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Searching for a sustainable model to manage and treat wastewater in Jalisco, Mexico

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Abstract

The goal of this paper was to determine the general status of wastewater treatment facilities in Jalisco State, the main issues faced by the municipalities of the State to keep them in operation and the issues that need to be solved for the future to achieve a sustainable sanitation service. To achieve this goal, several official sources were reviewed and analyzed, interviews with decision makers in several municipalities where carried out and technical literature on sustainable technologies for sewage treatment systems was reviewed. According to official records, in 2013, Mexico achieved a sanitation coverage of 47.5% and in Jalisco State 50.5%. Nevertheless, 43.5% of the installed wastewater treatment infrastructure in the state does not operate or was abandoned due mainly to high energy, maintenance and operating costs. Most of the treatment plants in Mexico have technologies based on centralized systems using conventional processes such as activated sludge or aerated lagoons, requiring high energy and specialized personnel. This situation led us to consider the possibility of a different way to manage the sanitation plans for the state of Jalisco and for Mexico in general, as a developing country. At the global level, emerging technologies based on low carbon footprint technologies are offering an alternative to manage sewage treatment in a sustainable way.

Keywords: Waste Water Treatment, Decentralized Sanitation Systems, Natural Treatment Systems, Water Reuse, Sustainable Wastewater Management

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1. Introduction

In Mexico, water has been recognized as a strategic issue involving national security, and has become a central element to the current environmental and economic policies, as well as a key factor of social development (de la Peña et al., 2013). Surface water must be kept free from untreated wastewater discharges, to avoid affecting the natural capacities of receiving waters to assimilate and dilute pollutants and to ensure that all water resources provide flow to meet the needs of the population and to contribute to economic growth and quality of life (de la Peña et al., 2013), as well as to provide for ecological services.

According to the national inventory of municipal wastewater treatment plants (WWTP) of the National Water Commission (CONAGUA, 2014a), at the end of 2014, there were 2,337 registered WWTP facilities in operation, with an installed capacity of 151,883.43 l/s and a treated flow of 111,253.51 l/s. This capacity resulted in a nationwide average treatment of municipal wastewater of 52.7%. This figure is below the national average achieved by other countries in Latin America. For example, Argentina and Chile have achieved a coverage of over 80% (BID, 2015). In the state of Jalisco, the treatment of municipal sewage was 50.5% in 2013, a similar figure to the national average (CONAGUA, 2014b). However, this level of treatment is still below some other states in Mexico such as Tamaulipas, Nuevo Leon and Chihuahua where they have achieved a coverage close to or greater than 80% (CONAGUA, 2014b).

To determine the status of municipal WWTPs in the state of Jalisco and the problems they face, the official information at federal and state level was analyzed, newspaper reports were reviewed and field interviews were carried out in several municipalities. The results from these sources were all similar. Several of the treatment plants installed during previous municipal administrations are now out of operation despite being reported in official statistics as still in operation (CONAGUA, 2014a). This paper explains the situation that has led to several municipalities in the state of Jalisco stopping operations and even abandoning these wastewater facilities. It also discusses some of the consequences that these decisions have had to the environmental heritage of the state, as well as some potential solutions that can contribute to solving the problem.

2. Problem statement

2.1. Public health and water-borne diseases

The lack of basic sanitation infrastructure and inadequate wastewater management in both rural and urban areas are determining factors in the incidence of water-borne diseases, among which the most common are intestinal infectious diseases in developing countries (de Abreu-Azevedo, 2005; O'Ryan et al., 2005). More than one billion diarrhea episodes occur every year among children younger than five years old in socioeconomically developing countries causing 2 to 2.5 million deaths per year (O'Ryan et al., 2005).

In Mexico, intestinal infectious diseases are among the top 20 causes of death; diarrheal disease is the fourth leading cause of infant mortality and ranks second among the leading causes of illness in the general population. In 2005, there was a mean of 4.9 cases for each 100,000 inhabitants and 17.4 in the case of children under 5 years old (Riojas-Rodriguez et al., 2010).

In Jalisco State, the prevalence of acute diarrheal disease in children under five years old was 15.4% in 2006 and 10.1% in 2012 (INSP, 2013), and the infant mortality rate for each 100,000 inhabitants under five years old recorded by acute diarrheal disease was 16.6 in 2000 and 10.4 in 2005 (Secretaría de Salud, 2008).

2.2. Situation of municipal sanitation infrastructure in Mexico

Most of the technologies implemented in the country are based on centralized wastewater treatment systems, where complex technologies are used in the treatment process requiring specialized personnel and high maintenance and operating costs (Lahera-Ramón, 2010). The provision of low-cost, reliable and affordable wastewater treatment services in urban, peri-urban and rural areas is a growing challenge in many parts of the world, particularly in developing countries (Massoud et al., 2009). The problems today for most municipalities in Mexico are the relatively high costs of energy, operation and maintenance (EO&M) of a centralized system and the required investment in sewerage networks compared to the municipal revenues generated in the regions where these services are required (Noyola et al., 2013).

Mexico, as in many other developing countries, has some difficulty in securing financing required for the construction of centralized wastewater treatment systems, as well as acquiring the skills to manage and maintain them in operation (Lahera-Ramón, 2010). Once the facilities are in operation, the municipalities face the problem that available resources are insufficient to keep them in operation, because the EM&O costs increase annually beyond what was originally estimated in the budget (Noyola et al., 2013). Given this fiscal reality, most of the municipalities that have built these facilities, after some years or even months, may decide to cancel the funds for operation, because of the reasons previously discussed and additionally because these activities do not give prominence to the political party in power, resulting in the facility being abandoned (Lahera-Ramón, 2010). After the municipal managers make such a decision, the impacts on the environment, public health and in the local and regional economy, may result in pollution of river ecosystems and a decrease of the quality of life of the local population and in the populations living downstream.

3. Materials and methods

For the development of this paper, official reports related to the state of sanitation in Mexico and particularly in Jalisco State were reviewed. The information of the National Water Commission in Mexico was arranged and analyzed in an Excel program to list the wastewater treatment technologies used at municipal level and also to estimate the total installed capacity for sanitation in the country. The same analysis was carried out with the official information of the State Water Commission for Jalisco State. In this case it was possible to find the status of each installed wastewater treatment plant in the state of Jalisco. Additionally, through the information published by the federal and state health secretariats, we found the public health problems associated to water-borne diseases. Municipal mayors and wastewater managers of Jalisco State were interviewed to determine the issues that led some of the municipalities to stop the operation of the WWTPs or to abandon them. Local and regional newspaper reports were reviewed and field visits were conducted in the municipalities that face problems in maintaining the operation of their WWTP. Regulations published in the official journal of the federation was analyzed to determine all the possibilities that the National Water Commission in Mexico offers to the municipalities to improve the sanitation conditions. Specialized literature in the field of decentralized wastewater treatment systems was reviewed, to determine the advantages and disadvantages involved in the strategy based on centralized systems to provide safe sanitation services to municipalities with insufficient resources. Finally, we explored the technologies based on natural systems as an option for developing countries to reduce the expenditures in energy, maintenance and operation of municipal WWTP.

4. Results

In 2010, there were 2456 municipalities in Mexico, but only 692 had potable water, sewage and wastewater treatment services representing scarcely 28.2% of the total (INEGI, 2013). Regarding wastewater treatment for the municipalities, in 2012 the sanitation coverage in the country was 47.5% (de la Peña et al., 2013). To cover the sanitation needs in the country, a variety of technologies of different levels were used. Table 1 shows the most commonly used processes and the number of plants reported operating in 2013 (CONAGUA, 2014a). The National Water Commission (CONAGUA, 2014a) highlights that the most widely used technologies for the treatment of wastewater are the activated sludge system which treats 59.50% of the total wastewater, followed by stabilization ponds at 12.53%, aerated lagoons at 6.51% and sprinklers, biofilters or percolators at 4.81%. In regards to the WWTPs shown in Table 1, the highest numbers use stabilization ponds and advanced primary systems (Shao et al., 1996; Jimenez et al., 2000) followed by anaerobic systems such as septic tanks and Upflow Anaerobic Sludge Blanket (UASB). The rest use a variety of technologies. In relation to the state of the treatment plants, the report shows that some plants are under construction, others require an expansion project, and in some cases the existing facility has to be deregistered and a new plan developed for the WWTP.

In the state of Jalisco, there are 149 operating WWTPs, having an installed sanitation capacity of 15,391.9 l/s, treating a flow of 12,362.1 l/s (CONAGUA, 2014a). The National Water Commission (CONAGUA, 2014b), however, mentions that sanitation coverage in the state was 50.5% in 2013 and that in the same year, the number of plants in operation was 154, the installed treatment operation capacity was 15,435 l/s and the treated flow was 7,797 l/s. On the other hand, the State Water Commission in Jalisco reports that there are 273 treatment plants of which 50 are out of operation, 22 have been abandoned and 63 are in the process of being deregistered (see Table 2) (CEA, 2015). The operating plants have an installed capacity of 15,369 l/s which is close to the data reported by the CONAGUA (2014a). Additionally, the CEA (2015) mentions that, of all plants installed in the state, only 50.6% are in operation; nevertheless, these plants treat 90.4% of the sewage in the State (see Table 2).

Table 1. Treatment processes and operating capacity of the municipal WWTP installed in Mexico (Source: CONAGUA, 2014a)

Wastewater Treatment Technologies	WWTP in use	%	Q_{op} (l/s)	%
Aerobic	9	0.39	48.9	0.04
Anaerobic	71	3.04	533.0	0.48
Biological	24	1.03	447.9	0.40
Biological disks or Biodiscs	18	0.77	703.0	0.63
Dual	17	0.73	5,779.5	5.19
Sprinklers or biofilters or Percolators	40	1.71	5,356.5	4.81
Septic tank	101	4.32	126.0	0.11
Septic tank + biofilter	24	1.03	20.3	0.02
Septic tank + Wetlands	93	3.98	135.1	0.12
Constructed wetlands	71	3.04	517.9	0.47
Aerated lagoons	32	1.37	7,239.6	6.51
Stabilization Ponds	718	30.72	13,941.6	12.53
Activated sludge	709	30.34	66,199.2	59.50
Advanced primary	10	0.43	4,300.0	3.87
Primary or Sedimentation	21	0.90	1,600.4	1.44
UASB + Biological filter	40	1.71	323.8	0.29
UASB	137	5.86	1,464.1	1.32
UASB + Constructed wetlands	27	1.16	226.3	0.20
Enzymatic reactor	56	2.40	112.7	0.10
Sedimentation + Wetlands	18	0.77	28.2	0.03
Imhoff tank	50	2.14	343.1	0.31
Imhoff tank + biofilter	18	0.77	129.6	0.12
Imhoff tank + Wetlands	2	0.09	7.0	0.01
Tertiary	6	0.26	203.0	0.18
Oxidation Ditches	17	0.73	1,431.5	1.29
Others	8	0.34	35.5	0.03
Total	**2,337**	**100.00**	**111,253.7**	**100.00**

Table 3 shows the technology used by the WWTPs in Jalisco State. The technologies treating most of the waste water discharges are based mainly on four technology types, namely: conventional activated sludge (72.4%), activated sludge with N and P removal (14.6%), extended aeration activated sludge (7.9%) and the trickling filter or aerobic biofilter systems (1.46%). In regards to the number of WWTPs most of the installed facilities are conventional activated sludge (31.7), extended aeration activated sludge (30.9%), and up flow anaerobic filter (19.4%). Other treatment systems based on passive methods of treatment such as oxidation ponds, facultative ponds, artificial wetlands or the combination of septic tank wetlands have minimal contribution to the volume of treated water.

Table 2. Status of wastewater treatment plants in the state of Jalisco (Source: CEA, 2015)

State of the WWTP	Number	%	Installed capacity (l/s)	%
In operation	138	50.6	15,369	90.4
Non-operating	50	18.3	969	5.7
Abandoned	22	8.0	179	1.1
Asset retirements	63	23.1	479	2.8
Total	**273**	**100.0**	**16,989**	**100.0**

Table 3. Technologies used in municipal wastewater treatment systems in Jalisco State (Source: CEA, 2015)

Wastewater Treatment Technologies	WWTP in use	%	Q_{op} (l/s)	%
Biodiscs	2	1.44	25	0.16
Upflow anaerobic filter	27	19.42	88	0.57
Trickling filters (biofilters)	2	1.44	225	1.46
Dissolved air flotation	1	0.72	150	0.98
Artificial wetlands	3	2.16	13	0.08
Oxidation pond	6	4.32	53	0.34
Aerated lagoons	2	1.44	26	0.17
Facultative lagoons	1	0.72	4	0.03
Extended aeration activated sludge	43	30.94	1,216	7.91
Activated sludge with N and P removal	1	0.72	2,250	14.64
Conventional activated sludge	44	31.65	11,133	72.44
Sequential Biological Reactor (SBR)	1	0.72	60	0.39
Sprinkler system with dual filters	1	0.72	30	0.20
Primary system	1	0.72	3	0.02
Imhoff tank	1	0.72	40	0.26
Imhoff tank with trickling filters	2	1.44	50	0.33
Septic tank with wetlands	1	0.72	3	0.02
Total	**139**	**100.00**	**15,369**	**100.00**

After visiting and interviewing representatives from different municipalities in Jalisco State, such as Cihuatlán, Ciudad Guzman, Encarnación de Diaz, Teocaltiche, Tapalpa, among others, we found similar problems in each of them, which are often cited by the media (del Castillo, 2014; ECOTICIAS, 2015; Carapia, 2016; Ortíz, 2016), namely- plants with expensive technologies; plants that are centralized to cover mainly urban areas; plants that have high energy consumption; a lack of specialists to operate the plants; and a lack of municipal resources for their operation. Today, some costly facilities are in a state of neglect, out of operation, without meeting the official standards, or are operating at a lower efficiency compared with the original design. Even in some of the municipalities where the plants were put into operation in recent years, they are now out of operation, because the municipality still has commitments to pay the debt incurred for their construction by the previous administrations (see Figure 1, Figure 2 and Figure 3). Because of these problems, some experts said that the national percentage of plants in operation is less than 50.5%, as declared in official reports, and that the real percentage of sewage treated in a WWTP could be less than 20% (Noyola et al., 2013).

Figure 1. Abandoned wastewater treatment plant in the municipality of Ciuhuatlán, Jalisco. The wastewaters are still collected in an extemporary pond flooding the WWTP.

Figure 2. Plant out of operation in the municipality of Teocaltiche, Jalisco.

Figure 3. Plant out of operation in the municipality of Encarnación de Díaz, Jalisco.

5. Discussion

The problems facing the state of Jalisco in regard to management of water resources and in particular the treatment of wastewater have different causes, some of which were identified in this study and are mentioned below:

a) The centralization of municipal wastewater treatment service involves the commitment to invest, build and operate a complex facility requiring regular payment of high expenditures for EM&O.

b) In most of the cases, the treated water does not have a reuse plan, resulting in the municipality losing the opportunity to have a revenue from the concession to farmers to use treated wastewaters in irrigated crops or another productive uses.

c) In general, waste water and rain water are mixed in the same pipeline, which means that many WWTPs are built larger than the size needed if they were just treating waste water. There is no infrastructure to infiltrate the rain water to recharge the local aquifers.

d) The lack of long term political continuity in the municipalities to get financial resources with the state and federal agencies that manage the water resources affects plans to expand the sanitation coverage and the renewal of existing sanitation infrastructure.

e) Poor communication between municipal, state and federal agencies means that there is a lack of integrated management of wastewater in each municipality and in the entire State.

f) The absence of a vision of integrated water management based on the hydrological resources of the basins and sub-basins.

g) The absence of effective government programs to involve academia in research, technology development and innovation to strength capacities in the field of integrated watershed management and management of municipal waste water effluents.

h) Lack of expertise and research programs to accelerate the research and development activities to offer alternative treatment technologies that takes into account low energy consumption and low carbon footprint.

i) The loss of continuity in municipal dealings with state and federal entities which manage water resources, interrupts the plans to expand the sanitation coverage and the strengthening of the existing infrastructure.

j) The absence of government programs such as tax incentives for the private sector which invest in sanitation infrastructure for private developments, to reduce the organic load in municipal plants and promote a culture of care and reuse of treated water at all levels of society.

k) The poor linkage of the programs and projects established by agencies such as the National Water Commission (Federal level), the Ministry of Environment and Territorial Development (State level), the State Water Commission (State level) and the Inter-municipal water and sewerage system, among others, has led to a poor management of the water resources of the state.

5.1. Decentralization of wastewater treatment services

The decentralized approach to wastewater treatment using a combination of in-situ systems in groups of small communities is gaining increasing attention (Wilderer and Schreff, 2000; Massoud et al., 2009; Avendaño-Leadem, 2016). This new approach has, among other advantages, the local reuse of wastewater for various purposes (Wilderer and Schreff, 2000). For example, in rural areas it is possible to reuse treated water in agriculture, generating aquaculture, aquaponics and hydroponics, and in urban and peri-urban areas, water for irrigation of landscaping, car washing, and cleaning floors; and depending on the level of treatment achieved, it could be reused in domestic toilets.

5.2. Tax incentives for private decentralized projects

Today in Mexico, the private sector including housing developers and non-contaminant generating industry, have no tax incentive for them to consider the treatment and local reuse of sanitary wastewater, because it is easier and does not represent any cost to them, to use the installed municipal sewage or to build a septic pit to solve their wastewater problem. In both cases an important opportunity to increase the sustainability of water resources by reducing the water extractions from surface and ground water sources is being lost. If the municipality were to offer an incentive for new developments and to non-contaminant industry to build a decentralized wastewater treatment system, it would give the opportunity to reuse the treated water locally, thus reducing substantially the demand for water for irrigation of green areas, street cleaning, car washing, industrial cooling systems, washing of equipment in production processes, water for construction works etc. that do not require water of drinking level quality (Gobierno de Jalisco, 2007).

5.3. Alternative methods for wastewater treatment with low carbon footprint technologies

During the last decade, new advanced natural treatment systems have been developed, such as the waste stabilization ponds (WSP), wastewater storage and treatment reservoirs (WSTR), constructed wetlands (CW), upflow anaerobic sludge blanket reactors (UASBs), biofilters, aerated lagoons, and oxidation ditches. These are technologies which are more appropriate for developing countries (Mara, 2003). These systems offer good opportunities for the treatment of a variety of industrial wastewaters having low to medium organic loading (500-1000 mg BOD/liter) and particularly for treating wastewater of low organic load, such as household and municipal wastewaters (Yu et al., 1997; Mara, 2003; Abdel-Halim et al., 2009). These kinds of systems have lower cost in EM&O, produce a minimal amount of biological solid waste and allow the quality standards in the discharges to be met (Cakira and Stenstrom, 2005). A good design can also generate environmentally friendly spaces or even energy production (Gopal, 1999; Kivaisi 2001) (see Figure 4, and Figure 5).

Despite the fact that treatment technologies based on passive methods are low in EM&O costs compared with the aerobic process, one must ensure that the acquired technology is sufficiently robust. Unfortunately, some WWTPs installed in small and medium size urban areas in the state of Jalisco, based on low EM&O technologies, operate inefficiently due to lack of trained personnel, or failures in the design and construction (see Figure 6).

5.4. Availability of governmental resources for municipal projects

In recent years, federal public resources have become available in the CONAGUA programs to support municipal water and wastewater treatment infrastructure (PROAGUA and PROSAN programs) (DOF, 2015).

The PROSAN program aims to support financially and technically, water managers of the municipalities and the states, to allow them to improve or rehabilitate the installed capacity for the treatment of the municipal wastewater to meet the corresponding official Mexican standards (DOF, 2015).

Figure 4. Treatment system located in Zapopan, Jalisco, based on a septic tank, anaerobic filter and artificial wetland which operates according to local water quality standards (Courtesy of CIATEJ).

In addition, the specific objective of this program is to increase and strengthen the treatment of municipal wastewater of communities in the states (DOF, 2015). The specific requirements for the water managers of the municipalities to have access to these resources are:

- To submit the investment proposal for the treatment of wastewater, based on the priority actions of the state planning for potable water, sewerage and sanitation which previously had to be validated by the National Water Commission.
- To have the legal possession of the land on which the works will take place and the respective permits for execution.
- To submit the letter of commitment of the operating agency that will assume the EM&O costs.
- To provide physical and financial progress in the case of works initiated and supported in previous years that require continuity, according to the financial support granted.

Figure 5. Wastewater treatment system based on anaerobic processes and artificial wetlands in Huaxin, Shanghai, China (Courtesy of Janisch & Schultz).

Figure 6. Treatment system with operational deficiencies installed in a rural community in the municipality of Teocaltiche, Jalisco. The system is based on a septic tank and artificial wetlands.

CONAGUA has selection criteria for the projects presented by each municipality, and the final decision will be subject to the yearly budget availability (DOF, 2015). These criteria are listed below:

- Work started in the previous year requiring continuity, proposals and determined by the CONAGUA as priority, the rehabilitations of PTAR's and those whose effluent will be reused.
- Localities that have more than 80% sewerage coverage.
- Works which consider reuse or exchange of wastewater.
- Locations of the 11 states (Campeche, Chiapas, Guerrero, Hidalgo, Michoacán, Oaxaca, Puebla, San Luis Potosi, Tabasco, Veracruz and Yucatan), which suffer a high to very high poverty level.
- Improved treatment process of a system of existing wastewater and operation to achieve a better quality to meet the official standards.
- Increase the treatment capacity in an existing and operating wastewater treatment system.
- Those WWTPs with the purpose of improving or developing wastewater management to support development of tourism in the municipalities, priority tourist destinations or those considered into the Magical Town Program (A Magical Town is a locality that has symbolic attributes, legends, history, transcendent facts, everyday life, emanating in each of its socio-cultural characteristics, for which they represent a great opportunity to promote tourist activities).
- Flow rate to treat greater than 200 l/s.
- Works that are part of a system of inter-municipal wastewater treatment where localities have more than 60% sewerage coverage.

The federal involvement in new construction or expansion or rehabilitation of infrastructure is only 60%. In the case of the rehabilitation of infrastructure not operating and start-up financing thereof, it is no more than 70%. Municipalities should have complementary resources to implement this type of work (DOF, 2015).

5.5. Limitation in the management of water resources

Although in Mexico there are federal resources that allow municipalities to expand potable water and sanitation coverage, there are limiting factors for which the municipalities are unable to access these resources, some of which are listed below:

a) Municipal administrations change every three years. With each change, the incoming administration has to restart the learning on the management of water related issues (drinking water, sewerage and sanitation).
b) Lack of awareness of state and federal programs to expand coverage of water and sanitation in the municipalities as well as special programs to provide these services to marginalized communities.
c) In most cases the new personnel responsible for providing potable water, sewerage and sanitation do not have the technical skills and experience to properly manage water resources.
d) The market dominance of conventional technologies and lack of alternative technologies for wastewater treatment results in municipalities investing their resources in the development of an infrastructure that can hardly be kept operating.

5.6. Absence of government programs to induce a culture of reuse of treated water

Moreover, due to the global trend in the concentration of population in urban and peri-urban areas, every year medium and large cities have to create infrastructure for wastewater treatment and reuse. They normally do not consider the WWTP since, in the planning stage in many of these developments, WWTP is allowed provisionally and especially in peri-urban areas. Lower cost treatment systems such as septic tanks, are used; eventually they pollute the sources of drinking water.

6. Conclusions

Technologies based on conventional wastewater treatment systems have resolved the problem of sanitation in a few municipalities, particularly in those having a process to manage public resources to keep these plants in operation. Most municipalities in the state of Jalisco have great difficulty maintaining the operation of wastewater treatment facilities, mainly due to high EM&O costs, the continual change in municipal administrations and the high turnover in positions responsible for the management of drinking water and sanitation services. Given this situation, it is worth examining new strategies to improve the wastewater sanitation services in the municipalities. Some of these strategies are suggested below:

a) Establish, as a legal requirement, the separation of wastewater from rainwater for new residential, commercial and industrial developments.
b) Create a program to generate decentralized wastewater sanitation infrastructure in municipalities.
c) Create tax incentives to promote new housing developments that consider management of sanitation and reuse of treated water.
d) Establish tax incentives for companies that promote infrastructure development for sustainable management of storm water, for wastewater treatment and for waste water reuse.
e) Promote government programs having technologies with a low carbon footprint to promote technologies with the lowest cost per cubic meter of treated water to meet the quality standards required by the regulations.
f) Create a certification system for the managers and operators of sanitation systems to establish the basis for generating a professional career service between those responsible in managing and operating water resources in municipalities.
g) Generate binding mechanisms that promote the integration of municipal, state and federal policies on water and sanitation.

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