**Chapter**

# Reuse of Treated Water from Municipal Treatment Plants in Mexico

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## Abstract

Wastewater treatment plants (WWTPs) receive a wide variety of contaminants that cannot be eliminated or completely removed with current conventional methods. In this sense, the development and use of advanced technologies is a challenge in countries where wastewater sanitation is hardly a guarantee. However, the reuse of treated urban wastewater can function as an alternative to mitigate water pressure and, at the same time, guarantees water quality for potential reuse in agriculture, in the irrigation of landscape or urban green areas, but especially for aquifer recharge. Therefore, this chapter is focused on reviewing the current state of WWTPs in Mexico and the potential reuse of treated water.

**Keywords:** water quality, water reuse, aquifer recharge, emerging contaminants, Acapulco

## 1. Introduction

Water is an indispensable natural resource for promoting economic and social development, as well as being of vital and critical importance for ecosystems [1, 2]. Rapid population growth, high rates of urbanization, and climate change are key factors that put pressure on water resources [3]. Of the approximately 1388 million $km^3$ of water on the planet, only 3% (41.64 million $km^3$) is freshwater and less than 1% (13.88 million $km^3$) is accessible for human consumption [4], with availability limited by quality. According to Wang et al. [5], millions of people die each year from water pollution-related diseases, and they estimate that by 2050 more than half of the world's population will live in water-scarce regions [6].

In addition to water scarcity, pollution has become a matter of global interest and concern [6], and even more so when considering the appearance of new pollutants called emerging contaminants (ECs), identified mainly in urban wastewater, a consequence of the consumption habits of modern society [7]. In this context, the role of wastewater treatment plants (WWTPs) to face the growing need for larger volumes of contaminant-free water, whose main objective is to ensure the safety of human health and environmental protection, trying to achieve sustainable urban development of local waters, stands out [8].

Conventional WWTPs consist of four stages for efficient treatment (preliminary, primary, secondary, and tertiary) [9]. However, most of these units fail to remove a wide range of emerging contaminants present in wastewater [10]. Currently, the development of new technologies can be considered as a viable alternative for the efficient processing of treated wastewater and potential reuse in water-demanding activities such as landscape irrigation, industry, agriculture, and even aquifer recharge [11].

Latin America is the region with the highest availability of freshwater; it has 33% of renewable water resources, although only part of it is accessible to the population [12]. In this part of the world, only 8% of the wastewater produced daily is treated. Another part is discharged into surface waters, and yet another part is used for irrigation, covering about 500,000 hectares, mostly with untreated water [13]. Countries such as China, Mexico, and the United States have been identified as those that reuse a large volume of wastewater for agricultural activities, and in some cases no efficient treatment is carried out [14]. In contrast, in other cities such as Windhoek, Namibia, and Orange Country, California, good practices in the reuse of treated wastewater (drinking water supply) have been documented [15].

According to Ghafoori et al. [16], Mexico uses wastewater to irrigate approximately 260,000 hectares of green areas (gardens), which is why this country continues to promote resource management for the construction, rehabilitation, maintenance, and operation of WWTPs [17]. On the other hand, Mexico has a comprehensive and modern regulatory framework that offers the possibility of recharging aquifers with reclaimed water under regulated guidelines, since it has a production potential of 144.7 $m^3/s$ through its 2786 installed WWTPs, among which activated sludge treatment predominates as the most widely used process (69.6%) [15, 18].

Some WWTPs in Mexico operate in optimal conditions according to different studies carried out by the scientific community and governmental institutions in the country [18–20]. Treated wastewater is an underutilized resource despite being considered as a viable alternative in a context of environmental degradation in various bodies of water. Therefore, this study was focused on reviewing the current state of WWTPs in Mexico and the potential reuse of treated water in one of its main municipalities, Acapulco. This port located in the South of Mexico has 18 WWTPs, and its effluents are discharged without any use to the Pacific coast and the city's main river. This chapter aims to strengthen Mexico's commitment to the 2030 Agenda and to cover at the local-level Goal 6 (ensure availability and sustainable management of water and sanitation for all), which includes in its third target "halve the proportion of untreated wastewater and substantially increase recycling and safe reuse." Finally, this study may allow other research to expand on the issues related to reuse of treated wastewater and may serve as a guide for making better decisions on the applications of treated wastewater in areas with greater water stress in Mexico.

## 2. Perspective of wastewater management in Mexico

### 2.1 Water pollution

The problem of water pollution began to be noticed in the early nineteenth century and has become one of the most serious environmental problems of our time, generating a global scarcity of clean water, hence the importance of conserving and maintaining the quality of natural water sources to ensure its sustainability and use for future generations [21]. It is of utmost importance to consider adequate wastewater treatment processes that comply with the required parameters for the different types of reuse [15]. Mexico's water resources are facing serious pollution problems due to the fact that water quality is below the permissible limits for human health, both surface water and groundwater are used as receiving bodies for heavy loads of conventional and nonconventional pollutants [22].

In recent decades, impacts to the aquatic environment have been detected by nonconventional pollutants, called emerging contaminants (ECs), and these compounds of different origin and chemical nature are originated by drugs, pesticides, surfactants, surfactants, surfactants, personal care products, and among others and have raised great concern to the scientific community, due to the environmental damage they generate by their physicochemical characteristics when combined with other substances, including water and bioacomulative through the trophic chain [23]. Currently, ECs are not considered in monitoring or regulatory programs, despite the existence of several studies on their occurrence, fate, behavior, and toxicological effects on terrestrial and aquatic ecosystems [24]. The overuse and misuse of antibiotics have become a global problem, as the discharge of antibiotics can not only chemically contaminate water but also induce antibiotic-resistant bacteria (ARB) and antibiotic-resistant genes (ARGs) [10].

Currently, more than 600 active pharmaceutical substances (metabolites and transformation products) have been detected in the aquatic environment belonging to different therapeutic groups worldwide [25, 26]. The widespread use and abuse of active substances have made it possible to be detected in different environmental matrices (e.g. surface water, groundwater, wastewater, and stormwater runoff in urban areas) in various concentrations [27–29]. Therefore, understanding the fate of these pollutants in wastewater treatment can contribute to better management and improve the quality of treated effluents [30]. In Mexico, several studies have been conducted on the presence of ECs in aquatic ecosystems [31–36]. Water quality problems are severe and have a significant lag in their attention compared to those related to quantity and provision of services to the population. Water quality monitoring is a process that must be effective, regulated, and updated. In the same way, water quality assessment is essential to guide efforts to promote water reuse [37].

### 2.2 Characterization of wastewater

Rapid population growth and high urbanization rates represent challenges in water management; among them, the increase in wastewater generation [38]. Wastewater (WW) consists of 99% water and 1% suspended, dissolved, and colloidal solids [4]. According to the National Water Law of Mexico, WW is "a varied composition resulting from discharges of urban, domestic, industrial, commercial, service, agricultural, livestock, treatment plants and, in general, from any use, as well as a mixture of them" [39]. Other important sources of pollution to consider are hospitals and clinics, where hazardous waste is disposed into municipal sewers [38].

According to Valdes et al. [2], 135,600 liters per second (L/s) of wastewater were treated in Mexico, which corresponds to 63% of the total water recovered from the country's sewerage systems. An estimated reuse rate of 39,800 L/s was also documented directly from treatment plants and 78,800 L/s indirectly after its first discharge into a water body. However, wastewater discharges cause a high

| Conventional contaminants | Treatment |
|---|---|
| Suspended solids | Sedimentation, roughing, filtration, and flotation. Addition of polymers or chemical reagents, coagulation-sedimentation. |
| Biodegradable organic matter | Activated sludge, fixed film: trickling filters, fixed film: biological disks, lagooning variations, intermittent sand filtration, and physicochemical systems. |
| Pathogens | Chlorination, hypochlorination, ozonation, and UV radiation. |
| Nitrogen | Variations of suspended cultivation systems (nitrification denitrification), variations of fixed film systems (nitrification denitrification), and ammonia entrainment (ion exchange). |
| Phosphorus | Addition of metallic salts, coagulation and sedimentation with salt, and biological removal of phosphorus. |
| Refractory organic matter | Carbon adsorption and tertiary ozonation. |
| Heavy metals | Chemical precipitation. Ion exchange. |
| Dissolved inorganic solids | Ion exchange, reverse osmosis, and electrodialysis. |

**Table 1.**
*Main conventional contaminants present in wastewater and their treatment [41].*

| Network | Area | Number of monitoring sites |
|---|---|---|
| Surface | Surface | 2512 |
| Underground | Underground | 1060 |
| Special studies | Underground bodies of water | 49 |
| | Surface bodies of water | 156 |
| Discharges | Underground | 8 |
| | Surface | 429 |
| Coastal | Coastal | 820 |
| | Total | 5034 |

**Table 2.**
*Sites of the water quality monitoring network in Mexico [43].*

degree of stress on aquatic ecosystems [40], due to the presence of various types of contaminants resulting from inadequate treatment. In this sense, **Table 1** shows the behavior of conventional-type contaminants, which is unpredictable during treatment since it can be very effective for some of them and null for others [41].

## 2.3 Water quality assessment

Water quality is assessed from physical, chemical, and biological characteristics, evaluated individually or as a group. Physicochemical parameters give extensive information on the nature of the chemical species in the water and their physical properties; these analyses are rapid and can be monitored frequently [42]. In Mexico, the water authority (CONAGUA) has a National Water Quality Measurement Network (**Table 2**).

The main objectives of the network are (I) to provide the water authority and users with reliable results, which can be transformed into information for decision-making, and (II) to obtain water quality results from more than 5000 monitoring sites with the highest quality standards. The criteria for the selection of sites to assess water quality are based mainly on representativeness, standardization, and reliability, considering sources of contamination, reference sites and/or areas (hydrological basins), and among others.

To assess surface water quality, the following indicators are taken as the main reference: Biochemical Oxygen Demand ($DBO_5$), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), *Fecal coliforms* (FC), *Fecal enterococci* (FE), *Escherichia coli* (*E. coli*), and Dissolved Oxygen Saturation (DO), taking the median of the set of data from each study site. Whereas, for acute toxicity, it is calculated as the maximum of the toxicities with Daphnia magna and Vibrio fischeri. As shown in **Figure 1**, water quality results are marked in red or yellow when one or more indicators are not met and marked in green when all water quality indicators are met.

The results presented in **Figure 1** show that of the 4233 study sites only 30% (1266 sites marked in red) did not meet the following parameters: $DBO_5$, COD, toxicity, and/or *fecal Enterococci*. While 29.1% (1228 sites marked in yellow) do not comply with the following parameters: *E. coli*, *fecal coliforms*, TSS, and/or percentage of DO. In addition, only 40.9% (1727 sites marked in green) met all water quality indicators in Mexico [43]. Although the water quality indicators assessed in Mexico can provide a lot of information about the state of water resources, they exhibit at least two important problems: water scarcity and contamination; however, the latter does not

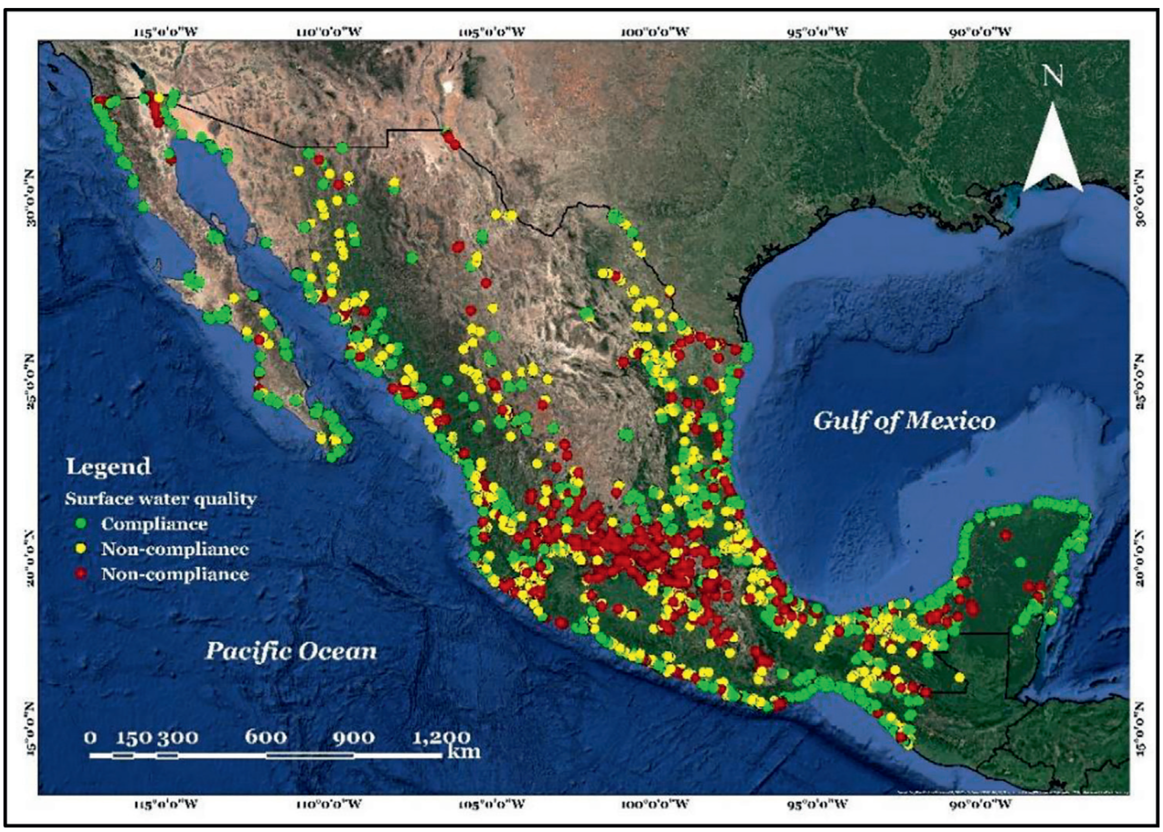


**Figure 1.**
*Study sites for the assessment of surface water quality in Mexico [43].*

consider the existence of multiple contaminants that, even in small quantities, can be harmful to health and/or the environment [43].

## 2.4 Sanitation systems in Mexico

### *2.4.1 Wastewater treatment plants (WWTPs)*

The technologies commonly employed in WWTPs started globally in the early twentieth century; however, today they work with low levels of efficiency and high levels of energy consumption [44]. This situation requires considerable financial investments to renew and update the infrastructures with a focus on new socioeconomic paradigms such as the circular economy that require better use and reuse of water resources [3].

There are two types of wastewater treatment systems: centralized and decentralized. The centralized system is more common in developed countries where economies of scale favor large facilities, while the decentralized system is more attractive in developing countries, which produces lower energy use and simpler designs, but still represent high operating costs for local governments. For example, Mexico has a large urban and rural area that depends on decentralized systems for wastewater treatment [45].

There are 2786 WWTPs in the country (**Figure 2**), which treat approximately 65.7% of the wastewater produced, 144.71 $m^3/s$. Wastewater treatment does not exceed 70% of the water collected in the drainage systems. Sewerage coverage represents 97.39% in urban areas and 77.52% in rural areas. Of which, 58.8% (1637 WWTPs) have a treatment flow of <5 l/s, 13% (363 WWTPs) have a flow between

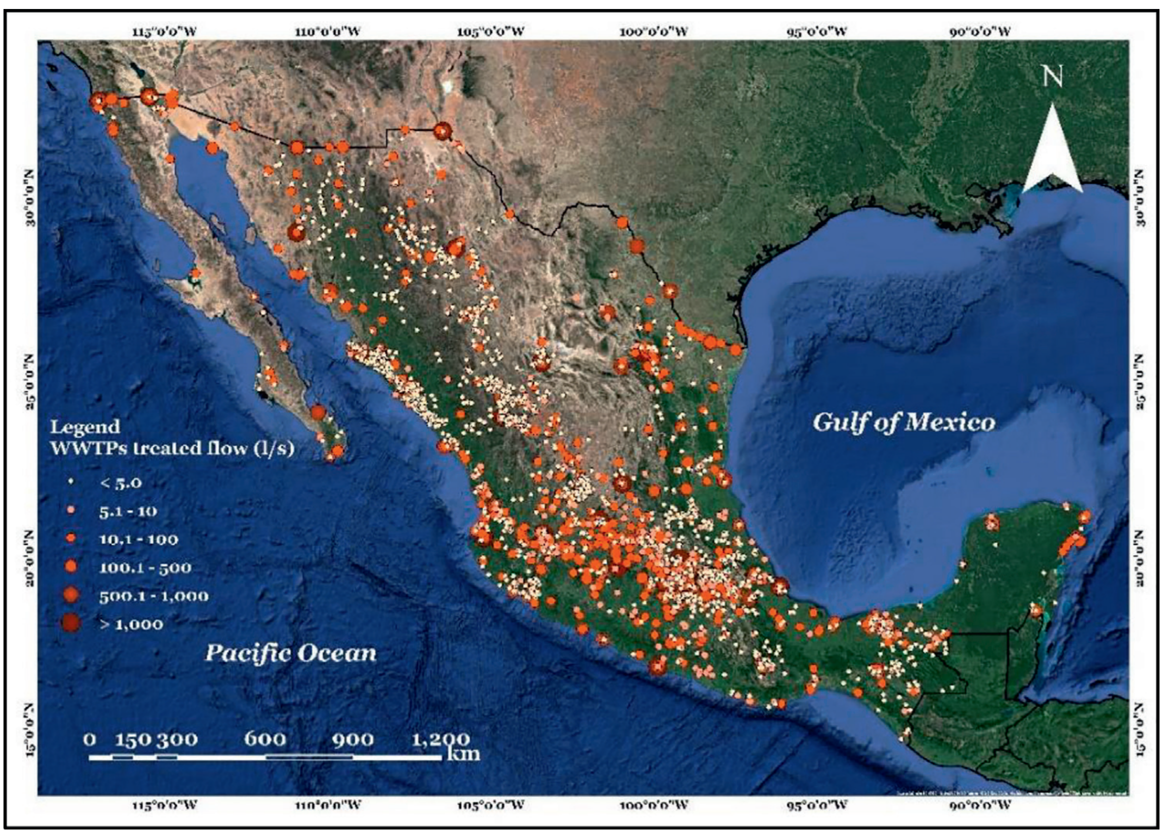


**Figure 2.**
*Wastewater treatment plants in Mexico classified by treated flow (l/s) [43].*

5.1 and 10 l/s, 22% (612 WWTPs) have a treatment flow of 10.1–100 l/s, 4.5% (125 WWTPs) have a treatment flow rate of 100.1–500 l/s, 0.8% (23 WWTPs) have a treatment flow rate of 500.1–1000 l/s, and 0.9% (26 WWTPs) have a treatment flow >1000 l/s [43].

The most recent information indicates that, until 2020, the country generated an approximate total volume of municipal wastewater of 8.82 thousand $hm^3$/year (279.80 $m^3$/s). Of this generated volume, only 6.79 thousand $hm^3$/year (215.40 $m^3$/s) were collected by the sewage systems. This means that 76.98% of the municipal wastewater was collected. In addition, only 4.56 thousand $hm^3$/year (144.71 $m^3$/s) were treated, which indicates that 51.7% of the total municipal wastewater generated was treated in that year. Whereas 67.15% of the wastewater that was collected by the sanitation systems was treated [43].

On the other hand, in the same period, sewerage coverage in Mexico reached 95.2%, which means that approximately 119.3 million people, in that year, had access to sewerage services. Therefore, the possibility of reusing municipal wastewater represents a promising alternative source of water supply. However, in the absence of efficient treatment, wastewater can constitute an important source of microbiological risk to human health. Available data on the inventory of WWTPs indicate that from 2004 to 2020 it increased from 394 to 2786 (**Figure 3**). This means that, on average, 85 WWTPs were built each year and the total increase is 316%. This indicates that there is a great effort in the country to increase the number of existing plants and that sanitation plans and policies have had results [43].

### *2.4.2 Types of wastewater treatment*

Wastewater treatment consists of a process to remove contaminants, mainly from domestic wastewater, which includes physical, chemical, and biological processes [46]. WWTPs in Mexico have different types of treatment (**Table 3**). The most used process in WWTPs is activated sludge (39.7%); this type of process can treat wastewater with high organic loads and has the potential to produce biogas, as they

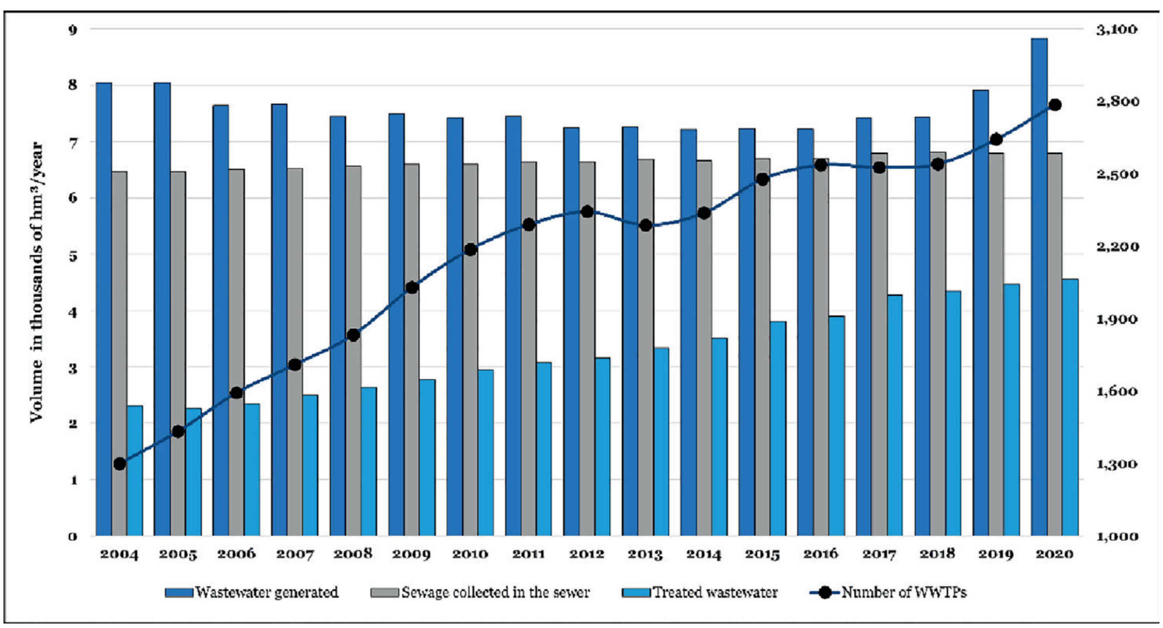


**Figure 3.**
*Number of WWTPs operating in Mexico and treated flow from 2004 to 2020 [43].*

| Description | Treatment (%) | Discharge volume in $m^3/s$ | Volume in thousands of $hm^3$/year |
|---|---|---|---|
| Activated sludge | 39.7 | 57.45 | 1.81 |
| Dual | 21.9 | 31.69 | 1.00 |
| Stabilization lagoons | 4.0 | 5.79 | 0.18 |
| Aerated lagoons | 3.9 | 5.64 | 0.18 |
| Advanced primary | 3.0 | 4.34 | 0.14 |
| Others | 1.9 | 2.75 | 0.09 |
| UASB* | 1.1 | 1.59 | 0.05 |
| Biological filters | 0.9 | 1.30 | 0.04 |
| Primary | 0.2 | 0.29 | 0.01 |

**Up-flow Anaerobic Sludge Blanket.*

**Table 3.**
*Main treatment processes and volume of wastewater discharge in Mexico [43].*

| Stages | Description |
|---|---|
| Preliminary | Large solids and sand are removed by sieving. |
| Primary | The water is left to rest so that solids can sink to the bottom and oil and grease can rise to the surface. |
| Secondary | Biological treatment usually based on the activated sludge process, used to remove dissolved and colloidal compounds from wastewater. The elimination of nutrients and the accumulation of biomass also occurs. |
| Tertiary | This can be considered as the final stage necessary to achieve the specific quality. In some cases, disinfection processes are carried out by applying chlorine, ozone, or ultraviolet (UV) radiation before the treated wastewater is discharged into aquatic ecosystems or reused. |

**Table 4.**
*Stages for wastewater treatment in a WWTP [9, 41, 46, 49].*

are considered simple to construct and have low operating costs compared to modern technologies. Modern technologies include membrane processes (reverse osmosis and nanofiltration), membrane bioreactors, advanced oxidation processes, ozonation, photocatalysis, and radiation, which are becoming attractive approaches for WWTPs despite their high maintenance and operation costs [44].

In this sense, conventional WWTPs also need significant financial investments to improve the facilities and processes in each of their stages, and this situation demands the implementation of new technologies [47]. Nevertheless, current conventional methods are considered a widely used technology, capable of producing a safe effluent to protect ecosystems and human health [48]. According to Hong et al. [9], conventional WWTPs operate with the following treatment stages: preliminary, primary, secondary, and tertiary (**Table 4**).

#### *2.4.3 Sanitation system in Acapulco*

The city of Acapulco, Guerrero, is a beach tourist resort located in southeastern Mexico at 16°56′56″ N and 99°55′12″ [50]. Its main urban area is developed around

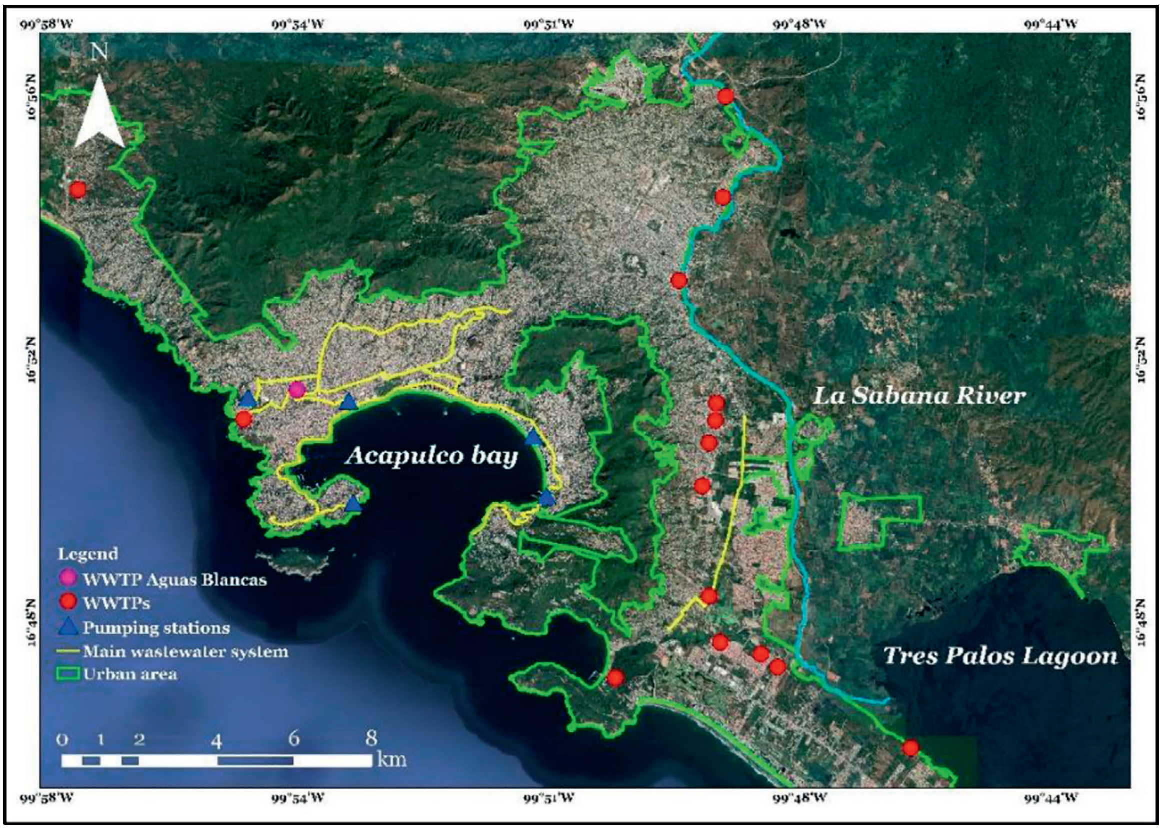


**Figure 4.**
*Location of WWTPs in the municipality of Acapulco [6, 34, 50].*

a semicircular bay characterized by a rugged topography (**Figure 4**). The climate is of the Aw1 warm sub-humid type with an average annual temperature of 27.8°C and an average annual rainfall of 561 mm [51]. The accelerated urban development that the city has experienced in recent decades and the deficiencies in public services have caused serious water and soil contamination problems, leading to social and environmental vulnerability [52].

Acapulco Bay and the La Sabana River are exposed to contamination due to wastewater discharges and poor solid waste management [53, 54]. To treat wastewater, the city has 18 WWTPs consisting of conventional treatment (activated sludge), managed by the local water agency. Wastewater is collected and transported through the sewerage network, directing the raw water to the treatment units, which are distributed in different parts of the city, discharging the treated wastewater into the La Sabana River or the Pacific Ocean coast [6]. As a study case, the "Aguas Blancas" WWTP was considered as one of the most representative of the city due to its level of efficiency, treatment capacity, and quality of treated water (**Table 5**).

## 3. Potential reuse of treated wastewater in Mexico

### 3.1 Reuse of wastewater from environmental, social, economic, political, and technical perspectives

Currently, wastewater treatment has two main purposes: sanitation and reuse [55], the first is related to human health and environmental protection, and the second to

| Features | WWTP Aguas Blancas |
|---|---|
| Location | 16.860015°–99.908553° |
| Process | Activated sludge |
| Type of treatment | Extended aeration |
| Type of wastewater received | Domestic |
| Capacity in liters per second (L/s) | 1350 L/s |
| Target population | 600,000 inhabitants |
| Sludge treatment | Centrifuge |
| Receiving body | Pacific Ocean coast |
| Tertiary treatment | UV rays |
| Efficiency level | 90% |
| Legal compliance | NOM-001-SEMARNAT-1996 |
| *Source: Information supplemented by Herrera-Navarrete et al. [6].* | |

**Table 5.**
*Characteristics of the main WWTP in Acapulco [6].*

mitigate contamination and scarcity problems. The reuse of wastewater is not a new practice; there are indications from ancient civilizations, where it was used for crop irrigation [16]. Among the wide variety of applications of treated wastewater are irrigation, groundwater recharge, domestic use, industrial applications, and even the production of drinking water with high-tech treatments [56].

**Table 6** shows the various reuses of treated wastewater using different degrees of purification, but it is also reused untreated, especially in underdeveloped countries in Latin America, Asia, and Africa, with water scarcity arises the need for high-quality effluents. Therefore, it is necessary to promote conventional and advanced tertiary treatments for wastewater treatment [57].

Globally, the largest demand for water comes from the agricultural sector, which accounts for approximately 70% of all freshwater withdrawals; therefore, the reuse of treated wastewater for this sector has become one of the most reliable and low-cost alternatives [58]. According to Valdes et al. [2] in several studies, the reuse of treated wastewater has been demonstrated; however, this practice reveals some advantages and disadvantages (**Table 7**). Therefore, the level of treatment for reuse depends on the water quality requirements for the intended use [59]. In this sense, it is important to determine the environmental, social, economic, political, and technical aspects involved in the reuse of treated wastewater [60].

### 3.2 Environmental aspect

WWTPs aim to protect water resources and human health by reducing nutrients and pathogens discharged to water bodies. However, global problems such as pollution and water scarcity induce toward reuse, an issue of high relevance [44]. The reuse of wastewater can be a viable alternative to solve problems mainly related to scarcity, but it is also important not to lose sight of the issue of ECs; WWTPs have been identified as major sources of this type of pollutants affecting aquatic ecosystems [61].

| Reuse | Description |
|---|---|
| Municipal | Irrigation of public parks, sports facilities, gardens, parkways; street cleaning; fire protection systems; vehicle washing and toilet flushing. |
| Agricultural | Irrigation of processed and unprocessed food crops, animal pastures, fodder, fiber, seed crops, ornamental flowers, orchards, hydroponic crops, aquaculture, greenhouses, viticulture, etc. |
| Industrial | Cooling water, cooling towers, washing water, concrete manufacturing, soil compaction, and dust control. |
| Recreational | Irrigation of golf courses, recreational reservoirs with or without public access (e.g. for fishing and navigation), and ornamental reservoirs without public access and artificial snow. |
| Environmental | Recharge of aquifers, wetlands, and swamps; ecological flows, wildlife habitat, and forestry. |
| Drinking use | Aquifer recharge and advanced treatment to obtain the quality of drinking water. |

**Table 6.**
*Possible reuse of treated wastewater on a global scale [57].*

| Advantages | Disadvantages |
|---|---|
| • Reduces stress from water sources. | • High investment. |
| • Minimizes freshwater pollution. | • Distance to transport water. |
| • Source of nutrients, useful as a fertilizer. | • It requires advanced technologies. |
| • Greater availability of freshwater resources. | • Social acceptance. |
| • Increased water availability for urban areas. | • It causes the accumulation of chemical and biological contaminants in the soil. |
| • Affordable prices for treated water. | • Emerging contaminants could enter the food chain. |

**Table 7.**
*Advantages and disadvantages of reuse of treated wastewater [2].*

### 3.3 Social aspect

One of the main challenges in the reuse of treated wastewater is the degree of acceptance, influenced by many factors: education, risk awareness, degree of water scarcity or availability of alternative water sources, calculated costs and benefits, trust and knowledge, issues of choice, environmental attitudes, and participation in decision-making, in addition to other cultural, religious, and socioeconomic factors [60].

### 3.4 Economic aspect

Water reuse for industrial or irrigation purposes is considered to have a lower environmental impact and cost compared to other alternative water supplies such as: water transfers or desalination; however, these practices are carried out in a limited way due to legal and social issues [62]. On the other hand, considerable investment is required to renovate and upgrade WWTPs to operate more efficiently [3]. The cost of water reclamation (including all costs, investment, operation, and maintenance) from wastewater to the level of drinking water which ranges internationally between 0.70 and 1 USD/$m^3$ [63, 64].

### 3.5 Political aspect

Decision-making is strongly based on political interests and social pressure. Alignment of common objectives on public health, environmental protection, and agricultural development between local authorities and different sectors is needed to overcome these challenges. On the other hand, they point out that the short terms of the municipal government affect the follow-up of a long-term improvement plan for the supply and sanitation of water, postponing financial resources with state or federal instances [60].

### 3.6 Technical aspect

Most WWTPs are not designed to handle the excess volumes of heavy rainfall, thus affecting the hydraulic systems and causing wastewater overflows. Another technical aspect refers to the managers of the water systems, since they do not have basic training in issues related to laws and regulations with water resources management or knowledge of urban hydraulic infrastructure [60].

### 3.7 Regulatory framework

The progress of planned wastewater reclamation and reuse depends not only on technological advances but also on the existence of a robust legal framework that establishes guidelines for reuse that does not entail risks for the beneficiaries. Legislation on wastewater reuse on a global scale is a complicated issue because, while there are countries with legal regulations, others only offer recommendations, each with its own parameters and indicators [65].

In Mexico, water is considered a public resource and is administered by the National Water Commission (CONAGUA) through the National Water Law, which is derived from the Mexican Political Constitution and is embodied in two regulatory articles of great interest, in addition to containing other mandatory regulations (**Table 8**). On the other hand, Mexico is a pioneer in establishing a regulation that describes the requirements for aquifer recharge with treated wastewater [68]. There is a strengthened legal framework; however, the lack of compliance with quality standards in water reuse, mainly in effluents, is noticeable. It is possible that strict legislation could lead to unsafe reuse due to the high costs involved in treatment and monitoring [45].

### 3.8 Proposal for the reuse of treated water: Acapulco, study case

According to the studies carried out by Martínez-Orgániz et al. [34] and Martínez-Orgániz et al. [69], the "Aguas Blancas" treatment plant complies with the requirements established according to Mexican Standards. The research proposes a modification in the treatment process to avoid the presence of various types of emerging contaminants, and microorganisms such as *E. coli*. It is important to note that this treatment unit discharges its effluent into the sea. Due to its level of treatment in recent years, it is considered one of the best plants nationwide; however, its efficiency potential can be improved under a design similar to the Orange Country plant (**Figure 5**), which is considered a model plant worldwide [15].

The city of Acapulco is one of the most important beach resorts in the country. The current economic situation of the municipality and of the Municipal Drinking

| Year* | Legal framework | Description |
|---|---|---|
| 1917 | Political Constitution | Article 27 establishes guidelines based on the types of water bodies. Whereas Article 115 establishes that municipal governments are in charge and responsible for the treatment and disposal of wastewater in Mexico. |
| 1971 | Federal Law to Prevent and Control Environmental Contamination (FLPCEC). | First environmental law to decree natural areas protected from contamination and overexploitation. |
| 1982 | Federal Law on Environmental Protection. | Law that replaces the FLPCEC from an environmental policy approach, ans it was broadened and oriented toward prevention and health. |
| 1988 | General Law of Ecological Balance and Environmental Protection | Article 117 establishes that "wastewater of urban origin must receive treatment prior to its discharge into rivers, basins, vessels, marine waters and other deposits or streams of water, including subsoil waters." |
| 1991 | Federal Law of Duties (Ministry of Finance and Public Credit) | It contains the obligation to pay duties for discharges of wastewater into national waters, such as riverbeds, lakes, or seas. |
| 1992 | National Waters Law | It declares of public utility the installation of wastewater treatment plants and the execution of measures for the reuse of such waters, as well as the construction of works for the prevention and control of water contamination. |
| 1995 | NOM-067-ECOL-1994 | It defines the general parameters of municipal wastewater discharges. |
| 1996 | NOM-001-SEMARNAT-1996 | Establishes the maximum permissible limits of pollutants in wastewater discharges into national waters and property. |
| 1998 | NOM-002-SEMARNAT-1996 | It establishes the maximum permissible limits of pollutants in wastewater discharges in municipal sewage systems. |
| 1998 | NOM-003-SEMARNAT-1996 | It establishes the maximum permissible limits of pollutants for treated wastewater reused in services to the public. |
| 2003 | NOM-004-SEMARNAT-2002 | It establishes the specifications and maximum permissible limits of contaminants in sludge and biosolids for their use and final disposal. |
| 2009 | NOM-014-CONAGUA-2003 | It establishes the requirements for the artificial recharge of aquifers with treated wastewater. |
| 2022 | NOM-001-SEMARNAT-2021 | It repeals the 1996 standard and updates some parameters. Effective April 2023. |

**Year of publication in the Diario Oficial de la Federación (DOF).*

**Table 8.**
*Evolution of the legal framework related to wastewater [18, 66, 67].*

Water and Sewerage Operation Agency (CAPAMA) does not allow for the implementation of treatment systems that involve large-scale restructuring. On the other hand, the Aguas Blancas WWTP is located within the urban area of Acapulco; an area with very few possibilities for expansion which limits the creation of new facilities containing other processes (e.g. Microfiltration, Reverse Osmosis, Granular Activated Carbon).

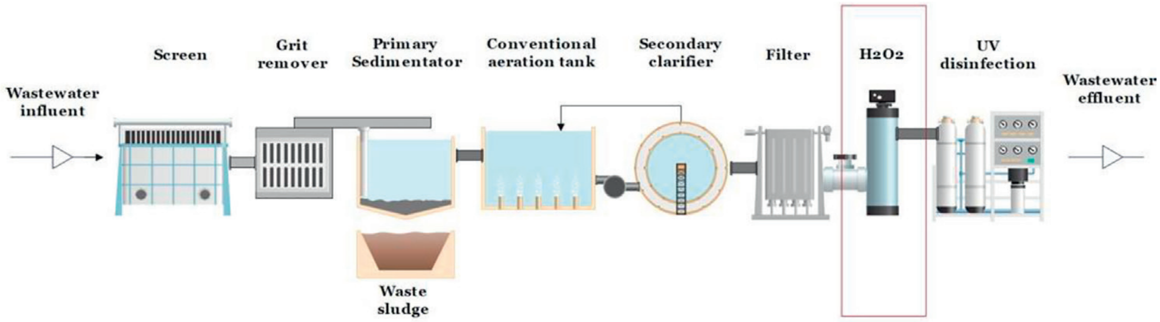


**Figure 5.**
*Outline of the process as a proposal for the Aguas Blancas WWTP (adapted from Orange Country [15]).*

Of the Advanced Oxidation Processes (AOP), Ozonation and Hydrogen Peroxide ($H_2O_2$) combined with UV (Orange Country) is the most efficient technology for the generation of hydroxyl radicals ($OH^-$).

In addition, hydrogen peroxide is considered a green oxidant, as it decomposes into water and oxygen, and its use in wastewater treatment has increased globally in recent years. Therefore, $H_2O_2$/UV is the best AOP in terms of meeting the technical, economic, and environmental constraints for advanced treatment [70]. The proposal is to modify the current treatment process to an Advanced Oxidation Treatment (AOP) using hydrogen peroxide ($H_2O_2$). Prior to additional UV treatment, it is suggested to consider lengthening the retention time, which can significantly reduce the discharge of several detected ECs and possible adverse effects to the environment and public health [70]. However, the implementation of this proposal could result in the potential reuse of treated water for agriculture, landscaping, and aquifer recharge, which are of great relevance for the development of the region.

### *3.8.1 Agriculture*

Agriculture consumes between 50% and 90% of the total water demand; therefore, wastewater reuse for this sector is considered a solution to overcome global water stress [71]. Valdes et al. [2] state that reuse of treated wastewater involves benefits and risks as demonstrated in many studies. However, the limitations are reduced with improved treatment technology, which increases the reliability of treated wastewater production and meet the standards. Consequently, many countries have succeeded in treating wastewater to an acceptable quality for unrestricted reuse in agriculture [72].

### *3.8.2 Landscape*

The reuse of treated wastewater for landscape irrigation, particularly on a regional scale, is an attractive option, since it can combine essential basic needs such as pollution control, preservation of water quality, and volume for sustainable irrigation of green areas; therefore, the reuse of treated wastewater in this area can be considered a viable alternative for irrigation of parks, sports areas, schoolyards, green areas of residential settlements, and golf courses [45, 59]. Landscape irrigation requires large volumes of freshwater; according to the World Health Organization (WHO), urban green areas are an important element for improving the quality of life [2].

*3.8.3 Aquifer recharge*

According to Seguí et al. [15], treated wastewater and rainwater represent a great opportunity for their use in the recharge of aquifers; however, to achieve this strategy, hydraulic infrastructure in optimal conditions is required, since they are mixed in the municipal sewerage systems. On the other hand, several studies assure a low public health risk caused by water contamination in the action that involves the recharge of aquifers with reclaimed water from WWTPs, a concern that leads to consider the application of a regulation in Mexico to guarantee the quality of treated water. In this sense, the recharge of an aquifer with reclaimed water is presented as the best environmental contribution to counteract water scarcity. Other benefits include the increase in groundwater reserves and the preservation of aquatic ecosystems [15].

## 4. Conclusions

The reuse of treated wastewater should be considered a common practice. It is convenient to establish effective social communication so that users are informed about the environmental benefits that this practice entails in their daily lives, and on the positive impact that its reuse would have on agriculture, a sector that demands large quantities of water. On the other hand, the optimal operational functioning of WWTPs must be a priority for local governments, which implies providing them with technical and financial resources, in addition to guaranteeing that treated wastewater effectively reaches the WWTPs through an effective collection system.

In this sense, the environmental legal framework related to water quality and mainly treated wastewater must be strictly and continuously monitored, as failure to comply not only implies sanctions, but also produces negative consequences for the environment. In order to strengthen current regulations, CEs must be taken into account, since they put public health at risk and cause adverse effects on aquatic ecosystems. Finally, this study proposes an adjustment to a WWTP in the municipality of Acapulco in its water treatment line, which consists of complementing the system with an advanced process (AOP) using hydrogen peroxide ($H_2O_2$) before UV disinfection. This improvement eliminates a wide variety of ECs and guarantees water quality for potential reuse in agriculture, in the irrigation of landscape or urban green areas, but especially for aquifer recharge. All these practices are of great relevance mainly for those that demand a greater volume of water.

## Conflict of interest

The authors declare no conflict of interest.

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