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Articles

Municipal wastewater treatment plants in Mexico: Diagnosis and public policy challenges

Plantas de tratamiento de aguas residuales municipales en México: diagnóstico y desafíos de política pública

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Abstract

The purpose is to identify the main challenges of municipal wastewater treatment policy in Mexico, through an original descriptive statistical analysis, distinguishing data from the country, as well as by states and municipalities. Five challenges are identified: good intentions; abandonment of treatment plants; operation and preventive maintenance; the vacuum of responsibility, and the priority of treatment in state agendas. The conclusion is that the professionalization of local water and sanitation agencies is key to aspiring to materialize good intentions that will be written in the new General Water Law.

Keywords: Public policy, wastewater treatment plants, sanitation, Mexico.

Resumen

El propósito es identificar los principales desafíos de la política de tratamiento de aguas residuales municipales en México mediante un análisis estadístico descriptivo original, que distingue datos del país, así como de estados y municipios. Se identifican cinco desafíos: buenas intenciones; abandono de plantas de tratamiento; operación y mantenimiento preventivo; vacío de responsabilidad, y prioridad del tratamiento en las agendas estatales. La conclusión es que la profesionalización de las agencias locales de agua y saneamiento es clave para aspirar a materializar las buenas intenciones que se escribirán en la nueva Ley General de Aguas.

Palabras clave: política pública, plantas de tratamiento de aguas residuales, saneamiento, México.

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Introduction

Wastewater treatment is one of the many Mexican challenges not respecting ideology. The political discourse of the current federal government in Mexico questions that neoliberal policies of past administrations and corruption have been the main burdens for which the country continues to be stagnant in inequality, while its opponents affirm that current policies will fail due to lack of market mechanisms and for being a product of hierarchical and unilateral decision-making. If this ideological tension represented the real problem, the task of governing would be so simple that the sciences of government and public policies would not be necessary and would have already disappeared due to their ineffectiveness. Fortunately for some and unfortunately for others, no single ideology is enough by itself to make public policies effective. Otherwise, just having good intentions would be sufficient to solve public problems.

Making public policies in a democracy necessarily means being faced with a complex scenario, where "truths" and "rights" are disputed between various actors, with different interests and ways of thinking, where the task of governing is science and also "an art" since it is difficult to immaculately implement decisions through different organizations and bureaucracies. The real Mexican challenges in water sanitation require intelligence processes to understand how a public problem can be faced, with what resources, who will the beneficiaries be, what the assumptions of government intervention are, and many other questions to be addressed with data and scientific knowledge, as a product of the physical-natural sciences, providing data such as infrastructure engineering and water quality, as well as from the social sciences providing data related to human behavior. This is where water research under the focus of governance, management, and public policy is currently standing.

Under this analytical focus, this article seeks to identify the main challenges of wastewater treatment policy in Mexico, seen from the public policy perspective, based on a statistical diagnosis. The structure of this document is divided into four parts. The first one describes wastewater sanitation policies in developed countries and Mexico. The second one shows the materials and methods used in this research. The third part presents the results for the Mexican case, as a diagnosis, about the current situation of wastewater treatment plants, through three statistical radiographs: national, state, and municipal. Finally, the main public policy challenges regarding wastewater treatment in Mexico are discussed.

Wastewater treatment and public policy

Wastewater treatment is a necessary element, but not sufficient for sanitation. On one hand, the fundamental objective of treatment is to reduce the concentration of pollutants in wastewater to a value low enough to discharge it into a receiving body, be it surface or underground. The effective discharge of treated wastewater depends both on the technical design of the treatment plant and on the elements that are found around compliance with federal, state, and municipal regulations (Hopcroft, 2015). On the other hand, sanitation addresses a more complex problem, above all due to the phenomenon of micro-pollutants, this is why a comprehensive vision with instruments that go beyond mere wastewater treatment and measures "at the end of pipe" is required (Metz & Ingold, 2014). Figure 1 shows a simple and non-exhaustive explanation of the relationship between the concepts of wastewater treatment and sanitation. This article exclusively addresses the issue of wastewater treatment.

Figure 1. Relationship between wastewater and sanitation, from the public policy perspective

The popular perception of sanitation is that it represents an institutional problem and not a personal one for each user, which should not change their lifestyle. However, the concept of water sanitation represents a commitment for both agencies and users. Trusting sanitation agencies is essential for clients to cooperate with the payment of appropriate fees. It also requires customers to modify certain behaviors on how they use water, especially true for commercial and industrial users. Sanitation is a broad concept addressing the complexity of the multiplicity of sectors related to wastewater. For instance, in addition to water treatment, sanitation focuses on promoting its reuse, and this can be done by strengthening rates and measuring water use, since with minimal rates and without water metering, the water reuse options or rainwater harvesting make no sense for users, since drinking water is cheaper than treated water. Therefore, the institutional dimension of sanitation is fundamental for the effectiveness of the water system (Gray, 2004).

A major challenge at the global level is to obtain financing to operate adequate sanitation systems, as well as establishing pricing and collection systems allowing water agencies to be self-sufficient (Raftelis, 2005). Unlike Mexico, in other countries, agencies providing water sanitation services operate in a private style, where price, costs, profits, and human resources are of vital importance to meet the client's requirements. This is due to the fact that sanitation systems are complex and interconnected with other sectors, such as health, so they require complex operations for customers demanding increasingly better service quality. Therefore, a water and sanitation agency requires highly qualified and motivated staff. To achieve this, it is essential to have recruitment processes and an organizational environment promoting motivation and retention of talent, to aspire to a professional career system in the sector (Wexelbaum, 2005).

In developed countries, the focus of sanitation agencies is towards obtaining profits allowing them to maintain and reinvest in the service. In many small towns in these countries, income from water treatment represents one of the few incomes they receive. If the agency is aggressive in rates, agencies use surplus money even to invest in other public services, but when the agency is cautious in rates, it is barely enough to maintain the treatment service (Davis, 2005). Moreover, in these developed countries, there has been a paradigm shift in terms of water quality. Whereas in the past, priority was given to controlling taste, color, odor, and coliforms in water, now new regulations are more sophisticated and expensive. To meet the requirements of the new water quality paradigm, it is necessary to start from a systemic vision, where different components and interrelations affect each other. Within this process of a paradigm shift, the concepts of "privatization" and "reengineering" haunt the corridors of water and sanitation agencies. In general, those advocating for privatization are on the ideological right, those advocating for reengineering are on the ideological left. Both "solutions" seek to strengthen agencies in terms of institutional capacity and coordination with other sectors (Drinan & Spellman, 2013).

This new paradigm has been driven by the appearance of emerging pollutants in water. For instance, these pollutants have been found in hospital wastewater containing high concentrations of chemicals (Verlicchi, 2018). In developed countries, these hospital wastewaters are usually discharged to a pre-treatment system, prior to discharge into the municipal network. In the case of developing countries, hospital discharges can affect the population and the environment to a higher degree, because they are usually discharged directly to municipal drainage, streams, rivers or lakes, without prior treatment (Al-Aukidy, Al-Chalabi, & Verlicchi, 2018).

The intervention strategies of the international grantee agencies have followed fashionable discourses, but the water sanitation projects have not been holistic and deep enough to be able to change the institutional restrictions keeping a status quo of local institutional weakness, so these projects have been very limited (Seppälä, 2002). In the case of Mexico, recent proposals regarding water management have arisen from the paradigm of integrated water resources management, where the coordinated management of water, land, and other related resources matters (Valencia, Díaz, & Ibarrola, 2004). Although this theoretical framework is sophisticated, the institutional restrictions of each country must be recognized (i.e., policies, laws, and traditions). Currently, in most of the Mexican municipal water and sanitation agencies, the Political Apparatuses' practices continue, manifested in the predominance of political criteria in recruitment, designation, and promotion of personnel. This occurs both in managerial staff - driven by the dominant political group in turn – and technical staff - driven by the labor union. - Usually, decisions on rates, collection, and micrometering are guided by political criteria, by the aforementioned technicians Cáñez, 2019; Hantke-Domas & Jouravlev, 2011; Krause, 2009).

In this context of institutional weakness, it is essential to strengthening municipal water and sanitation agencies to aspire to successful integrated management. My argument is that the wastewater treatment policy must be first resolved to the essential minimum, focusing on the agency providing the service, and then to aspire to move to a sanitation policy addressing the problem systemically and comprehensively, based on the relationship between a professional agency and the behavior of the different users and their interrelationships with other sectors, such as public health.

Public policy focus on defining a problem, with its causes, consequences, and solution instruments. This definition is circumscribed in each social context and its course is determined by the values of each society and the dominant political group in turn. In addition, public policy must be designed based on scientific knowledge, to be more accurate in dimensioning the challenges faced. For these public policies to work, a conducive institutional context is required for what is written in documents and laws becomes reality (Lasswell, 1951; Thoenig & Meny, 1992). Public policies are a reflection of the attention that society gives to its priorities. In the case of the attention and priority of the wastewater treatment policy in Mexico, it is the product of the international agreements signed by the federal government, such as the millennium and sustainable development goals. However, wastewater treatment is not one of the most visible issues on the agendas of governments in Mexico because it is a problem that "can not be seen" and wastewater treatment plants are far from population centers. Next, Table 1 shows a comparison between visions, definitions of problems, and solutions of the last three federal administrations.

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Table 1. Comparison between vision, problems, and solutions in the wastewater treatment plants policy for the three last federal administrations in Mexico. Own elaboration based on the Programa Nacional Hídrico (2007-2012; 2013-2018; 2019-2024) (Conagua, 2007; Conagua, 2014; Conagua, 2020).

National Water Policy	Policy vision	Policy problem	Policy instruments
2007-2012	Environmental sustainability: Water with strategic value, in search of efficiency to guarantee preserving the environment.	There is no payment culture in customers. Water treatment is not a priority on the state and municipal agendas. Insufficient funding, information, and citizen participation.	Convert wastewater treatment plants for minimal energy costs, new treatment techniques. Strengthen professionalization, technical development, and financial self-sufficiency of the water agencies, through appropriate rates.
2013-2018	Water security for sustainable development: Water as a priority and national security issue, with a comprehensive approach to move from a	Insufficient financial resources for building, rehabilitation, and maintenance (energy and chemical reagents) of treatment infrastructure. Lack of staff training; and	Build new wastewater treatment infrastructure and improve the existing one, through the promotion of renewable energies in sanitation processes. Civil service in agencies of the water sector. Transparency and

	reactive to a proactive style.	deficient culture of payment in users.	alliances with research centers.
2019-2024	Water for welfare: sustainable and coordinated water management with the participation of citizens, institutions, and government levels.	Insufficient and inequitable access to drinking water and drainage services, due to a weak financial and public information system, and a lack of democratic spaces for water management.	Promote the use of non-conventional technologies, encourage professionalization and permanence of the staff in water and sanitation agencies, including managers. Promote rehabilitation of abandoned wastewater treatment plants.

The last three national water plans coincide in the definition of the public policy problem and its solution instruments; however, the policy vision of the water sector is different. During the administration of President Felipe Calderón Hinojosa (ideological right), the water policy vision was focused on water management efficiency for environmental sustainability. Besides, President Enrique Peña Nieto (ideological center) bets on understanding water from a national security perspective. Currently, the focus of President Andrés López Obrador (ideological left) is water as a pillar of welfare. Despite the ideological and discursive plurality of these three national administrations, the definition of the wastewater treatment policy problem has not changed in 20 years. Insufficient financing for building, rehabilitation, and maintenance of treatment plants stands out, as well as the absence of professional civil service in the water sector, especially at the municipal level. In addition, they identify an absence of citizen participation, reliable information system, and the lack of payment culture of service users.

Furthermore, the policy solutions the last presidents identified are very similar: the conversion of treatment plants to low energy consumption systems, adoption of unconventional treatment technologies, promoting a professional civil service, and strengthening financial self-sufficiency of municipal water agencies. Despite the ideological changes in the last three national administrations and the maintenance of the same definition of the policy problem and policy solutions, results have been insufficient, mainly at the local level. However, the sector has made progress, mostly from 2000 to 2006, followed by 2006 to 2012, while from 2012 to 2018 progress was marginal compared to what had been achieved in the two previous six-year terms. With the statistical information available in this study, it is not possible to conclude about the factors showing the greatest influence on the wastewater treatment policy results. What can be sustained is that neither the discourse nor the narrative, by themselves, are capable of modifying reality. It is necessary to implement these discourses and public policy designs through capable, professional, and institutional water agencies (Domínguez, 2010; Torregrosa, & Jiménez, 2009). Table 2 shows the main aggregated results in municipal water sanitation in the last three full six-year terms.

Table 2. Wastewater treatment panorama in Mexico, from 2000 to 2018. Own elaboration based on Conagua (2019).

Feature	**Year**			
	2000	**2006**	**2012**	**2018**
Number of plants in operation	793	1593	2342	2526
Collected flow in sewer systems (cubic meters per second)	178.0	206.0	210.2	215.2
Installed capacity (cubic meters per second)	67.5	99.8	140.1	181.2
Treated flow (cubic meters per second)	42.4	74.4	99.8	135.6

Feature	**Growth rate (in percentage)**		
	2000-2006	**2006-2012**	**2012-2018**
Number of plants in operation	100.9	47.0	7.9
Collected flow in sewer systems	15.7	2.0	2.4
Installed capacity	47.8	40.4	29.3
Treated flow	75.4	34.2	35.9

Materials and methods

To identify the main challenges of wastewater treatment policy in Mexico, I present a statistical diagnosis based on the wastewater treatment plants database of Conagua (2016), this was obtained from the National Transparency Platform with the folio number: 1610100223917. This inventory contains treatment plants (active and inactive) at the local level, with the following data: installed capacity, treated flow, operation status, technological process, observations, water receiving body, year of construction, and beginning of the operation. The method is descriptive statistics, in order to obtain a current picture of the wastewater treatment situation at the national, state, and municipal levels. The statistics presented are the product of original and detailed work on cleaning, complementation, and the elaboration of graphs and tables.

The database has at least two biases. One of survival, since the treatment plants are out of operation, tends to disappear when the database is updated. Therefore, it is likely that the count of the out of operation treatment plants is undersized, that is, there are more non-active plants than what this database presents (Espinoza & Sepúlveda, 2015). In addition, this database has an investment bias in municipalities with the largest population, so the data likely have biases towards larger municipalities, which have a greater capacity to make a co-investment for the establishment of a new treatment plant.

Moreover, I used statistical information from Conagua (2019), about the situation of the drinking water, sewerage, and sanitation subsector. This official document of the national water authority contains accumulated annual information showing different statistical scenarios from 2000 to 2018. I also used information from INEGU (2010) to obtain the population size of Mexican municipalities, to obtain per capita statistics from the main database: Conagua (2016). I also used the Conapo (2015) database to obtain the marginalization degrees of municipalities. Also, I used De-Dios (2008) database to obtain the institutional capacity of Mexican municipalities.

The main method of this article is descriptive statistics which describes and analyzes data through numerical and graphical panoramas, without drawing causal conclusions or inferences. As the present analysis focuses on a highly heterogeneous context, such as Mexico and its diverse municipalities, I omitted a general analysis of measures of central tendency and variation of the data, since I here intend to show general pictures from national, state, and municipal levels. Indeed, I show the statistical analysis as large sections called "radiographs": on national, state, and municipal levels. Based on these radiographs, I show the public policy challenges shown by the data discussed here under the literature of sanitation and wastewater treatment, from the policy and management perspective.

Results

Diagnosis of the Mexican wastewater treatment plants

As a starting point, Table 3 shows the evolution of the main indicators of wastewater treatment plants in Mexico from 2000 to 2016.

Table 3. Evolution of the main indicators of wastewater treatment plants in Mexico from 2000 to 2016. Own elaboration based on the National Hydraulic Program (2001-2006) (Conagua, 2002) and Conagua (2016).

Basic features	**Year**	
	2000	**2016**
Total wastewater treatment plants	1018	3516
Active plants	793	2536
Inactive plants	225	980
Percentage of active plants concerning the total	**77.9**	**72.1**

For 16 years, the number of active plants grew more than 200 % and the number of inactive plants grew more than 300 %. The percentage of active plants concerning the total decreased from 77.9 % to 72.1 %. The growth of inactive plants is greater than the growth of active ones. The increase in the number of active plants is explained by the increase in federal financing for the construction and rehabilitation of treatment plants during those years (Conagua, 2019). Despite this, the growth rate of the inactive plants was higher in this period, because the municipal water agencies have abandoned them, mainly due to high energy costs. This situation shows the institutional weakness of these local water agencies (De Anda, 2017). After this brief analysis of the evolution over time, Table 4 presents the basic data of the wastewater treatment plants in 2016.

Table 4. Basic data of the register of wastewater treatment plants in Mexico, 2016. Own elaboration based on Conagua (2016).

Basic features	The year 2016	
	Number	**Percentage**
Total wastewater treatment plants	3 516	100
Active plants	2 536	72.53
Inactive plants	980	27.47
Plants (active) reusing some volume of treated water, concerning the total of active plants	465	18.32
Number of municipalities with at least one active plant, concerning the total number of municipalities with active plants	941	38.17
Basic features	**Liters per second**	
The treatment capacity of all active plants	180 570	

The treated water flow of all active plants	123 587
Active plant treatment capacity	**Number of plants**
Plants with a capacity of 1 liter per second or less	298
Plants with more than 1 and up to 5 liters per second	925
Plants with more than 5 and up to 10 liters per second	357
Plants with more than 10 and up to 20 liters per second	320
Plants with more than 20 and up to 50 liters per second	269
Plants with more than 50 and up to 200 liters per second	223
Plants with more than 200 and up to 1000 liters per second	112
Plants with a capacity of more than 1000 liters per second	**32**

Note: active plants tend to be of higher capacity, inactive plants tend to be of lower capacity. The active plants of lagoon technology are about 50 % of the total, however, they treat little flow.

National radiography

For 2016, 72.53 % of the total plants are active, of which 18.32 % reuse some volume of treated water. Even though one out of four treatment plants are inactive (this represents 10 % of the total treatment capacity). This means that most of the inactive plants have low treatment capacity, regularly belonging to small municipalities. Figure 2 shows the type of treatment technology in wastewater treatment plants country-wide, for both active and inactive plants.

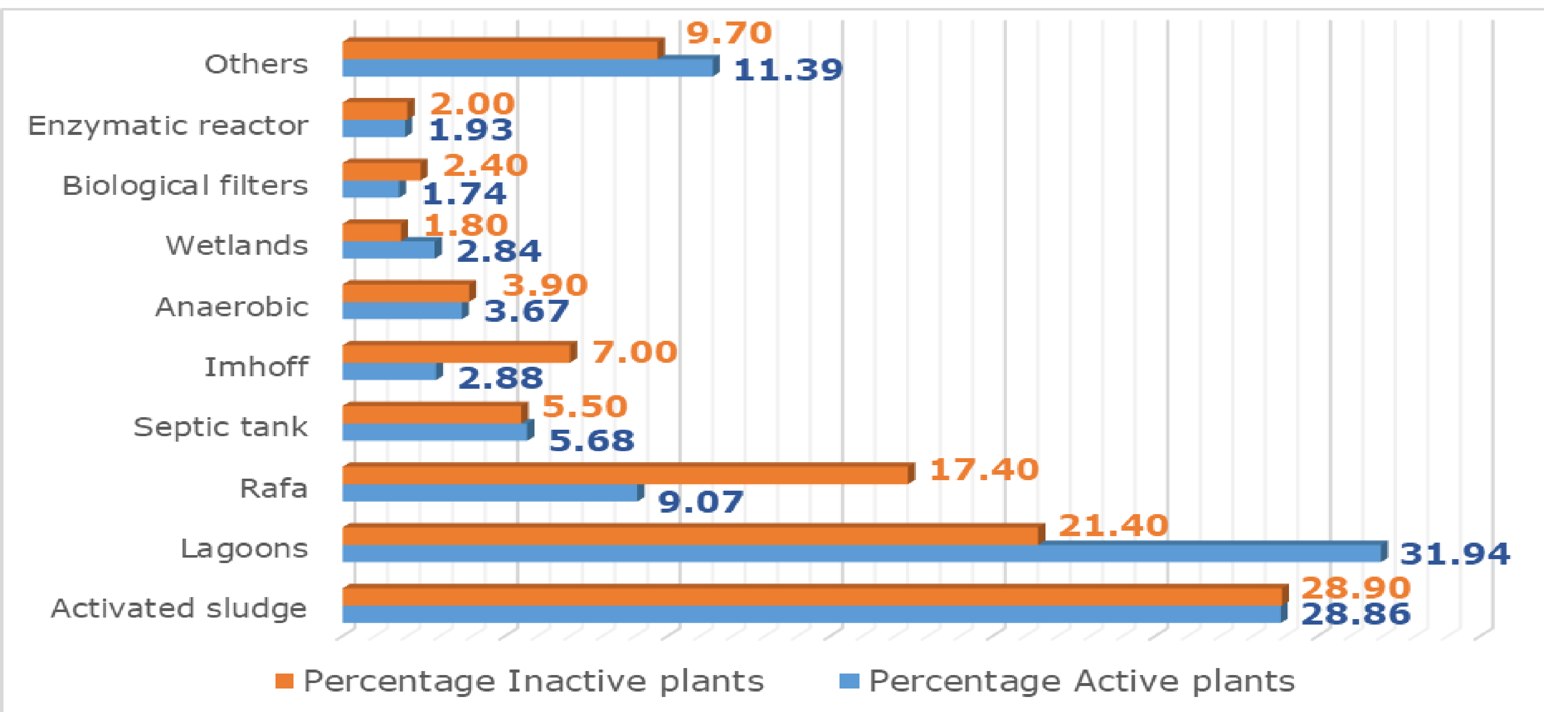

Figure 2. Type of treatment technology by the plant. Active and inactive. Own elaboration based on Conagua (2016).

The most common treatment plants in Mexico are activated sludge and lagoons (grouped in different types). While that activated sludge represents practically 30 % of the total active and inactive plants, lagoon technology has a difference of 10 % between the active and inactive ones, that is, lagoon plants have a lower abandonment rate than those of activated sludge. Figure 3 shows the main observations of the active plants in inventory.

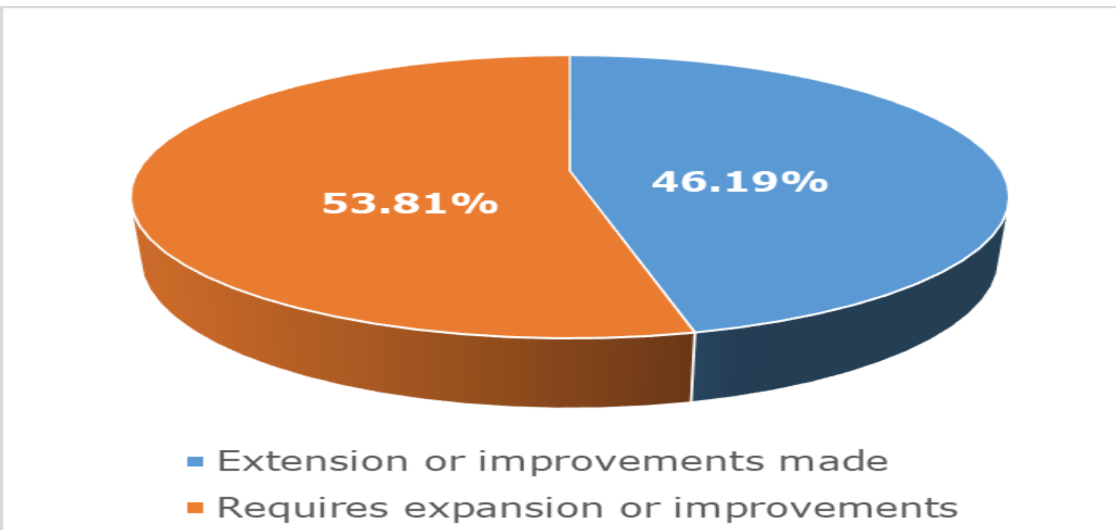

Figure 3. Main observations in active treatment plants. Own elaboration based on Conagua (2016).

More than half of the active plants with observations in the official inventory require expansion or improvements for their proper functioning, while 46.19 % of the plants were expanded or improved. According to Garzón, Buelna, and Moeller (2012), the most common causes of lack of preventive maintenance are the complexity of the operation for the available human resources, and the high investment and maintenance costs associated with conventional treatment plants, causes which are more common in small municipalities, with low human resource capacity and weak financial systems. Figure 4 shows the main observations in the official inventory of inactive plants.

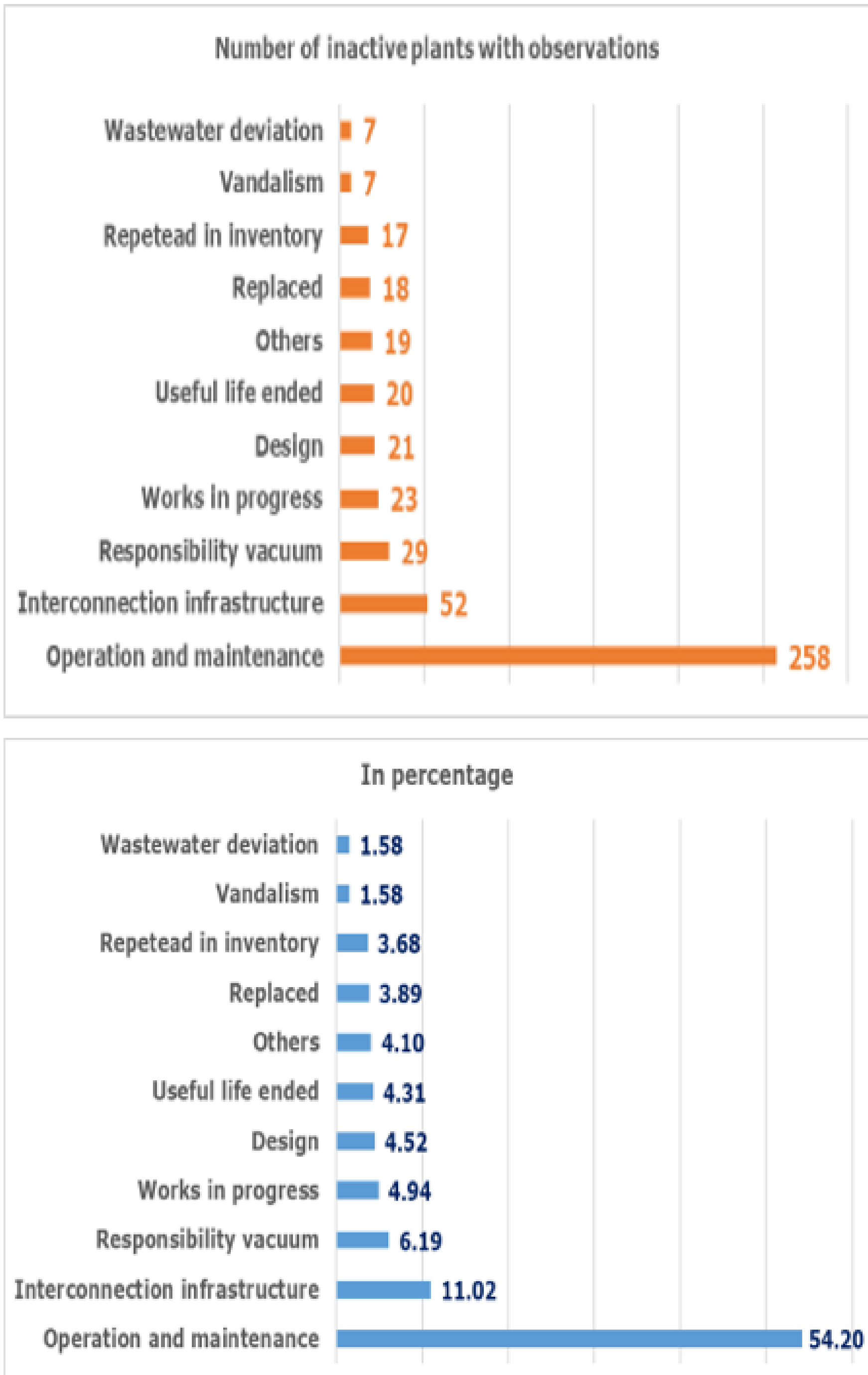

Figure 4. Main observations in inactive treatment plants, number, and percentage. Own elaboration based on Conagua (2016).

Out of a total of 980 inactive plants, 509 plants do not have observations specifying the reason for the abandonment of each treatment plant, while only 471 inactive plants do. Of those that have observations, more than half of the inactive treatment plants are out of operation due to problems in operation and maintenance, 11.04 % are due to lack of interconnection infrastructure, and 6.16 % due to responsibility vacuum between the responsibilities of different levels of government, or between municipal government and individuals. The fact that 4.46 % of the inactive plants have design problems, shows the lack of quality control by regulatory bodies.

State radiography

The states with the highest number of active plants are concentrated in the northwest of the country, Sinaloa (282), Durango (231), and Chihuahua (184). Those with the least active plants are Campeche (15), Coahuila (25), and Yucatán (27). Besides, the states with the highest percentage of active plants are Quintana Roo (100 %), Sinaloa (95.9 %), and Chihuahua (91.5 %). While the states with the lowest percentage of active plants are Tlaxcala (44.5 %), Chiapas (45.5 %), and Campeche

(45.5%) (Figure 5). Figure 6 shows the percentage of plants that reuse some volume of treated water and its most common reuse type, by state.

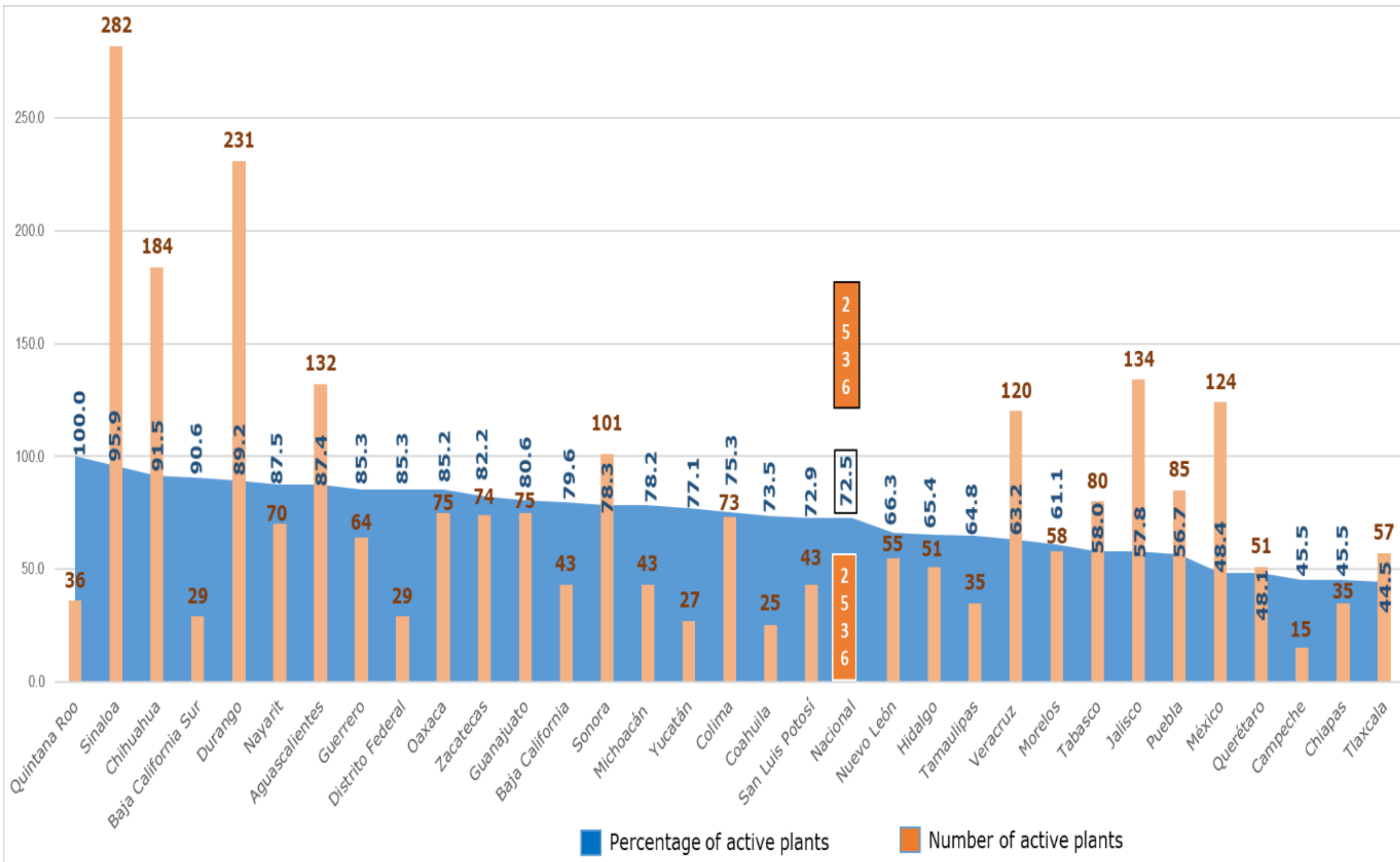

Figure 5. Number and percentage of active plants by state. Own elaboration based on Conagua (2016).

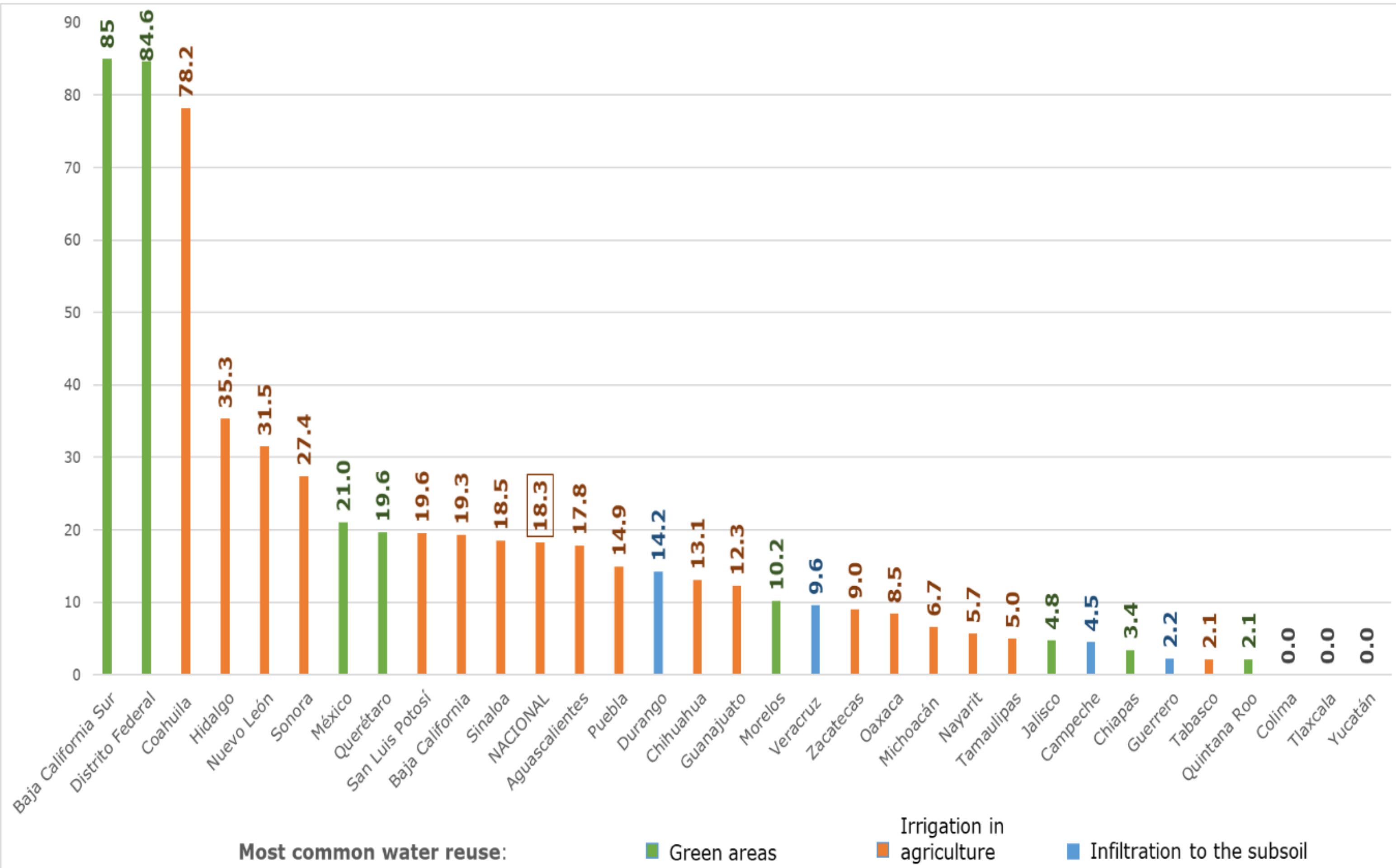

Figure 6. Percentage of plants that have some degree of treated water reuse and its most common type, by state. Own elaboration based on Conagua (2016).

The states with the highest percentage of treated water reuse in their treatment plants are Baja California Sur (85.0 %), Distrito Federal (84.6 %), and Coahuila (78.2 %). For the first two, the most common use is irrigation to green areas, while for the latter is irrigation. The case of Baja California Sur is explained by the municipality of Los Cabos with 11 treatment plants, most of which are activated sludge, providing irrigation water for green areas and golf courses in tourist complexes, on all aimed at international tourists. The Distrito Federal is explained because the water system of Mexico City has treatment plants in coordination with organizations such as the National University of Mexico, prisons, military schools, the National Oil Company, sports parks, among others, contributing for the most part to the irrigation of green areas. The high percentage of plants reusing treated water in Coahuila is explained by the fact that most plants contribute to agricultural irrigation, the largest being that of Torreón City, with stabilization lagoon technology, contributing to agricultural irrigation. Irrigation reuse of treated wastewater is the most common in Mexico, maybe because the land where the treatment plant is established is the product of a donation by private parties in exchange for treated wastewater for irrigation. Due to the characteristics of the land in Mexican municipalities, since generally the treatment plants are established in the peripheral areas of the communities, these land donations in exchange for treated water would be negotiated between the municipal governments and the Ejidos, which have an agricultural vocation and, therefore, an interest in more water for irrigation. The states with zero percent reuse are Yucatán, Tlaxcala, and Colima. The most common type of treated water reuse in Mexico is irrigation since it is the most common type in plants that reuse some volume of treated water in 18 states. It is followed by the irrigation of green areas with 8 states. Finally, there are 4 states in which underground infiltration is the most common.

The "most common use" refers to the highest percentage of plants in each state with some volume destined for reuse, they do not necessarily represent the plants with the highest flow. In addition, only the reuse in irrigation of green areas, agricultural irrigation, and underground infiltration are taken into account. Ecological use is left out of the analysis since the database does not have more information about it. All active treatment plants in Mexico deposit the treated water in a receiving water body, generally in streams and rivers. Therefore, in the present study, it is assumed that ecological use is what remains from the uses of irrigation to green areas, agriculture, and injection into the subsoil. Additional uses to the ecological use are highlighted, because they require an additional level of organization to channel the treated water to second use, which allows each water agency to have an additional volume of water and, therefore, to count with a more diversified portfolio of water sources. Figure 7 shows the average lifespan of treatment plants, by state and in years concerning the national average.

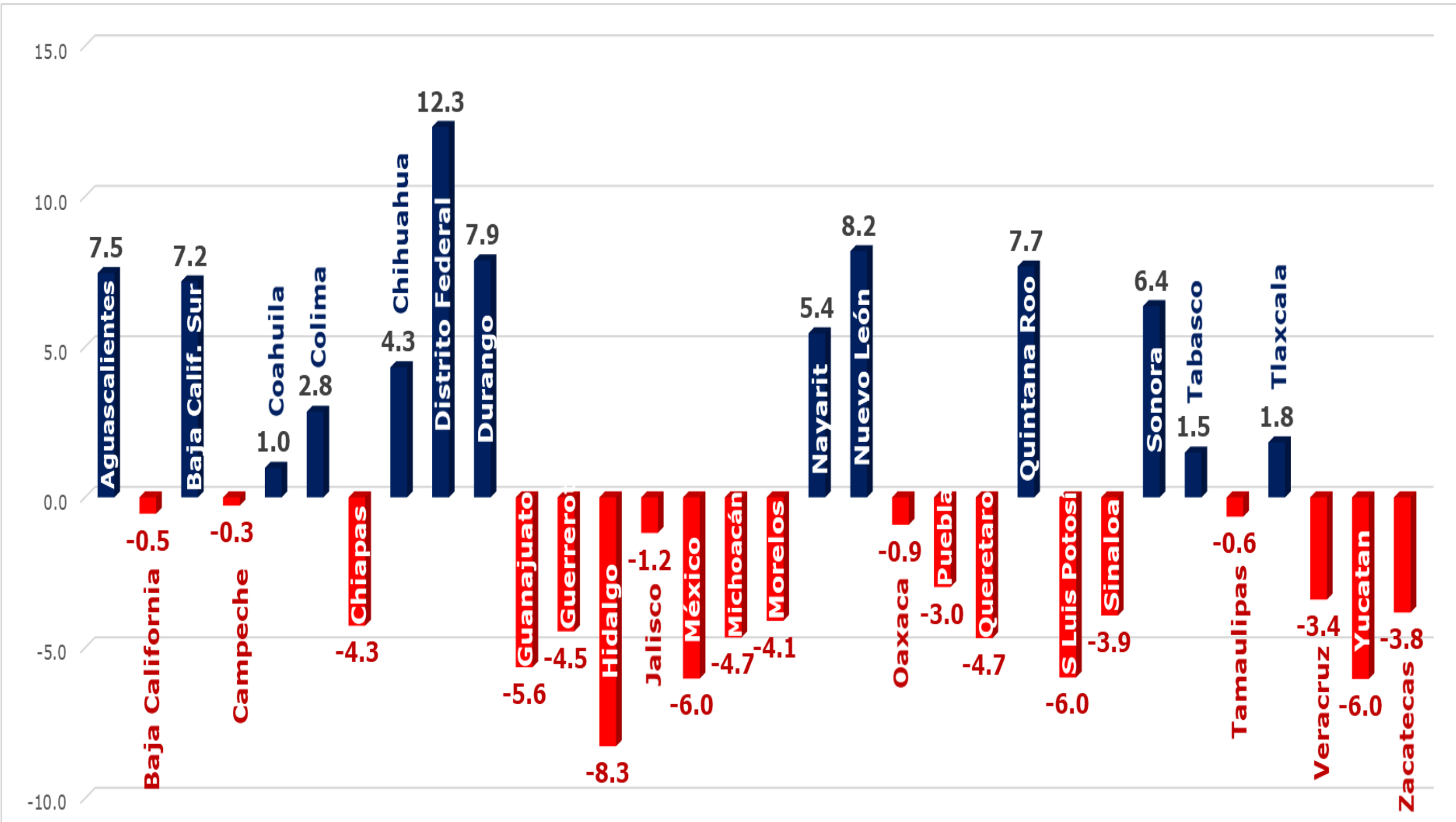

Figure 7. The average lifespan of treatment plants is in years for the national average lifespan by state. Own elaboration based on Conagua (2016).

The oldest treatment plants, on average and in years concerning the national average, are those of the Distrito Federal with 12.3 years, Nuevo León with 8.2 years, and Durango with 7.9 years. While the most recent treatment plants are in Hidalgo with 8.3 years less than the national average, followed by the plants in Mexico, San Luis Potosí, and Yucatán, with 6 years each. The state of Hidalgo is the state with the oldest treatment plants since it has been treating wastewater from Mexico

City for more than 10 years ago, leaving a volume of 52 cubic meters per second in the treatment plant in Atotonilco de Tula, Hidalgo. In addition, this area is paradigmatic in terms of the use of treated wastewater in agriculture, since there is the Mezquital Valley, one of the most important irrigation places in Mexico, with grey and treated wastewater (Cisneros & Saucedo, 2016). This is an example showing the interest in treatment plants, because of the impact on public health. Given the sanitary risk of irrigation with greywater, the government decided to invest in solving this problem, becoming a very visible issue. Figure 8 shows the number and percentage of municipalities, by state, with at least one active plant.

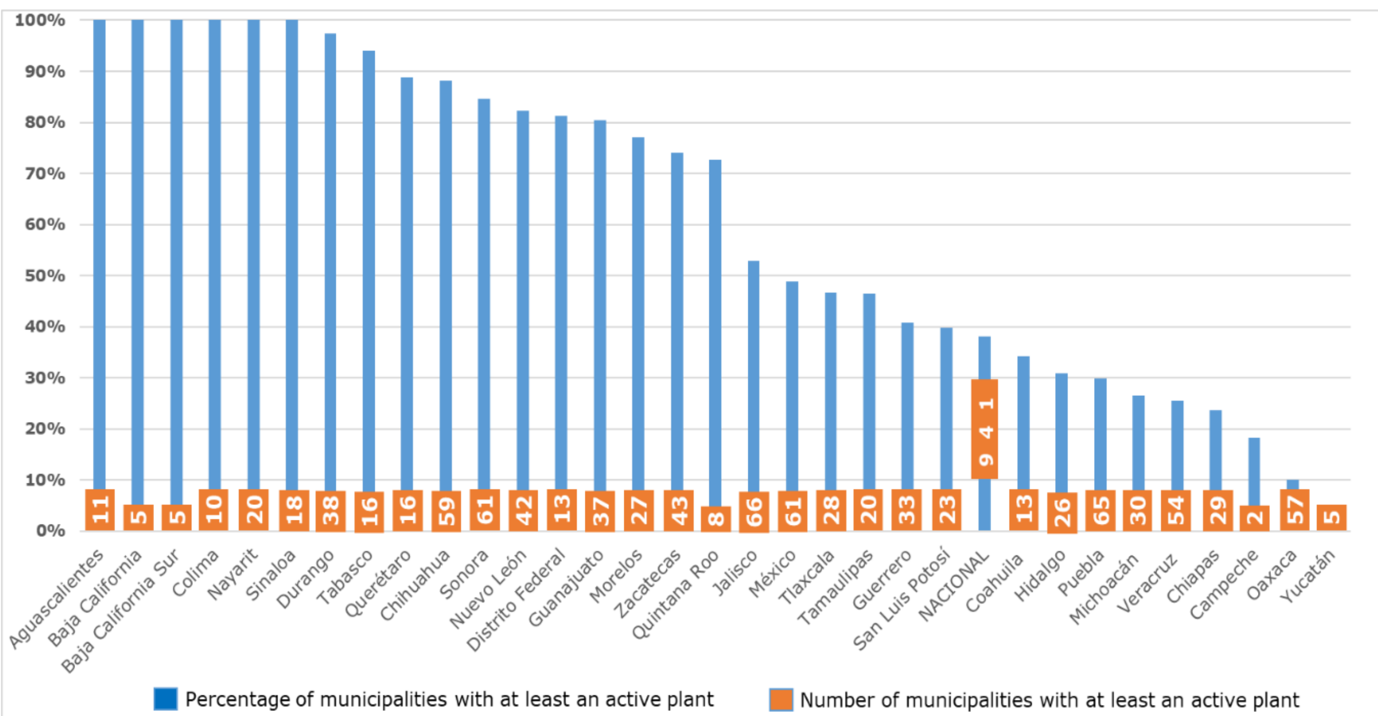

Figure 8. Number and percentage of municipalities with at least one active plant, by state. Own elaboration based on Conagua (2016).

At the national level, 941 municipalities have at least one active plant. This represents 38.3 % of all municipalities. Roughly, 6 out of 10 municipalities in Mexico lack wastewater treatment plants. The states of Aguascalientes, the Baja Californias, Colima, Nayarit, and Sinaloa, have 100 % of municipalities with at least one active plant. These states coincide in having few municipalities, which can facilitate the administration and attention of the state governments in supporting the management of the municipal water and sanitation agencies. According to Casiano *et al*. (2019), the crucial point of promoting sanitation policies in Mexico has been the role of state governments, because they have been able to reduce fragmentation in efforts of the local actors involved. The states with the lowest percentage of municipalities with active plants are Yucatán (4.7 %), Oaxaca (10 %), Campeche (18.2 %), and Chiapas (23.6 %). Likewise, it is observed that the states with the highest number of municipalities are those with the lowest percentage of municipalities with at least one active plant, with some exceptions. Figure 9 presents data on the treated flow per capita per 10 thousand inhabitants, by state, and in liters per second.

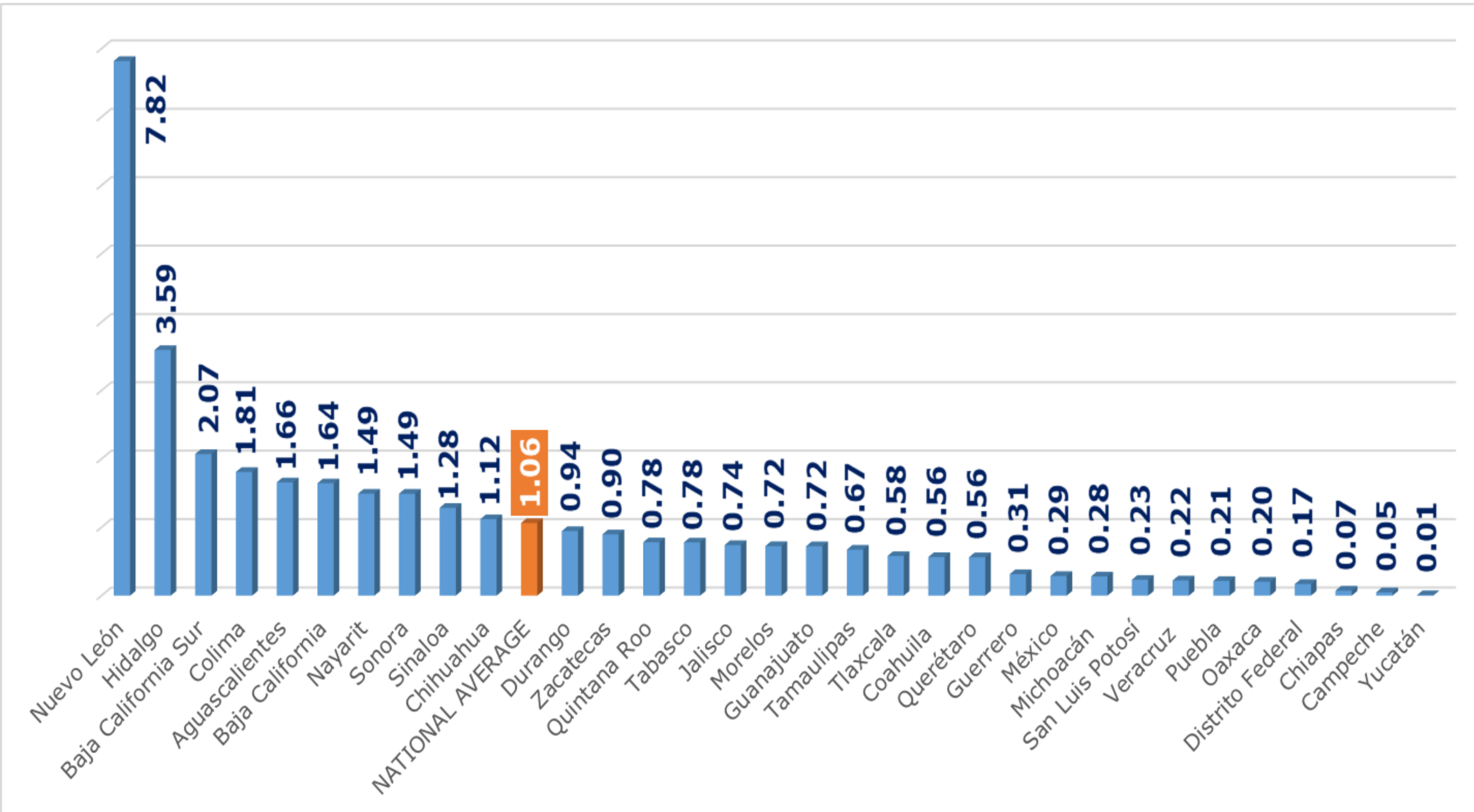

Figure 9. Treated flow per capita per 10 000 inhabitants, by state and in liters per second. Own elaboration based on Conagua (2016).

The national average of treated flow per capita per 10 000 inhabitants is 1.06 liters per second. Nuevo León stands out with six times more, Hidalgo with two times more, and Baja California Sur with double the national average. The success of Nuevo León may be related to the fact that it has a professional decentralized state body, with the demands of local businessmen, and because 90 % of its population in the state is concentrated in the metropolitan area of Monterrey. The Mexican state with the lowest treated water flow is Yucatán, with just 0.01 liters per second, followed by Campeche (0.05), Chiapas (0.07), Distrito Federal (0.17), Oaxaca (0.20), Puebla (0.21) and Veracruz (0.22). The case of the Distrito Federal does not reflect the reality of water treatment, since most of the treated water is accounted for in Hidalgo. Table 5 shows basic data related to inactive plants, to identify more elements of analysis related to the abandonment of wastewater treatment plants.

Table 5. Singularities related to inactive wastewater treatment plants, by state. Own elaboration based on Conagua (2016).

Singularity	States with the highest number of inactive wastewater treatment plants	Number	Percentage respect to the state total
States with the highest number of inactive plants, about the total of inactive plants in the country	México	132	14
	Jalisco	98	10
States where inactive plants with activated sludge technology represent their	Campeche	15	81
	Baja California	7	67

highest percentage of inactive plants			
States where inactive plants with Lagunas technology represent the highest percentage of inactive plants	Nayarit	9	89
	Sonora	22	81
States where inactive plants with RAFA technology represent their highest percentage of inactive plants	Querétaro	36	66
	Colima	12	2
Plants inactive due to design problems, relative to total inactive plants in the state	Aguascalientes	3	30
	Michoacán	2	29
Plants inactive due to operation and maintenance problems, about the total inactive plants in the state	Querétaro	11	100
	Guerrero	5	83
	Colima	17	77
Plants inactive due to lack of responsible authority to	Baja California	6	67
	Tlaxcala	10	20

assume it, about total inactive plants in the state			
Plants inactive due to problems of theft or vandalism, relative to total inactive plants in the state	Veracruz	5	16
	Hidalgo	2	13
Plants inactive due to intentional deviation of wastewater, relative to total inactive plants in the state	Colima	3	14
	Jalisco	3	10
Plants inactive due to connection infrastructure problems, about total inactive plants in the state	Sonora	4	36
	Jalisco	**9**	**31**

Of the 980 inactive plants, 471 inactive plants were taken into account for the singularities, the observations are distributed as follows: 21 for design problems, 258 for operation and maintenance, 29 for lack of responsible authority, 7 for vandalism, 7 for intentional diversion of wastewater, 52 for connection infrastructure problems. Besides, when

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Table 5 refers to treatment technologies, all inactive plants were considered. It should be noted that there is a specification bias in these data since the information was collected by different people without a common qualitative coding. These data are not intended to be comparative, but to show potential problems.

The 67.75 % of the inactive plants in Mexico are concentrated in three treatment technologies, activated sludge (28.88 %), lagoons (21.43 %), and RAFA (17.45 %). Moreover, practically one out of every four inactive plants are located in the states of Mexico and Jalisco. The highest percentage of inactive plants due to design problems is found in Aguascalientes and Michoacán, while the highest percentage of inactive plants due to operation and maintenance problems is in Querétaro, Guerrero, and Colima. The responsibility void has caused the most plant abandonments in Baja California and Tlaxcala. Tijuana, Baja California, is a revealing case in this regard because several abandoned plants never operated. After all, the local water agency did not formally receive them from the real estate companies that built housing units. The bet to have several small plants in that city was frustrated by a lack of understanding between what the local water agency requested and what the private companies delivered. In this void of public-private responsibility, several million pesos were wasted and caused grey wastewater to reach the sea, without prior treatment. Next, I present the municipal radiography of the treatment plants' situation. In Figure 10, I show the number of active and inactive plants inside and outside the municipal capital seats.

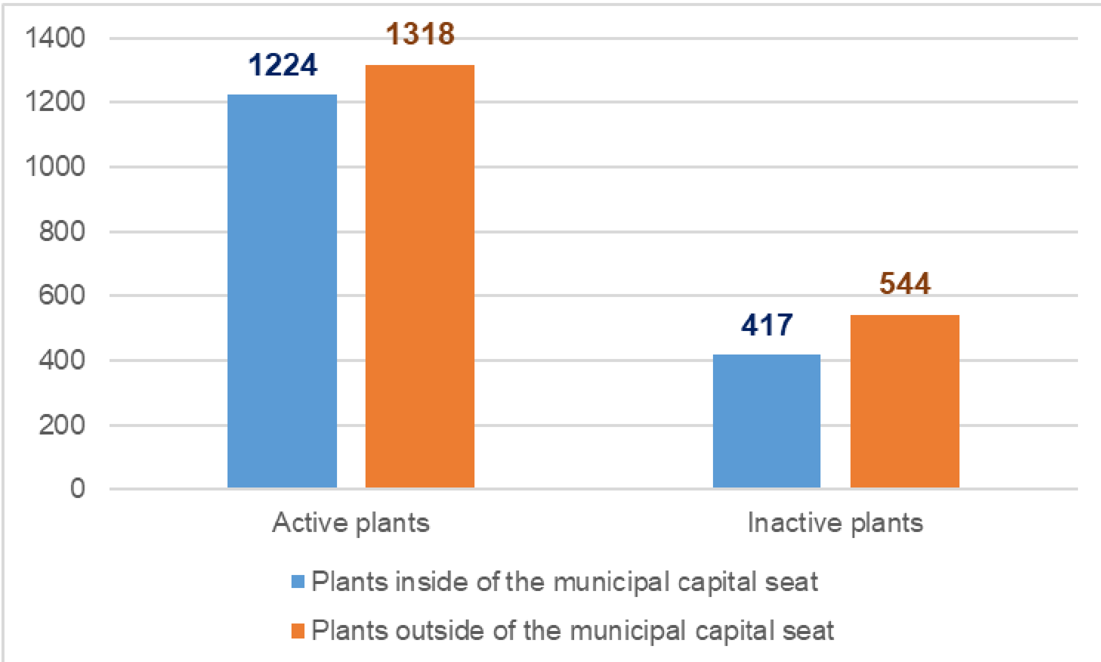
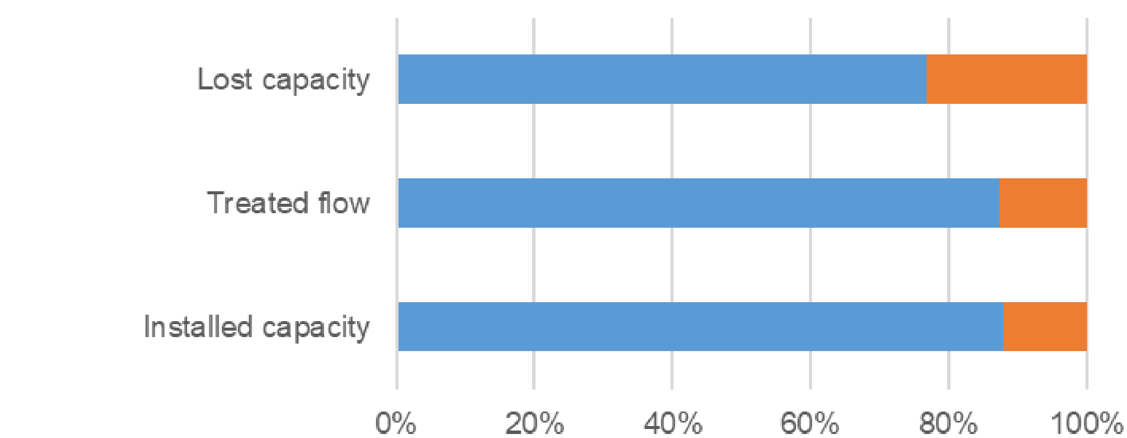


Figure 10. The number of active and inactive plants inside and outside the municipal seat. Own elaboration based on Conagua (2016).

Municipal radiography

The 53.15 % of the treatment plants are located outside the municipal seat, while 46.85 % are within the municipal seats. There is no significant difference between active and inactive plants inside or outside the municipal capital seats. The plants outside the municipal seat have a greater number of active and inactive plants than those found inside. This indicates that there is no significant difference between the institutional capacity of a local water agency inside or outside the municipal seat of government. Rather, the differences in institutional capacities are due more to the type of municipality than to the type of locality within them. That is, the probability that a plant is still active in a municipality with a strong local water agency is more or less the same inside as outside its municipal capital seat. Figure 11 presents the installed capacity and treated water flow in the treatment plants, inside and outside the municipal capital seat.



	Installed capacity	Treated flow	Lost capacity
Inside the municipal seat	157.6	106.2	14.5
Outside the municipal seat	21.7	15.2	4.4

Figure 11. Installed capacity and treated water flow of the Mexican treatment plants, inside and outside each municipal capital seat, in

thousands of liters per second and as a percentage. Own elaboration based on Conagua (2016).

Although there are not many differences between the abandonment of treatment plants between municipal capital and non-municipal capital seats, there is a considerable difference in terms of installed capacity and treated flow, since the plants in the municipal capital seats have six times more capacity than plants out of it do. Figure 12 shows the type of technology in treatment plants, active and inactive, inside and outside the municipal capital seats of the Mexican municipalities.

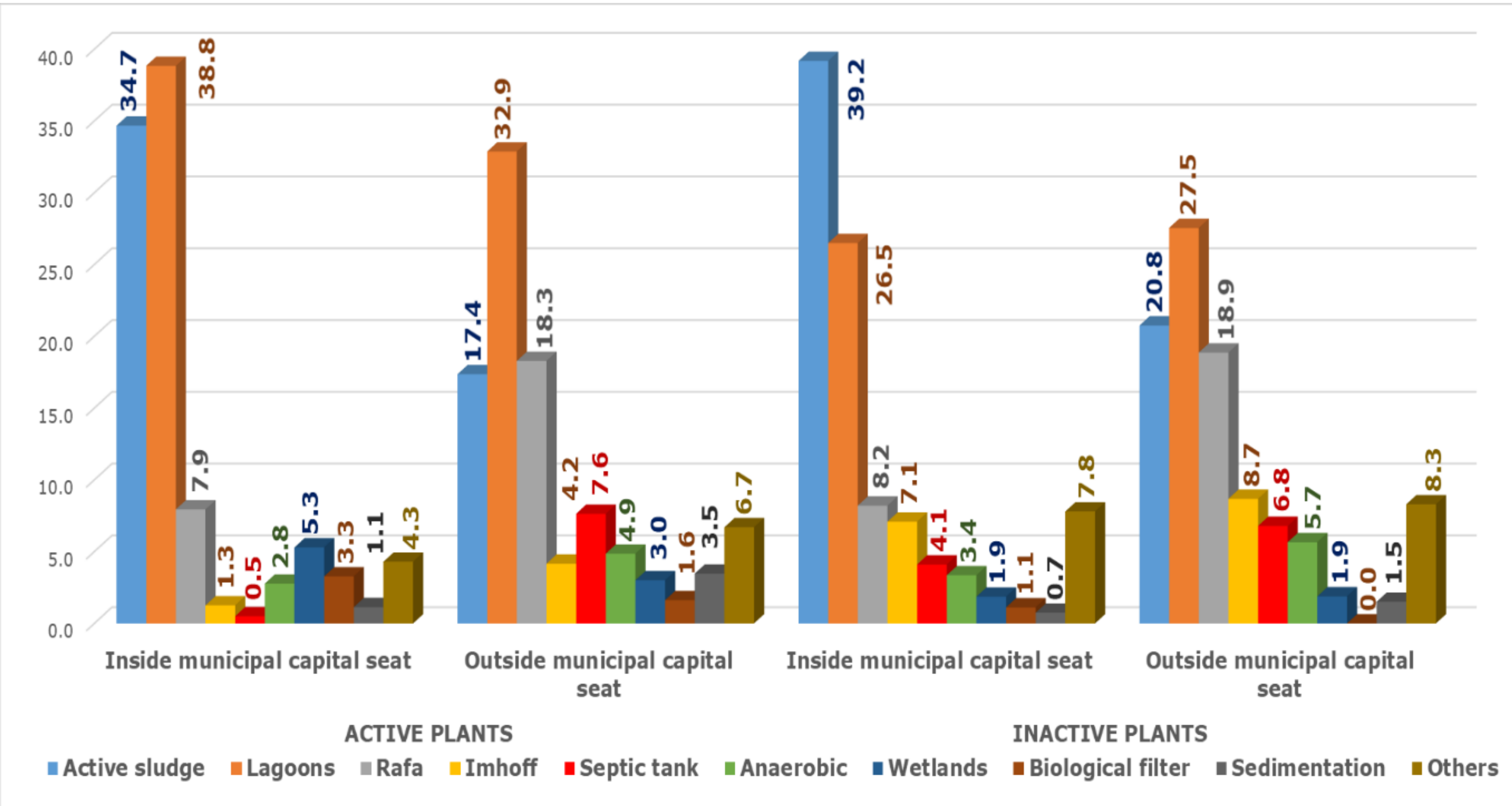


Figure 12. Type of treatment technology in active and inactive plants, inside and outside municipal capital seats. Own elaboration based on Conagua (2016).

In active plants, the most common technologies in municipal capital seats are lagoons and activated sludge (73.5 % both), while outside the municipal capital seat, lagoon technology maintains 32.9 %, and activated sludge reduces its presence to 17.4 %. In inactive plants, practically 4 out of every 10 plants within the municipal capital seat are activated sludge, while 1 in 4 are lagoons. Also, RAFA technology appears

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with a greater presence in localities outside the municipal capital seat, both active and inactive. Table 6 shows a comparison of some basic data on treatment plants by municipality size.

Table 6. Basic data on wastewater treatment plants, by municipality size. Own elaboration based on Conagua (2016).

Basic data	Municipal type (by population size)					
	Rural (0-2 499)	**Urban 1** (2 500-9 999)	**Urban 2** (10 000-49 999)	**Urban 3** (50 000-99 999)	**Urban 4** (100 000-499 999)	**Urban 5** (500 000-more)
Percentage of municipalities concerning the national total	15.1	28.8	39.7	8.1	6.6	1.7
Percentage of population with respect to the national total	0.4	3.5	20.3	12.4	30.6	32.8
Average life in years of active plants with respect to the national average	6.1	1.2	-1.5	2.9	-0.6	0.1
Percentage of municipalities with at least one active plant	15.4	28.3	40.3	64.6	77.9	92.9
The average percentage of active plants reusing some volume of treated water	15.8	9.7	12.5	16.6	22.5	45.5

Average percentage of active plants in municipalities	89.4	78.2	69.4	63.4	70.6	76.6
Average installed capacity per capita in liters per second per thousand inhabitants for municipalities with active plants	4.8	0.5	1.7	0.9	1.4	2.0
Average treated flow per capita in liters per second per thousand inhabitants for municipalities with active plants	2.9	0.3	0.9	0.6	1.0	1.5
Technology with greater presence in active plants and percentage that it represents concerning the total of technologies	Lagoons 62.3	Lagoons 42.8	Lagoons 37.1	Active Sludge 35.2	Active sludge 54.2	Active Sludge 57.1
Technology with the greatest presence in inactive plants and percentage it represents concerning the total of technologies	Septic Tank 33.3	Lagoons 40.1	Lagoons 26.8	Active Sludge 29.2	Active Sludge 33.0	Active Sludge 46.6

The 83.6 % of municipalities in Mexico have less than 50 000 inhabitants and 24.2 % of the population live in these cities. In contrast, 8.3 % of municipalities have more than 100 000 inhabitants and 63.4 %

of the population live there. The active plants have the longest age in municipalities with a population of less than 2 500 inhabitants, despite being the municipalities lacking the most treatment plants. On the contrary, 9 out of 10 municipalities with more than 500 000 inhabitants have at least one active plant. Also, in almost half of the largest municipalities in the country some volume of treated water is reused. It is in municipalities with 10 000 to 100 000 inhabitants where the average percentage of active plants is the lowest. Regarding installed capacity and treated flow per capita, it is in rural municipalities with less than 2 500 inhabitants where the coverage is the highest. Likewise, there is a tendency to use lagoon technologies in municipalities with less than 50 000 inhabitants. While in those with more than 50 000 inhabitants the most common technology is activated sludge.

Discussion

Based on the present statistical diagnosis, the main findings are summarized as five challenges for the wastewater treatment policy in Mexico.

1. **The challenge of abandoning wastewater treatment plants**. The growth rate of inactive plants is higher than the growth of active plants.

From 2000 to 2016, inactive plants increased by 300 % and active plants by 200 %. It should be noted that the highest abandonment of treatment plants has occurred in municipalities with a low and very low degree of marginalization, as shown in Table 7. It is worth remembering the investment bias commented in the materials and methods section, where there is a tendency to build treatment plants in municipalities with the greater population generally with lower degrees of marginalization. It should be noted that municipalities with low marginalization are abandoning treatment plants.

Table 7. Relationship between degree of municipal marginalization and abandonment of treatment plants in Mexico. Own elaboration based on Conapo (2015) and Conagua (2016).

Degree of municipal marginalization (2015)	Number of municipalities with at least one abandoned plant (2016)	Number of abandoned plants (2016)
Very low	171	348
Low	167	309
Medium	107	180
High	73	114
Very high	21	29
Total	**542**	**980**

* Note: Data from Distrito Federal were not included.

Two out of every three abandoned treatment plants (67.2 %) are located in municipalities with low or very low marginalization. This is because the database has an investment bias in municipalities with a larger population, which generally have lower marginalization rates than smaller municipalities. Besides, to solve the abandonment of treatment plants, specialists have recommended the promotion of artificial wetlands and alternative technologies for Mexican rural areas, because conventional technologies require intensive energy use and, therefore, higher maintenance costs (Zurita-Martínez, Castellanos, & Rodríguez, 2011; Castañeda & Flores, 2014; Lahera, 2010).

2. **The challenge of good intentions**. In the last three national administrations, water programs have identified the same policy problems and have proposed very similar policy solutions. The policy vision of the water sector is the one that changes substantially, from preferring market instruments, water as national security, or preference for assistance instruments aimed at the most vulnerable regions. However, problems are still there; the change of discourse does not change the reality of wastewater treatment policy. Table 8 shows the relationship between institutional capacity and the degree of marginalization in the municipalities of Mexico.

Table 8. Relationship between degree of municipal marginalization and municipal institutional capacity in the municipalities of Mexico. Own elaboration is based on De-Dios (2008) and Conapo (2005).

Degree of municipal institutional capacity (2004)	**Degree of municipal marginalization (2005)**					
	Very low	Low	Medium	High	Very high	**Total**
Very low	0	3	12	76	70	**161**
Low	13	30	74	244	126	**487**
Medium	63	164	200	342	79	**848**
High	107	154	152	104	11	**528**
Very high	67	45	19	11	0	**142**
Total	**250**	**396**	**457**	**777**	**286**	**2166**

* Note: few municipalities did not have information and they were omitted.

The 23.8 % of Mexican municipalities have a combination of a high to a very high degree of marginalization and a low to a very low degree of institutional capacity. In other words, 1 out of 4 Mexican municipalities has populations with severe social disadvantages and governments without enough capacity to change this situation. At the other extreme, 17.2 % of Mexican municipalities have a combination of a low and very low degree of marginalization and a high and very high degree of institutional capacity. In other words, less than 2 out of 10 municipalities have a controlled social situation and capacities to improve their situation. Due to the investment bias in large municipalities in the database, it is observed that 2 out of 3 abandoned plants are located in municipalities with low and very low marginalization, most of which have high institutional capacities. Thus, these data show that the current institutional capacities in Mexican municipalities are not enough to break the trend of abandonment of wastewater treatment plants. On the other hand, the good intentions embodied in water plans must take into account the complexity of local spaces, where different actors must negotiate to achieve balances in the distribution of water, especially in arid areas (Scott & Pineda, 2011). Alternatives to traditional water planning seem to be in the approaches based on a deep understanding of the actors' behavior (Bettini, Brown, De-Haan, & Farrelly, 2015).

3. **The challenge of the operation and maintenance of treatment plants**. More than half of the active plants with observations in the Conagua 2016 inventory require expansion or modifications. Also, more than half of the inactive plants were abandoned due to a lack of maintenance and operational problems. In addition to promoting the construction of new plants, the necessary reforms should be promoted so that municipal water and sanitation agencies move towards their professionalization and autonomy allowing them to have the incentives to think in the long term and carry out preventive maintenance in their treatment systems. The current inertia of recruitment, selection, and promotion of the personnel of these agencies, based on political motifs and loyalty to the dominant political group or the labor union will continue to leave out a meritocratic system that promotes technical decisions based on evidence. Table 9 shows the relationship between the degree of marginalization of the municipalities and tax collection effort.

Table 9. Relationship between degree of municipal marginalization and number of active plants in Mexico. Own elaboration based on Conapo (2015) and Conagua (2016).

Degree of municipal marginalization (2015)	Number of municipalities with at least one active plant (2016)	Number of active plants (2016)
Very low	235	984
Low	276	796
Medium	190	389
High	166	255
Very High	58	83
Total	**925**	**2507**

* Note: Data from Distrito Federal were not included.

Of the municipalities with at least one active plant, 55.2 % have a degree of low or very low marginalization, adding up to a total of 1 780 plants representing 71.01 % of the active plants in Mexico. This means that municipalities with the least degree of marginalization concentrate the active wastewater treatment plants, however, at the same time, these municipalities concentrate the highest abandonment of treatment plants. That is, despite being municipalities with low marginalization, they have institutional problems keeping their treatment plants active. As found by Espinoza and Sepúlveda (2015), the audit unit of the Mexican Legislative found that the budget for treatment plants was used inefficiently in the state of Mexico, so the analysis should not only focus on the lack of budget but also on its proper exercise.

4. **The challenge of the responsibility void**. The present statistical diagnosis provides evidence to know that there is no significant difference in the abandonment of treatment plants, inside or outside the municipal capital seat. More than the specific locality, it seems to be the municipality that determines the success of maintaining active plants. As a future research agenda, I will focus to understand what specific elements of the municipal water and sanitation agencies are correlated with active and inactive plants. Fragmentation in the institutional framework of decision-making represents one of the main challenges in sanitation policy in Mexico (Pacheco & Vega, 2008). In this regard, there is a paradigmatic case, the city of Tijuana where there was a policy of construction of small wastewater treatment plants in new housing developments, where the municipal government demanded businessmen that to approve and receive their housing developments, they had to build a treatment plant. To date, in that city, there are dozens of abandoned plants because the municipal government has not received such works, for not meeting minimum requirements. Besides, real estate entrepreneurs argue that minimum technical requirements were never previously set and that they complied with what was agreed (Cáñez, 2017). In this sense, the responsibility gap refers to spaces without clear accountable to carry out a certain task, be it a gap between levels of government, between public and private agents, or any other relationship without specific accountability.

5. **The challenge of wastewater treatment as a priority on state agendas**. The present diagnosis provides evidence of states with all their municipalities with at least one active plant suggesting that the role of state governments could have been decisive for the majority of their treatment plants to remain active. I believe that to the extent that state and municipal governments have professional water agencies, the issue of wastewater treatment will gain prominence on the public, governmental and legislative agendas. The data available for this study do not allow us to conclude about the success of states like Sinaloa and the failure of Jalisco and Mexico. A relevant future research agenda is to know the reasons why states such as Baja Californias and Sinaloa have total coverage of wastewater treatment plants in all their municipalities and find out why Jalisco and Mexico concentrate one of every 4 inactive treatment plants in the whole country. Various studies support the idea that the low effectiveness of sanitation policy in Mexico is due to the excessive dependence of local governments on the federal authority, in addition to local water agencies with little autonomy to operate with more technical and less politicized criteria, prioritizing the interests of political groups in turn and labor unions (Torregrosa & Jiménez, 2009; Godínez, Zaag, & Cauwenbergh, 2018; Jiménez & Torregrosa, 2007; Domínguez, 2010; Cáñez, 2019).

Conclusions

The new Mexican General Water Law will surely incorporate the best intentions and objectives followed by international organizations and developed countries, especially in the systemic approach and the human right to drinking water and sanitation. Also, speeches will appear where they say that wastewater treatment is not isolated, and "end of pipe" solutions should be avoided. However, one of Mexico's problems is that good intentions continue to be incorporated into water policies, without solving the minimum capacity requirements to operate these systems. In other words, the desire to study water sanitation in a systemic, comprehensive way, and with the collaboration of different actors comes from developed countries, which already have more or less solved technical problems of their wastewater treatment plants, because they have professional water agencies where their personnel respond to technical criteria and not to criteria of factions and ideologies. Then, the new General Water Law and the federal policies promoted by the national water agency will continue to be a dead letter, as long as the municipal water and sanitation agencies are not reformed and strengthened in autonomy and professionalization. In addition to this, it is important to strengthen monitoring and sanction capabilities by the water quality regulatory entity and wastewater discharges to water bodies, to build and strengthen the other parts of the system, to aspire to the interconnectedness of these parts in an integrated manner.

Professionalization of municipal water and sanitation agencies are not as simple as integrating these organizations with well-paid people with the right credentials, but it is about ensuring that those people, well paid and with a career perspective, really function as professionals, and for this, clear rules of the game are required, where performance evaluation is the fundamental requirement for these professionals to continue in their positions removing the predominance of particular interests as factions' views where loyalty is more important than merit from the current management style. Since, if that happens, the credentials of professionals will be of no utility.

The limitations of this article are its deep explanations since the statistical evidence only was enough to show a national, state, and municipal diagnosis of some basic indicators of wastewater treatment plants in Mexico. A future research agenda is proposed to know the essential factors through which one can move from a tradition of water management based on loyalty to political groups in turn towards a meritocratic tradition where technical and scientific knowledge is the center of gravity of local water and sanitation agencies in Mexico.

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