According to Rivas-Hernández and Cortés-Rodríguez (2024), such technology has lower associated costs compared to conventional treatment systems, which require greater investment and depend on electrical energy to function correctly.

In Mexico, the National Water Commission (CONAGUA) published a manual in 2018 that describes the process of designing, constructing, operating, and maintaining CWs (CONAGUA, 2018a). Similarly, other countries such as Australia, Canada, Denmark, France, Germany, New Zealand, the United Kingdom, and the United States also have guides or manuals published by their respective governments, as reported by Vymazal (2022).

CWs can be categorized based on the type of water flow: superficial (CW-S) and subsurface (CW-SS). In CW-S, water flows over the substrate or soil and remains in constant contact with the atmosphere. In CW-SS, water flows beneath

the substrate or soil and can be further classified based on the direction of water flow, into horizontal or vertical (Figure 1). The key components of a CWs are the substrate, vegetation, and microorganisms, as cited by Marín-Muñiz *et al.* (2020). CWs are a new technology that can be used for the management and protection of water bodies in urban areas, according to Pérez *et al.* (2022).

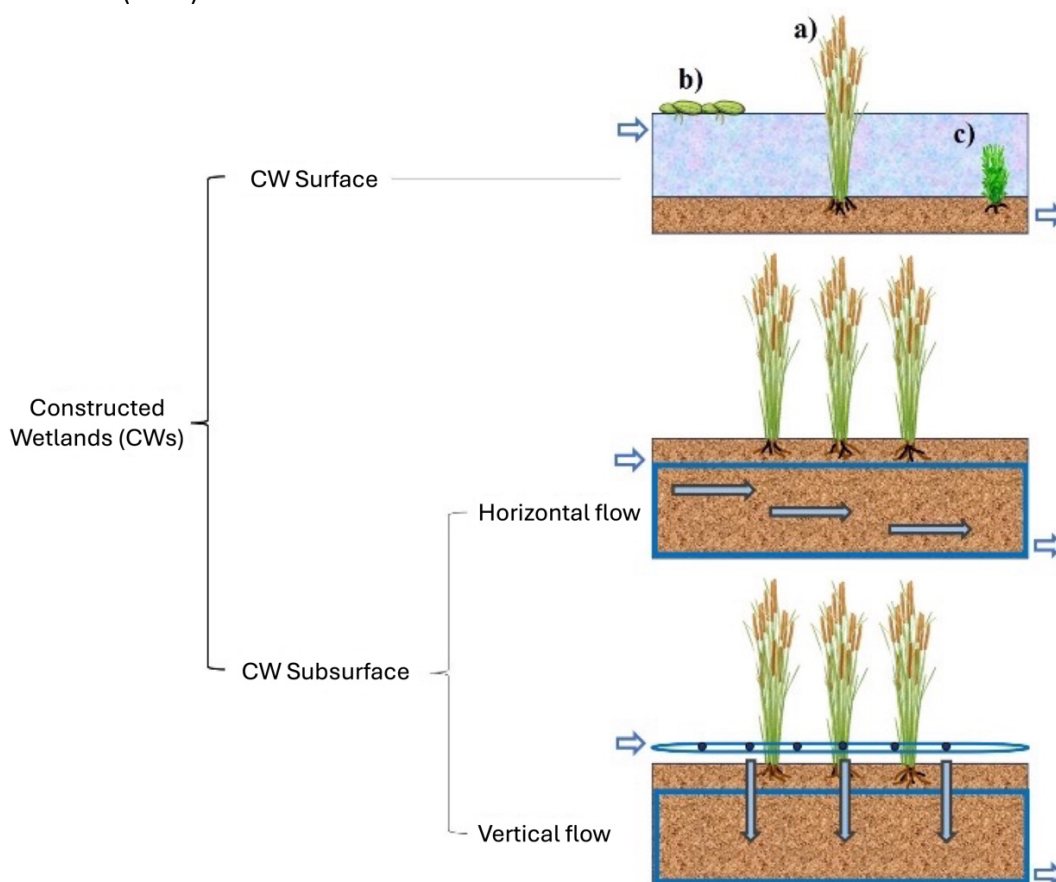


Figure 1. Classification of constructed wetlands. Surface wetland (a. emergent plants, b. floating plants, c. submerged plants). Adapted from Marín-Muñiz (2018).

Based on systematic literature review studies conducted in Peru by Salazar Torreblanca (2023), it was concluded that the regulations derived from the Framework Law for the Management and Provision of Sanitation Services (LMGPSS) enable the use of non-conventional technologies to treat residual wastewater in urban and peri-urban areas. Meanwhile, pre-feasibility studies carried out in Colombia by Soto Varón and Tobaría León (2020) concluded that the implementation of CWs in the country is feasible, thanks to the application of current regulations on water sanitation. Environmental impact assessment studies conducted by Jiménez Sanabria *et al.* (2023), in the same country, it was also concluded that the adoption and implementation of CWs have a positive impact on the environment, improving the quality of the water discharged into rivers.

Literature review and documentary research studies conducted in Panama City by Delvalle-Borrero *et al.* (2022) have concluded that the use of CWs to treat wastewater is suitable for urban environments. The implementation of CWs should not pose any legal, economic, social, or political challenges for governments. In contrast, technical and economic feasibility studies carried out in Guatemala by Cifuentes Castillo *et al.* (2023) suggest that in addition to legal aspects, the availability of land and the minimum area required per person, topography of the area, and the type of water to be treated should also be considered before implementing a CWs in urban areas. In the context of Mexico, the literature review did not reveal similar studies that address the feasibility or legal viability for the implementation of CWs in urban areas, specifically in MHUSI. This background is essential to know the regulatory support that CWs receive and their implementation in urban contexts, including the MHUSI in Xalapa, Veracruz, Mexico, as well as in other Latin American countries. For more clarify about legal viability, Is important to describe that according to Melendres Márquez (2021), legal viability refers to the support offered by regulations, including laws, regulations and decrees, to carry out a project correctly.

Urban environments are currently facing several socio-environmental challenges, including water pollution and flooding (Dieperink *et al.*, 2023). In Xalapa, the capital city of the state of Veracruz de Ignacio de la Llave, Mexico, the municipality is grappling with the issue of polluted urban rivers. The major rivers of Xalapa, such as Sedeño, Carneros, Papas, and Sordo, are facing grave health hazards due to the continuous dumping of wastewater into them (Paré, 2012; Roca Guzmán, 2019; Welsh Rodríguez and Pérez Córdova, 2020). It is important to consider that in Mexico, only 67.38% of wastewater collected through the sewage system received treatment in 2021, as reported by CONAGUA (2022). In Xalapa, Veracruz, specifically, municipal treatment plants one and two were only able to reach a treatment level of 70% in 2022 (according to CMAS, through personal communication on November 28, 2022). This highlights the serious issue of insufficient wastewater treatment in the country.

A feasibility study was conducted by Dünner Turner (2022) in Chile to evaluate the technical, legal, and economic viability of implementing a CWs system in an urban area. The study incorporated a survey of technical data and concluded that the installation of a horizontal flow CW-SS system in a building located in the urban area of Viña del Mar is a feasible option for treating domestic wastewater, from technical, legal, and economic perspectives. After conducting a literature review, it was found that no similar studies have been conducted in Mexico on the feasibility or legal viability of implementing CWs in urban areas, specifically in MHUSI. Thus, it is imperative to conduct a legal feasibility study on implementing CWs in urban areas in Mexico. It's worth mentioning that national studies indicate that the lack of implementation of CWs in the country is mainly due to a lack of knowledge of the strategy, insufficient government support, and the unavailability of manuals for construction, operation, and maintenance in Spanish that are easily understandable for the general public (Zurita *et al.*, 2011; Marín-Muñiz *et al.*, 2021).

Based on the assumption that the use of CWs is a feasible legal option for the treatment of wastewater in urban areas of Mexico, and founded in the research question: Do current regulations related to water and sanitation, urban development and environmental impact support the feasibility of implementing CWs in MHUSI in Xalapa, Veracruz, Mexico? this study aims to examine the legal feasibility of using CWs for treating wastewater in social housing units in Xalapa, Veracruz. The analysis will be conducted through a normative diagnosis by means of documentary research and content analysis.

Materials and Methods

A qualitative investigation was conducted to explore the viability of using CWs for wastewater treatment in the municipality of Xalapa, Veracruz, Mexico. The study focused on MHUSI and utilized secondary sources such as books, articles, laws, regulations, and standards to collect information (Hernández Sampieri *et al.*, 2014). The study was conducted in Xalapa due to the challenges it is currently facing, including population density, urban growth, pollution, and inadequate wastewater treatment. These challenges provide an ideal context to evaluate the legal viability of CWs as a wastewater treatment system in an urban environment that requires innovative and sustainable solutions for effective wastewater management.

In order to gather data and documents, tools such as Google Scholar were used. This resource provided access to a wide range of information, making it easier to identify topics and concepts relating to the legal and regulatory feasibility of CWs as a wastewater treatment system, specifically in MHUSI of Xalapa, Veracruz, Mexico. Details about the process for data and analysis collection are described in the Figure 2.

Phase 1. Data source

In this phase, the data sources to obtain the information were identified as follows: the regulations at the federal level (Mexico) were consulted in the Official Gazette of the Federation. At the state level (Veracruz) and municipal level (Xalapa), information was accessed from the Official Gazette of the State of Veracruz. In addition, the websites of the three levels of government were used as support to find regulations. Also, Google Scholar was used as an instrument to obtain information and strengthen the theoretical framework, background, and discussion of the manuscript.

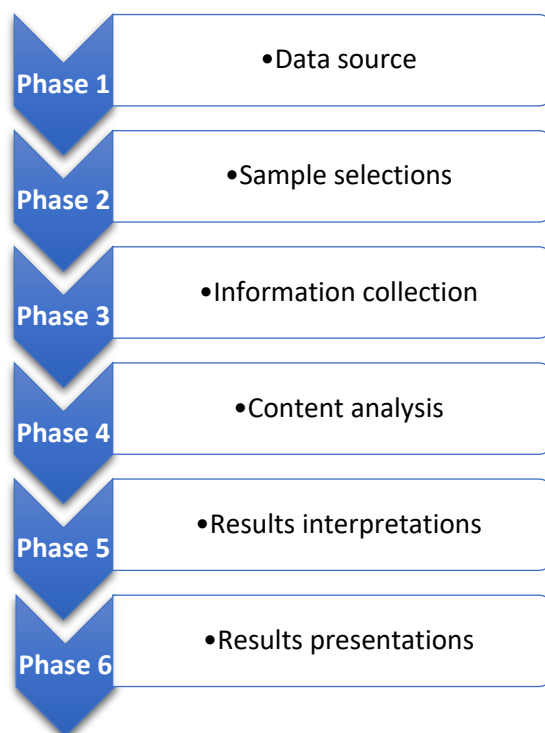


Figure 2. Process for data collection and analysis.

Phase 2. Sample selection

In this phase, the criteria to select the sample were defined, guaranteeing its relevance for the research objective, covering the areas of water and sanitation, urban development and environmental impact.

Thematic Relevance Criteria:

- The sample had to be directly related to the research objective.
- Regulatory instruments that address the aspects of water and sanitation, urban development and environmental impact were prioritized.
- Scope Criteria:
- The sample included regulatory instruments from the three levels of government: federal, state and municipal.
- Mexican laws, regulations, decrees and official standards (NOM) related to the topic were considered.

Phase 3. Information collection

In this phase, the following documents were collected: At the federal level (Mexico): General Law of Human Settlements, Territorial Planning and Urban Development, General Law of Ecological Balance and Environmental Protection, National Water Law, and Regulations of the National Water Law.

At the state level (Veracruz): Law 241 of Urban Development, Territorial Planning and Housing for the State of Veracruz, Regulation of Law Number 241 of Urban Development, Territorial Planning and Housing for the State of Veracruz, Law 62 of Environmental Protection of the State of Veracruz, Regulations on Environmental Impact of State Law Number 62 on Environmental Protection, Water Law of the State of Veracruz, and Regulation of Law Number 21 of Water of the State of Veracruz-Llave.

At the municipal level (Xalapa, Veracruz): Urban Development Regulations for the Municipality of Xalapa, Regulation of Ecological Conservation and Environmental Protection for the Sustainable Development of the Municipality of Xalapa and Internal Regulations of the Operating Agency of the Public Services of Drinking Water, Drainage, Sewerage, and Wastewater Disposal of Xalapa.

Phase 4. Content analysis

In this phase, the documents found were read and analyzed to identify the elements of the text, such as concepts and key words related to water and sanitation, environmental impact, urban development and specific provisions applicable to water treatment systems. residuals, which favor and facilitate its implementation in UHMIS of Xalapa, Veracruz, Mexico.

Objectives of content analysis:

- Identify the subsections, fractions and articles of each document at its three levels of government, categorized by type of regulation (environmental impact, water and sanitation, urban development), that contain information on wastewater treatment and specific provisions applicable to the UHMIS of Xalapa, Veracruz, Mexico.
- Classify the information according to the type of regulation and the three levels of government.
- Analyze the information to identify the elements that favor and facilitate the implementation of wastewater treatment systems, such as CWS, in UHMIS of Xalapa, Veracruz, Mexico.

At this point, it was decided not to use content analysis software as the data set is small and manageable, making it easy to perform analysis manually. Additionally, the manual method allows flexibility to identify details and exceptions that might not be detected with software. Finally, manual analysis provides an opportunity to improve understanding of data and develop qualitative analytical skills.

Analysis validation: the content analysis was enriched through an open peer review carried out by two experts in the field, both assigned to El Colegio de Veracruz. Their valuable observations contributed to improving the clarity, precision, and relevance of the analysis by identifying and correcting specific errors, strengthening both the methodology and the conclusions of the study. Based on this analysis, a recommendation was developed to promote a reform to the LDUOTV, with the objective of allowing the use of nature-based solutions, such as CWS, for the treatment of wastewater in the UHMIS, and incorporating these recommendations in the current legal framework.

Phase 5. Interpretation of results

To interpret the results, two main aspects were considered: first, relating the findings of the content analysis to the research objective; second, discuss the implications of these results in the use of CWS as a wastewater treatment system in the UHMIS of Xalapa, Veracruz, Mexico.

Phase 6. Presentation of results

In this phase and with the objective of graphically representing the results, it was decided to include the findings in tables and graphs according to the type of regulation at the three levels of government.

Results and Discussion

Urban infrastructure regulatory considerations for wastewater treatment in MHUSI

Based on Article 81 of the LGAHOTDU, the designated areas for social housing projects should comply with the current housing regulations. In the state of Veracruz, LDUOTV, along with its regulations, must be followed. For the municipality of Xalapa, the municipal Urban Development regulations will be applicable (Table 1).

As per the LDUOTV's third article's fourth section, the development of social housing units or subdivisions in the state is deemed to be of public utility. This implies that the law acknowledges and recognizes that the construction of such urbanization is a collective benefit and interest for society as a whole. Furthermore, according to the first section of article 45, literal a) of the same law, wastewater treatment systems are included as part of the urban infrastructure and equipment of the MHUSI. Therefore, the seventh section of article 189, subsection c) of the LDUOTV regulations, mandates that a wastewater treatment plant must be present in the MHUSI in cases where they cannot be connected to the municipal drainage and sewage network (Table 1).

Table 1. Specific regulations on urban development applicable for the implementation of CWs in MHUSI.

Urban development regulations for MHUSI		Articles
Federal	General Law of Human Settlements, Territorial Planning and Urban Development	Art. 81.
State	Law 241 of Urban Development, Territorial Planning and Housing for the State of Veracruz by Ignacio de la Llave	Art. 3, fraction IV. Art. 45
	Regulation of Law Number 241 of Urban Development, Territorial Planning and Housing for the State of Veracruz by Ignacio de la Llave	Art. 189, fraction VII. clause (c)
	Urban Development Regulations for the Municipality of Xalapa, Veracruz	Art. 1, fraction V.

The Urban Development regulations for the Municipality of Xalapa, Veracruz state in the fifth section of the first article that the regulation and installation of infrastructure works, such as treatment plants are considered a matter of public interest when it comes to urban development (Table 1). These works can be carried out by both the city council and individuals as well. As of September 29, 2023, there are 17 MHUSI in Xalapa, Veracruz, Mexico that do not have a wastewater treatment plant. However, all MHUSI are connected to the municipal sewage network, as per the information provided by the Municipal Directorate of Urban Development of Xalapa.

Considerations regarding the environmental impact of regulations for wastewater treatment in MHUSI

As per the regulations stated in Article 128 of the General Law of Ecological Balance and Environmental Protection (LGEEPA), Sections 4 and 147, and Article 156 of Law 62 of Environmental Protection of the State of Veracruz (LEPAV), urban wastewater that is collected and discharged into drainage and sewage systems must undergo prior treatment that meets the specifications outlined in the Mexican Official Standards (NOM). This treated water can be used for both industrial and agricultural purposes (Table 2).

Before the modification made by Decree number 814 in 2010, Article 39 of the LEPAV included a list of works or activities that required environmental impact authorization through an Environmental Impact Statement (MIA). One of the activities listed in section XVIII was related to the construction of wastewater treatment systems, drainage and sewage systems, banks, dams, and water purification plants on certain plots of land. After the publication of Decree 814 in the Official Gazette of the State of Veracruz on February 22, 2010, section XVIII of Article 39 of the LEPAV was repealed. Therefore, it is clear that the properties intended for the construction of wastewater treatment plants, among other things, will no longer require a MIA as part of their installation requirements.

Table 2. Specific regulations on environmental impact applicable for the implementation of CWs in MHUSI.

Environmental impact regulations for UHMIS		Articles
Federal	General Law of Ecological Balance and Environmental Protection	Art. 128
State	Law 62 of Environmental Protection of the State of Veracruz	Art. 39
	Regulations on Environmental Impact of State Law Number 62 on Environmental Protection	Art. 2, fraction X Art. 6 and 7
	Regulation of Ecological Conservation and Environmental Protection for the Sustainable Development of the Municipality of Xalapa, Ver	Art. 49 to 60

According to the regulations stated in Article 6 of LEPAV, activities and/or works that are exempted from submitting the MIA by the state authority as mentioned in Article 39 of the same law, they must first submit a written notice along with a Technical Report (MT) containing the specifications and formats published by the Secretariat of Environment of

the State of Veracruz (SEDEMA). Furthermore, as per the provisions of the last section and by Article 7 of LEPAV, SEDEMA holds the right to demand the submission of a MIA, if it deems it necessary after evaluating the MT.

According to Article 51 of the Regulations on Ecological Conservation and Environmental Protection for Sustainable Development (RCEPADS) of the Municipality of Xalapa, Veracruz, it is mandatory to present a MT on Environmental Impact for any projects that provide a service or make use of natural resources under municipal jurisdiction (Table 2).

Water and sanitation regulatory considerations for wastewater treatment in MHUSI

As per the National Water Law (LAN), the establishment of wastewater treatment plants and the reuse and exploitation of treated wastewater is deemed a public utility. Additionally, according to Article 136, section 3, paragraph 2 of the LAN regulations, individuals who discharge domestic and urban wastewater into municipal drains or sewers must adhere to the regulations outlined in NOM (Table 3).

Table 3. Specific regulations on water and sanitation applicable to the implementation of CWs in MHUSI.

Water and sanitation regulations for UHMIS		Articles
Federal	National Water Law	Art. 7, fraction VII
	Regulations of the National Water Law	Art. 136, fraction III, par. 2
	NOM-002-SEMARNAT-1996	
	NOM-003-SEMARNAT-1997	
State	Water Law of the State of Veracruz	Art. 15, fraction XIII Art. 44, 45 and 54
	Regulation of Law Number 21 of Water of the State of Veracruz-Llave	Art. 48
	Internal Regulations of the Operating Agency of the Public Services of Drinking Water, Drainage, Sewerage and Wastewater Disposal of Xalapa, Veracruz.	Art. 43, fraction V

Regarding the regulations of water, there are two important documents. The first one is NOM-002-SEMARNAT-1996, which sets out the maximum acceptable levels of pollutants in wastewater that is discharged into urban or municipal sewage systems. The second one is NOM-003-SEMARNAT-1997, which establishes the maximum acceptable levels of pollutants in treated wastewater that are intended to be reused for domestic purposes (Table 3).

According to Article 15, Section XIII of the Water Law of the State of Veracruz (LAEV), the State Water Commission of Veracruz (CAEV) will have, among other responsibilities, the support, through private entities, for the treatment of wastewater and its reuse. Article 54 of the law states that individuals can treat their wastewater after discharging it into the drain without the need for a concession. Additionally, articles 44 and 45 allow both the social and private sectors to participate in financing, constructing, operating, and maintaining wastewater treatment plants, as well as promoting water reuse (Table 3).

At the municipal level, section V of Article 43 of the Internal Regulations of the Operating Agency of the Public Services of Drinking Water, Drainage, Sewerage and Wastewater Disposal of Xalapa, Veracruz (RISPAPDAD) (Table 3) states that one of the responsibilities of the operation and maintenance management is to ensure compliance with the Mexican Official Standards (NOM), especially with NOM 001, 002, and 003. To comply with regulatory and legal requirements related to wastewater treatment, such as CWs in MHUSI, there are various considerations to be taken into account at different levels of government. These considerations are divided into three categories: urban development, environmental impact, and water and sanitation. When it comes to urban development regulations, federal regulations under the LGAHOTDU, state regulations under the LDUOTV and its corresponding regulations, and municipal urban development regulations specific to the municipality of Xalapa are all important to observe (as shown in Figure 3).

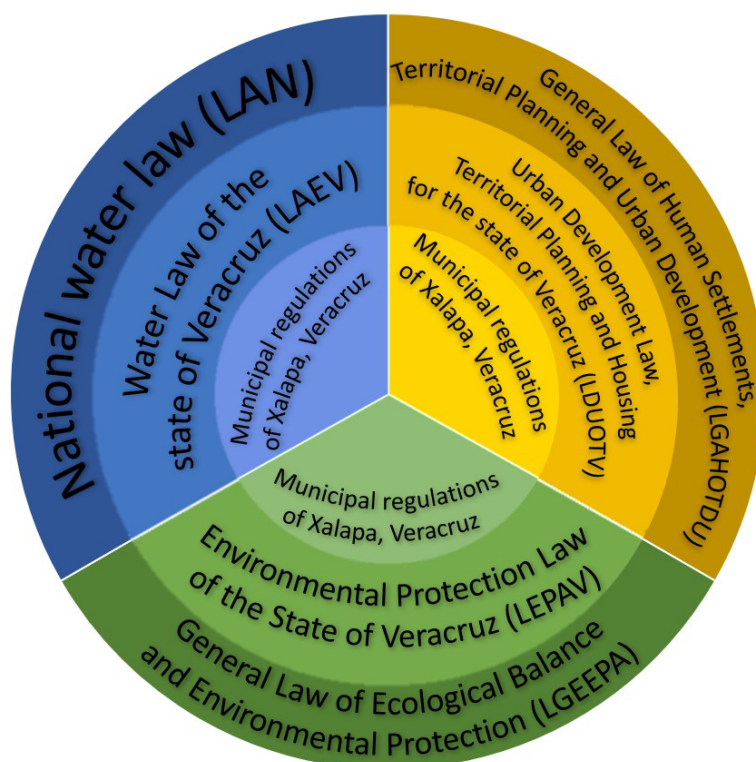


Figure 3. General regulations applicable for the implementation of CWs in MHUSI.

Concerning the regulations related to environmental impact, it is important to consider the LGEEPA and its regulations at the Federal level, the LEPAV and its regulations at the State level, as well as the RCEPADS. Similarly, for regulations related to water and sanitation, it is necessary to follow the guidelines established in the LAN and its regulations at the Federal level, the LAEV and its regulations at the State level, and the Municipal Regulations for water and sanitation of the Municipality of Xalapa (Figure 2). The findings related to the regulatory aspects of urban infrastructure for wastewater treatment in MHUSI confirm what was stated by the Secretaría de Desarrollo Social (2021) regarding MHUSI. The secretariat mentions that since MHUSI are institutional constructions, they must comply with the current regulations on housing and urban development. These results demonstrate that MHUSI are indeed subject to specific regulations and must adhere to the provisions of the LGAHOTDU, LDUOTV and their respective regulations, as well as the municipal regulations of Urban Development of Xalapa.

Similarly, the findings support the assertion made by Marín-Muñiz *et al.* (2023) about the significance of recycling and utilizing treated wastewater. Article 92 of the LGEEPA and Article 152 of the LEPAV state that the relevant authorities are responsible for encouraging the treatment and reuse of wastewater in both agriculture and industry. The ultimate goal is to ensure an adequate supply of water. In line with this, Rivas Hernández (2021) emphasized in his research that the active involvement of citizens is crucial in the implementation of clean water initiatives. The author's statement is supported by the results, as the LAEV and urban development regulations in Xalapa allow for the involvement of both the private and social sectors in financing, constructing, operating, and maintaining wastewater treatment plants, as well as promoting water reuse initiatives.

The CONAGUA has been collecting information on the use of CWs as a system for treating municipal wastewater in Mexico since 2004 (CONAGUA, 2018b, 2021b). According to the latest available data, there has been a significant increase in the deployment of CWs between 2018 and 2021. In 2018, there were only 74 CWs in operation, but in 2021, this number had increased to 230, representing a growth of around 310.81% (Table 4). You can find more information regarding this in Table 4. The results obtained have a clear connection with the date of publication of the manual by CONAGUA in 2018. Thus, it can be inferred that the increase in the implementation of CWs could have been a result of the dissemination of this document throughout the country.

Between 2004 and 2017, the number of CWs in Mexico increased by 17.19%, rising from 64 to 75 (CONAGUA, 2004, 2017). Although these data are provided by CONAGUA, a recent study by Marín-Muñiz *et al.* (2023) identified a total of 18 large-scale CWs systems in operation across the country. These systems have mostly originated from academic contributions and have established links with government institutions such as SEDEMA. SEDEMA, has financed the implementation of three CWs in the municipalities of Actopan, Naolinco, and Misantla through the "Projects for Environmental Promotion" program (SEDEMA, 2022, 2023). This initiative has resulted in significant environmental, social, and economic benefits for the local communities. Additionally, the CWs in Pinoltepec, Emiliano Zapata, Veracruz, Mexico, was funded by CONAGUA and serves as another successful example of collaborative efforts between the government, society, and the academic sector for the betterment of the environment (Pedraza López, 2014).

Table 4. Evolution of constructed wetlands as a system for municipal wastewater treatment in Mexico.

Process	Plants		
	2018	2021	%
Treatment Wetlands	74	230	310.81

Note. Adapted from the National Inventory of Municipal Purification and Wastewater Treatment Plants in Operation 2018 and 2021 issued by CONAGUA.

According to a study conducted by Salazar Torreblanca in Peru (2023), CWs have emerged as a promising technology for wastewater treatment. As a result, the author suggests that CWs can be included in the category of non-conventional technologies outlined in numeral 19 of the fourth article of the LMGPSS regulations. On the other hand, in peri-urban areas where access to sanitation may be a problem, the use of non-conventional technologies may be considered for the treatment of their water.

According to studies conducted by Soto Varón and Tobaria León (2020), as well as Delvalle-Borrero and colleagues in 2022, implementing CWs to treat wastewater in urban areas is legally feasible. These studies also support the related results in urban development. As per the LDUOTV regulations, specifically in subsection c), seventh section, Article 189, urban housing and municipal infrastructure services (MHUSI) are required to implement a wastewater treatment plant in their urban infrastructure if they don't have access to the municipal sewer water network. Although the term "CWs" is not defined in the regulations, CONAGUA has classified it as a system for treating municipal wastewater and included it in its inventory. This means that CWs can be considered a viable non-conventional technology for wastewater treatment in MHUSI from a legal standpoint. Moreover, recent data presented in Table 4 demonstrates a gradual increase in the implementation of CWs in Mexico.

Based on the findings related to environmental impact, the removal of Section XVIII of Article 39 of the LEPAV, which previously mandated the submission of a MIA for properties with plans to build treatment plants, supports the conclusions of Jiménez Sanabria *et al.* (2023). In his study, Jiménez Sanabria notes that CWs wastewater treatment systems or plants have a positive impact on the environment as they contribute to the prior sanitation of water before being discharged directly into rivers. According to Rivas Hernández's research in 2021, the implementation of CWs in Mexico has been mostly in rural areas, medium-sized cities, and housing developments. However, Rivas Hernández (2021) points out that the shortage of available land has made it challenging to implement CWs in urban areas. Cifuentes Castillo *et al.* (2023) supports this argument and concludes that the feasibility of installing a CWs depends primarily on the availability of land, as well as the topography and population density of each location.

The review of environmental impact regulations associated with water and sanitation is limited to a list and description of the requirements for installing wastewater treatment plants. To address environmental impact concerns, the regulations mandate the submission of an MT and a detailed report to the Environment Department of the City Council, describing all the components of the proposed work or activity. This report will be evaluated by the receiving entity. The entity may request the preparation of an MIA in exchange for the MT if it deems it necessary. Regarding water and sanitation, there are detailed regulations, specifically the NOM, which govern the maximum levels of contaminants allowed in wastewater discharge. This applies to both the sewage network and national assets, as well as its reuse in recycling activities in industry and agriculture.

Conclusions

The proposed hypothesis regarding the viability of implementing CWs as a wastewater treatment system in the MHUSI in Xalapa, Veracruz, Mexico is accepted. This is because it is legally permissible in terms of urban development and housing. However, the viability for the construction, operation and maintenance of CWs is conditioned on compliance with existing regulations on water and sanitation, in relation to the maximum and permissible levels of contaminants in wastewater discharges on national assets and in municipal sewage networks. On the other hand, in response to the research question, it is concluded that the current regulations on water and sanitation, urban development and environmental impact support the legal viability of implementing CWs as a wastewater treatment system in the UHMIS of Xalapa., Veracruz Mexico.

The CONAGUA, supports the incorporation and use of CWs as treatment plants within the urban infrastructure of the MHUSI. This is evident from the issuance of its manual and the inclusion of these treatment plants within its inventories as an accepted process for the treatment of wastewater. Such manual or guide covers the design, construction, operation and maintenance of CWs. In addition, these systems are included in the "Inventories of Municipal Purification and Wastewater Treatment Plants in Operation in Mexico" of the same institution, which officially recognizes them as an accepted process for wastewater treatment. It is suggested that governments, higher education institutions, and civil society work together to institutionalize CWs through a reform to the LDUOTV that allows the use of CWs as non-conventional systems for wastewater treatment. These systems can serve multiple purposes such as treating water for reuse in irrigation or urban gardening, functioning as recreational areas, areas to produce ornamental vegetation, and as ecosystems that attract pollinating insects.

Currently, government institutions such as SEDEMA are financing environmental promotion projects and working together with the community to face socio-environmental challenges, including the implementation of CWs for wastewater treatment. In this sense, it is important that these programs maintain continuity to mitigate wastewater problems in the communities of the state of Veracruz. However, at the municipal level, CWs still need to be implemented in housing units. Finally, this project would be presented to the legislative body of the Congress of the State of Veracruz, through a deputy, for discussion and eventual approval.

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