Treatment and use of wastewater in Mexicali, Baja California, Mexico

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Abstract

This study had, as its objective, the assessment of the current state of the treatment and use of domestic wastewater in the municipality of Mexicali, in the state of Baja California in Mexico. A diagnosis of the treatment process was undertaken and the quality of the effluent produced in 2010 by each wastewater treatment plant (WTP) was assessed. A comparison was then made with the limits established in the Mexican regulations for use of treated wastewater. Finally, an action plan was developed to improve the use of this resource. The results of the study show that none of the WTPs complied with the limits of the official Standard NOM-003-SEMARNAT-1997 for suspended solids (TSS) and biochemical oxygen demand (BDO_5). The WTP of greatest interest is Arenitas, because its effluent is being used for agricultural irrigation. Concentrations of fecal coliforms in the effluent of this WTP ranged between 340 and 86,740 MPN/100 ml over a six month period, while the limit is 240 MPN/100 ml. The concentration of total suspended solids (TSS) was detected at between 32 and 116 mg/l, while the limit is 30 mg/l. BDO_5 was detected at between 28 and 55 mg/l, while the limit is 30 mg/l. Only in the month of April did these measurements fall below the limit of 15 mg/l for grease and oil.
Keywords: water pollution, use of treated wastewater, agricultural irrigation.

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1 Introduction

Water is a vital resource for human activities, for economic development and public health. However, rapid population growth (especially in developing countries), the pollution of surface water bodies and groundwater, the uneven distribution of water resources and severe dry periods have forced the search for new water supply sources. Treated wastewater is, therefore, now regarded as an additional source to satisfy demand for this vital resource (Silva *et al.* [1]). Currently, the population in Mexico exceeds 112 million inhabitants, with an annual population growth rate of 1.8% (INEGI [2]). While Figure 1 shows a decreasing trend in the availability of water per capita per year from 1950 to 2010, an availability projection for the year 2030 was estimated at 3,783 cubic meters per capita per year.

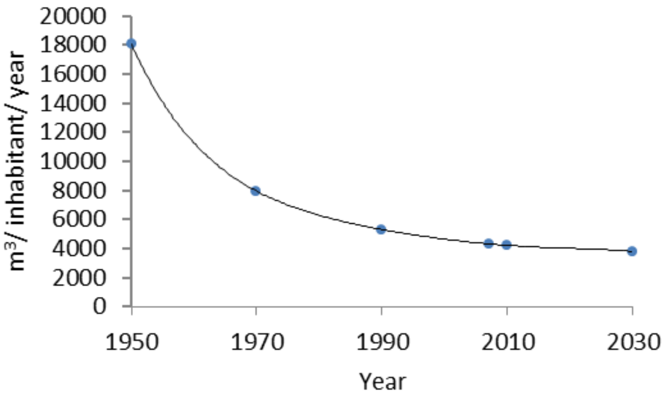

Figure 1: Natural average availability of water in Mexico.

Mexico has an estimated water resources amount to approximately 410,000 million cubic meters of water. Most of the water consumed (79.5%) is used in agriculture irrigation activities. The remainder used in the industrial and domestic sectors (CONAGUA [3]). It is estimated that by the year 2025, the global availability of freshwater per capita will descend to 5,100 m^3 per person per year (CONAGUA [4]). This trend indicates that Mexico will soon be facing serious problems with water availability.

1.1 Availability of water resources in Mexicali and the Mexicali Valley

The city of Mexicali in Baja California is located in the northwest of Mexico. Its climate is classified as arid and semi-arid, with 203.7 mm rainfall recorded in the state per year in the period between the years 1941–2009 (CONAGUA [3]). The low levels of rainfall in the state are especially serious for the recharge of aquifers, whose flow depends on rainfall infiltration (Colima [5]). Due to significant industrial and agricultural development in Mexicali, water consumption is high and supplies are limited, with most of this resource destined for agricultural activity. The city of Mexicali is supplied by 1,850 million cubic meters of water from the Colorado River, which flows from its source as snowmelt at an altitude of 14,275 meters in the Rocky Mountains in the North of the state of Colorado in the United States of America. The river runs along approximately 2,735 kilometers, and supplies water to about 30 million people, irrigating more than 1.5 million hectares of agricultural land in the states of Wyoming, Colorado, Utah, New Mexico, Arizona, Nevada, California, finally crossing the Mexican border into the state of Baja California, and emptying into the Sea of Cortez (as shown in Figure 2). The second source of water supply for the agricultural region of Mexicali comes from the extraction of an aquifer with a volume of 700,000 cubic meters, which is pumped from 725 deep wells located in the Mexicali Valley (Acosta [6]). The Colorado River enables the irrigation of approximately 200,000 hectares in the Valley's agricultural zone. It is expected that water availability will be reduced in the coming years (INEGI [2]).

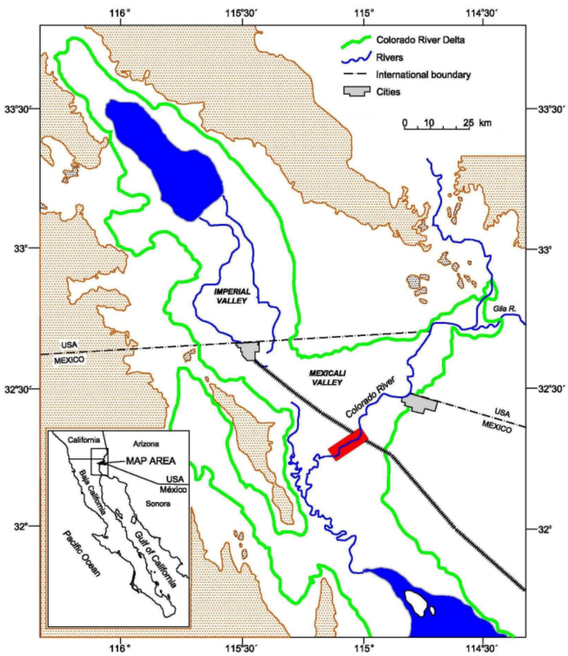

Figure 2: Pathway of the Colorado River in the study area.

1.2 Experiences in the use of treated wastewater

Experiments with use of treated wastewater have been conducted in different parts of the world, with Israel at the forefront of this research. It is estimated that a tenth or more of the entire world population currently consumes foods that are produced with wastewater, although they have not always been produced safely (Strauss [7]). In 2008, the Orange County, California in the United States launched a system for the recycling of wastewater for human consumption, which is capable of producing some 265 million liters a day. According to its managers, the treated water surpasses the State and Federal minimum limits (Fernández [8]), although among the general population there is resistance to use recycled water for human consumption. In Ibague, Colombia, there is a proposal for the use of the wastewater taken from the facultative lagoons used in the irrigation systems for rice, sorghum, pastures, soybeans, and cotton. The proposed volume to be treated was 1438.66 l/s, with health risks defined as the main impact of the indirect and unsure use of diluted wastewater (Cepis [9]).

2 Regulations for the use of treated wastewater in Mexico

The term water care relates to all actions that help to protect and reuse water responsibly, with the use of treated wastewater currently being one of the main strategies for this purpose (Rivera *et al.* [10]). For this reason, it is important to comply with the norms and standards established for the use of treated water. Regulations in Mexico permit the unrestricted use of wastewater for the planting, growing and harvesting of agricultural products limited to forages and grains, while its use is restricted solely to the irrigation of vegetables and legumes. The official Mexican standard NOM-003-SEMARNAT-1997 (SEMARNAT [11]) sets permissible maximum contaminant levels for the treated wastewater used in public services, in order to protect both the environment and public health. This standard establishes that the concentrations of basic pollutants, heavy metals and cyanides shall not exceed the value indicated as the maximum allowable limit. The permissible range of pH is from 5 to 10. The maximum permissible limits of the main pollutants in treated wastewater are illustrated in Table 1. Floating matter must be absent, according to the testing method established in the Mexican norm NMX-AA-006.

Table 1: Maximum permissible limits of main pollutants.

Purpose	Monthly average				
	Fecal coliforms MPN/100 ml	Helminth eggs (h/l)	Grease and oil mg/l	BDO_5 mg/l	TSS mg/l
Public services with direct contact with treated wastewater	240	≤ 1	15	20	20
Public services with indirect or occasional contact with treated wastewater	1,000	≤ 5	15	30	30

3 Method

A diagnosis of the treatment process used on the domestic wastewater produced by the city of Mexicali and the Mexicali Valley was undertaken in this study. An inventory of each WTP was developed, which included the volume of treated wastewater and the current or potential applications if treated wastewater is not used or partially used. Laboratory analysis, were performed for fecal coliforms, biochemical oxygen demand (BDO_5), suspended solids, grease and oil (helminth eggs were not analyzed). These analysis were conducted by the Comisión Estatal de Servicios Públicos de Mexicali (CESPM), which is responsible for water management in the municipality. The results of laboratory analysis conducted on the effluent from each plant were compared to the maximum permissible limits established by the Mexican Standard NOM-003-SEMARNAT-1997. The critical aspects in the treatment of wastewater and the use of effluents were identified, and, on this basis, a strategic plan to improve the use of treated wastewater was developed.

4 Results

4.1 Use of treated wastewater in Mexicali

The results show that in 2010, a total of 52,944,529 cubic meters of wastewater was treated. Table 2 shows the distribution of the uses of this water.

Table 2: Distribution of uses of treated wastewater in Mexicali.

Green areas	Industry	Agriculture	Ecological uses
1.1%	19.8%	14.0%	37.3%

A purple pipeline, covering a total area of approximately 22.3 kilometers, currently delivers treated wastewater to the urban area.

4.2 Inventory of wastewater treatment plants currently in operation

Mexicali has seven domestic wastewater treatment plants. The WTPs Zaragoza and Arenitas, are important because they treat the largest volume of wastewater. This is due their close proximity to the urban area and, primarily, because their effluent is being used in the industrial sector, for ecological applications, for the irrigation of green areas, to supply the purple pipeline for fire hydrants, and to recharge rivers for both agricultural and recreational activity. Table 3 presents the inventory of the WTPs, detailing the volume of water treated, the various uses given to each fraction of that volume, and the potential uses to which it can be applied.

Table 3: Inventory of wastewater treatment plants.

WTP	Volume Treated in 2010 (m^3)	Current use	Potential use
Zaragoza	25 448 039	Cooling water for electric generation plants. Irrigation in Module 20. Recharge of Salton Sea	Extension of the irrigation area of Irrigation Module 20
Las Arenitas	23 459 783	Agricultural irrigation and ecological use in the Hardy River	Aquifer recharge.
Estación Coahuila	280 240	Not currently used	Agricultural irrigation. Irrigation of urban green areas.
Algodones	227 501	Not currently used	Agricultural irrigation. Irrigation of urban green areas. Aquifer recharge.
Ciudad Morelos	475 424	Not currently used	Agricultural irrigation. Irrigation of urban green areas.
Ciudad Victoria	826 410	Not currently used	Agricultural irrigation. Irrigation of urban green areas.
San Felipe	2 227 132	Irrigation of agricultural and green areas. Golf course irrigation. Aquifer recharge.	Irrigation of agricultural and green areas. Golf course irrigation. Aquifer recharge.

4.3 Laboratory results and comparison with official standards

The results of the physical, chemical and bacteriological analyses of each WTP effluent were compared with the maximum permissible limits established by NOM-003-SEMARNAT-1997. The review of laboratory analysis results revealed that the effluent from the seven plants does not comply with the permissible limits for direct contact. None of the WTPs complies with the limit of the concentration of suspended solids and biochemical oxygen demand. In addition to the above parameters, in some months the WTPs shown in Table 4 do not meet the limit for fecal coliforms.

The WTP of greatest interest in Mexicali is Arenitas, because it is one of the plants which treats the highest volume of water, with its effluent being used to irrigate agricultural crops and for ecological use in the Hardy River. This river is used for intensive recreational activity involving direct contact with water.

Figure 3 shows that, throughout the year, the BDO_5 limit for direct contact (DCL) was exceeded, while the limit for indirect contact (ICL) was only complied with for two months in the year. It was also noted that the concentration of suspended solids exceeded both the 20 and 30 ml/l limits

Table 4: Fecal coliforms in WTPs not meeting the standard in 2010.

	PLANT				
	Estación Coahuila	Los Algodones	San Felipe		
Month	Fecal coliforms (MPN/100ml)			DCL	ICL
Jan	3	3	< 3	240	1000
Feb	3	3	3		
Mar	3	3	3		
Apr	3	3	6		
May	3	614	3		
Jun	26	562	3		
Jul	26	3	787		
Aug	42	3	131		
Sep	161	79	788		
Oct	146	18	1122		
Nov	2.4×10^7	3	3		
Dec	2.4×10^7	3	3		

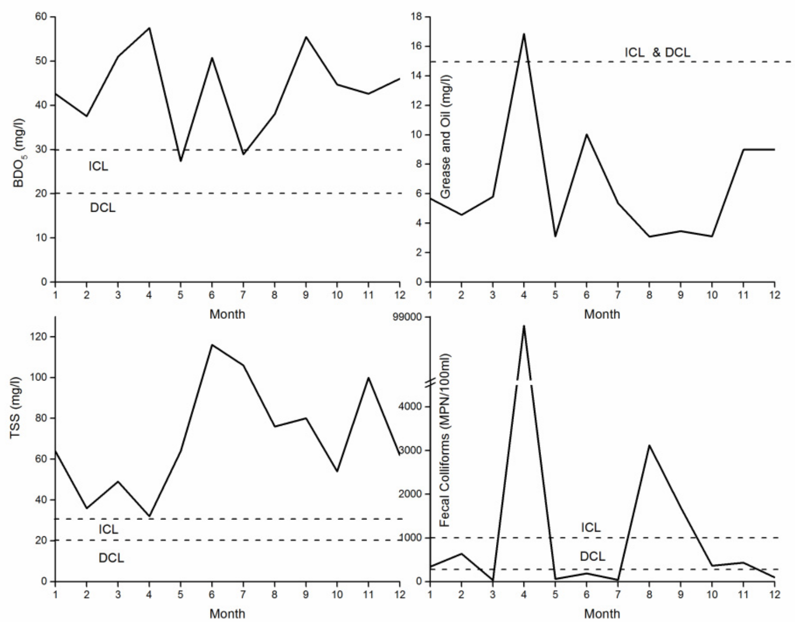

Figure 3: Results of parameter analyses for WTP Arenitas.

throughout the year. The 15 mg/l limit for grease and oil was met, with the exception of the month of April. The concentration of fecal coliforms was in the range of 340 to 86,740 MPN/100 ml during the months of January, February, April, August, September and October, while the limit for direct contact was 240 MPN/100 ml and 1000 for indirect contact.

4.4 Proposals to improve the use of treated wastewater

The bacteriological quality of water is considered the main reason for the establishment of guidelines and regulations for the safe use of treated waters in different applications. The World Health Organization considers that studies are necessary to ensure the effective and safe use of treated wastewater, as this increases the levels confidence found in the wider community (WHO [12]).

Some studies indicate that the determination and classification of effluent is of great importance for the adequate use and management of this resource, especially in the context of sustainable productivity and the rational use of natural resources (Ortiz [13]). The United States Environmental Protection Agency (EPA) considers that it is important the development of the preliminary environmental impact surveys on proposed irrigation systems using treated or untreated wastewater (EPA [14]). This study presents a plan of strategies to improve both the quality of effluent water, and the use of treated wastewater.

Table 5 shows the main aspects identified by this study which should be considered to ensure the best and most responsible use of wastewater treated by Mexicali's WTPs, which includes, among other things, measures to ensure crop quality, protect public health, and maintain the quality of the ecosystem.

5 Conclusions

In Mexicali, the reuse of water constitutes one of the most valuable tools we have to control pollution, recharge aquifers, and to face the challenge of increasing agricultural production. However, limited understanding of domestic wastewater within Mexicali, and incomplete water quality data make water reuse programs tentative and do not ensure agricultural sustainability and protection of public health. Although the effluent from the wastewater treatment plants does not comply consistently with the maximum permissible limits established in the Mexican Standard NOM-003-SEMARNAT-1997, the water is being used in the irrigation of crops and, as such, represents a risk to public health. The irrigation personnel and others who have either direct or indirect contact with water of poor quality could develop health problems, mainly as a result of bacteriological water pollution, while suspended solids can also affect the permeability of soils.

For many years, the lower section of the Colorado River has been a clear example of poor sustainable management practices and poor use of water, which have brought, as a consequence, an increase in the pollution of bodies of water and a decrease in the volumes of water destined for the maintenance of the

Table 5: Proposals to improve the use of treated wastewater.

Important item	Proposal
Quality of water treated for ongoing compliance with NOM-003-SEMARNAT-1997	To make the necessary adjustments in each plant to optimize treatment processes. Periodic training for the operators of each plant. To establish a program of periodic monitoring of the quality of the effluent from the WTP. The following additional proposal is made for WTP Arenitas: To make the requisite financial arrangements for the construction of a second treatment stage, ensuring the implementation of an activated sludge treatment system, or a similar system that permits to improve the quality of effluent for reuse that complies with NOM-003-SEMARNAT-1997.
Infrastructure for transport of treated water for agricultural irrigation.	To install purple lines for the conveyance of the effluent to the agricultural and green areas to be irrigated.
Publicity and awareness campaigns for users, especially regarding the technology involved.	To establish a program of publicity and training regarding the advantages of the use of treated wastewater, and to change the paradigm dictating its use once the water quality established in NOM-003-SEMARNAT-1997 is reached as a constant.
Public health.	To provide users of wastewater, and the personnel involved in irrigation, training in protection measures for the safe handling of residual water. To provide the necessary protective equipment to those irrigation personnel who are in contact with treated wastewater.
Ecosystem preservation	To devise measures to avoid harmfully affecting the natural state of flora and fauna with bad effluent quality.
Survey	To increase the number of inspection visits to WTPs, which are to include the revision of each process in order to improve effluent quality.
Certification of quality.	To urge the National Water Commission to establish a program for the periodic certification of the quality of treated wastewater.

Colorado River Delta's wetlands. Treated wastewater is, therefore, a valuable resource for agriculture and the maintenance of the ecosystem in the region; however, it must be used responsibly.

Both the comprehensive management of wastewater and the participation and commitment of all stakeholders concerned, such as the institutions responsible for the administration and treatment of wastewater, community organizations and farmers, are vital if we are to manage our water resources efficiently and effectively.

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