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The evolution of waste management in countries of transition

A Master's Thesis submitted for the degree of
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supervised by
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Vienna, October 2013

Affidavit

I, Yves Jean-Paul Reynaud, hereby declare

1. that I am the sole author of the present Master's Thesis, "THE EVOLUTION OF WASTE MANAGEMENT IN COUNTRIES OF TRANSITION", 79 pages, bound, and that I have not used any source or tool other than those references or any other illicit aid or tool, and

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Abstract

Urban migration is a worldwide phenomenon, driven by economic prospects not possible in rural areas. The resulting population growth requires governments and urban planners to foresee and adapt the city infrastructure to cope with increasing demands. With restricted budgets, developing countries have to prioritize, often leaving waste management at the end. As protection of public health is one of the top priorities on low-income countries, a case can be made that sewage systems deserve more attention as part of a comprehensive waste management strategy. By describing the socioeconomic, technical and political factors of Vienna, Mexico City and São Paulo, this comparative investigation aims to highlight the evolution of sewage systems and solid waste management practices, demonstrating the stark differences in history that shaped their development. The subsequent literature review examines the potential health issues associated with multiple exposure pathways in the case of insufficient wastewater treatment and inadequate solid waste management. The quantitative analysis compares the potential emissions of nitrogen and total organic content via leachate migration from landfills and reemission of untreated wastewater into groundwater respectively. The literature review indicates that landfilling deserves special attention if groundwater quality is to be maintained. However, in light of the research, sewage collection and wastewater treatment are more important with respect to public health. Finally, the paper presents its conclusions and its implications for infrastructure planning in developing countries.

Acknowledgements

I would like to express my deep gratitude to Prof. Johann Fellner, my research supervisor, for his patient guidance, and invaluable critiques of this paper. I would also like to thank my family for proofreading the early stages of work and assisting in the research of Mexico City. My grateful thanks are also extended to Ms. Maria Aledo, Ms. Raquel Aledo as well as Ms. Maíra Andrade for their help in translation, research and overall contributions to the sections on São Paulo.

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List of Abbreviations/Acronyms

ABES - Brazilian Association of Sanitary Engineering and Environment 35

BOD - Biological Oxygen Demand 46

CESB - State Water and Sanitation Companies 19

COD - Chemical Oxygen Demand 46

COMAPA - Metropolitan Commission for the Preservation and Control of Environmental Pollution 32

CONAPO - National Population Council 29

CTL - Waste Treatment Center East 49

CTVA - Landfill Caieiras 49

DOS - Department of Sanitary Works 17

EbS - Simmering disposal plants 25

FESB - State Fund for Sanitation 18

HCl - Hydrochloric acid 41

HF- Hydrogen fluoride 41

IBGE - Brazilian Institute of Geography and Statistics 22

INE - National Institute of Ecology 33

INEGI - National Institute of Statistics and Geography 30

LGEEPA - General Law of the Ecological Equilibrium and the Protection of the Environment 31

LGPIR - General Law for the Prevention and Integrated Management of Wastes 33

MA48 - Municipal department 48 23

NAFTA - North American Free Trade Agreement 33

NOM - Official Mexican Standards 31

PE - Population equivalent 46

PGIRS - Program for Integrated Solid Waste Management 33

PLANASA - National Sanitation Plan 18

1. Introduction

History has developed very differently in different parts of the world. Even though these historical inequalities constitute the most basic fact of world history, the requirements for societies to develop remain the same, regardless of location. The link between water and humans is as old as the origin of civilization itself. Any urban center needs to find ways to regulate water usage for its society to thrive. The creation of artificial canals is what allowed early cultures to move from the river to more arid areas and turn them into fertile valleys. With a larger agricultural capacity, primitive cultures started to grow in size. As more food and materials where being used in the urban centers, increasingly more solid waste was generated. While history was unfolding at different rates in many parts of the world, similarities in part due to modern trade and globalization began to shrink more and more, leaving behind a stark contrast of development. This paper will emphasize the differences of waste management systems, comparing the development of sewage systems and solid waste management in Vienna, Mexico City and São Paulo. As previously mentioned, the need for water and public health is universal. Yet how some cities were able to meet their needs, while others are still struggling, requires an understanding of how socioeconomic, technical, and political phenomena affected them and their current situation. Most studies in the area of waste management focus on the time of their publication. Material covering urban development of individual cities and techno-centric research on waste management is abundant. Yet academic literature seems remarkably void of comparative studies in the history of waste management. In order to improve waste management in developing countries and their living conditions, it is indispensable to understand their unique context. To unravel the differences in the evolution of waste management is not only interesting, but of significant importance today, as we seek to grasp our past's lessons for a future where climate remains uncertain.

1.1. Problem

For well over a century, developed countries have been exposed to industrial and urban activities, becoming aware over time of the challenges that urbanization brings along. Environmental awareness has yet to manifest itself, as many parts of the world have yet to achieve adequate standards of living. The safe disposal and subsequent management of municipal solid waste alongside sanitation represents two of the most essential urban environmental services. Other vital infrastructures and utilities such as energy, water supply and housing receive more attention and more budget. Nevertheless, the inability to manage properly the 'back end' of the materials cycle has a strong impact on health, longevity, and the environment (Un-Habitat, 2010). It logically follows that if developing countries are mainly concerned with the protection of human health then waste management ought to have importance. The question to ask then is: What area of waste management is more important for the protection of human health, sewage systems (including wastewater treatment) or solid waste management?

1.2. Hypothesis

Based on the priority of protecting human health, developing countries implement wastewater treatment first and only subsequently manage municipal solid waste.

2. Materials and Methods

If public health is the main priority of waste treatment, then population density is a key variable to be taken into consideration. For this study, preference is given to urban centers from developing countries since they offer insight into areas where water is a scarce resource.

With the development status, population density and use of untreated water for irrigation as selection criteria in mind, three cities have been chosen. Taking into account its highly developed sewage system and solid waste management, Vienna will be used as a reference. Identified as one of the most densely populated cities in the world and covered in numerous studies as an urban center suffering from water scarcity, Mexico City will be included in this paper (Romero Lankao, 2010). In contrast, São Paulo is one of the freshwater abundant cities in South America and possesses an extensive drainage system, yet water scarcity is prevalent in many municipalities. In 2008, the urban population in Brazil made up 80% of all 190 million inhabitants, yet less than 75% of the sewage created in the cities was collected and treated (Observatório Cidadão, 2013). São Paulo is cited to emphasize the differences of waste management systems and compare the development of sewage systems and solid waste.

First, a historical analysis will highlight the socioeconomic and political factors have led to the development of current waste management practices, for both sewage systems and solid waste management. The historical analysis of wastewater treatment and municipal solid waste practices will be followed by the second part, consisting of a qualitative analysis of health hazards, both occupational and residential related to sewage and improper waste management. Special attention will be given to the use of untreated wastewater for agricultural irrigation, as it constitutes a main pathway for pathogenic organisms into the human population via direct or indirect consumption. Additionally health impact resulting from the lack of adequate sewage systems will be highlighted. A description of the different disease vectors will be presented and their impact on human health and exposure pathways will be evaluated.

Finally, the third part will cover a quantitative analysis estimating the emission load of contaminants that leaked from the leachate of improper solid waste management and emissions from untreated sewage. The results will be used to show the impact

of improper municipal solid waste on water quality. This multifold approach may support a possible recommendation on the priorities of waste management strategies in developing countries, to best allocate what is their largest budgetary item and to achieve their priority of protecting public health.

3. Historical review of sewage systems

In ancient as well as in modern times many of the challenges faced by the local population to achieve development depended on the territory. The following passage will give insight into the different historical developments of the cities under review to underpin the underlying factors of the evolution of their respective waste management systems over time.

3.1. Vienna

The history of Vienna's sewer system is over 2,000 years old and dates back to the Roman era around 100 AD. During that time Vindobona, as it was called by Romans, was a military camp and exhibited already an impressive sewer system by modern standards. The bottom of the sewers was composed of tiles while the covers were made of stone slabs and smaller canals even had hardened clay pipes. Towards the end of the Roman era, the high standard of Vienna's sewer system started to vanish. Despite these technological advances, Vindobona suffered from the same hygienic conditions as any other European cities; garbage was disposed in the streets and sewage flew into different streams of the Danube. It was not long before these environmental conditions set the stage for a wave of epidemics.

Near the end of the fifteenth century, several canals existed in Vienna's city center, the first district. The yearly floods following heavy rainfalls, combined with the piled up and rotten waste (including dead animals) led to major health problems. Research in the field of sewage systems (Gantner, 2005), indicates that the pest epidemics in the years 1679 and 1713 had their origin in these unhygienic conditions. The sluggish construction of sewer systems experienced a strong lift following the second Turkish siege in 1683. The progress attained in 1739, made Vienna the first fully channeled city in Europe. Nonetheless, inhabitants in the suburbs led their waste and sewage into the Wienerwald streams, which were not only used for washing but also water wells. The consequence was the pollution of the groundwater for several days (Gantner, 2005).

In the 1800s the Wien River had the raw sewage of 4,000 tenement blocks along its banks. The complexity of the undertaking the city government was facing, became apparent in the beginning of the nineteenth century, when large parts of the

technical infrastructure were ready built. Sanitation in the City of Vienna only started in 1829 with the impetus for reform in this period, not coming from the natural sciences as assumed, but caused by the tremendous pollution of the cities at that time. In the course of the first three decades of the nineteenth century, public and private canals were systematically built, whereby the private "household waste canals" only moved the feces from the toilets to the home-owned cesspools or if present, fed directly into a road sewer. Finally, the building code of 1829[1] demanded the erection of walls around canals and the prohibition of new cesspool constructions, to help control the situation (Csendes and Opll, 2006).

This ambitious new construction laws but were not executed until a real disaster hit the Vienna's population. In 1830, a combination of high waters and ice dammed up tributaries of the Danube caused a flooding and widespread contamination of ground water leading to a cholera epidemic killing over 2,000 people. Following this tragic event, the City of Vienna started one of the largest construction projects in the city's history, which would last 70 years. Open streams in the city were covered and two additional collection channels[2] were quickly integrated into a storm and sanitary sewers system in parallel to the Wien River, resulting in the building of the first large sewers leading to the Danube (Gantner, 2005).

In the 1840s, the concept of clean drinking water started to gain importance among the population. The actual development of waste management infrastructure started to take off in 1848, most likely for political reasons, in particular under the influence of the great cholera epidemic and the first scientific epidemiological studies, which demonstrated the emergence of cholera caused by germs and bacteria. In addition, following the expansion of new water lines, more people in Vienna were able to receive fresh water. As a result, Vienna effectively exterminated many negative factors involved in the 40 year period in which cholera reigned over the city. From 1850 on, the sewer system was extended to the point that associated risks of diseases were finally banned.

In particular, the supply of fresh, clean water helped to disprove the miasma theory[3], and was seen as the most effective measure against diseases and epidemics. The

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[1] The *Bauordnung von 1892* defined several building requirements for the City of Vienna, including the connection of communal canal.
[2] These channels were referred to as *Cholerakanäle* in German.
[3] The miasma theory was popular until the 1730s and stated that cholera and other disease were caused by miasma, a form of bad air emanating from rotten organic matter.

construction of canals and the disposal of garbage resulted only in improvements, but were not the driving force in the fight against the plagues and epidemics. It was rather, the breakthroughs in various fields of research that made it possible to gradually understand the relationships between the living conditions and health status. Nonetheless, deaths attributed to contaminated water were still frequent, not least because heavy rainfalls in the canals led to overflows in the Wien River.

As the medical discoveries of the time started to influence the technical development, which was controlled by political powers. the conceptual work started to become more prevalent, as the city government tried to preconceive situations instead of fixing problem by problem. To achieve this goal, a plan for the maintenance and cleaning of the streets and public places, as well as the clearing of human excreta and sewers was developed. Under this new model, all sewers were to be cleared on a monthly basis. Two main collectors were built along the Donaukanal, to combat the resulting odors from the feed-in of the sewers. Contacts with the major European cities[4] were established to exchange experiences and expertise but most importantly avoid committing the same mistakes. It was becoming apparent that the efforts required to clear and transport the cesspool contents were just too big. Using other European cities as a reference, it became evident that for hygienic reasons, cesspools provided only a temporary fix and not a solution to the sanitation problem (Ossberger, 1997). The municipal authorities set the ambitious goal to solve the question of sanitation on all fronts. Especially Hamburg, Berlin and Graz would turn out to have a distinct influence on the subsequent development of waste management in general in Vienna. What remained unclear was whether to remove the human waste through a water carriage system or to keep clearing it from the sewers. The lessons learned from Berlin seemed to indicate that the introduction of a sewer system would benefit street sanitation. With the exponential growth in urban population, Vienna's wastewater volume also grew requiring further upgrades, in particular the building of sanitary sewers on both side of the Danube Canal and the extension of the central sewer system to outer districts. In particular, since 1873 after the city had a comprehensive water supply system in place, the population grew and the rate at which Viennese households were attached to drinking water and sewage system grew quickly. This also meant that in addition to increasing hygiene challenges, odor control soon

[4] Municipal authorities were exchanged information Paris, London, Munich, Hamburg and Berlin.

became a main requirement in the city and the spread of cholera was under control (Ossberger, 1997).

During this period, various entrepreneurs and scientists started to look for new ways to recycle the cesspool contents[5]. Even though more than ten different bids from all around the world were made to solve Vienna's human waste problem, the condition persisted beyond 1874. The technical innovations had not resulted in the intended improvements for the sewer system. Despite regular channel clearances, it was inevitable to dispose of waste. Sewer and cesspool contents, which were not used for wastewater irrigation, ultimately ended up being disposed of in pits near the banks of the Donaukanal until 1879. Once the molesting odors created by the built up fecal matter could not be ignored, the waste was shipped onto the Danube in 1880. Following the foundation of new nation-states and the Constitution of Austrian in 1920, much of the former empire's important economic regions disappeared. The uncertain economic conditions and political turmoil between left and right wing paramilitary forces that followed in Vienna between 1920 and 1930 slowed down the improvements of the sewer system.

The city's sewer system continued to improving until its severe damage by the bombings of World War II. During the war, the Viennese sewer system received 1,800 hits from bombings. It was not until 1950 that the city was able to repair the damages from the war (Gartner, 2004; Brunner and Schneider, 2005). While the issue of hygiene in the city seemed resolved, the untreated wastewater reached Vienna's river network. Thus, the city of Vienna began with the construction of two wastewater treatment plants. The first wastewater treatment facility in Vienna was built in the 23rd district and was operational from 1950 to 1970 processing clearing the sewage of a catchment area[6]. In 1970, the treatment facility "Blumental" also located in the 23rd district started to treat wastewater coming in from two collection channels through the stream Liesing, using an organic cleaning process. Next, the clean water was conducted back to the stream Liesing (City of Vienna, MA 53). Ten years later, in 1980, the construction of main wastewater treatment facility[7] of Vienna. Because it is the lowest geographical point in Vienna, the 11th district was

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[5] Among them was the attempt to collect all human waste and process it subsequently into fertilizer. Yet another solution foresaw the conversion of fecal matter into compost.
[6] *Gelbe Haide* catchment area in Wien Inzersdorf.

[7] *Hauptkläranlage Wien* in German

chosen as location to build the treatment plant. This natural incline facilitated the flow of wastewater via the 2,400 km long sewage network of Vienna into the treatment plant. The opening of the main wastewater treatment facility represented a new milestone in the environmental history of the city of Vienna. As time went on, the streams coming into the wastewater treatment facility “Blumental” were having a strong impact on the stream Liesing. Thus, the wastewater treatment was stopped in 2005. Since then, wastewaters are conducted via the newly constructed Liesingtal canal into the main wastewater treatment facility. In the years between 2000 and 2005, the facility was upgraded and expanded through the introduction of a second organic cleaning (nitrogen reducing) process to further improve the treatment [8]process and the resulting water quality of Vienna (Lukschanderl and Klager, 2005).

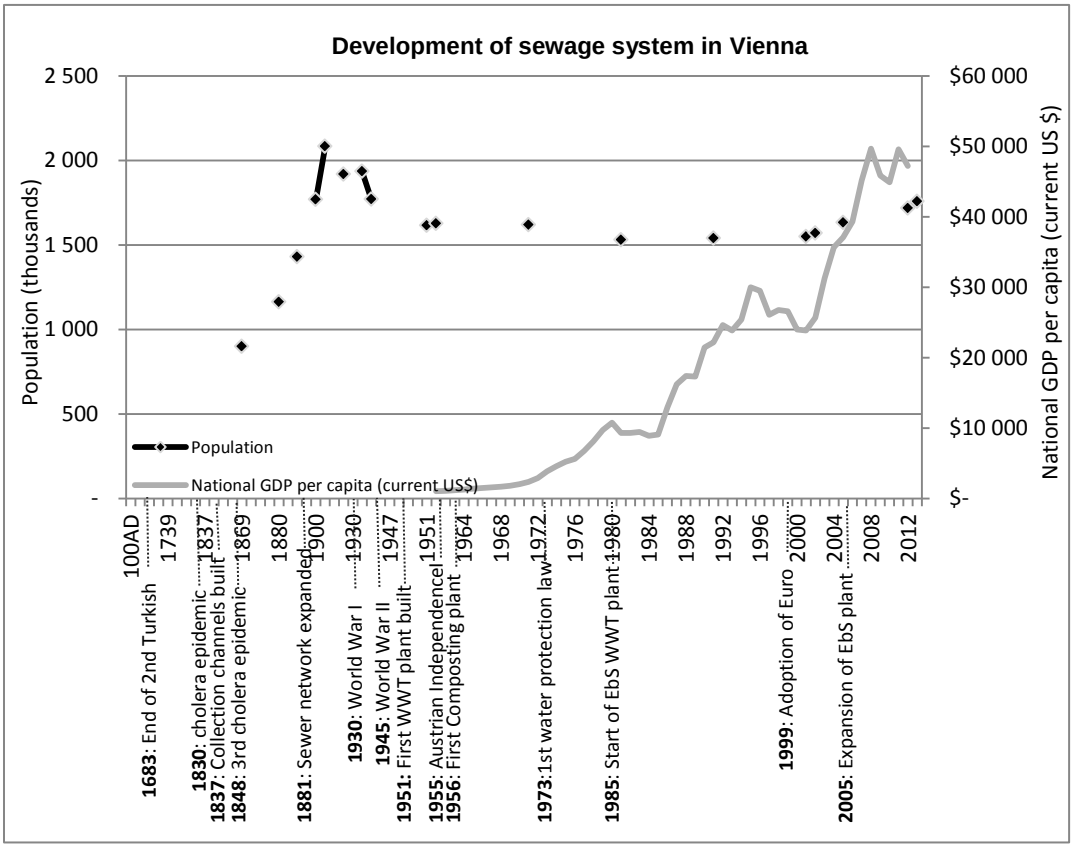

Figure 1 Development of sewage system in Vienna

Sources: Statistik Austria and Worldbank

3.2. Mexico City

The capital of Mexico is situated in the lower part of the Mexico Valley Basin, approximately 2,200 meters above sea level, surrounded by mountains reaching above 5,000 meters in altitude. Because of its location, Mexico City had to confront for several centuries, the problem of flooding. The Aztecs first arrived during the thirteenth century in the Valley of Mexico and settled on the island of Tenochtitlán in the Lake Texcoco, one of the five lakes[9] that formed the lake area nowadays known as now the Valley. The closed basin fed on the rains, mountain rivers and small springs. Its location and characteristics caused constant floods during periods of continuous rainfall (Herzog, 2001). During the pre-Hispanic period, the Aztec state employed different methods to take advantage of water. To control the water, an impressive hydraulic system, composed of roads, dikes, locks and aqueducts was built as recorded by Spanish chroniclers, who were surprised by the systems used. The sophistication of such a system was likely closely related to the population of Tenochtitlan[10], which at its peak in the late fifteenth century was estimated at half a million, making it one the world's largest cities of its time (Romero Lankao, 2010). In 1521, Tenochtitlán fell to the Spanish and the hydraulic system was destroyed, initiating a new colonial era, which lasted until 1821.

During the colonial era, a project to rebuild the pre-Hispanic hydraulic system on behalf of vice-regal authorities was underway. While one of the original ideas of Hernán Cortés[11] was to find a new seat to fund the capital of New Spain, he eventually decided to reconstruct the pre-Hispanic hydraulic system, despite the constant danger of floods, because all currents were heading to the valley. In 1555, came the first great flood of colonial Mexico, and the builders, made up of indigenous and Spaniards, saw the need to find solutions, among other measures, following indigenous techniques, a pre-Hispanic dam made of stones[12] was rebuilt, which provided some support but not enough to completely solve the problem (Rojas et al., 1974).

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[9] The five lakes composing the Valley of Mexico are: Zumpango, Xaltocan, Texcoco, Xochimilco, Chalco
[10] The capital city of the Aztec empire
[11] Hernán Cortés led the expedition of Spanish Conquistadores during the early 16th century bringing large parts of Mexico under Spanish rule eventually causing the fall of the Aztec Empire.
[12] A*lbarradón* in Spanish

During that time, another plan appeared, consisting of building an artificial drain. Each time the great floods came, the capital resorted to that solution. Finally, the decision was made in 1607 to build the Nochistingo canal in order to drain the Lake Zumpango and the Cuautitlán River. The capital depended on a series of filtration tanks and pipes to transport sewage and household wastewater through the city from west to east and finally towards a large dike[13] northeast of the city. Because the citizens would use it to dispose of their waste and trash, it would inevitably end up clogged, turning it eventually into a source for cholera, typhus and other diseases, which would repeatedly afflict the population. Since these were open systems, their contamination contributed significantly towards a further deterioration of water quality via the connecting aqueducts public supply sources (Romero Lankao, 2010). Unfortunately, the capacity the Nochistingo canal was insufficient and did not decrease the volume of water required. During all those years, the criticisms were harsh, other specialists were consulted, and authorities ordered to suspend the work. The most serious problem arose in 1629, when there was a disastrous flood. Following heavy rainfalls and fearing that the incoming water may prove too much for his newly constructed drain to resist and may be destroyed, Enrico Martínez[14] decided to block the drain channel input. His decision turned out to be catastrophic, as the river extended to Mexico City, reaching a considerable height. The losses were tremendous: death, emigration, property destroyed and economic paralysis. Records of that period describe how even after ten years, the damage was noticeable, the city itself being under water for five years (Caistor, 2000).

After 11 years of armed struggle, on September 27, 1821, Mexico awoke as an independent nation, but among the main problems inherited from the colonial past was the drain of the capital city. While the need for a technical and administrative body responsible for the supervision of the works was apparent, the lack of money in the treasury and the constant political conflicts prevented a long time its creation, limiting the efforts to maintenance works and minor repairs. At first advances came fast during the excavation of the pit and the tunnel, but as they reached deeper, costs and barriers increased. There were constant leaks and risks of floods and landslides. The ports that were built were protected by masonry or wood, so each time progress was slower. During the fall of the Juarez government, works were

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[13] The *San Lázaro*

[14] Enrico Martínez was cosmographer to the King of Spain, interpreter for the Spanish Inquisition, publisher, and hydraulic engineer leading the construction of the drain channel.

once again paralyzed. The capital was flooded in the rainy season, which, in addition to the civil unrest, and chaos caused a spreading of diseases. The area surrounding Mexico City was abundant in water sources during the colonial era. However, its uneven distribution created problems of scarcity. While some places had natural springs and public wells, others had none; a condition that has lasted into the present.

Seizing the power from Emperor Maximilian in a coup in 1876, Porfirio Díaz and his allies ruled the country until 1911, a period commonly referred to in Mexico as the *Porfiriato*. It was not until the year 1884, when President Porfirio Díaz began his first re-election that works on the drain-in tunnel resumed. The progress was slow, as it was a complex task, especially the channel tunnel, because while the pit was almost completed, the chosen machinery turned out to be not suitable for the task. For these reasons, Porfirio Díaz considered that such work should be in the hands of foreign technicians. In 1889, several British and American companies, among others were hired. Finally, after many changes and mistakes by the foreign contractors, the tunnel of 10,021 meters was officially completed in December 1894 and officially inaugurated by President Diaz in 1900. While a lot of resources and efforts were spent, it was clear that it would not be the ultimate solution to the problem, as the flooding was not over and the population of Mexico City had grown at a breakneck pace. The regimes which originated from the 1910 Mexican Revolution were able to consolidate the system manage and supply water created during the dictatorship of Porfirio Díaz. Nevertheless, the *Porfiriato* regime was able to improve the quality of fresh water thanks to the introduction of a closed distribution system in the water supply. The completion of the project to drain the basin of Mexico City, which had been contemplated since the seventeenth century, represented a milestone in the urban history of the country. For its time, the Gran Canal[15] grouped with a closed network of combined secondary and tertiary drainage, resulted in a system able to cope with floods. Thus, this state-of-the-art system vastly improved the sanitary conditions of Mexico City (Romero Lankao, 2010). In fact, much of the *Porfiriato* era hydraulic system remains operational today. Yet because the system had artificially unified those basin spaces through the provision and removal of water through supply, sanitation and drainage infrastructures, the basin's hydrological cycle was completely modified to the point where rainwater

[15] The Gran Canal was for the most part an open main drainage channel transporting sewage.

would no longer follow its path of infiltration, changing the proportions of storage in aquifers and evaporation in lakes (Romero Lankao, 1999). Consequently, a significant portion of water would be captured and removed from the basin and all the residual water left in it, through a system of pipes before it could even reach the lakes and aquifers. The additional groundwater extraction, which started towards the end of the nineteenth century, resulted in the collapse of the Gran Canal. This created an absurd situation in which storm and wastewater was and still is being pumped out of the basin, while more than a third of total drinking water is brought from increasing distances, further increasing the energy and money needed to be pumped into the basin (Tortajada, 2006). During that period, a large share of the canals in Mexico City was contaminated with wastewater. In response, the so-called Viaducto canal was constructed in 1940 as means to transport the sewage. An increase in immigration resulting from the introduction of national policies to attract investment reinforced the large-scale growth of Mexico City's urban industries and the lack of economic prospects in the rural areas, represented new challenges both to those who ruled the capital and those dedicated to its construction. The population continued to suffer from floods, particularly during 1950 and 1951.

Table 1 Construction of wastewater treatment plants in Mexico City

Year of construction	Wastewater treatment plants
1956	Chapultepec
1958	Coyocan; Ciudad Deportiva
1959	San Juan de Aragon
1965	Tlatelolco
1971	Iztacalco; Cerro de la Estrella
1973	Bosques de las Lomas
1975	Acueducto de Guadalupe
1981	El Rosario; Reclusorio Sur
1989	San Luis Tlaxialtemalco
1993	San Nicolas Tetelco; Abasolo
1994	Santa Fe; La Lupita; Parres; San Miguel Xicalco
1997	San Pedro Atocpan; San Andres Mixquic
1998	San Lorenzo
2000	El Llano
2005	Sta. Martha Acatitla

Sources: Secretaría del Medio Ambiente del D.F. (SEDEMA)

At that time many areas of Mexico City were affected by the level reached by the water, sometimes reaching up to seven meters as recorded in local newspapers photographs. In order to address this problem, the Commission of Hydrology for the Valley of Mexico was created. In 1958, the wastewater treatment plant “Coyoacan” began its operation.

A comprehensive plan was drawn to deal with subsidence, floods and water supply. The proposed solution to the problem would be the realization of a deep drainage system that would allow keeping the sewer service and leveraging wastewater for irrigation and industrial uses. Finally, in 1967 began this important work of twentieth century Mexican engineering (Cohen, 1999). In 1971, the wastewater treatment plant[17] started its operation processing most of the water for re-use as water for irrigation in agriculture. Later commercial and industrial sectors would follow and use the treated wastewater.

At the beginning of the twenty-first century, the capital of Mexico faced the challenge to supply its inhabitants with enough water. This was mainly due to two trends; an increase in population and the overexploitation of the aquifer. Its geographic location, also contributed to water related problems such as floods and shortages of drinking water.

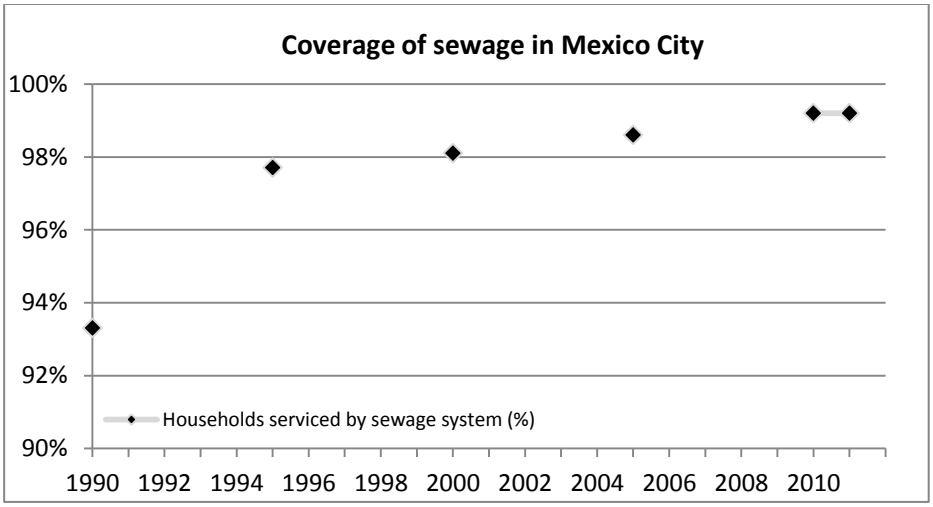

Figure 2 Coverage of sewage in Mexico City[18]

In 2006, the nearest source of water was already being tapped, but meeting future needs was uncertain. As the aquifer systems located below the City provide nearly

[17] *Cerro de la Estrella*
[18] Sources: Sistema de Aguas de la Ciudad de México (SACMEX)

75% of the total water supply and the demand increases, the only way to satisfy the demand was to extract water at above replenishment rate (Carrera-Hernández and Fischer, 2006). Notwithstanding the increase in economic activity in the post-war period, Mexico City's economy was not able to absorb all of the labor force. It appears that underemployment will continue to persist as a structural problem. As the migrants struggle to find employment they lack the resources necessary to afford basic housing, driving a large segment of the population to build their own dwellings on unserviced peripheral land. In fact, lack of housing provision resulted in the increase of over 60% of the city's growth, mainly on land without access to electricity or sewage (Connolly, 1999).

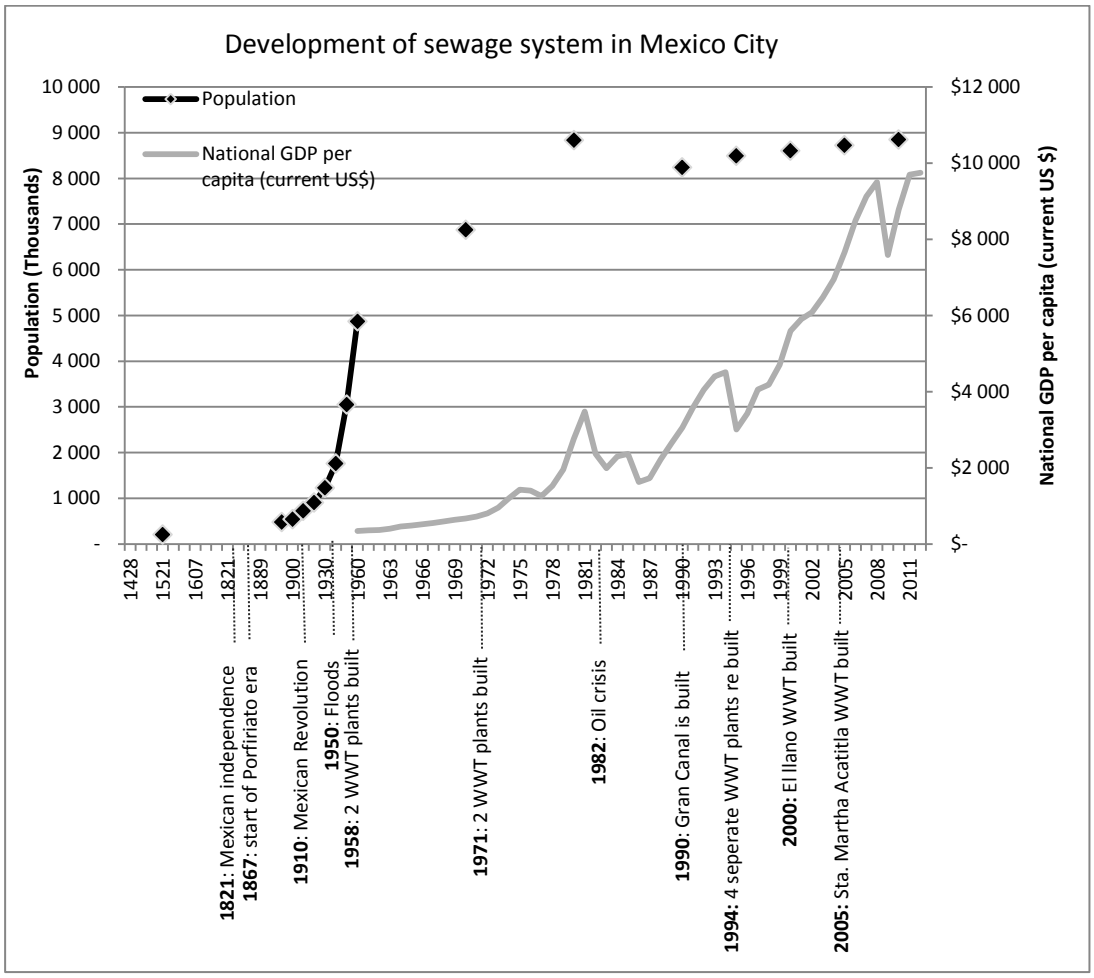

Figure 3 Development of sewage system in Mexico City[19]

[19] Sources: INEGI and Worldbank

3.3. São Paulo

In pre-colonial times, indigenous communities in Brazil already worried about sanitation. Water would be stored in clay jars or stone buckets for later consumption. Delimited areas were reserved for the disposal of human waste. During the early 1800s, Rio the urban center of the country at that time nearly doubled its population in less than two decades, reaching 100,000 inhabitants by 1822. This dramatic change in population made households in the area, to have sanitary installations that allowed for the collection of human waste in special barrels. When these barrels were filled after several days of use, slaves dubbed "*de tigres*" carried and dumped the resulting load of infected waste on the public square of the sea, where the containers were washed for reuse. Access to drinking water in a home was a privilege in the imperial era, since no water supply infrastructure existed back then, and relied heavily almost exclusively on slaves to transport the water from public wells to the residences (Buff, 2009).

Between 1830 and 1851, there were no less than twenty-three lethal epidemics in the major cities, in particular of yellow fever. At the end of the nineteenth century and early twentieth century, Brazil was known abroad for being a place where epidemics of yellow fever, smallpox and bubonic plague proliferated. São Paulo and other cities constituted nurseries for rats, mosquitoes and other disease vectors. Due to the gravity of the situation at that time, an aggressive campaign to combat the outbreak of yellow fever in São Paulo was initiated, attacking the breeding grounds for mosquitoes that transmit the disease. From 1836 to 1874, the urban population experienced an above average increase growing from 9,391 to 19,347 inhabitants. São Paulo's water supply network and sewer system was introduced only after 1876 as part of an official project launched by the local government in 1842. (Kahlouni, 2004).

During the post-colonial Empire of Pedro II in 1877, water privatization started to take off as private entrepreneurs created the Cantareira Company for Water and Sewage[20], which entered into a partnership, forming a mixed company with the state government the following year. In 1878, Emperor Pedro II inaugurated the new water supply of the city and in 1883 the first district sewers of São Paulo. Due to the Cantareira Company's unsatisfactory services, the state government did not renew its concession contract. In response, the state government created the Division of

[20] *Campanhia Cantareira* in Portuguese

Water and Sewer of the Capital[21], subject to the Secretary of Agriculture, Commerce and Public Works. During that period, there were two water supply sources in the city of São Paulo; the Ipiranga, which captured the waters of the stream of the same name, and the Cantareira, which captured the springs located in the hills.

With the end of the reign and the beginning of the first republic[22] in 1889, the city of São Paulo, as well as the state of São Paulo, experienced great economic and population growth, aided by major European and Asian immigration to São Paulo. Industrialization and enrichment in São Paulo increased substantially due to profits from coffee farming in this era. Major changes were occurring in the city between 1899 and 1919. During this very important period, São Paulo saw yet another increase in urban population growth. Between 1890 and 1900, the city of São Paulo went from 64,934 to 239,820 inhabitants, nearly quadrupling its population. This tremendous increase required the building of large avenues, the rectification of the River Tietê as well as significant extensions of the water and sewage systems, leading to the emergence of the first services provided directly by the public sector.

Starting 1917, the capacity of water supply was expanded through the water collection in the Rio Cotia and in 1925, the Division of Water and Sewer of the Capital was fetching water in the Rio Claro, in the *Serra do Mar*[23]. In 1929, the first agreement was signed between the State Government and the Light & Power Company to regulate the water supply of the city of São Paulo and necessary works were carried out to ensure the increase of water supply to the population.

In the period of Constitutionalist Revolution of 1932 also known as the Paulista War, the population of the state of São Paulo revolted against the 1930 coup d'état whereby Getúlio Vargas assumed the nation's Presidency. During World War I, the city grew tremendously because of restrictions in international trade. This forced São Paulo to start developing its own industry. As of 1941, the city of São Paulo had a population of 1.3 million people and received water from the Cantareira Cabuçu Cotia, Santo Amaro and Rio Claro, for a total of nearly 470 million liters per day. In 1950, the Department of Sanitary Works[24] was created to operate the water and sewerage services in the counties of the state.

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[21] *Repartição de Águas e Esgotos da Capital (RAE)* in Portuguese
[22] *República Velha* in Portuguese
[23] A 1,500 km large mountain range and forest next to the Atlantic Ocean supplying water
[24] *Departamento de Obras Sanitárias (DOS)* in Portuguese

The growth in urban population in São Paulo really started in the 1960s and brought along with it an acceleration of the metropolization process, where the state has always had a leading role in the implementation and management of water and sewage services. With the accelerated growth of the urban center, the need to deploy infrastructure sanitation emerged as a major concern of the public administration from the mid-nineteenth century on. Since then, the sanitation systems have evolved closely linked to the process of economic development and urbanization. In addition to the fast economic growth in the region, the area has recently become one of the largest urban spaces worldwide. This explains why in spite of its proximity to the headwaters, a relative scarcity of water resources prevailed and required water management as well significant financial resources.

In 1964, following yet another military coup, major investments in energy and transportation infrastructure were made. The economic project deployed in the country after 1964 supported the centralization of decision-making, and created nationwide bodies responsible for the formulation and management of urban policies, including sanitation.

The metropolitan water company of São Paulo was launched in 1968, to capture, treat and sell wholesale drinking water to 37 municipalities in the greater area of São Paulo, as well as the state fund for basic sanitation[25]. Until then, the responsibility for São Paulo's water supply and sanitation services were municipal, as laid out by the Federal Constitution of 1967 (Seroa da Motta and Moreira, 2006). During this period, coverage rates remained low, lacking the necessary institutional structure to improve the situation. Conceived in 1970, the metropolitan water company of São Paulo was responsible for the catching, treating, treating and processing and the final disposal of sewage. Over the 1970s, the population in the metropolitan region of São Paulo went from 8 to 12 million inhabitants, amassing around 50% of the population in the state. This increase in urban growth demanded once more the expansion of the existing infrastructure. Thus, in 1970 the first Metropolitan Plan for Integrated Development[26] (PMDI) for the region was drafted. Following the creation of the Financial System of Sanitation [27] and the National Sanitation Plan

[25] *Fundo Estadual de Saneamento Básico* (FESB) in Portuguese
[26] *1er Plano Metropolitano de Desenvolvimento Integrado* (PMDI) in Portuguese
[27] *Sistema Financeiro de Saneamento* (SFS) in Portuguese; linked to the National Housing Bank

(PLANASA)[28], guidelines for the sanitation sector were implemented. Launched in 1971, PLANASA mobilized national[29] and external[30] sources with the goal of offering a water supply and sanitation service of, 80% and 50 %, respectively, to the urban population of the country until 1980. Based on the philosophy of viable water and sewage services through economies of scale, the plan relied heavily on concentrating sanitation services in the hands of state companies, to the detriment of municipal management. This gave rise to the creation of the 27 existing State sanitation companies in Brazil. Likewise, the national policy resulted in the creation of several companies and state organizations, which centralized regionally the sanitation services in São Paulo. Thus in 1971, various (State Water and Sanitation Companies (CESBs) started to spring up in every single state in Brazil.

The process of centralization of sanitation services finally reached its end when in 1973 the basic sanitation company of the state of São Paulo[31] was created.. Currently the SABESP is responsible for water and sewage services of 365 municipalities, and distributes treated water to about 22 million people. Like most other state companies in the sector, SABESP is a public-private entity owned by the government of São Paulo. In the state, as indeed throughout the country, the centralized model, on one hand, enabled significant growth to cover the necessary water supply and sewage collection; however, it also hindered the development of autonomous municipal sanitation systems. To cope with this situation, the state government of São Paulo created the SANEBASE program, aimed at financing projects and services for water and wastewater systems in municipalities that had not joined the PLANASA. In 1974, the main provider for water supply in the metropolitan region of São Paulo, the Cantareira system starts its operation, supplying 60% of the population in north of the city. The sewage treatment program for Greater São Paulo (SANEGRAN) was approved in 1977 for the consolidation of sewer systems. The SANEGRAN program undertook the deployment of three sewage treatment stations, which reached the so-called secondary level, the equivalent of a 90% reduction of total pollution load in wastewater.

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[28] *Plano Nacional de Saneamento* (PLANASA) in Portuguese
[29] *Fundo de Garantia por Tempo de Serviço* in Portuguese
[30] International Bank for Reconstruction and Development and Inter-American Development Bank
[31] *Companhia de Saneamento Básico do Estado de São Paulo (SABESP)* in Portuguese

During the second half of the 1980s the sanitation management at the federal level underwent a chaotic process of transfers between different ministries. On the other hand environmental issues began more and more to be a topic in the public sphere and it was not long until it become an issue in the field of public policy. Thus, the National Environmental Policy[32] and the National Council for the Environment[33] were created in 1981. Two years later, the state council on the environment was conceived in São Paulo interconnected to the Governor's office. The positive performance of Brazil's economy supported the expansion of the water supply and sanitation network because vital funding was made available. In the years from 1970 to 1990, PLANASA was able to expand sanitation services from 24% to 42% amid the urban population (McNallen, 2005). Nonetheless, expansion in sanitations services occurred unequally among regions. This was mainly due to the economic incentives of the expansion taking place. Because water charges provided rapid return on investment, priority was given to the wealthier regions of Brazil. Subsequently most of the investments were focused in particular in the wealthier districts of Brazil's larger cities like São Paulo.

With the adoption of the Constitution in 1988, the trend was to politically and administratively decentralize the country. In fact, the constitution devotes an entire chapter (Chapter IV) to the environment, resources, water and sanitation, beginning a new phase of discussion and formulation of policies, both at federal and state levels, to incorporate issues related to sustainable development. Established in the 1990s, the Department of Urban Policy (SEPURB) was responsible to ensure improved quality and higher efficiency via policies in the areas of housing, sanitation and urban development. Other aspects that became increasingly important was the adoption of an integrated view of the sanitation process, in particular the participation of civil society in the planning and control of services and sanitation works. In the specific case of the State of São Paulo, discussed below, recognizes clearly these aspects. During this period, the water supply networks served all of the urban population. However, the challenge was to maintain this level of service, quality and regularity, as well as the provision to other sanitation services.

The population of São Paulo was estimated at 11,253,503 inhabitants in 2010 with 94% living in urban areas of 645 municipalities. Approximately 63.5% of this

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[32] *Política Nacional de Meio Ambiente (PNMA)* in Portuguese
[33] *Conselho Nacional do Meio Ambiente (CONAMA)* in Portuguese

population is concentrated in only 9.2% of the total area of the state and overcrowded cities with large numbers of people occupy watershed areas, riverbanks and steep slopes. This situation represents a challenge to the implementation of effective sanitation and demand a great effort at all government levels to find solutions. In the end, the evolution of the sanitation and sewage systems in major urban centers in Brazil such as São Paulo was led by the population growth but more importantly, it was promoted by the growth in labor supply and the subsequent increase in economic activity. As has been shown, it was the prevailing economic vision of the government that dictated the process of developing isolated aspects of the urban area. The result of this approach was that the local government implemented public works in an isolated fashion. The specialization of management systems of the city's infrastructure resulted in a fragmented water resource management (Kahlouni, 2004).

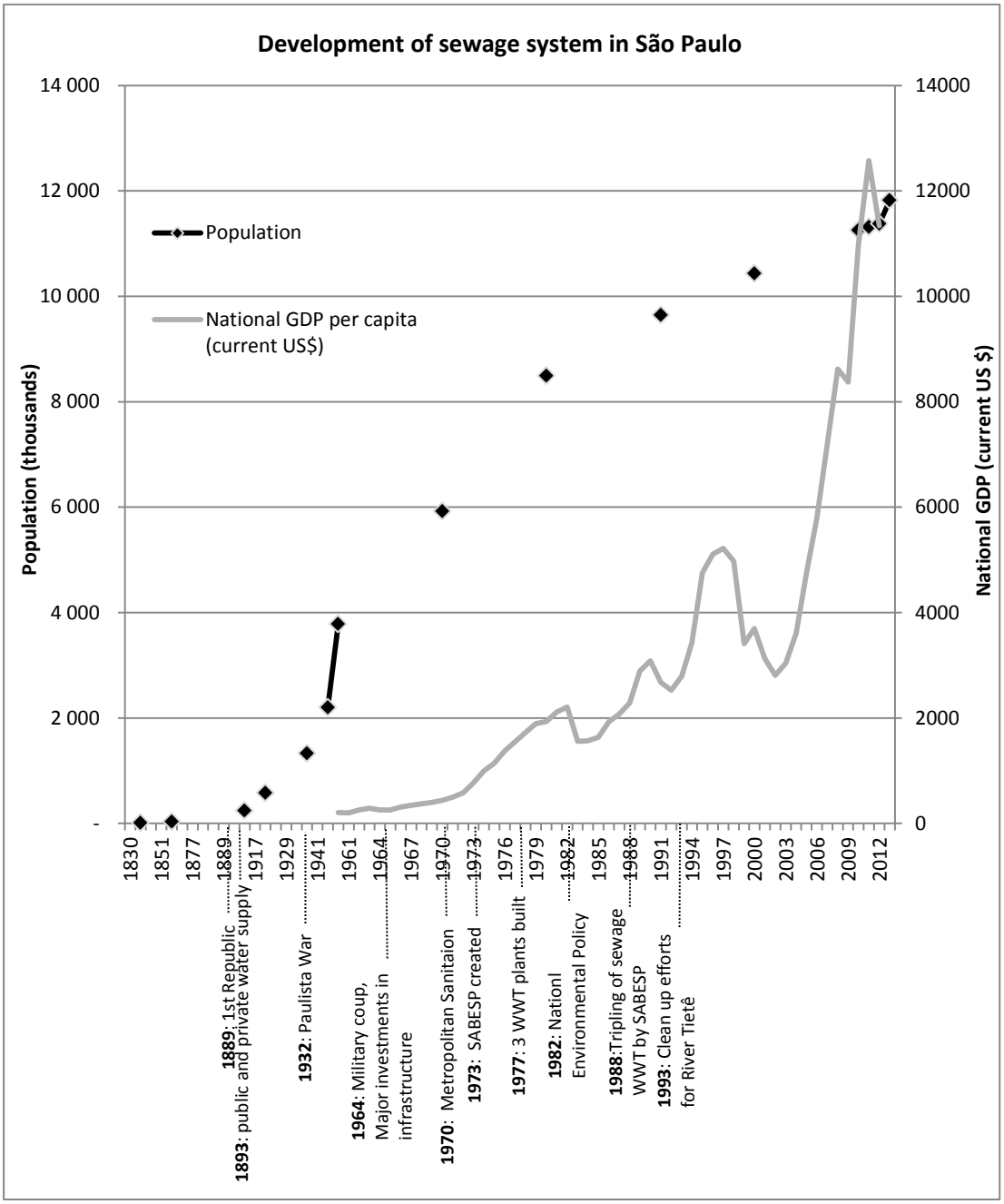

Figure 4 Development of sewage system in São Paulo[34]

[34] Sources: IBGE and Worldbank

4. Historical review of waste management

Considered usually an urban issue, municipal solid waste is less prevalent in rural areas as its population has a reduced economic capability to purchase items resulting in more waste (Hoornweg and Bhada-Tata, 2012). As current urbanization is to increase in the future, the adequate management of municipal solid waste will continue to be a challenge.

4.1. Vienna

While hygienic conditions in the second half of the eighteenth century improved, it was not for the purpose of disease control in itself, but initially only served to improve the health of the soldiers and officers. Albeit too late, Maria Theresa realized that a major reason for the devastating defeat in the war over Silesia, layed in the poor general state of her army (education and health). Therefore, the promotion of hygiene and medicine were considered crucial prerequisites to sanitize the city. Joseph II recognized that public health was reflected in the economic development and as such put great emphasis on general medical care. Advances in science and knowledge about the origin of epidemics, provided an additional impetus to clear districts of waste and debris and laid the foundation for the technical discipline known today as waste management.

Since its early beginnings, street cleaning and waste collection was a simple process. As stated by official decree, household waste was to be moved outside the city. The lack of enthusiasm by the population at large however ensured that most of the trash stayed within city confines. As a result, the city government started to offer inhabitants the possibility to let garbage fleet collect their household waste (MA48, 2013a). Waste management in the 1800s was a first measure to keep the city clean and hygienic to ensure the public health and therefore the economy (Ossberger, 1997). Only in 1839 was the first garbage collection system established and made compulsory. Back then, the so-called "*Mistbauer*", in essence people that collected the garbage from the Vienna's inhabitants in their own homes, ensured the transport and further disposal with their vehicles. It is interesting to point out that the city government had no legal responsibility to provide garbage collection to its citizens even though the provided service remained free of charge until 1934.

As of 1880, the solid waste collected by the "*Mistbauern*" was deposited in the landfill site "Bruckhaufen" in Vienna. Around 1895, this landfill led to the sprawl of illegal settlings in its surroundings creating what was referred to as the slums of the district (Licka and Krippner, 2011). In the year 1904, Vienna was already operating a fleet 104 horse powered collection chariots. Within the city center's first district, garbage was collected on a daily basis, or at least once to twice a week. The collection was advertised by bell sounds, upon which households prepared and moved their trash outside their homes for collection.

Towards the end of the nineteenth century, the city's sanitation requirements had increased. Thus, the lack of effectiveness of the uncovered and street polluting chariots became apparent to the public. Consequently, household waste was placed into standardized containers or bags prior to collection. During several years, the city experimented with different attempts to improve solid waste management, such as the introduction of waste container switching system[35] consisting of switching full containers against empty ones. After many trials and errors, Vienna decided in 1913 to settle for the "container-emptying solution". With the start of World War I, waste management became a low priority.

In the years up to 1918, significant changes took place in the areas of sewage and solid waste disposal that lasted up until today. Some of these new constructions included the re-organization of pre-existing garbage collection services, and the definition of future requirements for the garbage truck fleet infrastructure. It was only in 1918 that certain districts in Vienna tried implement the "*Colonia*" system[36], which consisted of placing tight-sealing garbage containers in buildings throughout the city to be collected later at regular intervals by the fleet. The collection was almost free from dust emissions and the handling of the containers was simple. From 1923 to 1928, the transition to the "*Colonia*" system was fully completed in all of Vienna and the horse-powered chariots were phased out. In 1928, the City of Vienna had already 901 of these containers.

Waste management in the years until 1938 was primarily influenced by the attempt of improving the logistics by the introduction of the new collection system. Technical innovations in recycling and disposal did not occur; the potential progress in the installation of waste incineration failed due to lack of money, as well as the invasion

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[35] *Wechselkastensystem* in German
[36] Named aptly after the city in which it was invented, Cologne.

of the German army. Despite the strict government guidelines and ambitious goals of the Nazi regime, the success was limited because the responsibility to manage waste was divided and delegated to various communities, multiple parties and private enterprises, which was coherent with the typical Nazi polycracy. Vienna's population peak of 2 million inhabitants as well as the prognosis of 3 million people by the year 1950 resulted in oversized garbage disposal facilities, which nowadays still allow the city of Vienna to make necessary adjustments in these areas. After 1945, Austria was able to regain its political self-determination, and establish relations with the wealthiest countries in the world in the subsequent years of economic growth resulting in additional exchange of goods crossing the borders. Vienna possessed relatively early, since the year 1956 various waste treatment plants[37] most of which were still in use until the 1980s (Ossberger, 1997).

In the years 1956 and 1963, the construction of the first composting plant for organic municipal solid waste and the waste incinerator in Flötzerstieg was finished. The growth of the Austrian economy in the postwar years until 1970, and thus the rise in the standard of living of the population was clearly coupled to an increase in energy and resource consumption. Greater than ever before, the amount of material resources consumed and produced had a major impact on waste management up until the 1990s. Due to the lack of regulations and laws, the disposal of waste went up in the 1970s caused mainly by the unorganized dumping of that time. Because of the illegal nature of this waste dumping activity, available data on waste quantities and types of recovery is poor at best. Following the impact of the report of the Club of Rome, "Limits to Growth[38]" and various environmental disasters in the 1970s, people began to pay increasingly more attention to environmental concerns. In the 1970s a separate Ministry of Environment was established closely followed by federal legislation on waste management (Ossberger, 1997).

In 1981, the incinerator for toxic waste at the waste disposal plant in Simmering (EbS)[39] plant was built. The beginning of the 1980s was marked by a critical view of the management of solid waste in Vienna, specifically the increased use of waste incinerators at the expense of reduced recycled materials. In response to these

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[37] With the exception of organic matter (*Biomüll* in German)
[38] *The Limits to Growth* is a 1972 book commissioned by the Club of Rome in which a computer model simulated potential scenarios and consequences of the interaction between the Earth's and human systems.
[39] *Entsorgungsbetriebe Simmering* in German

criticisms the Department of waste management and street cleaning (MA48, 2013a), developed a municipal solid waste management plan for Vienna in 1985. This plan was presented to the city council of Vienna containing objectives such as, the prevention or where not possible the reduction of volume of waste resulting from the production processes of services and goods with respect to quantity and quality of the waste produced. Additionally, waste separation was to be implemented, to facilitate the re-use and further treatment in recycling plants (e.g. production of secondary raw materials and direct use of energy present in solid waste). The waste that could not be re-used was to be disposed of in such a way as to cause the smallest possible impact on the environment. To achieve these objectives several activities were considered; among them was the collection of toxic domestic waste, an increase in the collection of recyclable materials, the rebuilding and modernization of the Rautenweg landfill, the upgrading of Vienna's waste incinerators with state-of-the-art air pollution control systems as well as the modernization of toxic waste incinerator in EbS Simmering

As population and waste were growing in Vienna and it became increasingly difficult to find new spaces to create new landfills, it became necessary to reduce the waste generated. A proposal put forward the collection of organic waste such as food waste and plants for composting as part of political efforts to reduce waste and re-use materials. Due to the social and political conditions at the time, the debate and the resistance to create additional landfills and waste incinerators materialized into a ban prohibiting the construction of new units indefinitely. The plan was to use the only landfill in Vienna; only possible with a reduction of municipal solid waste. Based on this diagnosis, goals were defined in the new environmental policy objectives in 1985. Vienna's solid waste management established the reduction of the volume of waste produced, the recovery and treatment of waste (secondary raw materials, organic materials and energy present in waste) and the treatment and final disposal of waste as its main priorities. These priorities reflected the main objectives of solid waste policy in the 1990s in Europe, represented by guidelines published by the European Community. The waste management law of 1990[40] was essentially composed of guidelines in part from the Swiss waste management practices and pieces of legislation, which originated in different Austrian states. Since then, the

[40] *Abfallwirtschaftgesetz* 1990 in German also referred to as AWG 90.

perception of waste management has shifted from a technical to an environmental issue to protect the life and natural resources (Ossberger, 1997).

In 1994, Vienna had a population of approximately 1.6 million inhabitants and produced approximately 1,800 tons of waste per day. A significant share of this waste was collected and separated, with the remainder being sent to landfills or incinerators, which had to comply with strict environmental control standards (Demajorovic, 1994).

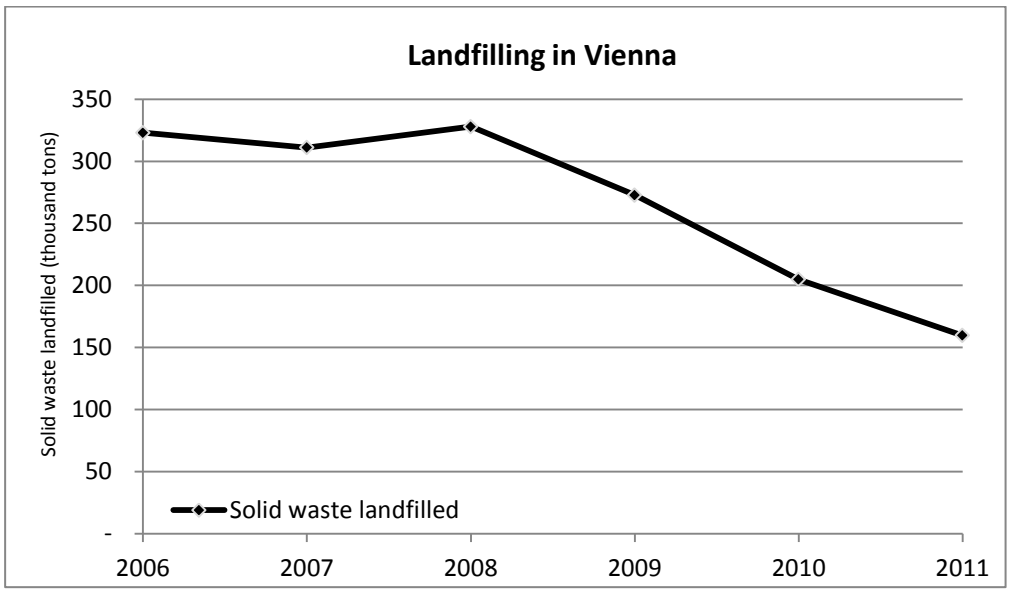

Figure 5 Landfilling in Vienna[41]

Based on the waste management hierarchy, Vienna's strategy based of reducing waste early in the material lifecycle has helped it to minimize the amount of solid waste deposited in landfills.

[41] Sources: MA48

4.2. Mexico City

During pre-Hispanic times, the problem of garbage in Tenochtitlán[42] was the responsibility of noble men and monarchs who decided to forbid the sale and purchase outside market areas. Therefore, trash was rarely found on streets outside markets. The cleaning system under the Aztecs was attended by over a thousand men, which carried out their work with pride and satisfaction of having a clean city. Later in colonial times, the viceroy Revillagigedo established the first group of horse-drawn carts that collected garbage and deposited it in landfills.

In the early beginnings of independent Mexico, a sanitation system was established in the Federal District with carts drawn by horse power, which in the morning and at night passed through the streets ringing a bell for people to come and deposit their trash. Failure to comply resulted in penalties in the form of fines imposed on those who threw garbage in the street[43].

At the end of the nineteenth century, garbage collection was carried out by a fleet of about 80 carts. Councils in villages designated people to act as “salubrity police”[44] and were in charge of cleaning the streets, markets, public squares, hospitals, prisons, and remove everything that could alter public health (Reyes, 2004). In 1981, the health council created Mexico’s first sanitary code (Ortega Gonzales, et al., 2010).

In year 1936, the garbage collection and cleaning employed around 2,500 people, while the vehicle fleet already included dump trucks handling the larger loads within the city and delegating the mule carts to service the outer areas of the city. From 1940 on, two approaches were proposed to handle waste. The first was to recycle the waste since it was one of the primary causes for contaminating the soil, air and water. The second approach was to keep waste dumping sites as far away as possible from the city. It was only a year later that both approaches were adopted and Mexico City saw the construction of two of its first landfill sites[45]. Because of the development model in force, which gave priority to the industrial sector over

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[42] Tenochtitlán was the Aztec city-state that became the capital of the expanding Mexican Empire of the 15th century, and following its capture by the Spanish in 1521, was eventually renamed to "Mexico".
[43] These fines supposedly increased with the number of offences, with 2 pesos for the first time; 4 pesos the second and third 6 pesos.
[44] Salubrity refers to the promotion of good health. *Policia de salubridad* in Spanish
[45] The landfills *Santa Cruz Meyehualco* and *Santa Fe.*

agriculture, Mexico's urban development in the last century was characterized by a marked trend towards concentrating the population in a few cities. Between 1940 and 1960, Mexico City, being the most important economic center, was the first destination to migrate to for a large number of people further increasing its population from 1.7 to 4.8 million people between 1940 and 1960, looking for employment and alternatives to rural life.

In the early 1960s the Urban Services Department was established and with it the office of Solid Waste Collection, which up until now is responsible for the collection, transportation, treatment and disposal of solid waste in the city of Mexico. In the mid-seventies, the capital found itself with an exceedingly large concentration of people and thus began to emerge as an expulsion zone, since it began to reduce the number of its residents in midst its districts, a situation that persisted until the late nineties (Castillo, 2005). During the urban sprawl spread to the neighboring municipalities of the Federal District[46], there was a significant shift from the center to the periphery, constituting what is nowadays known as the metropolitan area of Mexico City[47] (ZMCM), which saw its population grow from 5,4 to 13 million between the years 1960 and 1980 respectively (CONAPO, 1995). Thus, Mexico City's problem with solid waste in a broad sense cannot be reduced to the scale of the Federal District, since its development implies growth and geographic expansion of its metropolitan zone, and from an environmental point of view the whole basin of the Valley of Mexico. Like elsewhere during the 1970s, Mexico experienced public interest on environmental issues leading to the formation of the Environment Improvement Undersecretary in 1972, which launched a countrywide program to manage municipal solid waste. The program resulted in the establishment of technical regulations for municipal solid waste (Ortega Gonzales, et al., 2010).

Faced with a high scale of urbanization from 1950 to 1970, the demand for public services increased drastically, eventually leading to a crisis in 1980. At this stage, traditional waste management was not able to meet public demand resulting from the impact of modernization in the Federal District. In 1980, a series of conditions became apparent. For one, open dumping was common practice in the city; there

[46] Throughout this paper Mexico City may be referred to its coterminous Federal District (stemming from its name in Spanish México, D. F.)
[47] *Zona Metropolitana de la Cuidad de México* in Spanish

were nine open dumps[48], which accumulated all of the waste arriving from Federal District and parts of neighboring municipalities. The garbage truck fleet was in a deplorable condition with outdated models that were not in service due to lack of maintenance. Only 60% of the vehicle fleet was used at a time. Mexico City had permanently many illegal dumping sites in vacant lots, alleys, canyons, etc. There was and still remains a strong presence of groups of scavengers, represented by leaders who exploit their labor in waste separation. These scavenger groups are part of an informal economy with all the implications of such working conditions. Similarly, while official garbage collection and cleaning workers are in the payroll of the city government and receive a salary, they constitute an organization that works in a private manner based on parallel profits to their salary in the form of "tips" paid by the public.

After a period of solid economic growth, falling oil prices coupled with increasing world interest rates and increasing inflation caused Mexico to experience a severe economic crisis in 1982 leading to high levels of unemployment and further stimulating migration to the capital. Between the years of 1983 and 1988, President Miguel de la Madrid launched the National Plan of Development[49], effectively integrating environmental issues into the political agenda for the first time (Valenzuela, 2005). As of 1983, a reform of the Mexican constitution specified in its 115th Article that municipalities would be in charge of street cleaning, waste collection, transportation, treatment and final disposition of solid wastes.

Moreover, the year 1983 saw to closure and rehabilitation of Meyehualco Santa Cruz landfill, which consisted of covering solid waste with clay composites and drilling holes to vent the biogas generated by the anaerobic degradation. The closure of this landfill stimulated the development of others[50]. This exacerbated the problem for garbage disposal in the Mexico City. One topic of interest was the spread of ecological deterioration in neighboring municipalities of the Federal District caused by the inadequate management of solid waste, which had reached worrisome proportions, since no control mechanisms were in place and in many cases solid waste had exceeded the administrative capacity and management of state and local governments. Between 1950 and 1993, Mexico City had almost

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[48] The nine open dumps were *Santa Catarina, San Lorenzo Tezonco, Tlalpan, Cuautepec, Milpa Alta, Santa Fe, Tláhuac, Venustiano Carranza and Gustavo A. Madero*
[49] *Plan Global de Desarrollo* in Spanish
[50] *Santa Catarina, San Lorenzo Tezonco, Tláhuac, Milpa Alta, Tlalpan* and *Bordo Xochiaca*

tripled the amount of solid waste produced by its inhabitants, while simultaneously changing the composition of the waste from close to 5%, to 40% of non-organic waste (INEGI, 1994).

In 1984, the city government decided to reverse this situation, implementing the first solid waste strategy (PMRS)[51], created by the Urban Services Department. The main goals of the strategy were to close down, clean up and rehabilitate the ten biggest dumps in Mexico City. Moreover, the strategy included the renewal of the garbage vehicle fleet and the expansion of the areas covered. A major infrastructure was created to allow the efficient transfer of waste solids from large trucks and guarantee the eventual arrival to its final disposal site. Programs for the removal of illegal dumping sites were introduced throughout the city. Additional landfills were built to control the disposal of municipal solid waste. One of the world's largest landfills, the "Bordo Poniente" was opened in 1985 including high-density polyethylene barriers to protect leaking of leachate. The strategy also foresaw the planning and formal management of solid waste, taking into account various studies and data to identify the type of waste and its generation. These goals were accomplished in large part to try to maintain the control and solid waste management in the Federal District. Yet these changes led to strong clashes with groups of workers of the Department of the Federal District and scavengers groups, who saw the prospect of seeing their economic and political power vanish, and did not allow modifying the processes necessary for real change in the city's solid waste management. The misalignment of political interest explains best why waste management in Mexico City has suffered from "up and downs" up until its present state.

In 1988, a new law known as the General Law of the Ecological Equilibrium and the Protection of the Environment (LGEEPA) [52] was created to establish the responsibilities and environmental duties of the Mexican government (Valenzuela, 2005). This enactment of this law resulted in the creation of the Official Mexican Standards (NOM)[53], in charge of the location, design, building and operation of the different landfills used for MSW final disposition.

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[51] *Plan Maestro de Residuos Sólidos* (PMRS) in Spanish
[52] *Ley General del Equilibrio Ecológico y la Protección al Ambiente* in Spanish
[53] *Normas Oficiales Mexicanas* in Spanish

The creation of the Metropolitan Commission for the Preservation and Control of Environmental Pollution (COMAPA)[54] in 1990 was the first attempt to take action against solid waste. The Federal District established an organizational structure that allowed it to manage the problem. Nonetheless, in neighboring municipalities the situation became worse. A clear inequality in waste management existed between Mexico City and its neighboring municipalities, making it necessary to create a regional authority with the concrete responsibility to develop and operate a comprehensive strategy to manage solid waste in the whole area.

By 1990 the metropolitan zone of Mexico City had become the most densely populated area in the country with around 17 million people, corresponding to around 20% of the total population in Mexico, a number that has more or less held steady over the last decades. Eventually the city started to show symptoms of overpopulation, with its public service infrastructure not being able to meet the demand, the irregular use of land, settlings on inadequate areas, and an accumulated deficit in the provision of urban facilities in general. All this contributed to create social pressures and different levels of social marginalization and policies for its inhabitants. Given this situation and the need to solve these problems, the first agreements had already emerged in 1988 between the Department of the Federal District[55] and the State of Mexico to coordinate actions and provide comprehensive solutions to the metropolitan area (Castillo et al., 1995).

As of 1991, the waste generated in Mexico City ended up in three giant landfills[56] to replace six other sites that were closed[57]. In that same year, the gas from uncontrolled waste caused thirteen fires and resulted in the death of numerous victims, including children who lived in the surrounding area of the landfill. This event led to the creation of the Programme of Metropolitan Solid Waste Management in the year 1992 (Reyes, 2004). In the same year signed the convention on sustainable development and biodiversity in Rio de Janeiro, laying the path for new reforms at the national level and the creation environmental organizations. In the same year, the National Ecology Institute (INE) was created.

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[54] *Comisión Metropolitana para la Preservación y Control de la Contaminación Ambiental* (COMAPA) in Spanish

[55] The now dissolved *Departamento del Distrito Federal* used to be the public organ in charge of the government of Mexico City.

[56] *Bordo Poniente, Mountain Meadows* and *Santa Catarina*

[57] *Milpa Alta, Tlalpan, Tláhuac, Tezonco San Lorenzo, Santa Fe* and *Meyehualco Santa Cruz*

The Office for the Attorney General for Environmental Protection (PROFEPA) was established to monitor and survey the implementation of new environmental laws. With the opening of its markets and its entrance in the NAFTA agreement of 1994, Mexico had to comply with a series of environmental regulations, in particular the regulation of waste management leading to new reforms of the LGEEPA in 1996 (Valenzuela, 2005). In 1994, the prior fishing agency was expanded to give it new environmental functions resulting in the creation of the Secretariat of Environment and Natural Resources (SEMARNAT)[58].

The General Law for the Prevention and Integrated Management of Wastes (LGPIR) [59] was enacted in 2003, improving the lack of MSW management regulations. With this law waste was considered, as a potential contaminant that had to be avoided and where possible reduced to allow for its environmentally adequate management. More importantly, waste was redefine as material with value because of its potential reuse, recycling and the energy contained within (Cortines de Nava, 2001).

In 2004, the Program for Integrated Solid Waste Management[60] (PGIRS) was launched with the goal of improving the coverage and effectiveness of public cleaning and minimizing the generation and disposal of waste. For the first time, education and communication strategies were considered essential for the implementation of the remaining PGIRS strategies and currently pursued in search for a cleaner city (SMA, 2010). In the same year, the NOM included updated technical specifications for the design and construction of landfills in Mexico. This new norms, defined separate leachate treatment, as well as biogas collection from solid waste degradation as new standards.

Nowadays the various districts in Mexico City are themselves responsible for collecting their solid waste and its subsequent transport to transfer stations. One aspect that still has to be considered is the collection efficiency, which is largely influenced by the type and model of the collection vehicle. The most efficient results are obtained when using rear loading vehicles, because more waste can be

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[58] From 1982-1994 *Secretaría de Pesca*, from 1994-2000 *Secretaría de Medio Ambiente, Recursos Naturales y Pesca* (SEMARP), from 2000 until present *Secretaría de Medio Ambiente y Recursos Naturales (*SEMARNAT).
[59] *Ley General para la Prevention y Manejo Integral de Residuos* (LGPIR) in Spanish
[60] *Programa de Gestión Integral de Residuos Sólidos* in Spanish

compacted and thus the loading height can be maintained, in turn resulting in less trips to transfer stations and lowering fuel consumption.

4.3. São Paulo

In São Paulo until the year 1869, there was no regular garbage collection and residents of São Paulo had to bury the trash in the backyard or use it to fertilize their gardens since there was no garbage collection in the city. First attempts to manage waste in the city of São Paulo dates from the nineteenth century. At that time, certain areas far away from city center were designated for garbage disposal. The responsibility of transport was up to the interested citizen. In 1869, the City Council hired for the first time, a private company to perform home collection. In 1892, the Office of Public Hygiene was established, and in 1893, a contract was signed with a cleaning company, that included street and sewer cleaning, waste incineration and cleaning markets.

In the twentieth century, solid waste management in Brazil was determined by population growth and migration to the cities via changes in the consumption patterns (Lopes, 2006). In the early twentieth century, the population of the city of São Paulo had 240,000 and produced an average of approximately 10 tons per day of waste, which were disposed of in uncontrolled open dumps (ABES, 2006). In 1913, the city began to tackle municipal solid waste, building a waste incinerator in the city district of Araça with a capacity of 40 tons per day and introducing animal driven carts to collect household waste. Before that, garbage was in large part composed of organic matter and reused by residents for multiple purposes such as building homes, as fertilizer or simply burning fuel. Garbage was also distributed to carters, who fed it to animals. In 1914, the mayor of the city determined that the cleaning services ought to be operated directly by the Municipality. As of 1925, it started using a fermentation process stations, which can be considered as precursors to composting systems. In 1940, São Paulo already had around 1,500 horse-powered vehicles at its disposal to keep the city clean.

The population reached 2 million people in 1950, and was generating about 1,000 tons of solid waste per day. At that time, thanks to its prior inauguration in 1949, the *Pinheiros* incinerator based on American technology, was already operational. Another incinerator, the *Ponte Pequena*, with a capacity of 150 tons per day, was installed within 1959, and later on, in 1968 two additional incinerators in the neighborhoods of Vergueiro and Ipiranga were built, with a capacity of 150 tons per day. Yet the option of incineration as a way of disposing solid waste did not really offer a significant change to the way waste was managed in the city of São Paulo,

because it represented only a small portion of the total waste generated in the city. In 1970, the population of São Paulo reached 6 million inhabitants. Meanwhile, the same time, the capacity of the three incinerators totaled 500 tons per day. With the addition of composting plants [61] an additional 600 tons per day or organic waste could be disposed of. Still until the early 1970s, open waste dumping was common, particularly in the outer regions of São Paulo and along major rivers. In 1971, plastic bags made out of polyethylene started to make their way into the solid waste stream and the city was generating close to 12,000 tons of solid waste per day.

A Master Plan for Solid Waste Disposal[62] in São Paulo, was drawn-up in 1977 representing a major shift in the policy for management of waste, in so far that landfills were identified as the most suitable and cost effective method to dispose of solid waste. On this basis, it was proposed to build 16 landfills in a timeframe of 15 years. By the year 1979, four new landfills[63] were built and private companies were hired to operate and maintain the waste disposal services. However, the remainder of the plan could not be carried out due to evaluation errors made during the study. Many of the foreseen areas for the construction of landfills were not immediately expropriated because many were occupied by people who had newly migrated to São Paulo, or because they were in watershed areas which are now protected by law. Another factor was the growing awareness of the population in the suburbs, which also started to mobilize against the construction of landfills in fear of reduced living conditions and swindling property prices. In 1979, "Energetic Landfills"[64] were proposed for the first time to combine the objectives of an environmental alternative and economic rentability. In the end, the projects were limited to traditional constructions excluding the investments of the proposed new generation landfills.

From 1979 until 1994, few changes were made to São Paulo's waste management model. During the government of Janio Quadros[65], bids were made to build two new incinerators and composting plants respectively. These bids were eventually denied due to the lack of convincing environmental impact studies and lack of definition of the areas where the facilities were supposed to be built. In the end, the required impact studies were carried out, but the projects were never resumed. During the

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[61] *São Mateus* and *Vila Leopoldina*
[62] *Plano Diretor para Disposição Final de Resíduos Sólidos* in Portuguese
[63] *Lauzane Paulista, Banderiantes-Perus, Sapopemba* and *Sao Mateus*.
[64] *"Aterros Sanitários Energéticos"* in Portuguese refer to waste incineration power plants
[65] Jânio da Silva Quadros served as mayor of São Paulo from 1986 to 1989.

Luiza Erundina administration from 1989 to 1992, the São João landfill was built to dispose of household waste, while the Itatinga landfill was destined for inorganic waste. Even though this administration started a program of waste separation and collection, building a separation plant for the recycling of plastic, aluminum, glass and paper, efforts proved too small since the actual quantity separated represented around 1% of total household waste collected (Demajorovic, 1994).

As of 1994, São Paulo used a mix of landfills, waste incineration power plants and composting plants to manage the city's waste. The waste separation program was disabled. Landfills in the São Paulo area suffered under the absence of a system suitable to collect the leachate produced and the lack of control mechanisms to track efficiency and accurately define the degree of environmental degradation. With a population of approximately 11.5 million, the city of São Paulo was generating approximately 13,500 tons of waste per day (Demajorovic, 1994). The city's waste was deposited in landfills, composting plants, incinerators and transfer stations. However, none of these units had been constructed to avoid environmental damage and is nowadays obsolescent. The operation of the current system of solid waste management reflects two striking features valid for most municipalities; the neglect of damage on the inhabitants of urban centers especially those living in remote areas and the impact on the environment. The majority of waste treatment plants are installed in neighborhoods far from the city center, saving the residents of the central districts the inconvenience caused by unsuitable units and transferring these problems to the residents of more distant neighborhoods. In 2006, three landfills were in operation[66] receiving around 90% of the waste produced in São Paulo. At that time, São Paulo had only two composting plants[67]. Hospital waste was disposed of in two incinerators[68]. The *Pinheiros* center sorted and recycled materials. Two transfer stations exist to reduce transportation costs. In addition, the city plans on building two incinerators within the city to extend the life of existing landfills.

Currently, the technical, economic and institutional situation in Brazil presents many challenges to adequately manage solid waste in São Paulo. One often-ignored aspect is the financial sustainability of the waste management services. In Brazil, more than 50% of municipalities do not charge for the public services of urban sanitation, and, when collected, these values are insufficient to cover the costs of

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[66] *Bandeirantes, São João* and *Santo Amaro*
[67] *Vila Leopoldina* and *São Matheus*
[68] *Ponte Pequena* and *Vergueiro*

providing the services. Moreover, it is commonly accepted, that especially in Brazilian cities, that any type of transition towards a more efficient and sustainable solid waste management without ensuring equal coverage for all levels of society with adequate services for water, sewage and energy is not feasible (Jacobi and Besen, 2011).

Likewise, it is becoming increasingly apparent that the fee structure has to be flexible, in order to increase efficiency in waste management. In other words, the applicable rate has to be proportional to the waste quantity generated to make this public service sustainable and more importantly raise awareness and educate citizens to encourage them to reduce the quantities of waste produced. Currently the federal government is investing in the construction of landfills and energy recovery, central sorting stations, composting centers and training for informal waste workers (scavengers). However, the Brazilian reality requires the commitment of municipal leaders to choose appropriate solutions with reduced costs and technologies compatible within the local context, as well as a fair remuneration for the service rendered by waste pickers. Strategies to promote waste reduction of the generating sources through a combination of environmental education and permanent waste separation services that include informal waste workers to reduce waste disposal on the ground have yet to emerge. The lack of land for waste disposal is a global problem, and São Paulo is no exception. Even though an increase in public awareness has been observed, São Paulo's residents have little information on what happens to their trash and thus have little say to decide on how best to manage it. In addition, there are institutional spaces for dialogue with the city universities and nongovernmental organizations that work with solid waste management for the construction of a model of management for the city.

Of course, barriers associated with the private economic interests do exist and are part of a vicious cycle which is incentivized by contracts that focus on the collection, transfer and landfilling. At present, the challenge is to reverse the prevailing logic and invest more in the reduction of overproduction and waste, as well as separate collection and composting, and less on the final destination. In São Paulo, there is already a large contingent of collectors arranged. The expansion of waste sorting is urgent and strategic. If well conducted in the future, it may represent an opportunity to reduce the costs of the city, as these services will generate thousands of jobs and promote a greater sense of co-responsibility among citizens in regards to urban sustainability (Jacobi and Besen, 2011).

5. Qualitative analysis of disease vectors for untreated wastewater versus inadequate landfilling

The risk for disease transmission from contaminated solid waste through the handling and disposal of contaminated food, waste from pets and baby napkins may be the same as through the collection and disposal of excreta and sewage (WHO, 1991). This insight demands that solid waste and related health risks be assessed to establish clear guidelines on the priorities of waste management implementation

5.1. Health issues of untreated wastewater

The potential for pathogenic proliferation in water is great because inadequately treated wastewater effluents can cause eutrophication in receiving water bodies and thus lead to the creation of environmental conditions that favor the proliferation of waterborne pathogens of toxin-producing cyanobacteria. Despite the beneficial role that various microorganisms play in wastewater systems, a great number are thought to contribute to various waterborne outbreaks. Additionally, analyses of wastewater effluents have revealed a range of anthropogenic compounds, many of which have endocrine-disrupting characteristics (Akpor and Muchie, 2011). Transmission of diseases encompasses humans and animals, increased levels of nutrients may cause eutrophication of water bodies leading to other unwanted side effects for aquatic organisms and subsequently for the rest of the food chain. Around 90% of wastewater produced globally causes water pollution because it remains largely untreated in developing countries.

As water is ever more becoming a precious and rare resource in some parts of the world, the use of untreated wastewater is affecting agriculture (Scheierling et al., 2010). The link between agriculture and wastewater is amplified in the case of developing countries where the majority of the livelihoods depend on the resulting agricultural output. Due to the relentless increase in urban population worldwide, local farmers have to compete with municipalities for water to irrigate their crops. As agriculture is competing with expanding industry and municipal use of water, wastewater irrigation becomes a welcome solution. The concept of using agricultural lands to dispose of wastewater and simultaneously enrich soils is not a new one by any means, but the disadvantage of this solution is that it effectively provides a

closed-loop system for pathogenic microorganisms to propagate, manifesting itself in the spread of diseases (Loehr, 1977). The implication of these conditions becomes clear; with a lack of wastewater treatment and limited access to clean water, in developing countries whose economies rest on agricultural output and have to use untreated wastewater for irrigation even if it represents a health risk to their population. Despite the long tradition of wastewater irrigation, efforts to quantify the location and amounts of re-used wastewater are confronted with methodological problems (Khouri et al., 1994).

Because wastewater carries pathogenic organisms, it can have serious consequences, particularly if the produce is consumed raw. While no complete inventory on global wastewater irrigation exists, global figures usually cite around 10% of irrigated land. Used for irrigation, wastewater can be raw (untreated) or reclaimed (treated) and can be applied directly to crops or indirectly through dilution in rivers and reservoirs after discharge. While reuse can be an intentional part of a project, in developing countries, it just happens. The use of wastewater depends on the region and the wastewater treatment in that region. Nonetheless, because the costs of improving sanitation are considerable compared to other more immediate needs, it seems that for the foreseeable future raw wastewater will continue to find its way on to agricultural lands (Jimenez, 2006). Despite the inconclusive literature regarding the impact of wastewater irrigation on public health, studies in Mexico City using non-specific parameters, such as TOC[69] (Mazari-Hiriart et al., 2008) confirm that its addition as a fertilizer supplies a considerable nitrogen load to the aquatic system, offering a suitable conditions for the propagation of microorganisms.

5.2. Health issues of inadequate solid waste management

Since landfills represent the most cost-effective waste management solution they tend to be prevalent in particular in developing countries, including the cities within scope of this study. Thus, the question remains; is it the most effective method to achieve the long-term goal of protecting human health? Another major health hazard is the incineration of solid waste without the appropriate emission controls. The resulting gas of burning the waste may contain high amounts of toxic and hazardous materials, such as HCl, HF, Furans and Dioxins. Residential areas in close proximity

[69] Total Organic Carbon

to these incineration processes may be at risk. While deserving of a more in-depth review in itself, incineration is not considered in this paper, since it does not represent a common waste management strategy in the cities chosen.

Solid waste management has historically represented a risk factor for the health of human beings particularly in urban areas. Yet its risks are not exclusive to those directly involved in the handling of the waste but also nearby residents. Depending on the actual exposure time of workers, the occupational health risk may be less than the environmental health risks of residents whose exposure times are often longer than those of the workers (Cointreau and Mundial, 2006). Causal links between landfill sites and adverse effects on health in neighboring residential areas is a topic of continuous concern. However establishing whether such as link actually materializes is a complex process, crossing many areas of expertise. Most studies to-date have been epidemiological in nature and thus cannot confirm an isolated causal link (Hester and Harrison, 2002). The available epidemiological literature tends to focus on hazardous waste sites and their effects on human health. The landfill sites reviewed in these studies tend to be large, old, and subject to limited environmental controls while receiving liquid chemical and/or hazardous wastes (Fielder et al., 2000; Roberts et al., 2000). As rigorous epidemiological studies are extremely difficult to achieve and by their very nature cannot demonstrate causality.

Health issues arising from inadequate solid waste management practices are multifold. Fecal matter often found in municipal solid waste can leak into the groundwater via leachate of landfills. The attracted insects and rodents from the waste can lead to the spreading of diseases such as cholera and dengue fever. More critically the irrigation of crops, bathing and drinking of untreated water leads to the consumption of pathogenic organisms and other contaminants (Hoornweg, 2000). In fact, improper solid waste management has been linked to 22 diseases by the U.S. Public Health Service (Hanks, 1967).

The principal infective agents in solid waste have their origin in the contamination through fecal matter. Therefore, solid waste contaminated with fecal matter may contain four groups of pathogens: viruses, bacteria, protozoa, and helminthes (Feachem et al., 1983).

Potential risks to human health in solid waste require the presence of a particular pathogen as a pre-condition. Moreover, a complex system involving multiple interrelated factors influences the resulting impact in measurable terms of human

disease or infection. A potential health risk for humans from exposure to solid waste is only possible if an infective dose of virulent pathogens is present. The probability that the threshold dose for a specific pathogen and for a route is reached, is highly dependent on several characteristics of the pathogen itself. These properties include the concentration of pathogenic organisms, the time it takes between the first pathogenic release to the environment and infectivity (latency), the actual survival rate of the pathogens in the environment (persistence) and the ability of the pathogen to multiply in that environment. While many of these properties vary depending on the pathogen and the environmental conditions, the evidence seems to support that many pathogens can survive for extended periods of time on water, ranging from days to several months (WHO, 1991).

While the possibility that pathogens in solid waste may be aerolized or inhaled by the public or, in this case more likely solid waste workers does exist, it is considered a very unlikely transmission pathway and thus a low-risk exposure mechanism. Transmission through direct contact, such as cuts or abrasions embodies a real risk, yet is mostly limited to the direct handling of waste typically performed by solid waste workers, scavengers, and children.

Alternative routes of disease transmission are through passive vectors, such as insects. The two relevant main groups of insects are the two-winged fly (Diptera) and cockroaches (Dictyopera). While not many insect species have the ability to use waste storage and disposal as breeding sites, those that do can result in very large numbers. As a result, they may reach numbers high enough to endanger public health. Apart from mosquitoes, the families of the housefly (Muscidae) and the blowfly (Calliphoridae) are the most common ones linked to waste since they breed in fecal matter and come into contact with humans when feeding on his diet as adults. Cockroaches on the other hand are drawn to the moisture of waste systems and are potential carriers of fecal pathogens. The significance to human health of the pathogenic carriage by these insects is dependent on their behavior and other transmission modes of these pathogens. Poor or inadequate solid waste practices particularly in landfills, may also attract rodents.

Infection through ingestion caused by inefficient composting treatment processes offer another ingestion route. Helminthes have been shown to have high persistence levels (survival rates) in the environment and the final compost product, especially if the composting system itself does not achieve 100% kill of these organisms.

Subsequently this fertilizing agent is applied to land, where its potential for health issues is even greater, as it eventually finds its way into the human body by consumption of crops. In cases of raw or uncooked, and thus unsterile consumption such as salads, the risks of contamination are even greater.

Solid waste practices are also associated with other health risks, such as poorly controlled landfills or abandoned landfill sites, as these cost-effective waste management practices can cause the pollution of groundwater via leachate. However, the groundwater pollution is unlikely to be pathogenic in its form, since the soil acts as an efficient filtering device for the leachate. Nevertheless, if connected to the water supply without adequate treatment, leachate will affect groundwater quality and consequently human health as it contains many toxic materials (WHO, 1991). Regarding the viable pathogenic presence in leachate reaching the soil, few of the reports in the technical literature indicate any scientific investigation. Numerous studies cover the persistence of non-pathogens (bacteriophages) in water and soil, others were performed under laboratory conditions. Thus, any conclusions on the health hazards that exposure to pathogenic organisms via waste disposal on soils might represent is limited. Moreover, a multitude of existing information regarding the survival of organisms is largely controlled by a great number of variables that make the results even harder to reproduce (Loehr, 1976). The inconclusive findings from literature, while deserving of a separate in-depth review, remain outside the realm of this paper. In summary, the potential of disease-transmitting agents to survive in soils receiving waste is regulated by a great deal of variables. Longevity and pathogenicity depend on many factors; pathogenic persistence drops when placing these microorganisms placed into the chemically hostile environment that is soil. Organisms adapted to certain temperatures and the nutrition of host cells, are particularly vulnerable to the biologically competitive conditions of soil. The presence of dangerous bacteria, protozea and other infectious agents in receiving soils ought not be ignored, but the scientific observations of close to 100 years have identified hardly any instance, where appropriately treated human or animal waste caused disease when applied to agricultural land in a careful manner. However, the limitations of the previous statement regarding the safety of applying waste to soil must be emphasized; If food crops are consumed too soon after application of pathogen-containing waste, if leachate was to reach ground water, then direct or indirect waste application to soil can be considered a dangerous health risk. When compared to several available

alternatives to utilize or destroy the vast quantities of anthropogenous biological waste, the choice of soil disposal seems to be the lesser of two evils (Loehr, 1976).

Rainwater percolating through solid waste also carries a large amount of pollutants to the groundwater in the form of leachate, particularly if the underlying strata tends to be pervious or fissured (Bhide and Sundaresan, 1983). While legislation and high standards of practice in developed countries avoid leachate contamination of groundwater by using impermeable barriers in the landfills, these precautions are rarely implemented in developing countries.

While the literature on global soil properties is expanding at a rapid rate, the selection of landfill locations particularly in countries like Mexico seem random, not taking into consideration any previous analysis of environmental impact. The disperse population distribution in these areas seems to be a crucial factor in the uncontrolled dumping of solid wastes, turning these regions into sources of groundwater contamination (Reyes-López et al., 2008).

Landfill gas emissions: Landfill gas consists mainly of methane (CH_4) and carbon dioxide (CO_2) but contains also a range of organic gases in trace amounts. Rather than the bulk gases it is the trace gases (e.g. H_2S) that are of concern in public health assessments (Hester and Harrison, 2002). The exposure to landfill gas depends on the atmospheric dispersion of the emissions between the source and the receptor location. As the gaseous emissions disperse in the atmosphere, the trace constituents a diluted. Moreover, the level of dilution depends on many factors, such as distance and orientation between source and exposure point, as well as climatic conditions[70]. Whilst in theory the existing epidemiological data on landfill studies indicates that a source-receptor pathway may potentially result in exposure by inhalation to gaseous contaminants from landfill sites, the ambient air concentrations of trace gases are not sufficiently high to represent a theoretical basis for adverse health effects. Ultimately, additional studies examining real-world measurements of pollutant concentrations in landfill neighboring communities are needed to confirm or refute this conclusion (Hessner and Harrison, 2002).

[70] Wind speed, direction and atmospheric stability

6. Quantitative analysis of TOC and nitrogen emissions from untreated wastewater and improper landfilling

6.1. Untreated wastewater

In the field of environmental chemistry and water quality, in particular when performing quantitative assessments of pollution in wastewater, it is common practice to make use of the population equivalent (PE). The population equivalent serves as a reference value for the emission load in wastewater. According to the main wastewater treatment plant in Vienna, the typical PE value for untreated wastewater is PE60. It can contain the biological oxygen demand period (BOD)[71], the chemical oxygen demand (COD)[72] and total organic carbon (TOC)[73]. TOC is an established technique to gauge water quality when performing environmental analysis and is non-specific of all organic materials present. Moreover, high concentrations of TOC can confirm the presence of potentially harmful organic chemicals. This quantitative analysis will focus on the TOC of untreated wastewater for the cities covered (Andrew, 2005).

Table 2 Established values for TOC and N contents in estimations

Medium	TOC	Nitrogen
In untreated wastewater	45 g per capita/d[74]	11 g/d[75]
In solid waste[76]	250 g/kg	4 g/kg

For an explanation of the full procedure, please refer to annex 1 and 2.

[71] The BOD5 measures the amount of dissolved oxygen required by aerobiological organisms in water to digest present organic material for specified amount of time and is a solid indicator of the degree of organic pollution (Andrew, 2005).
[72] The COD provides a value of the amount of organic compounds present in the water (Andrew, 2005).
[73] In this context, the TOC quantifies the amount of carbon in water.
[74] As mentioned in (Gujer, 2007; Arceivala and Asolekar, 2007)
[75] idem.
[76] However, since 2008, only incineration residues have been landfilled in Vienna. Thus, a TOC content of 30g/kg and a nitrogen content of 0.4g/kg will be assumed.

Table 3 Estimated TOC and N in untreated wastewater[77]

	Austria (2012)[78]	Mexico City (2011)	São Paulo (2010)
Population	8,219,743	8,851,080	11,253,503
Households with sewage system (%)	99%	99.20%	96.11%
Wastewater treated (%)	99%	79%	75%
Untreated wastewater	1.99%	21.63%	27.92%
TOC in untreated wastewater (tons/year)	135,009	145,379	184,839
N in untreated wastewater (tons/year)	33,002	35,537	45,183
Total TOC emitted (tons/year)[79]	**2,690**	**31,450**	**51,600**
Total N emitted (tons/year)	**660**	**7,690**	**12,610**

[77] Final values have been rounded to 2 significant digits. For detailed figures please refer to annex 1 and 2.
[78] Due to the lack of available data in the case of Vienna, estimations for the emissions in Austria were performed

6.2. Improper landfilling

To estimate the amount of TOC and nitrogen in leachate, it is necessary to establish how much solid waste goes into landfill sites. The estimations distinguish between different landfills depending on the technical specifications of the leachate treatment in place. Where this is not possible due to lack of data, established values in the literature indicating solid waste generated per capita are used.

The assumption is that landfills fall into three main categories. Generally defined the 3 classes of landfills are:

- Sanitary landfills with state of the art leachate treatment
- Landfills with poor leachate treatment
- Open dumping

6.2.1. Vienna

The sanitary landfill site also known as “Deponie Rautenweg” in Vienna is the only landfill currently operating in the city and as such is responsible for the disposal of all residual waste. As of 2012, 125,758 tons of solid waste found their way into this landfill (MA48, 2013b). On its boundaries the surroundings of the landfill site Rautenweg are protected by two leak-proof walls separated 8 meters from each other. In addition, both walls go deep enough into the aquiclude[80] to separate the groundwater under the landfill from the surrounding groundwater. Moreover, the space between the two leak-proof walls has been sub-divided into 49 leak-proof chambers. Water from the landfill is pumped out and channeled into the sewage plant in Simmering for further treatment (MA48, 2013c). As a result of such high safety standards, the “Deponie Rautenweg” can safely be considered a class 1 landfill. Vienna deposits 125,758 tons of solid waste per year on the landfill site Rautenweg. Because the rest of the waste is accounted for and processed in different waste treatment plants, it is assumed that open dumping is non-existent in Vienna (MA48, 2012).

[80] The aquiclude or aquifuge is a geological formation that absorbs and holds water but does not transmit it

6.2.2. Mexico City

Due to the overwhelming number of landfills in Mexico City, finding accurate data on amount of solid waste deposited remains a challenge. Fortunately, established values for the average per capita waste generation in Mexico do exist and will be used to perform the approximations. Yet the numbers published depend upon multiple factors such as size of city and economic development. Studies in the field suggest 1.13 kg per day (Valenzuela, 2005) and yet others such as the secretary of social development go as low as 0.870 kg per day, while INEGI suggest values between 0.068 kg to 1.33 kg per day (de Vega, et al., 2006). For the purpose of simplicity, the calculations will use a value of 1 kg per capita per day of solid waste generation.

6.2.3. São Paulo

The city of São Paulo generates daily a total of 18,000 tons of solid waste. Of this amount 10,000 tons come from households (Prefeitura São Paulo, 2012a). As of 2013, two landfills are in operation serving São Paulo. One is the “Central de Tratamento de Residuos Leste” (CTL), the other is the “Aterro Caieiras” (CTVA). Other landfills such as the Aterro São Joao and Aterro Bandeirantes have been closed down in 2009 and 2007 respectively (Prefeitura São Paulo, 2012b). The CTL landfill has a leachate treatment station, where the fluid is collected and delivered for further treatment. The landfill also captures gas and transforms waste into energy through pipelines transporting the methane and burning it. Thus, the technical description classifies the CTL as a class 1 sanitary landfill.

The CTVA landfill is the largest central treatment and recovery plant in Latin America with an area of 3.5 million m². The landfill has a base sealing system consisting of a 2-meter thick ground layer as well as a synthetic geo-composite barrier and high-density polyethylene geo-membrane. The leachate generated during the decomposition of organic matter in municipal solid waste and rainwater is collected thorough a drainage system and then transported to storage tanks for subsequent appropriate treatment at the Brazilian waste management company

SABESP[81]. The biogas[82] generated in the landfill is pumped through drains and transported to the burners for combustion (Caieras, 2013; Candiani and Silva 2011). As a result the CTVA can also be considered a class 1 landfill.

Table 4 Classification of landfill sites

Classification	Description	TOC and N content in leachate post-treatment
Class 1	Sanitary landfills with state of the art leachate treatment	0- 10%
Class 2	Landfills with poor leachate treatment	10-50%
Class 3	Open dumping	50-100%

Since their inception, both landfills have been operating at full capacity. The CTL receives on average 1.74 million tons of household waste a year (6,000 tons per day). The CTVA receives 7,000 tons of solid waste a day (Silva et al., 2013).

[81] SABESP is owned by the state of São Paulo and is the world's largest waste management company by market capitalization.

[82] Primarily consisting of methane, carbon dioxide, oxygen and other trace gases.

6.2.4. Estimating TOC and nitrogen content for unaccounted solid waste in Mexico City and São Paulo

Based on the comprehensive study of the Brazilian Institute of Geography and Statistics the shares of unaccounted solid waste (not being disposed in class 1 sanitary landfills) has been estimated in order to calculate their emission load. Inferred from the study, the following percentages for cities with more than 1 million inhabitants have been calculated and are subsequently used as a basis to estimate solid waste shares in class 2 and class 3 landfills (IBGE, 2008)

Table 5 Estimated shares of solid waste between different landfill classes[83][84]

	Total solid waste (tons/year)	Solid waste deposited in class 1 (tons/year)	Solid waste deposited in class 2 (tons/year)	Solid waste deposited in class 3 (tons/year)
Shares (%)	100%	81.89%	15.97%	0.02%
Mexico City	3,162,470	2,645,730	515,960	780
São Paulo	6,570,000	4,745,000	1,822,230	2,770

The following table presents the total amounts of TOC and N contained in all solid waste deposited across all landfills. Minimum and maximum values of the different ranges were defined as part of the landfill classification.

Table 6 Estimations of TOC and N emitted by landfilling[85]

	Minimum TOTAL of TOC emitted (tons/year)	Maximum TOTAL of TOC emitted (tons/year)	Minimum TOTAL of N emitted (tons/year)	Maximum TOTAL of N emitted (tons/year)
Vienna	-	4	-	1
Mexico City	1,290	7,110	50	420
São Paulo	4,560	23,970	150	1,110

[83] Adapted from IBGE. For full a explanation please refer to annex 4, 5, 6 and 7.
[84] Final figures have been rounded to 2 significant digits. For detailed figures please refer to annex 3,4,5,6 and 7.
[85] Idem.

7. Results and Discussion

The obtained results and their interpretation are dependent on certain set of assumptions. While every precaution has been taken to use official government sources for the data sets wherever possible, the results can only be read as indications due to the limitations of the study.

Table 7 Comparison of estimated emissions via untreated wastewater and leachate[86]

	Total TOC emitted by untreated wastewater (tons/year)	Total N emitted by untreated wastewater (tons/year)	Maximum TOC emitted by leachate (tons/year)[87]	Maximum N emitted by leachate (tons/year)[88]
Austria (2012)	2,690	660	4	1
Mexico City (2011)	31,450	7,690	7,110	420
Sao Paulo (2010)	51,600	12,610	23,970	1,110

For one, the available data restricts the direct comparison of results between the cities chosen for the study. This is mainly due to the format in which some countries publish their data. In larger countries, it is common to publish data by municipality instead of cities. This makes sense in those countries, because the municipalities are the legal authorities in charge (in all things water supply, sewage service and waste management) for the agglomeration of cities that make up the actual municipality.

Moreover, the data necessary for the impact assessments for the same timeframe was not available at the time of writing, thus further limiting a direct comparison between the regions in the same years. Due to the differences in dimension and more importantly lack of available data in the case of Vienna, the calculations compared the emissions of Austria (and not Vienna), Mexico City and São Paulo for the pollution load in untreated wastewater.

Given that soil and groundwater pollution via leachate, happens over a period of approximately 100 years, the obtained results of potential pollution load would have

[86] Final figures have been rounded to 2 significant digits. For detailed figures please refer to annex 3,4,5,6 and 7.
[87] Values for Vienna
[88] Idem.

to be sustained for the same period of time in order for the full contamination to take effect on its environment. Nonetheless, assuming that current practices in wastewater treatment and landfilling prevail for the next 100 years, the values proposed in this study do give an estimate of potential emissions.

The results from the previous estimations demonstrate in numeric terms that in the case of Austria, Mexico City and São Paulo untreated wastewater contains a larger amount of TOC and nitrogen. Nevertheless its implications remain clear; the untreated wastewater in all three cases contains a higher contaminant load and thus represents a higher impact on both public health and the environment.

However, the investigation does not cover the final disposal of leachate and thus a definite conclusion on its impact in all three cases remains elusive. Notwithstanding its limitations the calculations are an indication of potential environmental pollution and its negative effects on public health.

8. Summary and Conclusions

The historic reviews of Vienna, Mexico City and São Paulo presented changes in the handling of sewage and waste management as a product of political, economic and social factors. The gradual evolution of sewage, water treatment and waste management was the result of constant and continuous improvements supported by environmental and public health legislations as well as institutional and legislative infrastructure. All cities have at some stage in their history experienced disease epidemics as direct consequence of inadequate sewerage and treatment of wastewater.

The resulting losses in human life have so far proven to be the main catalyst for rapid improvements in sewage and later wastewater treatment by their respective governments to remedy the situation. Environmental protection remains a low political priority in many developing countries that must focus on economic growth. Consequently open or uncontrolled dumping, as practiced in industrialized nations up until the 1960s is still common practice in developing countries. Only upon tragic events, such as major landslips[89], immersing whole communities in waste, do local governments react or intervene to improve the situation. A clear progression in urban infrastructure from water supply network, to sewage service and eventual wastewater treatment has also been observed in all three cities. Albeit sluggish, trends over the last decade for sewage coverage of households and wastewater treatment in Mexico City and São Paulo represent improvements in infrastructure and living standards. It remains to be seen if governments will be able to maintain the rate of improvement in face of a growing urban migration, which will undoubtedly create more demand on these services. While water privatization has been touted as a possible way to accelerate increase water and sanitation access in to the poor areas in Brazil, studies remain inconclusive and at times even suggest that private incentives result in reduced coverage of such areas (McNallen, 2005; Olivier, 2006).

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[89] On the 21st of February 2005, the landslide disaster at the Leuwigajah disposal site in Bandung, Indonesia following rain fall ended up costing 140 lives, bringing the issue of municipal solid waste management into the political debate and, can be considered a turning point in which public awareness was heightened in regards to waste management (Chaerul et al., 2007); On the 10th of July 2000 after ten days of heavy rain fall a landslide was triggered at the Payatas Landfill in Quezon City, Philippines burying over 300 people in the process (Merry et al., 2005).

The contrast between Vienna and cities in developing countries is decreasing, however the key priority for cities worldwide still remains the same as in Europe and North American up to the 1960s, in other words ‘getting the waste out from the foot’. Due to the tropical climate of many emerging countries and the resulting increase in waste degradation, the need for daily collection is much greater and not surprisingly often costs 10 to 20% of a city’s budget (Wilson, 2007). Waste has a considerable value particularly in the informal sector, as it represents a key driver to collect, separate and resell recovered materials to make a living in many parts of the world (Wilson et al., 2006). While this paper did not adequately cover the economic importance of landfills for the informal economy in Mexico City and São Paulo, its role as a deterrent for the reduction of solid waste deposited in landfills, must be acknowledged.

The literature on possible health risks via different exposure pathways has shown the risks associated with both, untreated wastewater and inadequate landfilling practices prevalent in developing countries. The property of water to not only offer a breeding ground for pathogenic organisms but also to toxic substances and transport disease vectors in space, suggests that developing countries should focus their efforts on suitable water management to transport and treat raw sewage in order to protect human health.

The results of the quantitative analysis performed estimated the potential emission loads for TOC and nitrogen in untreated wastewater and leachate in landfills as way to compare their impact on the environment. Due to the constraints of this methodology used in this investigation, such timeframe and location. As previously mentioned, it would take around 100 years for leachate to fully contaminate its surroundings. Moreover, it is assumed that unaccounted solid waste (i.e. that is not landfilled) is deposited in open landfills. Therefore, the geographic location of such dumping sites plays a critical role in determining its effects on the degree of pollution, since a higher distribution of such sites over a larger area would result in a lower contamination of the location. Geological variables such as the depth of groundwater and composition of the soil in the location of landfill sites have not been included in the study. Yet their importance in terms of filtering toxic substances and disease vectors cannot be neglected. Due to these limitations, the results offered cannot provide any clear evidence. Nonetheless, the estimative values obtained do indicate the relative importance of treating wastewater to minimize environmental damage and public health risks.

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Annex

Annex 1. Procedure for estimating the TOC content in untreated wastewater

The estimated ground water accumulation of TOC will depend on the following factors:

Variables	Values
TOC in untreated wastewater	45g per capita per day
Population of Austria (2012)	8,219,743 inhabitants
Timeframe	365 days
Households serviced by sewage	99%

The calculations used to assess potential loads of TOC and nitrogen load release into the water are as follows:

TOC in untreated wastewater x population x 365 days = Total TOC in untreated wastewater

→ 45g/c/d x 8,219,743 x 356 days = 135,006 tons of TOC per year in untreated wastewater.

If we take into account that only over 99% of households in Austria are serviced by the sewage system and that close to 99% of the wastewater is treated, the total amount of untreated wastewater that is reemitted can be calculated:

Percentage of households without sewage + Percentage of untreated wastewater = Total amount of untreated wastewater reemitted.

→ $\left(1 - \frac{99}{100}\right) + \frac{99}{100} \text{ x } \left(1 - \frac{99}{100}\right) = 1.99\%$ of untreated wastewater reemitted

Thus, the total amount of TOC emitted in a year is:

Percentage of untreated wastewater reemitted x Total TOC = the total amount of TOC emitted in a year.

→ $\frac{1.99}{100} \text{ x } 135{,}006 = 2{,}687$ tons of TOC where emitted in Austria in 2012.

Annex 2. Calculations for nitrogen in untreated wastewater

To estimate the amount of nitrogen released into the water the same procedure is used:

Variables	Values
N in untreated wastewater	11g per capita per day
Population of Austria (2012)	8,219,743 inhabitants
Timeframe	365 days
Households serviced by sewage	99%

Nitrogen in untreated wastewater x population x 365 days = Total N in untreated wastewater

→ 11g/c/d x 8,219,743 x 356 days = 33,002 tons of N per year in untreated wastewater.

If we take into account that only over 99% of households in Austria are serviced by the sewage system and that close to 99% of the wastewater is treated, the total amount of untreated wastewater that is reemitted can be calculated:

Percentage of households without sewage + Percentage of untreated wastewater = Total amount of untreated wastewater reemitted.

→ $\left(1 - \frac{99}{100}\right) + \frac{99}{100} \text{ x } \left(1 - \frac{99}{100}\right) = 1.99\%$ of untreated wastewater reemitted

Thus, the total amount of N emitted in a year is:

Percentage of untreated wastewater reemitted x Total N = the total amount of N emitted in a year.

→ $\frac{1.99}{100} \text{ x } 33{,}002 = 657$ tons of nitrogen where emitted in Austria in 2012.

Annex 3. Basic parameters for calculations

	Vienna (2012)	Mexico City (2012)	São Paulo (2012)
Population	1,718,084[90]	8,851,080[91]	11,376,685[92]
Total waste generated (tons/day)			18,000[93]
Total waste generated (tons/year)	1,054,799[94]		6,570,000[95]
Established solid waste generated (kg/cap/day)		**1**[96]	
Total waste using assumed per capita value (tons/year)	-	3,230,644[97]	-
Number of landfills	1[98]	N/A	2[99]
Content of TOC in solid waste (g/kg)[100]	250	250	250
Content of N in solid waste (g/kg) [101]	4	4	4

[90] Statistik Austria for 2012 in the 1st Quarter accessed through STATCube
[91] INEGI retrieved from: http://www3.inegi.org.mx/sistemas/sisept/Default.aspx?t=mdemo148&s=est&c=29192
[92] IBGE retrieved from: ftp://ftp.ibge.gov.br/Estimativas_de_Populacao/Estimativas_2012/populacoes_estimativas_municipios_TCU_31_10_2012_pdf.zip
[93] Prefeitura Sao Paulo, retrieved from: http://www.prefeitura.sp.gov.br/cidade/secretarias/servicos/coleta_de_lixo/
[94] MA48, retrieved from: http://www.wien.gv.at/umwelt/ma48/service/publikationen/pdf/leistungsbericht-ma48-2012.pdf
[95] Obtained via calculation of total waste generated (tons/day) x 365 = 6,570,000 (tons/year)
[96] Based on values from studies (Valenzuela, 2005; de Vega, et al., 2006)
[97] Based on ((population x Established sold waste generated) x 365) /1000 = Total waste using assumed per capita value (tons/year)
[98] MA48, retrieved from: http://www.wien.gv.at/umwelt/ma48/service/publikationen/pdf/leistungsbericht-ma48-2012.pdf
[99] Diario Sao Paulo retrieved from: http://diariosp.com.br/noticia/detalhe/21558/Cidade+absorve+apenas+a+metade+do+seu+lixo
[100] Assumed value
[101] Idem.

Annex 4. Daily amount of solid waste deposited by final destination for cities with more than 1,000,000 inhabitants (adapted from IBGE, 2008)

	Total	Solid waste deposited in class 1 landfill (tons/year)	Solid waste deposited in class 2 landfill (tons/year)	Solid waste deposited in class 2 landfill (tons/year)
Original data for São Paulo (2008)[102]	49,472	40,515	7,901	12
Inferred proportions (%)[103]	100%	81.89%	15.97%	0.02%
São Paulo (2012)	6,570,000	4,745,000[104]	1,822,232	2,768
Mexico City (2012)	3,162,469	2,645,730	515,955	784

[102] IBGE. (2008). Pesquisa Nacional de Saneamento Basico 2008 [National Research on Basic Sanitation 2008], Tabela 93. p 163. Retrieved from: http://www.ibge.gov.br/home/estatistica/populacao/condicaodevida/pnsb2008/PNSB_2008.pdf

[103] Proportions of solid waste in deposited in class 2 and class 3 landfills were obtained via the following calculations: Solid waste deposited in class 1 landfill/ Total solid waste x 100 = Inferred proportion for class 1 landfill.

[104] Daily values for both CTL and CTVA landfills have been scaled up to a year and added up:
CTL landfill receives 6,000 tons daily --> 6,000 x 365 =2,190,000 tons/year retrieved from: http://diariosp.com.br/noticia/detalhe/21558/Cidade+absorve+apenas+a+metade+do+seu+lixo
And Aterro Caieiras landfill receives 7,000 tons daily -->7,000 x 365 =2,555,000 tons/year (http://www.scielo.br/pdf/esa/v18n2/a01v18n2.pdf) p96
2,190,000 tons/year + 2,555,000 tons/year =4,745,000 tons/year in class 1 landfill

Annex .5 Calculations for TOC and nitrogen contents in leachate post treatment in Class 1 landfills

Landfill class 1	Vienna (2012)	Mexico City (2012)	São Paulo (2012)
Solid waste deposited in class 1 landfills (tons/year)	125,758	2,645,730	4,745,000
Amount TOC in leachate	1%	1%	1%
Amount of N in leachate	20%	20%	20%
Remaining TOC in treated leachate (min)	0%	0%	0%
Remaining TOC in treated leachate (max)	10%	10%	10%
Remaining N in treated leachate (min)	0%	0%	0%
Remaining N in treated leachate (max)	10%	10%	10%
TOC in landfill waste (tons/year)	31,440	661,432	1,186,250
N in landfill waste (tons/year)	503	10,583	18,980
TOC in leachate emissions (tons/year)	314	6,614	11,863
N in leachate emissions (tons/year)	101	2,117	3,796
Remaining minimum of TOC in leachate post treatment (tons/year)	-	-	-
Remaining maximum of TOC in leachate post treatment (tons/year)	**4**	**661**	**1,186**
Remaining minimum of N in leachate post treatment (tons/year)	-	-	-
Remaining maximum of N in leachate post treatment (tons/year)	**1**	**212**	**380**

Annex 6. Calculations for TOC and nitrogen contents in leachate post treatment in Class 2 landfills

Landfill class 2	Mexico City (2012)	São Paulo (2012)
Solid waste deposited in class 2 landfills (tons/year)	515,955	1,822,232
Amount TOC in leachate	1%	1%
Amount of N in leachate	20%	20%
Remaining TOC in treated leachate (min)	10%	10%
Remaining TOC in treated leachate (max)	50%	50%
Remaining N in treated leachate (min)	10%	10%
Remaining N in treated leachate (max)	50%	50%
TOC in landfill waste (tons/year)	128,989	455,558
N in landfill waste (tons/year)	2,064	7,289
TOC in leachate emissions (tons/year)	12,899	45,556
N in leachate emissions (tons/year)	413	1,458
Remaining minimum of TOC in leachate post treatment (tons/year)	**1,290**	**4,556**
Remaining maximum of TOC in leachate post treatment (tons/year)	**6,449**	**22,778**
Remaining minimum of N in leachate post treatment (tons/year)	**41**	**146**
Remaining maximum of N in leachate post treatment (tons/year)	**206**	**729**

Annex 7. Calculations for TOC and nitrogen contents in leachate post treatment in Class 2 landfills

Landfill class 3	Mexico City (2012)	São Paulo (2012)
Solid waste deposited in class 3 landfills (tons/year)	784	2,768
Amount TOC in leachate	1%	1%
Amount of N in leachate	20%	20%
Remaining TOC in treated leachate (min)	50%	50%
Remaining TOC in treated leachate (max)	100%	100%
Remaining N in treated leachate (min)	50%	50%
Remaining N in treated leachate (max)	100%	100%
TOC in landfill waste (tons/year)	196	692
N in landfill waste (tons/year)	3	11
TOC in leachate emissions (tons/year)	2	7
N in leachate emissions (tons/year)	1	2
Remaining minimum of TOC in leachate post treatment (tons/year)	**0.98**	**3.46**
Remaining maximum of TOC in leachate post treatment (tons/year)	**1.96**	**6.92**
Remaining minimum of N in leachate post treatment (tons/year)	**0.31**	**1.11**
Remaining maximum of N in leachate post treatment (tons/year)	**0.63**	**2.21**