UNIVERSITY OF ECONOMICS IN PRAGUE, FACULTY OF INTERNATIONAL RELATIONS

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Assessment of Policy Changes of the Impacts of Urbanization, Economic Growth and Decentralization of Water Services with Regard to Water Quality in Mexico

(PhD thesis)

Author: René Fernando Lara Cervantes
Supervisor: Prof. Ing. Petr Šauer, CSc

Statement:
I hereby state that I elaborated my PhD thesis on my own and that I included all of the citations from the literature.

In Prague, July 1, 2016

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Signature

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List of abbreviations

AAG (Atlas del Agua en México) – Atlas of Water in Mexico

AGA (Agenda del Agua 2030)- Water Agenda 2030

BOD (Biochemical Oxygen Demand)

COLMEX (El Colegio de México) – College of Mexico

CONAGUA (Comisión Nacional del Agua) – National Water Comission

EAM (Estadísticas del Agua en México)- Statistics of Water in Mexico

HAR (Región Hidrológico-Administrativa) – Hydrological-Administrative Region

MONET (Monitoring Sustainable Development)

MWC (Muncipal Water Companies)

NDP (National Development Plan)

OECD (Organization for Economic Co-operation and Development)

SAYEN (South Asia Youth Environment Network)

SEMARNAT (Secretaría de Medio Ambiente y Recursos Naturales)- Ministry of Environment and Natural Resources

SINA (Sistema Nacional de Información del Agua) – National System of Information of Water

UN (United Nations)

UNESCO (United Nations Educational, Scientific and Cultural Organization)

WNP (Programa Nacional Hídrico) – Water National Program

WRP (Programa Regional Hídrico)- Water Regional Program

WWAP (United Nations World Water Assessment Programme)

WWFMD (World Water Forum Ministerial Declaration)

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Introduction

This research aims to study the causes of water quality deterioration in Mexico as a critical factor for abating water scarcity. In this regard, the inadequate institutional changes performed throughout Mexico´s history will be assessed in the most productive Hydrological-Administrative Regions (HARs) of the country. A more comprehensive definition of HARs will be provided in Subchapter 4.2.1, but broadly speaking, they are territorial areas defined based on hydrological criteria and are different from those areas delimitated in Mexico´s political division.

This study highlights the institutional response to addressing water quality as a fundamental factor for preventing water scarcity, especially in the most populated and productive areas of the country. Moreover, the exploitation of natural resources has consequences for society´s welfare. Independent of the type of natural resource, the form of exploitation changes the social distribution of benefits from its use and its preservation. In this regard, water is a good example of the complex interactions that can be established among the natural, social, economic and institutional environments, which determine the welfare level of a certain population. Also, water is a strategic element for securing the lives of future generations.

The relevance of water is evident especially given its social implications. Sustainable water management has been addressed worldwide in the development agendas of several countries; also, several international organizations, universities, research centers, firms and the civil society agree on the need to implement technological and cultural changes in exploitation and water management. In this regard, countries have undertaken efforts to form the right institutions for sustainable water management. Institutions are crucial to achieving sustainable development goals since they protect the environment by setting boundaries for human behavior.

Moreover, they reduce uncertainty and increase the efficiency and accuracy of the measures that decision-makers take to achieve sustainable development goals.

The latter information is important with regard to water resources since currently, countries featuring 40% of the global population are experiencing some degree of insufficiency of water resources, which could lead to social and political conflicts (Saleth & Dinar, 2004). Also, according to United Nations World Water Assessment Programme (WWAP, 2016) between 2011 and 2050 the world population could grow from seven billion to 9.3 billion; this will increase the water demand for food production and for industrial and human consumption purposes, especially in urban areas.

In the case of Mexico, water resources are critical for development; however, the country is prone to suffering absolute scarcity in the near future. Thus, the concern about problems with sustainably providing water for human activities is escalating. Still, Mexico is addressing the issue by introducing only half measures. In the country, institutional, environmental and economic policies have changed to address immediate problems instead of setting the conditions for avoiding them in first place. Moreover, after decades of centralized planning, the abrupt transition to economic liberalization and decentralization came with additional challenges to water management, such as increasing stress over water resources due to urban settlements in the country.

Nowadays, the population is mostly settled in urban areas. According to *Atlas del Agua en México* (AAG) by the year 2030, the trend will continue, and estimations have shown that 80.4% of the population will live in the cities (AAG, 2014, pp. 12, 14). Moreover, the population is settled in the urban areas in the dry parts of the country with the largest share of the gross domestic product (GDP).

This is the case of HAR XIII Waters of the Valley of Mexico, HAR VI Bravo River and HAR VIII Lerma Santiago Pacific, which together constitute almost half of the

population of the country and 56.76% of the GDP. Also, they have high levels of water stress. Moreover, the lack of treatment of industrial, agricultural and domestic wastewater has polluted approximately 96% of the superficial water resources in the country (Saltiel, 2008). For Mexico, this is a fundamental issue given that the availability, consumption and uses of water are unequal. Therefore, it is necessary to develop alternatives to improve the development of the water sector. However, it is not an easy problem to address considering the ecological, technical, financial, political, social and cultural restrictions linked to the development of solutions to guarantee sufficient and good-quality water with the lowest possible social and ecological costs.

Given demographic and economic features as well as the degrees of water stress in HAR XIII, HAR VI and HAR VIII, the situation demands serious changes in management due to restricted access to water resources. The ecological costs of the overexploitation of water resources are increasingly higher; this has been acknowledged more formally in the National Development Plans (NDPs) since the 1980s and was reasserted in the Water Agenda 2030 (AGA, 2011). In this regard, several policies have been created in the field of sustainable development; however, they lack an adequate design for introducing necessary changes in water management.

In Mexico, several complications are linked to the historical changes of certain institutions and legislations. Before the 1990s, the country's policy and institutions associated with water management were characterized as being centralized and public oriented. After several years of political tension due to the Mexican Revolution, the country entered an era of stabilization, where most of the country´s resources were nationalized—nevertheless, at the cost of a large concentration of the government´s power and the need for economic growth (Roland & Cárdenas, 2010). With regard to water, the nation's policy was focused on the expansion and construction of the hydraulic infrastructure required for development.

The state dedicated considerable resources for this purpose; however, in 1981, the economic crisis pushed Mexico to undertake reforms in the water sector with the main purpose of reducing the financial burden of the federal government. During the 1990s, due to a lack of funds, the state attempted to involve private companies in the water sector. It also founded Semarnap (ministry of environment, natural resources and fisheries), which is a specialized environmental institution designed to support sustainable development goals. An additional important change was the decentralization of water services, which transferred the responsibilities of water management to municipalities. To provide administrative, normative and technical support for municipalities, the National Water Commission (Conagua) was created.

Nonetheless, the prolonged application of the centralistic approach had some negative impacts in the development of the sector since nowadays, municipalities still have a strong dependency on federal funds and technical support.

Given the problems explained before, the hypotheses of this research are the following:

1) The public administration centralistic approach that lasted several decades, along with the need for economic growth, increased the resistance to institutional and policy changes linked to water management issues. This is currently blocking the achievement of sustainable water management, which is sharpening water scarcity.
2) The impacts of economic activities and the increasing urbanization have a negative impact on water quality in the HARs with the largest GDP. Thus, this may contribute to increased water scarcity.

The research objectives are the following:

1) To provide a historical perspective of Mexico's policy and institutional issues to track down the episodes that lead to aggravated water scarcity. This information could help authorities to innovate the sustainable exploitation of water resources by not repeating mistakes from the past.

2) Given the scarce quantitative literature about water scarcity in Mexico, the assessment of factors linked to water stress will provide hints for establishing the policy priorities to abate water scarcity. Also, the analysis will serve as a test of the quality of the statistical data on water resources.

The methodology consists mainly of conducting documentary research to identify the relevant literature in specialized journals, books and official documents about water management in Mexico.

The first hypothesis will be developed following a historical analysis of institutional change to show the changes in water management and their effect on Mexico´s conditions when it comes to tackling water scarcity. These changes will be discussed comprehensively based on the institutional, policy, physical and economic dimensions that Dinar (2004) suggested, which are key issues in the study of water management. The dimensions mentioned will be developed in Chapter 2. Afterward, evidence will be provided with the analyses of the performance of municipal water companies (MWCs) in Chapter 3.

The second hypothesis will be assessed through regression models and qualitative criteria to compare factors that affect water quality in three comparable regions of Mexico and to determine the policy priorities. The variables were selected based on a quantitative literature review and on experts´ opinions, which were obtained through questionnaires. Afterward, the results of the regression models obtained after two rounds of modelling for each region are compared and discussed against the findings

of previous studies and are complemented with the information that the consulted experts provided (more detailed information about this methodology is given in Subchapter 4.3).

The thesis is structured as follows:

In Chapter 1, “Fundamental Issues in Water Management,” definitions and key concepts are presented. These concepts will provide the theoretical background necessary to understand the outcome of the research. In this chapter, theories and concepts about institutions and natural resources management are described. The chapter also includes a discussion about the concept of sustainable development and implications for operationalizing it through the principles of weak sustainability and strong sustainability. Afterward, the international debate about the nature of water and about the decentralization and privatization of water management is analyzed based on the results of the World Water Forum events continuing today. Finally, the effects of the privatization of water services in developing countries are shown.

In Chapter 2, “Political Implications and Institutional Change in Water Management Evolution in Mexico,” the changes in the policy, institutions and legal framework in the transition from the centralization to the decentralization of water management are shown. The chapter also provides a comprehensive description of the changes in the Mexican water institutions based on an extensive documentary research where regional differences in terms of access to water resources and water uses are described.

In Chapter 3, “Water Scarcity and Environmental Problems of Urbanization in Mexico,” the main challenges of water management in urban areas are presented. In this chapter, evidence is presented to prove how the policy and institutional changes lead to sharpened water scarcity and quality conditions. Here, it is shown how increasing urbanization and population growth became a major source of water pollution. Also, it is shown that the current decentralized management structure has

not been able to fulfill the goals of sustainable water provision and use given the capacities of municipalities.

In Chapter 4, “An Assessment of the Policy and Institutional Changes in Water Quality of the Most Productive Hydrological-Administrative Regions,” the factors of water pollution are analyzed. The chapter describes briefly the main features of the three most productive HARs; afterward, their factors of water stress are quantitatively tested. Three regression models are calculated, each corresponding to one HAR, and the results are compared against the existing quantitative literature and are explained more comprehensively with qualitative criteria.

Finally, conclusions based on the main findings are elaborated along with policy recommendations and considerations for future research.

CHAPTER 1: FUNDAMENTAL ISSUES IN WATER MANAGEMENT

There is huge interest in the outcome of natural resources management. This concern has been addressed in the discussion on the determinants of environmental performance, which are related to economic and institutional factors. In this chapter, the concept of institutions, sources of institutional change and the role of institutions will be described to understand their impact on the managerial implications of water management. The topic of water management will further be discussed from the notion of sustainable development and the international political discussion about the categorization of water resources as an economic good or a human right. This has important implications in less-developed countries and in the sustainable development goals linked to water resources management.

1.1 Definition of institutions and theories of institutional analysis

Institutions are often difficult to define; nevertheless, the various existing definitions converge in their types, features and purposes for setting boundaries for human behavior.

As Raymond, Weldon, Kelly, Arriaga, and Clark (2014) stressed, at minimum, institutions are systems of rules that work together to restrict social behavior. These systems combine formal norms and social norms to achieve their purposes.

For Saleth and Dinar (2004, pp. 24, 25), overall, institutions are codified knowledge derived from natural principles and from the collective human knowledge. Also, institutions set the boundaries of individual behavior in a given context; they constitute society´s rules of the game, define the incentive structure for human exchanges and reduce uncertainty in everyday transactions. Thus, they can be considered a set of ordered relationships among people, which define their rights,

exposure to the rights of others, privileges and responsibilities. In this regard, Prado and Trebilcock (2009) defined institutions as those formal and informal bodies in charge of making, administering and enforcing laws and policies.

Culas (2006) provided a similar definition that regards institutions as constraints defining the structures of political, economic and social interaction. Institutions consist of informal constraints, such as sanctions, taboos, customs and traditions, and formal rules, such as constitutional decrees, laws and property rights, which are their main elements. Similarly, Hearne (2007) stressed that institutions are rules and norms that guide societal behavior. Therefore, they play a crucial role in the formulation of formalized rules of governance, which need to be updated as societies become more heterogeneous. Also, Mohr and White (2008) defined institutions as those mechanisms that connect the desired social behavior at the micro, meso and macro levels of social organization.

According to Hodgson (2006), institutions are the structures that matter most in the social realm since they rule social life through the recognition of structured terms or implicit rules. Meanwhile, Tauheed (2013) defined institutions as an emergent process by which internal and necessary relations are mediated through an agency, which results in the control, expansion and liberation of individual actors. Skoog (2005) defined institutions as behavioral rules for social interaction in recurrent situations. Institutions form the "the rules of the game," which are formed by norms, codes of conducts and routines that count with sanction enforcement mechanisms. In this regard, Lara and Hak (2009) defined institutions as regulators that guide human behavior to obtain the desired social outcomes.

Philips, Lawrence and Hardy (2004) gave an alternative definition that considers institutions to be constructions produced by texts rather than actions themselves. The authors explained that once texts are interpreted and discussed, they will enable the unification of thoughts, which will transcend into actions. Thus,

institutions are constituted by structured collections of texts in a given context that produce norms and shape the understanding and behaviors of actors.

Thus, institutions have the purpose of facilitating decision-making by reducing the uncertainty of behavior, which is a crucial social function for structuring and stabilizing society. Given the previous definitions, overall, it is possible to define institutions as rules that third-party mechanisms enforce to regulate transactions and to establish the boundaries of social behavior. In this regard, in the existing literature, formal institutions and informal institutions are considered the two main types. Formal and informal institutions are complementary and share the same goal; however, they are different in their enforcement mechanisms and explicitness.

Formal institutions

Formal institutions are normally a set of explicit written rules that are applicable for all members of a society and have enforcement mechanisms that a third party applies.

According to Grzymala-Busse (2010), formal institutions are regarded as written-down rules enforced by the legal recognition of the modern state. According to Lisnyak and Sharipov (2015), formal institutions are those that receive legislative frameworks that judicial authorities support. Also, they are officially described in documents and apply to all individuals. These institutions are created to serve the interests of the involved parties. Skoog (2005) defined formal institutions as those rules consciously designed and often codified in written form, such as constitutions or regulations. These rules are applied by an external authority with the duty of enforcing the rule of law, as well as supporting organizations.

Similarly, Williamson and Berekes (2011) argued that formal institutions are found in constitutional constraints that are watched over by judicial courts that determine whether or not to apply a sanction. Also, Azari and Smith (2012) defined formal institutions as the written rules that govern behavior and also punish violations if they occur. The definition of Raymond and Cárdenas (2014) contains similar

elements since they consider formal institutions as constellations of explicit rules that governments create and enforce.

According to Mantzavinos, North and Shariq (2004), institutions are rules imposed externally to a society and are a product of the evolution of the interaction among rulers to stabilize expectations and to provide discipline.

Informal institutions

Informal institutions are equally important for institutional arrangements; however, they have several differences from their formal counterpart. The main differences are that the rules are not explicit and that the sanctions are self-enforced by individuals.

Overall, Mantzavinos et al. (2004) defined informal institutions as endogenous rules produced internally in a society where social conventions, moral rules and beliefs are crucial to shaping these types of institutions. Several authors provide more comprehensive definitions. According to Grzymala-Busse (2010), informal institutions are defined as consciously followed rules enforced with the independence of the officially sanctioned channels. In this regard, the involved actors teach and widely recognize informal institutions. Lisnyak and Sharipov (2015) described informal institutions as the ethical codes and conventions of conducts linked to culture. These rules apply to limited homogeneous groups and regulate power; moreover, they are formed spontaneously as a product of people´s interaction in pursuing their own interests.

Skoog (2005) described informal institutions as unintentional or spontaneous rules that evolve due to human interaction. They are not explicit and involve convention, routines, customs and codes of conduct for behavioral norms. These rules are self-enforced, and most actors would adhere to them if it yielded benefits. Those who do not stick to the informal rules of a society will be expelled from the group. Similarly, Willamson and Berekes (2011) argued that informal institutions are those rules outside of the legal framework that shape human behavior. They include social

norms, customs and beliefs about right and wrong, as well as enforcement mechanisms.

Additionally, Azari and Smith (2012) considered informal institutions to be shared expectations outside of the official rules that lead to a collective pattern of understanding of the right behavior to improve the social equilibrium. Also, Raymond et al. (2014) defined informal institutions as the implicit rules created, communicated and enforced outside of the official sphere to constrain social behavior in a given context.

Relations among formal and informal institutions and theories of institutional analysis

In the existing literature, the relationship between formal and informal institutions is considered to be complementary to fill the gaps left by each type of institution. As Skoog (2005) argued, this complementary relationship between formal and informal institutions occurs since it is not possible to design formal rules for all possible types of situations; thus, informal rules emerge to take care of the situation. However, if the formal rules are not consistent with the informal rules of society, they will lack legitimacy and will be ignored unless coercive mechanisms are enforced. This issue was addressed by Grzymala-Busse (2010), who considered that informal rules could either reinforce or weaken formal institutions. Also, Azari and Smith (2012) stressed that informal institutions are complementary to formal institutional arrangements by fillings the gaps left by formal institutions or by serving as bridges to the formal-institution realm. This will depend on whether or not informal institutions show favoritism or give special treatment to specific groups.

There are several theories for institutional analyses, which use different perspectives of the causes of institutional emergence given their selected main behavioral problems. The main features of the most representative theories are shown in Table 1.

Table.1. Main theories for the study of institutions

Aspects of comparison	**Old institutionalism**	**Neo-institutionalism**	**Meso-corporatism, policy community, networks**	**Game theory**	**Transaction cost theory, agency theory, theory of contract**
Generic scope	Macro-analysis of complete institutions	Macro-analysis of incomplete institutions	Variations of micro-analysis of incomplete institutions	Micro-analysis of complete institutions	Micro-analysis of incomplete institutions
Assumptions: Interdependence Information Rationality	No Complete Comprehensive	No Incomplete Bounded	Yes Incomplete Bounded	Yes Complete Comprehensive	Yes Incomplete Bounded
Unit of analysis	Institutional structures	Institutional structures	Meso-institutional structures	Institutional structures	Institutional transactions
Casual explanations	Institutional structures determine individual behavior.	Incomplete institutions create incentives for opportunistic behavior.	Actions of individuals are rendered compatible through efficient and equitable use of incomplete institutions	Rational individuals select equilibrium solutions.	Incomplete institutions create incentives for opportunism, which induces individuals to invest in institutions that minimize cognitive competence and opportunism.
Focus	On formulation of classifications of institutional structures	On opportunities and constraints built into meso-institutional structures.	On opportunities and constraints built into meso-institutional structures	On the degree of stability of equilibrium solutions	On technical coordination, warranty, monitoring and costs of incentives
Limitations	High level of aggregation Ad-hoc description Individuals do not calculate.	High level of aggregation Ad-hoc explanations	Average level of aggregation Ad-hoc explanations	Institutions arhighly abstract. Institutions are exogenous. Institutions are minimal.	Difficult to derive equilibrium solutions

Source: Saleth and Dinar (2004), p. 47

The different theories shown in Table 1 still require some innovation given the numerous tangible and intangible factors linked to human behavior that impose limitations in developing durable solutions.

Another crucial issue for institutional analysis is to distinguish between institutions and organizations. In this regard, the institutional environment is composed of a set of fundamental political, social and legal rules that establish the basis for human activities. Meanwhile, institutional arrangements are those that provide the structure for cooperation or competition; they include the governance structure and evolve through interaction with the institutional environment. Also, the institutional arrangements include organizations that are the main agents of institutional change (Saleth & Dinar, 2004, p. 25). Moreover, according to Mantzavinos et al. (2004), while institutions are regarded as the rules of the game, organizations are the players and are formed by individuals who share a common objective.

Therefore, organizations are agents of change and are also important for instrumenting the institutional arrangements defined by the agreed-upon set of rules; however, they must not be confused with institutions themselves.

1.2 Emergence of institutions, drivers and agents of institutional change

The literature features several explanations and approaches regarding the emergence of institutions. The different existing approaches refer to different sources of institutional emergence and change; however, they share the goal of addressing a particular problem to improve the actual situation.

According to Saleth and Dinar (2004, pp. 36–41), three main theories of institutional emergence exist:

1) Theories of evolutionary emergence of social conventions: Institutions evolve from changes in the political and judicial processes of decision-making, as well as from the activities of private and collective organizations where economic efficiency is important but is not the dominant factor. In this theory, institutional change is endogenous to the economic system; thus, conquest, war, culture and changes in ideology have a greater impact.

2) Market-based theories and selection through competition: This theory is based on a contractarian approach stemming from a free voluntary exchange in the political market. Institutions will change if the benefits of transformation exceed the costs of achieving a new status quo. The theory does not consider equating property rights to institutional arrangements. Also, the costs of change are assessed for different interest groups. Finally, endogenous factors (nonmarket forces) are accounted for.

3) Bargaining theory explaining institutions in terms of asymmetries of power: Institutions will rise from extreme uncertainty, and the chosen arrangement will not worsen the situation for individuals. The theory involves rational choice for driving innovation by comparing alternative solutions to be included in the institutional arrangements.

Skoog (2005) provided a more general approach to institutional emergence. Concerning informal rules, when a new problem arises and uncertainty exist, the actors rely on their past experiences to assess the situation and think about a behavioral solution for such a problem. Thus, an informal rule may emerge spontaneously and will be a product of the past and the present institutional and ideological contexts. After several trials, a new rule of social interaction with self-enforcing mechanisms will be developed to address the particular problem. With

regard to formal rules, the author stressed that the process consists of two stages: First, a process leads to the creation of a nominal rule, and second, a process renders the nominal formal rule effective in practice. The first process takes place among the political system as well as economic, social and political organizations to negotiate the change. This is driven by the expected benefits; thus, political power is crucial in negotiations.

In the final and third situation, Skoog (2005) stressed that suppliers of change, usually government actors, face incentives and have the power to change formal rules from within the political system itself. First of all, some actors use entrepreneurial creativity to either challenge the formal rules, by breaking or circumventing them, or to innovate, by changing lower-level rules within their own domains of control—for example, property rights and work practices. The emergence and change of formal rules requires the public sector since it owns the supply of formal institutional change. However, this process demands special abilities and capabilities beyond the willingness to change, as formal changes must avoid inconsistencies with the rest of the formal and informal rules.

Although all theories and dynamics mentioned before consider different reasons for institutional emergence, they will endure only if they have the capacity to change. For institutions to prevail, they need to adjust the established rules to adapt to new situations (Foa, 2009). The evolution of institutions depends strongly on their path dependence, determined by their historical backgrounds. In this regard, informal institutions play an important role in the evolution process since they are a product of path dependence (Saleth & Dinar, 2004, p. 27). According to Mantzavinos et al. (2004), path dependence is important for understanding how reality is perceived and its implications for institutions. Path dependence is given once the content of shared learning is similar over a number of periods, which grants some inflexibility to belief systems. Therefore, the players will have the same mental models to begin solving

several social problems and will determine the shapes of the desired institutions, culminating with certain outcomes.

Hearne (2007) argued that path dependence affects the rate of change depending on the influence of history. Moreover, Prado and Trebilcock (2009) argued that path dependence is a crucial issue that reformers must consider to understand why some key features of institutional arrangements have prevailed. These should focus the attention toward contextual factors to study institutional evolution in order to develop optimal institutional reforms that would lead to improvement.

Tension always exists between changing formal rules and persisting informal rules; the self-enforcement mechanism of the latter makes it difficult to reverse the path. Moreover, the mental models described in path dependence provide stability and durability for institutions. Both issues are crucial to consider when proposing institutional changes, at least in the formal arena, given that reforms could be rejected or produce outcomes different from those originally imagined.

However, the abrupt changes of formal rules are possible through revolution or conquest; nonetheless, they still have to face rigid informal institutions. Thus, stability is possible partly thanks to the slow change of informal rules and partly to due to the complexity of hierarchical formal rules that make them more costly to avoid (Saleth & Dinar, 2004, p. 28). In this regard, Gruzewska (2014) argued that informal rules are uncontrollable and do not change easily or in a desired direction. The process of change for informal rules depends on the development of a society that strongly sticks to the past. This interaction will make the simultaneous change of all of the institutional elements impossible.

According to Saleth and Dinar (2004, pp. 34–35), the main agents of institutional change are located in the governance structure and involve political and economic organizations. Moreover, economic organizations can drive changes in the institutional environment only through political organizations. Endogenous

preferences prove to be a subjective influence in institutional change because they might be unlinked from the institutional arrangement. They feedback the institutional arrangement that affect such preferences as well; otherwise, new behavioral attributes will not be introduced. Also, the authors explained that exogenous changes, such as technology, trade and investment, drive economic organizations to induce political organizations to make changes. Skoog (2005) described a similar structure for institutional change. The author mentioned organizations within the state, municipalities or individuals as institutional change drivers. These actors need the political system to introduce the modification of the desired rules.

Theoretically, institutional change follows this process: 1) mind change, 2) political articulation, 3) institutional change and 4) actual impact. This process is circular, and reforms will be the product of the relative bargaining strengths of political parties and other interest groups (Saleth & Dinar, 2004, p. 39).

Skoog (2005) argued that institutional change is a sequence of events in causal and chronological stages over time. The process is described as follows: 1) Identify promoters and dissidents of change, 2) identify the specific cause of change, 3) identify behavioral incentives and uncertainties and 4) identify the sequence of events that will be altered with change. Both approaches are very similar and consider relevant dimensions of institutional change, which have to be considered during the process of institutional analysis.

Azari and Smith (2012) highlighted the dynamic interface between formal and informal institutions and the mutual impact they have on each other. Therefore, changes and gaps in formal institutions will stimulate social actors to revise institutional arrangements to stabilize expectations and avoid conflicts. In addition, violations of dissatisfaction with informal rules could motivate actors to alter or create formal institutions. Similarly, according to Mohr and White (2008), in the event of a disagreement about the outcome of rules, a reformulation of institutions will occur

after a process of chaos and conflict. The promoters of the new institution will try to impose their paradigm and break apart previous institutional antecedents.

According to Philips et al. (2004), institutions must have a discourse that constitutes it and that prescribes actions. If the discourse does not support the mechanisms of compliance, then the actors will have an incentive to revise multiple sets of texts and discourses to reach a new level of agreement in terms of norms and behavior.

According to Raymond et al. (2014), when rules appear to be weak, a reliability to keep social coordination opportunities for institutional change occurs. The institutional change will happen once an agreed-upon change is disseminated and adopted by a majority, which is crucial for the imitation of behavior. Also, the main agents of change are considered to be policy entrepreneurs and social movements to introduce improvements to the status quo.

The proposal of Prado and Trebilcock (2009) of formal institutional change stressed that this can occur to switch ambiguous costs and institutional interdependencies across the political and bureaucratic arena. Therefore, it is important to understand the nature of how the enforcement mechanisms were conformed to introduce effective reforms to provide larger benefits for society.

As shown earlier, different approaches exist to explain institutional change and emergence. All of them converge on the need to address a particular problem to improve an initial situation by increasing benefits for a society; however, the introduction of change is not an easy task given the number of conditions that the new institutions must fulfill to be accepted and implemented.

1.2.1. Institutions and sustainable water management

An adequate institutional design is a key determinant for the sustainable management of natural resources. In the literature, it is stressed that if institutions are conformed correctly, they will establish the proper rules and will also provide incentives for environmental protection and natural resource conservation.

In general, the main impact of institutions is related to changes in governance. Žák and Vymětal (2005), who performed a comparative evaluation of institutional change in the European Union´s post-communist era, showed convergence toward free-market economics. However, the quality of formal rules and governance was crucial for stimulating economic competition. Similarly, Acemoglu and Johnson (2005) studied the institutional impact of the economic performance of former European colonies. After analyzing a sample of 71 former colonies through regression models, the authors found institutional arrangements to be important for economic performance.

According to Mehlum (2006), natural resources management is important to maintain sustainable economic growth and for conservation reasons. The author argued that in countries with an abundance of natural resources, economies grow more slowly than they do in countries without substantial resources. Moreover, the study stressed the importance of the shapes of institutions since grabbing-friendly institutions encourage predatory behavior in comparison with producer-friendly institutions, which could lead to better outcomes. The author estimated regression models to analyze a sample containing data about economic activity, an abundance of natural resources and institutional factors for 87 countries. The results showed that in countries with weak institutions, natural resources are easily lootable, which is harmful for their economic performance. Thus, these countries lose the advantage of having an abundance of natural resources in terms of economic development and the environmental protection necessary to introduce sustainability criteria.

According to Tlaiye and Biller (1994), in the particular case of natural resources, institutions can also be defined as regulators that correct market failures to prevent externalities. Moreover, Lara and Hak (2009) stressed that well-designed institutional arrangements are capable of internalizing the environmental externalities necessary to abate in order to improve environmental performance. Also, the possibility of enforcing regulation will be an incentive for the agents to diminish the costs of the pollution of control; also, this will depend on the frequency of monitoring activities (Foa, 2009). Thus, the main goal of institutions is to prevent any type of predatory behavior from governmental and private actors, which is crucial for natural resources management (Williamson & Berekes, 2011).

In terms of environmental performance, many advantages exist to developing appropriate institutions, which are reflected in the reductions of transaction and production costs and in a more efficient allocation of resources. Thus, institutions are critical for establishing the desired boundaries of the agents´ behavior that could contribute to the improvement of environmental performance (Culas, 2006). Societies with transparent, honest and effective institutions are more successful in the abating of environmental degradation than are those countries with high levels of corruption (Duit, 2005). Additionally, the functionality of institutions is important in explaining variations in environmental outcomes. Trusted, impartial, uncorrupted and universal institutions with democratic participation are able to provide higher levels of social welfare (Foa, 2009).

Given the features of institutions, they can be considered a powerful tool in the allocation of natural resources and in the abatement of environmental externalities, especially when addressing notions linked to sustainable development.

As Wutich (2009) stressed, institutions are crucial for the exploitation and preservation of common pool resources. In this regard, institutions will grant authority to the users of pool resources to organize and control natural resources exploitation.

Also, the study of Lara and Hak (2009) showed that institutional arrangements affect the environmental performance of countries. The authors estimated a panel-data regression model for 27 countries of the European Union, where they tested formal institutions´ indicators related to each country's environmental performance. The results showed that the strengthening of formal rules associated with environmental issues are likely to improve the environmental performance of countries, hence the need to improve these rules to achieve sustainable development goals.

Similarly, Yami (2009) showed that institutions contribute to the sustainable management of common pool resources. The author studied the area of Sub-Saharan Africa, where he found that informal institutions have a more significant impact than its formal counterpart does. Also, the decentralized management approach contributed to improve sustainability due to the heterogeneity in beliefs and the contextual features of this region. Hearne (2007) stressed that well-designed institutions help to meet local needs, such as a potable water supply, flood control, recreation and development. Also, institutions are crucial to avoiding friction among local the local and federal governments, if local authorities have certain degrees of autonomy. This will help with monitoring the water needs of the society and with the formulation of solutions to water scarcity problems with the highest-possible level of efficiency.

Although the study of Lara et al. (2013) focused on the study of the outbreak of violent conflicts, their results showed the relevance of counting with good institutions and also the importance of abating water scarcity. The analysis consisted of two pooled-data regression models to assess the impact of several variables in conflict outbreaks. The first model assessed institutional, cultural and economic variables for 53 African countries and conflict outbreaks, whereas the second one included data on natural resource depletion for 48 African countries. The authors found that corruption could increase the probabilities of conflict outbreak; however, good governance has shown that it can counteract the effects of corruption. With regard to natural resource depletion in the case of water, the authors found that an

increase in freshwater withdrawals reduces the probabilities of conflict outbreaks; this means that securing sufficient water for human needs is crucial to maintain political stability.

However, according to Oran (2003), the alleviation of large-scale environmental problems requires very complex institutional designs. Thus, it is important to perform a rigorous institutional diagnosis to introduce efficient solutions for environmental problems. In this regard, Meyer et al. (2007) showed that the promotion of local environmental institutions requires a solid foundation and knowledge. The author argued that this is important since sometimes decision-makers do not have a clear idea of the real purpose of those institutional arrangements, which is crucial given the goals of enhancing environmental quality.

The literature shows the positive relations among well-designed institutions and the rational use of natural resources. Nevertheless, to achieve success, it is necessary to perform an institutional diagnosis to find the areas that should be strengthened in the public administration before resulting in institutional changes and reforms.

1.3 The concept of sustainable development, definitions and operationalization considerations

The concept of sustainable development is very popular among policy makers and has been acknowledged as crucial to achieving balanced progress in terms of environmental criteria and economic and social development. The state of these factors varies among contexts and are crucial for defining realistic sustainable development operationalization. Thus, it is crucial for policy makers to perform a conscious exercise of conceptualization linked to contextual reality to develop an

adequate definition for sustainable development, its associated policies and indicators for tracking its performance.

According to Herdiger (1999), sustainable development is a normative concept that allows numerous interpretations and definitions. This has led to the reassertion of the concept at different political levels, sometimes as a moral principle or a vision of the future, which still requires evidence to support its validity (Byrch, Milne and Morgan (2007). Also, as Keiner (2003) indicated, still missing is a profound theoretical basis for justifying sustainable development as an overall guiding principle that diminishes its political substance.

The latter could create conflicts between the actors and the goals, and it could affect the trade-offs agreed upon in the sustainable development strategy. Moreover, the interdependence of the social, economic and social dimensions, and their subsystems, will increase the complexity of achieving a feasible development path. In this regard, sustainable development must be acknowledged as a gradual process for making the demand and supply for natural resources conjoin with the premise of Williams and Mellington (2004). The United Nations (UN) (2010) stressed that indeed, sustainable development is widely accepted, and progress has been made in the creation of indicators. However, the implementation is not yet completely successful due to tensions among the pillars of environmental improvements, economic development and social development. Efforts to implement sustainable development have developed especially in an environment of economic criteria and market-based investment oriented toward maintaining overall growth and raising living standards.

According to Mukheibir (2010), to balance the three dimensions of sustainable development, science and good governance are crucial. The role of science is to help man to analyze himself and the variables required to create a new complex and long-term process of development to make the future safer (Iacob, 2014). Additionally, the

popularity of sustainable development has proved to have the potential of developing new ideas and uniting the political and scientific communities (Williams, 2004).

In this regard, Byrch et al. (2007) argued that considerable effort has been made to improve the understanding of sustainable development and even to institutionalize sometimes competing views. In many countries, environmental ministries and agencies are becoming important actors through cooperation with corporations and non-governmental organizations that are introducing progressive changes in governance (Meadowcroft, 1999).

Sustainable development is an issue that seems destined to occupy a strategic place in the operation of different policies during the years to follow. Therefore, it is crucial to study the provided definitions and how they could be operationalized to achieve sustainable development policy goals.

1.3.1 Definitions of sustainable development

Several definitions of sustainable development have been proposed during recent decades; however, all of them have the same goal. Their differences lie in the specificity of their goals and in the areas where the policies will be applied; therefore, the definitions are critical to determining its operationalization.

The most common definition was formulated by the UN World Commission on Environment and Development (1987): "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Soubbotina, 2004, p. 90). This definition has been universally accepted and has been the starting point of most of the conceptualization attempts that international organizations, national governments and academics have made to improve the definitions of sustainable development.

For example, the definition of sustainable development that South Asia Youth Environment Network (SAYEN, 2007, p. 9) proposed is the following:

> "Sustainable Development (SD) implies economic growth together with the protection of environmental quality, each reinforcing the other. Sustainable Development, thus, is maintaining a balance between the human need to improve lifestyles and feeling of well-being on one hand, and preserving natural resources and ecosystems, on which we and future generations depend".

The World Bank's definition of sustainable development is a more practice-oriented definition (Soubbotina, 2004, p. 93): "Sustainable development is a process of managing a portfolio of assets to preserve and enhance the opportunities people face." This definition includes economic, environmental and social features that can be achieved with the rational management of natural resources and the necessary human resources.

The Organisation for Economic Co-operation and Development (OECD; 2008) provided the following definition of sustainable development (p. 4):

> "Members of the OECD agree that Sustainable Development stands on three pillars: economic, social and environmental. And, in fact, the aims of the OECD, as set forth in its Convention drafted some 44 years ago, targeted Sustainable Development. The first part of Article I reads: *to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy."*

Also, the OECD (2008) stressed that sustainable development should last for several generations; thus, increasing consumption, environmental concerns and other economic issues must be taken into account to at least preserve the current well-being.

The definition of sustainable development of the United Nations Educational, Scientific and Cultural Organization (UNESCO) (2005, p. 2) stressed the following:

> "A vision of development that encompasses populations, animal and plant species, ecosystems, natural resources – water, air, energy – and that integrates concerns such as the fight against poverty, gender equality, human rights, education for all, health, human security, intercultural dialogue, etc."

Also, UNESCO (2005, p. 11) suggested eight key dimensions for operationalizing sustainable development, which are: "Population and Human Resources, Industry, Food Security, Species and Ecosystems, The Urban Challenge, Managing the Commons Energy Conflict and Environmental Degradation."

Another definition of sustainable development was proposed in 2001 by the Swiss project MONET (Monitoring for Sustainable Development): "Sustainable development means ensuring dignified living conditions with regard to human rights by creating and maintaining the widest possible range of options for freely defining life plans."

Also:

> "The principle of fairness among and between present and future generations should be taken into account in the use of environmental, economic and social resources. Putting these needs into practice entails comprehensive protection of bio-diversity in terms of ecosystem, species and genetic diversity, all of which are the vital foundations of life." (Keiner, 2003, P.380)

As in the previous definitions, the MONET definition stresses the need to go beyond environmental issues to foster economic and social development that will not deteriorate the situation of any of these dimensions.

According to Iacob (2014, p. 92), sustainable development is defined as follows: “Sustainable development offers a support by which communities can use resources as efficiently as possible; they can create infrastructures, protect and improve the standard of living, and create trade activities to consolidate their economy.”

The author also stressed that, through sustainable development, it is possible to support both the current generation and future generations by addressing environmental protection given the increase in consumption and industrial activity.

In the study of Herdiger (1999, p. 1124) sustainable development was defined as follows:

> “Correspondingly, sustainable development is an important concept of integrating social, economic and ecological dimensions of development and jointly addressing objectives conservation and change. Since these objectives cannot be achieved simultaneously as a rule, trade-offs across the various objectives are inescapable.”

The author considered that, for the concept to become operational, the institutional limitations and technologies under the control of individuals must be taken into account, along with the current capacities of the environment as our life-support system.

The policies necessary to achieve sustainable development goals sometimes are difficult to determine given the flexibility of the concept, which largely depends on contextual features (OECD, 2008). For example, according to Duit (2005), the environmental performance of the states in the area of sustainable development can be defined as the extent of the possibilities of the production of environmental public goods. Some examples of these goods are the conservation of ecosystems and the

reduction of polluting emissions. In this regard, the internalization of externalities is a critical issue. According to Kates et al. (2005), the concept of sustainable development must address the limitations of the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities in a given context.

To make a realistic definition of sustainable development, policy makers must consider the contextual economic, environmental and social welfare issues (Harris, 2003). Moreover, as Lara and Hak (2009) stressed, being aware of the multidisciplinary nature of sustainable development will be crucial to meeting the needs of future generations.

The consideration of the previous issues will determine the instrumentation of policies for achieving sustainable development goals as well as the development of indicators for measuring the progress of the chosen strategy. Thus, it is particularly important to assess the conditions and availability of economic, human and natural resources to develop an adequate model based on contextual features. Additionally, for this reason, it will be necessary to settle the debate between weak and strong sustainability, which are concepts that will be analyzed in the next subchapter.

1.3.2 The debate of strong sustainability and weak sustainability

The concepts of strong and weak suitability are crucial for the operationalization of sustainable development. As it will be shown, both concepts encompasses the concept of natural capital, although they regard its linkages with economic and social capital in different ways. On the one hand, weak sustainability considers economic capital to be a substitute for natural capital; on the other hand, strong sustainability addresses them as complements. This has led to a debate concerning how sustainable development goals should be designed and measured, especially in terms of social welfare and environmental protection.

The categorization of natural resources as natural capital follows the neoclassical economic notion of utility. Natural capital can be considered the overall natural resource base that encompasses renewable and nonrenewable natural resources, landscapes and other ecological factors (Hediger, 1999). According to Ang and Van Passel (2012), nature is considered natural capital only when it serves human needs; moreover, natural capital stock can be valued in terms of the ecosystem services it provides, which means that the complex relationship between humans' well-being and nature must be carefully studied. This was highlighted by Ross (2009), who stressed that if the environment is regarded as another form of capital, the trade-offs among nature, economic development and society must be considered if they are meant to remain mutual reinforcing pillars. In this regard, Hediger (1999) stressed that especially the ecosystem´s carrying capacity must be linked to economic capital to define the sustainability criteria accurately.

Thus is crucial for settling the discussion of the interaction and development of the different types of capitals to determine the sustainability criteria in terms of environmental protection so as to foster social and economic development.

The study of Keiner (2003) showed several examples of how these types of capitals have been addressed in different sustainable development models. Broadly speaking, capital stocks for sustainable development are the sum of the capital stock of the environment, the capital stock of the economy and the capital stock of society. Based on this the model, the prism of sustainable development was created and encompasses four dimensions: the economic dimension, which is measured and defined in terms of man-made capital; the environmental dimension, which is defined as natural capital; the social dimension, which addresses human capital considerations; and the institutional dimension, understood as social capital. Each of the referred-to dimensions has norms for ruling them and indicators for measuring the progress of sustainable development. The author also described the model Egg of Sustainability and Well-being, which puts the environment in the center of the

discussion for being a precondition for human development. This model illustrates how people relate to ecosystems as a circle inside another; thus, humans are within the ecosystem and depend on one another to maintain its welfare. Therefore, development is possible if it the ecosystems' carrying capacity allows it.

The model that Eurostat (2015) used is a variant of the capital stocks model, which contains more specific dimensions for balancing the trade-offs among the environment, economics and society. The sustainable development model is based on addressing sustainability by achieving eight objectives (Eurostat, 2015, p. 26):

> "Reviving growth; Changing the quality of growth; Meeting essential needs for jobs, food, energy, water and sanitation; Ensuring a sustainable level of population; Conserving and enhancing the resource base; Re-orienting technology and managing risk; Merging environment and economics in decision making; Re-orienting international economic relations."

Although progress has been made in the development of sustainable development models, the debate continues to define the extent of environmental concerns in such a manner as not to inhibit economic and social development.

Weak sustainability

The concept of weak sustainability is very polemic in the literature and has been broadly criticized by the scientific community. This occurs since it addresses natural and economic capital as substitutes; moreover, in some cases, it considers that, through science and technology development, some services of environmental could be replaced.

According to Ang and Van Passel (2012), weak sustainability is a concept developed to find an optimal path of the extraction of nonrenewable natural resources. This approach values natural capital stock and environmental services in monetary terms. Moreover, natural capital and human-made capital are regarded as interchangeable to improve well-being. In this regard, the depletion of natural resources can be compensated by reinvesting in economic capital to maintain the level of welfare. This means that sufficient technological progress can improve well-being in the event of environmental degradation.

Nevertheless, in weak sustainability, it is stressed that environmental damage is allowed only when environmental functions irreplaceable by human inventions remain unaffected.

Getzner (1999) argued that weak sustainability is a concept that economists developed to operationalize ecological sustainability. Moreover, they have focused on the assumption of substitutability between natural and man-made capital to justify the trade-offs among each other. In this regard, sustainability is achieved as long as the total capital is non-decreasing over time, which means that losses in ecological benefits can be compensated by other means. The substitutability assumption is strictly anthropocentric, and its optimism in innovation puts a lot of pressure on technological progress in the event of the depletion of natural resources. Also, the monetary valuation of natural capital is crucial in trade-offs based on individual preferences. Nevertheless, this criterion may not include some preferences or values, which could represent a serious risk for sustainable development if no boundaries exist that respect the physical limits of ecosystems.

Similarly, Grissom (2014) highlighted the substitutability relationship between natural capital and human capital, and the need to reinvest in other forms of capital to compensate for the depletion of natural resources. In this regard, weak sustainability is operationalized through capital switching to enable the possibility of getting future

benefits that are not reachable if natural capital remains constant. Nevertheless, the rule to follow is to produce a constant flow of services equivalent to the losses of natural capital. The main problem with this approach is related to the valuation of natural capital to determine resource management and to establish environmental sustainability goals.

Hediger (1999) defined weak sustainability as an economic principle of neoclassical economics that stresses the need to sustain the value of aggregate capital. In this regard, the substitutability of natural resources and human capital must be carefully taken into account given that, to enable constant consumption, the productive capacity must be maintained at least intact. Thus, weak sustainability requires a suitable defined value of environmental services and capital stocks to evaluate as accurately as possible the trade-offs of changes in environmental quality. These issues will be crucial to determining the outcome of sustainable development goals.

According to Bonevac (2010), weak sustainability allows the use of natural capital to accumulate economic capital. Environmentalists find incentives for promoting their goals since, although economic capital and natural capital are substitutes, we must not decline the total supply of capital. Thus, weak sustainability requires the sum of the impacts to be at least nonnegative, which means we should contribute to replacing what we take.

Williams (2004) stressed that weak sustainability is an anthropocentric approach since it regards nature as resources where we have rights or dominion. This implies the perception that people are separated from nature, and the idea that natural resources will be used to benefit society. In this regard, technological development will allow people to manipulate natural resources to cover their demands and needs. This human-centered and growth-oriented approach could risk in the future the stock of natural resources.

The different authors described above showed the most relevant features of weak sustainability, which has been more broadly discussed in the literature than the concept of strong sustainability has. Since economic development is a crucial issue in weak sustainability, so is the definition of the substitution relationship between natural and economic capital, to avoid an environmental crisis that could become a matter of survival.

Strong sustainability

The concept of strong sustainability is the opposite of weak sustainability since it considers natural capital to be the core dimension for human activities and survival. In the literature, this concept stresses that no change in the stock and quality of natural resources is allowed. Therefore, it assumes economic capital and natural capital to be complements instead of substitutes.

As Ang and Van Passel (2012) indicated, strong sustainability aims to maintain the economic value of natural capital. This approach considers natural capital to be limited to justify conservation efforts to avoid its decline. As in the case of weak sustainability, natural capital is measured in monetary terms, but it must not lose its value over time.

According to Grissom et al. (2014), strong sustainability addresses a complementarity relationship between human and natural capital; moreover, natural capital does not decline over time. Therefore, under this perspective, the supply of natural resources faces more constrains than in the case of weak sustainability.

Hediger (1999) defined strong sustainability as a basic paradigm of ecological economics, where the economy is a subsystem of the finite global ecosystem. In this regard, strong sustainability requires that natural capital remain constant over time.

Moreover, to operationalize this concept, it has been transformed into principles to maintain minimum and safe sustainability standards. Thus, the main contribution of this concept for sustainable development is to introduce the set of ecological criteria. As the principle of environmental conservation, strong sustainability aims to maintain the value of aggregate environmental assets. Nevertheless, it must be clear what it is trying to preserve based on the interdependencies of ecosystems that function as our life-support system. This is crucial for enhancing the ecological capital base if it is desired that changes in the economy be introduced. However, this requires plenty of improvement in the institutional arena, human capital and technological progress to develop an integrated framework.

Bonevac (2010) indicated that the most important feature of strong sustainability is that it does not allow capital substitution. In this regard, the author stressed that it is very restrictive since it is difficult to justify increases in social or economic capital even if it means gains in the capital available for future generations. The rigidity of this concept means that it is not possible to trade natural for economic gains, and vice versa. To avoid this situation, it is necessary to understand the interdependencies between ecosystems and mankind, to define the exact link where substitution is not allowed.

Williams (2004) argued that strong sustainability is devoted to the protection of natural ecosystems by granting some sort of rights to nature. Thus, the concept is opposite that of weak sustainability, which grants the domination of nature to humanity. In this regard, strong sustainability is a critique of economic development and its endless materialistic pursuit of materialism.

Also, Ross (2009) stressed that strong sustainability can limit considerably the extent to which man-made capital and natural capital are substituted. To avoid this situation, the concept must define certain key environmental assets for human and natural capital survival.

The authors described above stressed the most relevant features of strong sustainability and their implications for development. Since natural capital conservation is crucial in strong sustainability, the definition of minimum environmental conditions for survival is required to analyze the possibility of types of substitution between human-made capital and natural capital. This a necessary condition to satisfy to operationalize sustainable development goals.

The debate about progress or stagnation and the implications for strong and weak sustainability

The concept of weak sustainability is associated with the notion of progress and development, whereas strong sustainability could be associated with stagnation. The debate revolves around these implications and is crucial for the outcome of sustainable development goals.

In the confrontation between weak and strong sustainability, the environmentalist's paradox is embedded. According to Ang and Van Passel (2012), the environmentalist´s paradox is linked to the notion that environmental degradation leads to declines in human well-being; however, there has been some evidence that contradicts the statement. The author stressed the results of the Human Development Index of 2005, where improvements in GDP per capita, life expectancy, literacy and education attainment were achieved regardless of the increase of the demand of ecosystem services in the past 50 years. Therefore, the notion of natural and human-made capital substitutability has some bases for justification. Nevertheless the degree of substitutability is a variable depending on the context and human actions affecting the natural world, whereas in the case of strong sustainability, it may be unreasonable to forbid completely environmental degradation due to the trends of the growth of the world population. These factors impose several question for future generations given

the constant disruptive relationships between humans and nature, and it will also be important for settling the weak and strong sustainability discussion. Therefore, it will be crucial to develop an adequate concept and valuation of capital that encompasses the complex features of the environment.

Getzner (1999) stressed that the discussion of weak and strong sustainability can be addressed in a discussion of environmental economics and ecological economics, where the debate revolves around optimism for future technologies and strict conservation goals for maintain the environment. Both approaches provide advantages for sustainable development. For example, strong sustainability can define the minimum standards of environmental protection once key interdependencies among capitals are detected to allow economic activities to increase human well-being if possible.

According to Grissom et al. (2014), the discussion between weak and strong sustainability can be settled by addressing the issue of natural resource use, ecosystem interdependencies and their valuation. This will help with making progress and with achieving the objectives of sustainable development to respect the needs of future generations and assist them in the understanding of sustainability.

Hediger (1999) indicated that the differences between both concepts arise from different visions about how sustainability should look like. With regard to weak sustainability, the discussion cannot be reduced to differences in productive processes and assumptions about substitutability between natural and human-made capital. This issue should go beyond this and consider the way in which the environment functions and how it is valuated. Therefore, weak sustainability can be meaningful for sustainable development as a principle to evaluate the trade-offs among goals. Also, it requires the minimum criterion of maintaining environmental quality from one generation to another. Strong sustainability will also be necessary to promote the sustainability and integrity of ecosystems. This is meant to strengthen ecological and

human resilience by identifying key non-substitutable environmental services that will simultaneously allow one to introduce development policies. Therefore, it will be necessary to reconcile the satisfaction of preferences with the minimum ecological conditions for securing human survival.

The debate shows that weak and strong sustainability have advantages for sustainable development. In this regard, they contribute to operationalizing sustainable development models by providing notions of the valuation of capitals and the development of indicators for measuring their performance. Moreover, based on the discussion, strong sustainability seems to be complementary to weak sustainability by stressing the relevance of natural capital as being crucial for human survival. Also, as many authors have stressed, valuation criteria and contextual differences must be addressed first to operationalize a sustainable development strategy, as understanding the trade-offs between mankind and nature is the key to responsible progress and growth.

1.4 Sustainable development and decentralization of water management

The decentralization of natural resources management is a common strategy employed in several countries in order to improve the probabilities of achieving the sustainable development goals by increasing the number of actors involved. In the literature about water management, a well-planned decentralization at the municipal level is a useful case of water management to ensure the provision of sustainable and high-quality water services.

According to Saleth and Dinar (2004), in the international environment, within their political constraints, countries are trying to set the right institutional foundation necessary to promote demand-side solutions in water management (pp.178–182). There are similar features, such as the relevance of market-based allocations,

decentralization and privatization, integrated water resources management and economic viability and physical sustainability.

Dutta (2009) stressed that a main advantage in the decentralization of water services is the increase of well-being by paying fare tariffs. The author stressed that well-planned decentralization allows financially viable provision and expansion of water services in urban areas. This is crucial since, under water scarcity conditions, the involvement of communities in water management is a socially desirable alternative.

Vásquez (2011) argued that decentralization of water services is often proposed as a way to increase the efficiency and equity in the water sector. This is possible since local governments have better knowledge of local water demand and have more direct political incentives to efficiently use the available resources. However, in order for decentralization to work, it is necessary to strengthen the managerial and financial capacities of municipalities.

Daigger (2009) stressed that decentralization is a consequence of the need to achieve sustainable development goals. With regard to water resources, the author argued that with the correct conditions, decentralization could foster the introduction of advanced technologies to cope with water scarcity by providing modern water services. Nevertheless, the governance structure and economic conditions are critical for this purpose. Similarly, Kirksey (2010) argued that the decentralization of water services could be the natural response to introduce innovation in order to prevent or abate water scarcity. In order to introduce decentralization, it is necessary to strengthen communities' financial and human resources to develop collaborative programs for the water sector.

According to all the authors, decentralization can provide very important advantages to achieve sustainability in water management. Nevertheless, prior to transferring the responsibilities to local governments, local human and financial

resources must be prepared in advance to take charge. If this is ignored, decentralization will not succeed and new problems will arise for the local and federal governments.

1.4.1 International political debate to address water resources management

Water management is inscribed in the notion of sustainable development; however, there are several complications in determining strategies to achieve the sustainable use of water resources.

Most of the debate focuses on the struggle among the managerial implications of water as an economic good or a human right. According to Caldera and Torregosa (2010), water management is fragmented due to different logics and conflicts of interest that undermine the rational use of water resources. The authors described that international agencies, such as the United Nations, the World Bank, the Global Water Partnership and the World Water Council, promote the idea that local successful experiences in the reduction of the overexploitation of water resources have institutional designs in common, where users have an active role and their interests and preferences are represented. Nonetheless, they have fundamental differences regarding the legal nature of water that will determine its use and allocation.

In 1977, the Conference of Water of the United Nations, which was developed in Argentina, addressed the issue of water crisis for the first time. The goal of the conference was to assess the status of water resources to prevent a world crisis by the end of the 20th century. Also, it was acknowledged that every human being has the right of equal access to enough water in terms of quantity and quality to cover his needs. However, during the 1980s, many developing countries experienced an economic crisis that eventually led to the introduction of neoliberal economics.

The promotion of neoliberal ideology in the water sector in less-developed countries focused on a major private participation in the provision of water and sanitation services with economic and efficiency criteria (Castro, 2008). The supporters of these measures were international financial organisms like the World Bank, which specified that in order to grant access to funds for the development of water projects, countries should decrease state´ intervention. Due to domestic and international pressure, many developing countries agreed to apply this policy; however, this will bring more challenges than solutions in the future of the water sector.

In 1992, the International Conference of Water and the Environment of the UN celebrated in Dublin changed the orientation of water policy in the world. In their principles, water was deemed a vulnerable and limited resource for life. Thus, water management had to be based on economic criteria and a participative framework of all the users in the formulation of policy. This was criticized by professionals of developing countries, since water management had to also consider inequality and poverty conditions; moreover, turning water into an economic good has potentially exclusive impacts and a limited distribution of the benefits (Castro, 2008).

The new paradigm formulated in Dublin reinforced the role of institutions such as the World Bank, which granted funds for water projects based on economic criteria. Nonetheless, there has been a continuous debate about the nature of water that could be tracked through the outcomes of several World Water Forums.

1st World Water Forum, Marrakech

In 1997, the World Water Council organized the 1st World Water Forum. The main result of the meeting was the recognition of clean water and treatment to conquer poverty, which was included in the United Nations Development Objectives of the

Millennium in 2000 in terms of reducing by half the population without access to drinking water and treatment (Caldera & Torregosa, 2010).

Moreover, the need to approach water management was more comprehensively addressed in the WWFMD (1997):

> "We recognize and note the urgent need for a better understanding of all the complex issues- quantitative and qualitative, political and economic legal and institutional, social and financial, educational and environmental- that must go into shaping a water policy for the next millennium." (p. 1)

The WWFMD (1997) also stressed the importance of cooperation among the civil society and governments to secure water as a human right rather than manage water as an economic good.

2nd World Water Forum, Hague

In 2000, the United Nations' position was distanced from the World Water Council. Now the outcome of the forum considered water as a scarce resource that should be allocated in competitive uses; nonetheless, human needs should not be impeded. In this regard, the prices of water should promote conservation, rational use and maintain social welfare (Caldera & Torregosa, 2010). Nevertheless, the provision of drinking water was addressed as more of an economic than a social criteria. This was expressed in the WWFMD (2000):

> "To manage water in a way that reflects its economic, social, environmental and cultural values for all its uses, and to move towards pricing water services to reflect the cost of their provision. This approach should take account of the need for equity and the basic needs of the poor and the vulnerable." (p. 3)

Therefore, supporters of water as a human right formed organizations such as the Network of Parliaments for Water, World Court of Water to organize alternative forums. In 2001, the German government and the United Nations called a meeting with the International Conference of Potable Water. The main outcome of the meeting was the recognition of the poor's water needs.

3rd World Water Forum, Kyoto

In 2003, water resources management was once more addressed in the political discussion as an economic good that should satisfy a basic human need, which is social good. This recognized the relevance of public-private associations and the option of access to international private funds in order to foster the development of water services (Caldera & Torregosa, 2010).

This can be found in the WWFMD (2003), attached in the Final Report of the 3rd World Water Forum:

> "Addressing the financial needs is a task for all of us. We must act to create an environment conducive to facilitating investment. We should identify priorities on water issues and reflect them accordingly in our national development plans/sustainable development strategies including Poverty Reduction Strategy Papers (PRSPs). Funds should be raised by adopting cost recovery approaches which suit local climatic, environmental and social conditions and the "polluter-pays" principle, with due consideration to the poor. All sources of financing, both public and private, national and international, must be mobilized and used in the most efficient and effective way. We take note of the report of the World Panel on Financing Water Infrastructure." (p. 110)

The main outcome was to shape a model of sustainable water management that could fulfill the goal to preserve water resources by achieving a balance between social welfare and private sector participation.

4th World Water Forum, Mexico

The forum was organized in 2006, and the policy debate regarded the discussion of the legal nature of water. The main outcome was the consensus toward water access as a human right rather than managing water as an economic good (Caldera & Torregosa, 2010).

This was stressed in the WWFMD (2006), attached in the Final Report of the 4th World Water Forum, 2006:

> "Reaffirm the critical importance of water, in particular freshwater, for all aspects on sustainable development, including poverty and hunger eradication, water related disaster reduction, health, agricultural and rural development, hydropower, food security, gender equality as well as the achievement of environmental sustainability and protection. We underline the need to include water and sanitation as priorities in national processes, in particular national sustainable development and poverty reduction strategies." (p. 221)

This trend to consider water provision as a human right has been a key element in the political discussion on the next editions of the World Water Forum, where the debate has emphasized the importance of local and regional authorities' involvement.

5th World Water Forum, Istanbul

In 2009, the main topic again involved the discussion about the consideration of water as an economic good or a human right. However, regardless of the persistence in

considering water as an economic good, water as a human right is becoming more universally accepted as a crucial issue in water management (Caldera & Torregosa, 2010).

> This is shown in the WWFMD (2009):
> "We support country-led development projects in different sectors related to water, especially with regard to energy and food security and poverty eradication. We will work to build new and maintain, strengthen and improve existing infrastructure for multiple purposes including water storage, irrigation, energy production, navigation and disaster prevention and preparedness that are economically sound, environmentally sustainable and socially equitable." (p. 2)

It is possible to see that there is a stronger commitment of governments to develop projects in order to support sustainable management of water resources and maintain or increase social welfare.

6th World Water Forum, Marseille

This forum was celebrated in 2012, and it showed an expansion in the political discussion of how to accelerate the development of water management to address water provision as a human right.

In the forum, the need for cooperation and coordination at the different levels of governance was stressed in the World Water Forum Ministerial Declaration (WWMD) to clarify their corresponding roles; nonetheless, regional cooperation requires support and endorsement from the higher governmental sphere to support local initiatives (WWMD, 2012, p. 18). The improvement of governance is crucial to secure universal and sustainable water access for urban and rural areas. Therefore, it

was agreed that local stakeholders should have the technical, regulatory and financial capacities to perform this task in the long run, and these conditions are critical for providing the necessary affordable sanitation services to conserve water resources and implement water as a human right (WWMD, 2012, p. 25).

The governments' commitment with these issues was expressed in the WWFMD (2012):

> "We are therefore determined to achieve access to safe drinking water and sanitation for all with the required availability, quality, acceptability, accessibility and affordability, focusing on the most vulnerable and taking into account non-discrimination and gender equality. To improve the situation of the billions of people without access to safe drinking water and proper sanitation, we intend to focus our efforts on local and national planning and coordination, adequate financing and investment, and robust regulatory, monitoring and accountability frameworks, involving all stakeholders…
>
> Good water governance requires multi-stakeholder platforms and legal and institutional frameworks enabling the participation of all, including indigenous peoples, marginalized and other vulnerable groups, promoting gender equality, democracy and integrity. Given the particular role of local and regional authorities, in the principle of subsidiarity, we recognize the need to strengthen their capacity to fulfil their responsibilities, as appropriate." (pp. 5-7)

Therefore, the path to follow after the forum is the acceleration and strengthening of the conditions necessary to decentralize water services in order to achieve local solutions for water problems.

7th World Water Forum, Daegu and Gyeongbuk

This forum took place in the Republic of Korea in 2005, and the political discussion focused on decentralization as a key factor for the achievement of sustainable water management to ensure water provision as a human right.

One of the main outcomes of the forum was the strengthening of cooperation and exchange of experiences among local and regional authorities. The purpose to increase the exchange of information at the local and regional levels is the improvement of water management and to enable environments' achievement of national and global goals (WWMD, 2015, p. 5).

The latter is critical given the political intentions expressed in the WWFMD (2015), which stressed the following:

> "We reaffirm that water is at the core of sustainable development and support the inclusion of one dedicated water goal and water-related targets in the Post-2015 Development Agenda. We note that Integrated Water Resources Management (IWRM) and its balanced relation with food and energy is important to effectively cope with increasing food and energy requirements towards sustainable development.
>
> We reaffirm our commitment to the human right to safe drinking water and sanitation and ensuring progressive access to water and sanitation for all." (pp.1–2)

Thus, the enhancement of local capacities is critical given the political commitment to secure the human right to water; moreover, the forum's discussions stressed the importance of the decentralization processes of water services in order to secure the human right to water and sanitation.

As shown before, the political discussion of the legal nature of water has been addressed differently through several international fora. This is important since once the legal nature of water resources is defined, the decisions taken by the authorities will determine the outcome of water management and the impacts on social welfare. Although decentralization is mentioned as strategic to secure the human right to water and sanitation services, in the mentioned debates, there is not explicit preference for private- or public-owned water utilities, which is a critical aspect in the outcome of water services performance and its social impacts.

1.4.2. Privatization and market approach to water management

In general, changes in water management have been driven by endogenous factors, such as water scarcity, performance deterioration and financial nonviability, as well as exogenous factors, such as macroeconomic crisis, political reform, international agreements, natural calamities and technological progress (Saleth & Dinar, 2004, pp. 184–187). For instance, the macroeconomic crisis of the late 1980s was a motive to initiate reforms for countries like Mexico and India. Moreover, the impact of reforms depends on the gap between their intentions and requirements, willingness and capabilities. According to Barbier (1999), in less-developed countries, economic growth depends on the exploitation of natural resources. Thus, resource depletion and environmental degradation could lead to an outbreak of conflicts and diminish the process of economic and institutional innovation in these kinds of countries.

The acknowledgement of water management is oriented to cover a basic need from a public perspective that obeys empirical evidence. It is argued that the increase of private sector participation is justified since the state was not capable of providing universal, efficient and affordable water services (Castro, 2008). This paradigm

belongs to neoclassical economics that stress superiority of the private sector in water management rather than the public administration.

Regarding water management, the debate is about the provision of affordable services with sustainable criterion. According to Mukheibir (2010), several solutions have been proposed that involve the privatization of water services, which have failed to support sustainable development in most of the less-developed countries.

It is often assumed that market-oriented policies could substantially contribute to sustainable water management, given that private actors have resources for investment. Also, market incentives will help to allocate water resources where they are needed. However, in the event of conflict, institutions are required to secure property rights so that the users assume the costs of their actions (Romero, 2007). Moreover, the free market approach considers partially ecological impacts and often lacks incentives for investment to improve water services, and it ignores the inequality problems that are very common in developing countries (Rojas, 2013). Thus, the state should focus on providing legal and institutional conditions to define the property rights as well as ensure social welfare in order for the market to work as an intermediary in the allocation of natural resources.

In less-developed countries, the belief that the private sector has the resources to invest in water projects is not likely to occur. Two examples of this include the water company Aguas Argentinas in 1993 and the case of the company operating in the Mexican city of Aguascalientes. Both cases are evidence that, under market-oriented policies, water users are subjected to change from holders of a social right to merely consumers.

The Aguas Argentinas company

In 1993, in the city of Buenos Aires, an Argentina private firm was given the concession to provide and improve water services and sanitation. However, it only invested 2.6% of the total funds since most of the resources came from government subsidies. More importantly, once the company declared bankruptcy and was given the conditions of poverty and economic inequality of the city, water access was very limited for low-income population segments that were unable to afford the service.

The case of Aguascalientes

The city of Aguascalientes had an economic boom in the decade of the 1990s, and, in 1993, water services and sanitation were privatized. By the time the concessionaire became operational, economic inequality was sharp since 70% of the domestic users were considered to have low income. Also, these users represented 91% of the customer base. In order to make the concession profitable, the increase of tariffs was estimated to be 170%; therefore, since the start of operations, the price of water increased 10% every two months. In 1994, with the upsurge of the economic crisis, low-income users found themselves unable to pay for water services. Additionally, the concession almost collapsed, but it was rescued by the government and renegotiated (Castro, 2008).

In countries where private participation is higher, water services and sanitation were developed as a universal right. Lobina and Hall (2000) recognized that, in practice, the private sector should increase resources for investment and the efficiency of water services. However, the authors stressed that the private firms of water services in particular are more prone to show distortions of a monopolistic type, such as management inefficiency, excess of pricing, excess of profits and low water quality and problems in delivering development objectives.

This is critical in developing countries where free market reforms were implemented in a very short time. According to Spicer et al. (2000), in economies in transition, a progressive privatization is preferable to a rapid change in order to allow countries to adapt a new institution and legal framework as well as regulate market forces. These factors could also weaken the rule of law, which entails a skewed legal treatment favorable to the protection of corporations from the state and civil society (Allina-Pisano, 2009).

According to Hájek and Petružela (2016), public water supply and sanitation services are characterized by monopolistic features. They are a local natural monopoly based on the source of water and the use of a unique infrastructure, public subsidies and strong links in the social, environmental and safety areas. However, it is well known that monopolies react differently than the social planners. This could create new problems for sustainable water management in terms of social welfare and environmental degradation. The monopolists respond mostly to market incentives, especially to shifts in the costs of production, prices and demand of the offered goods in order to obtain the highest profits (Laxmirayan et al., 2005).

The literature shows that changes were driven with market policies criteria that worsened the problems of water management in developing countries. Moreover, this has led to the reduction of welfare, given the levels of poverty and economic inequality that prevail in these types of countries; also, the risk is increasing for these countries to have more serious problems linked to water resources degradation, which will increase their challenges in terms of sustainable development.

CHAPTER 2: EVOLUTION OF WATER MANAGEMENT IN MEXICO

In this chapter, the evolution of water management will be analyzed based on relevant historical events, which lead to significant changes of water policy and water uses in Mexico.

As stressed in the introduction, in order to comprehensively address the problems of water management, it is necessary to assess the physical, economic, policy and institutional dimensions of water, which are critical for the water sector performance (Saleth & Dinar, 2004). In Mexico, the study of these four dimensions helps to comprehensively construct the orientation of water management, since it will help to understand the evolution of water use throughout history.

2.1 Policy dimension

Water policy mainly defines the different uses of water and the allocation of water resources in a given region or country. Additionally, the goals and priorities of water policy will be an expression of the interests of the relevant actors linked to the exploitation of water resources.

As stressed by Roland & Cárdenas (2010), in Mexico, the evolution of water policy has been influenced by the political and economic situations in the different stages of Mexican history. Both factors have been key determinants in the transition of local water management to national water management and from national water management to the decentralization attempt of water services.

2.1.1 Local water management period

This period goes back to the Colonial era and approximately to 1890; also, this is the first period where some information about water management exists, and it was featured by a monarchic type of organization due to the presence of Spaniards in the country.

In this era, the scale of the use of water resources was small and management was fragmented; moreover, water was considered to be private property. During the Spanish colony, water was allocated among municipalities, state governments and private agents like neighborhood organizations (Aboites et al., 2010). The colonial management of royal concessions lasted until the middle of the 19th century, and during this time, several works were completed in order to increase water availability for agricultural and urban supply.

Under a framework of privatization, water service concessions are granted after a public tender process. However, sometimes governments discard the best feasible option and choose the water project that would secure the highest revenues (Lobina & Hall, 2000). Therefore, the authors proposed developing a public-owned enterprise for providing water services. These companies are not less efficient than private firms, and although they operate with a cost recovery framework, however, they reinvest their additional resources into the maintenance and development of the new water infrastructure. This topic will be discussed in more detail in Chapter 3.

The legal nature of water will have an important outcome in the sustainable development goals of each country. Therefore, it is important to address the most important political, economic, institutional and physical features of the context in order to define water management. The study and assessment of these dimensions can provide a more comprehensive picture for the implementation of policies for sustainable water management.

Masonry dams were built to store water for irrigation purposes. Also, urban water supply was provided by water sellers, the construction of aqueducts, rainfall catchment systems and channels to deviate water from rivers and crooks; nevertheless, the water per capita consumption was reduced (Sánchez, 2009).

After the Independence War of 1810, water management followed the same policy used during the colonial era, and water was still administered locally for several more years. In 1857, with the purpose of increasing the federal budget, the liberal governments attempted to turn water into a public good through Article 27 of the Constitution, which included the notion of public utility of property. However, it was not until the administration of Porfirio Díaz that the most serious attempt to centralize water management occurred to prevent conflicts among the users and foster economic growth. Aboites et al. (2010) stressed that Díaz's industrial policy depended on the use of water to produce electricity; also, the agricultural goals required of large-scale irrigation projects and the modernization of urban settlements included the installation of pipe networks for the water supply.

During the Porfirio Díaz administration, the outbreak of the Mexican Revolution began in 1910 and ended approximately in 1917 with the creation of a new constitution.

As referred by Núñez (1960), the rise of the Mexican Revolution was due to a strong resentment against Porfirio Diaz's regime. This was fueled by factors such as the excessive concentrations of land ownership in a few hands; the growth of the rural population; the peasants' excessive labor offer and the low salaries paid in the estates; low living standards and a judicial system that mostly favored the owners of capital. Also, there were discontent elites who were isolated from Diaz's policies and did not perceive the same benefits as the groups close to the president. The involvement of some excluded elites in the Mexican Revolution was more for political reasons; nevertheless, they destabilized enough of the current political regime and functioned

as leaders who were followed by the peasant masses, which ultimately took to arms. According to Cerda (1991), the outbreak of the Mexican Revolution was also due to economic reasons. During the first decade of the 1900s, the Mexican economy was in crisis due to inflationary pressures, economic recession, unemployment and problems with public finances. These problems reached almost everybody in urban and rural locations where the income was insufficient, and living conditions decreased.

The latter gave rise to the ideals of the Mexican Revolution, which included social justice, liberalism, tolerance and intellectual freedom (Chilcote, 1967). Also, these ideals shaped the constitutional structure of 1917 and also left a strong nationalistic spirit as a legacy.

However, it was difficult to reach agreements due to the differences and conflicts among the revolutionary factions. Basurto (2010) stressed that the different social groups had their own interests to get involved in the armed conflict. This led to confrontations among the revolutionary groups and extended the political instability that affected the revolutionary governments for a longer time. Over the years, it became evident that the prestige and skills in the battlefield were not enough to lead the country (Knight & Urquidi, 1989). Therefore, in order to conserve legitimacy and achieve political stability, the new revolutionary elites incorporated intellectuals and academics to their administrations and reached a consensus about changes in policies.

Overall, Knight (1986) stressed that the Mexican revolution was successful in the elimination of the estates' property system, which was the main feature of the old regime. Nevertheless, as in during Díaz's presidency, the revolutionary governments pursued the consolidation of the Mexican state and capitalistic economic development.

The revolutionary governments found the means to achieve this goal in the centralization of power and management of most of the productive activities as well as natural resources.

2.1.2 National water management period

This period was highlighted by a very aggressive nationalization process of many assets in the country, including natural resources. The main reason was the need for governments to secure stability and ideological conflicts linked to private property; moreover, during this period, the governmental investment was crucial for the modernization process of the country in many areas, including water resources.

The post-revolutionary governments developed a centralized management of water resources in order to end the ideological conflict with private property. After reforming Article 27 of the Constitution, water became national property and could only be accessed by private parties with the approval of the state; also, for several decades, further development in the water sector was financed with federal funds (Aboites et al., 2010). The agrarian reform and allocation of land among farmers demanded an increase in water for domestic, industrial and rural uses. This increase in the water supply responded to the fulfillment of development goals based on economic criteria and the overexploitation of natural resources, including water that prevailed at least until the 1980s (Rojas, 2013). Since 1926, the modernization of the agricultural water uses was possible for the generation of electricity and the hydraulic pump, which allowed the drilling of wells for irrigation and the expansion of sowing surfaces, especially in the northeast of the country (Sánchez, 2009). However, given the priority of agriculture, improvement of the infrastructure for drinking water supply, industrial uses and hydropower received significant funding almost 20 years later.

According to Aboites et al. (2010), the government invested in the expansion of water distribution networks and sewage, thus increasing the number of households with access to these services from 17% in 1950 to 77% in 1970 without any concern of water quality and efficiency criteria. Also, until the 1970s, the awareness arose about pollution problems affecting water quality; however, the state's investments

could not follow to address these issues due to economic crises that reduced its budget (Rojas, 2013; Sandoval, 2010).

In 1983, with the reform to Article 115 of the Constitution, water management was decentralized by transferring the obligation to municipalities in order to provide water services with the help of the private sector. Although the reform argument was to democratize water management through decentralization, the main reason was to release the fiscal burden of the federal government in the sector (Aboites, 2010).

Moreover, during the presidency of Carlos Salinas de Gortari (1989–1995), the nature of water changed from being a social good to an economic-environmental good. According to Rojas (2013), in the last decade of the 20th century, water management revealed preferences on water allocation to the most profitable rural and urban activities; thus, it excluded some social groups. The NDP (1989–1994) acknowledged the priority of addressing water scarcity by increasing physical and commercial efficiency of water utilities and abatement of water pollution with the increase of wastewater treatment (pp. 143–146). The deepening of water management as an economic good to secure efficiency and sustainability continued in the subsequent presidential periods; however, the challenge was greater since economic growth remained a priority.

The NDP (1995–2000) of the Ernesto Zedillo administration stressed the need of sustainable economic growth to overcome the economic crisis of the past years; also, the NDP reaffirmed the allocation of funds in the water sector based on economic criteria and supported by the private sector (p. 106; pp. 134–136).

The situation in the next presidential period was not very different; nonetheless, a more conscious consideration was given to sustainable development in a period of political transition. The uses of water did not change significantly in the next years, but the awareness about environmental protection and sustainable development became more important. In the NDP (2001–2006), President Vicente Fox proposed

an economic model based on the sustainable use of resources and an absolute respect for the environment (p. 19; pp. 35–56; pp. 122–123). Those who would engage in economic activities should comply with these conditions; moreover, the model addressed the abatement of water pollution as a task for all private, governmental and social actors.

Afterward, during the presidency of Felipe Calderón, the NDP (2007–2012) featured sustainable development more comprehensively than in any other presidential administration in the past (pp. 24–26). The plan reasserted the need of a sustainable economic development supported by public policies that would include the environmental dimension to reconcile economics with environmental protection. Also, according to the NDP (2007–2012), besides the traditional uses of water, the provision of environmental services was explicitly included for the first time; also, in order to abate water pollution and scarcity, the promotion of economic instruments as a reward for improving efficiency would be a key factor in the fulfillment of this goal (pp. 118–135).

According to the latest NDP (2013–2018) of Enrique Peña Nieto, the promotion of sustainable development and economic growth remains an important challenge, and the plan especially addresses the need to improve water availability by strengthening the states' capacities of and municipalities for more adequate water management (p. 71; pp. 134–135).

More detailed information about the uses and status of water resources in the 21st century will be provided in the "Economic Dimension" section. However, in order to better understand the actual situation of water resources, the institutional dimension must be analyzed first.

2.2 Institutional dimension

Several historical events influenced the construction, changes and objectives of institutional arrangements linked to water management. Throughout the history of Mexico, the most common problem that institutions had to address was the allocation of water resources and conflicts associated with property rights. As will be shown in the following subchapters, the nationalization of assets and a strong state intervention in water management and economic development later became a source of stress for water resource quality and availability.

2.2.1. The colonial era and period of 1888–1917

The colonial era is included in this subchapter since the information about water management for this period is limited. Water management during the colonial period was featured by royal decisions to allocate water resources and disputes between the Spaniards and the indigenous population.

In 1536, during the Spaniard colony, water was considered to be royal property, and it was allocated according to the decisions of the viceroy Antonio de Mendoza (Semblanza Histórica del Agua en México, 2009). The distribution of royal concessions granted users access to streams and springs, and in the event of a dispute, the users appealed to their concession documentation. The purpose of the concession system was to allocate water resources among the indigenous population and Spaniard settlers, where the latter were most benefited; moreover, conflicts were normally solved among the interested parties in order to stick to their customs and habits (Aboites et al., 2013, Semblanza Histórica del Agua en México, 2009).

The colonial organizational regime prevailed long after the Independence War (1810-1821), until Porfirio Díaz set the basis for the development of different institutional arrangements in Mexico in 1888.

Before 1888, despite the efforts of liberal governments in the decade of the 1850s to change the legal nature of water from a corporate good to a public good, the property of the water was still distributed among a large number of private agents. It was not until 1888, during Porfirio Díaz's presidency, that a more serious attempt to centralize water property in the hands of the federal government occurred in order to achieve the goals of economic development and urbanization (Birrichaga, 2009).

With the creation of the Law of General Communication Routes in 1888, the federal government claimed property on several streams used for irrigation. The new federal concession system had the main goal of fostering large-scale irrigation projects and hydropower generation for industrial purposes. Also, the law aimed to increase private investment in the installation of pipe networks for water supply in order to modernize urban settlements (Aboites et al., 2010).

Afterward, in 1910, the Law of Exploitation of Water under Federal Jurisdiction was approved to strengthen the control of the federal government over water resources. The enforcement of these laws and conflict resolutions was the task of the Ministry of Development, Colonization and Industry (MDCI) (Birrichaga, 2009). However, during 1910, conflict arose with the outbreak of the Mexican Revolution, which lasted until approximately 1917. After the end of the Mexican Revolution, the government would achieve consolidating the centralization of the property of water resources. A summary of the institutional changes of this period is shown in Table 2.

Table 2. Institutional framework of water management from 1888-1917

Federal organisms linked to water and their tasks	Changes in the legal framework	Policy considerations
Ministry of Development, Colonization and Industry (1864-1917): Its main task was the enforcement of the legislation; however, it lacked the knowledge and experience to perform that duty.	Law of General Communication Routes (1888). Law of Exploitation of Water under Federal Jurisdiction (1910).	Water and Economic policy goals: Industrial development, hydropower generation and modernization of urban settlements. Environmental policy: No explicit or implicit goal.

Source: Elaborated with information from Birrichaga (2009); Escobar (2009) and Aboites et al. (2010).

As shown above, during this period, the first steps toward the centralization of water management were undertaken. More importantly, the changes in policy were mainly meant to foster economic growth without any explicit regard for water resource protection.

2.2.2. The period of 1917–1946

This period followed the end of the Mexican Revolution (1910-1921), and it was highlighted by the reassertion of centralization and state planning. This mainly occurred due to the conflicts about private property rights and the lack of compensation for the state, which led to introducing deeper changes in policies and institutions.

The post-revolutionary governments initially faced problems due to the fragmentation of power distributed among the different revolutionary groups.

According to Aboites et al. (2010), in 1929, the foundation of the National Revolutionary Party (PNR), which is nowadays known as the Revolutionary Institutional Party (PRI), supported the consolidation of a centralistic approach in several aspects of the economic and social sphere, which also reached water management. Also, post-revolutionary governments disliked the granting of concessions to private parties without compensation for the state during Díaz's regime (Birrichaga, 2009).

One of the social demands that led to the outbreak of the Mexican Revolution was distribution. Thus, the federal government distributed several lands and water among broad groups of the rural population, but not without the opposition of local authorities and other parties (Aboites et al., 2010). Through a reform of Article 27 of the Constitution, the government consolidated the nationalization of water resources and the role of the state as a sole administrator. This would allow the execution of development plans financed with public federal funds in the future (Birrichaga, 2009). Initially, the priorities linked to the use of water were agriculture and electricity generation.

Therefore, in 1926, the National Commission of Irrigation was created in order to foster agriculture, especially in arid areas of the northeast of the country; also, the National Commission of Irrigation was the first national organism with enough autonomy to perform its duties (Escobar, 2009; Sánchez, 2009). Regarding drinking water supply, the federal government substituted local and state governments since they failed to guarantee public water supply for urban settlements; however, as described in the Policy Dimension section, this occurred years later.

The main feature of this period was the consolidation of a centralized water management under the state's administration. The institutional framework is summarized in Table 2.1.

Table 2.1 Institutional framework of water management from 1917-1946

Federal organisms linked to water and their tasks	Changes in the legal framework	Policy considerations
Ministry of Agriculture and Development (1917-1926): Administrate the water resources of federal property and address rural matters. National Commission of Irrigation (1926-1946): Construction of large scale agricultural infrastructure. Department of Health (1926-1946): Provision of drinking water supply and sanitation. Ministry of Communication and Public Works (1926-1946): Flood control and water for the industry.	Constitution of the United States of Mexico (1917). Law of Irrigation with Federal Waters (1926). Law of National Property of Waters (1929). Rule book of the Law of National Property of Waters (1936).	Water and economic policy: Strong focus on the development of agriculture over any other economic activities or types of uses. Environmental policy: Implicitly, the Department of Health had to address environmental concerns.

Source: Elaborated with information from Birrichaga (2009); Escobar (2009) and Aboites et al. (2010).

As shown above, the centralization advanced during this period in order to grant more control to the government in and enforce its policy decisions. This period was emphasized by the focus on agriculture, although some efforts were undertaken to improve the water supply for human consumption. In terms of environmental protection, no explicit goals were formulated, but the creation of the Department of

Health indirectly assumed the task of assessing the consequences of environmental degradation.

2.2.3. The period of 1946–1976

This period was featured by more intense efforts undertaken by the government to invest in the water sector. Several improvements were performed, including the infrastructure for urban water services thanks to the large amount of public funds available; moreover, given the increase in the investment, several changes occurred in the institutional and political arenas. Due to the expansion of agriculture in previous decades, Mexico achieved food self-sufficiency. Thus, in 1946, the government decided to diversify the investment in the water sector to increase the provision of drinking water, sewage and hydropower (Aboites et al., 2010).

The National Commission of Irrigation was substituted by The Ministry of Hydraulic Resources in 1946 with the task of addressing the exploitation and conservation of water; moreover, it was granted with a generous budget equivalent to 10% of the total federal funds (Escorbar, 2009). With the foundation of the Ministry of Hydraulic Resources, the government began extensive work in the drinking water provision and sewage coverage, which were significantly less developed than the agricultural hydraulic infrastructure; also, more funds were invested in the center and south of the country.

Nevertheless, the economic policy, based on an important substitution strategy, increased migration from rural communities to the cities and eventually turned Mexico into a mostly urban country (Sánchez, 2009). This led to an increase of water consumption of the cities and industry, which had to be complimented with the extraction of underground water (Aboites et al., 2010).

This period was also characterized by the state's centralistic management of water resources, which were devoted to industrial purposes and electricity generation. The institutional framework that prevailed during these years is shown in Table 2.2.

Table 2.2 Institutional framework of water management from 1946-1976

Federal organisms linked to water and their tasks	Changes in the legal framework	Policy considerations
Ministry of Hydraulic Resources (1946-1976): This organism allowed the federal government to intervene beyond irrigation issues. Ministry of Economics (1946-1976): Its main role was to administrate issues linked to hydropower. Ministry of Agriculture and Livestock (1946-1976): Operation of irrigation districts, but in 1951, the Ministry of Hydraulic Resources assumed the duties of the Ministry of Agriculture and Livestock.	Federal Law of Irrigation (1947) Regulatory Law of the fifth paragraph of Article 27 concerning underground water (1948) General Law of Sanitation Engineering (1956) Federal Law of Waters (1972) Regulation for Pollution Prevention and Control of Polluted Waters (1973)	Water and economic policy: Change in the investments to develop the industry. Water gained relevance in urban and industrial uses. Environmental policy: MHR was in charge of the allocation and conservation of water resources.

Source: Elaborated with information from Birrichaga (2009); Escobar (2009) and Aboites et al. (2010).

As shown above, there was a transition in water and economic policies focused on the improvement of economic growth in the country. Given the progress achieved in the development of agriculture, the policy switches to improve water allocation in urban areas and for industrial purposes. Moreover, this was supported by the creation of new governmental organizations to address particular policy issues. Another important feature during this period was the accelerated population growth and increases in economic activities that started since 1950; nevertheless, the evolution of both topics will be better explained in subchapter 2.3, and its implications on water management will be discussed in Chapter 3.

2.2.4. The period of 1976–1989

During this period, the consequences of promoting economic growth based on the exploitation of natural resources began to warn of the several problems associated with pollution. The increase in the urban settlements and economic activities started to became a problem since no serious environmental considerations were introduced in the past.

Water started to become scarce due to pollution problems related to the growth of urban settlements and the creation of large industrial centers without a proper infrastructure for wastewater treatment; thus, their residual waters were increasing the pollution of rivers and other water sources (Aboites et al., 2010). Also, the over-exploitation of underground aquifers mainly increased due to a considerable waste of water.

As Birrichaga (2009) stressed, water for urban and domestic consumption became a priority over agricultural and industrial uses, and in this context, the Ministry of Agriculture and Hydraulic Resources was created to address these policy issues. This increase of water requirements in the period of 1950-1970, caused by the

diversity of economic activities and low fees charged for water services, surpassed the financial capability of the federal government (Rojas, 2013).

The shortage of resources caused by the economic crisis and the decline in rents from oil exports pushed the federal government to start a process of partial decentralization through the reform of Article 115 of the Constitution in 1983. The federal government argued that the transfer of water services and sanitation to provisions states and municipalities was an effort to deepen democratization (NDP, 1983–1988). However, according to Sandoval (2010), the decentralization was a decision taken due to fiscal reasons in order to lighten the financial burden of the federal government. Also, the changes in the institutional arrangements were driven by the macroeconomic crisis of the late 1980s (Saleth & Dinar, 2004). Additionally, with the outburst of the crisis in 1982, the government received financial aid from international organisms like the World Bank, which was an additional source of influence to encourage the decentralization process (Olivares, 2008).

In the practice, these changes became an instrument of power for state governments that were better prepared to face the challenge, but it was an impossible task for the municipalities that lacked the capacity to take over water management. In 1980, the Ministry of Human Settlements and Public Works started the transfer of water utilities to municipalities, with the expectation of increasing economic resources for the federal government, by charging contributions for the use of water (Escobar, 2009).

This period marked a turning point in the Mexico water management. The institutional and legal framework to support this process is shown in Table 2.3.

Table 2.3: Institutional framework of water management from 1976-1989

Federal organisms linked to water and their tasks	Changes in the legal framework	Policy considerations
Ministry of Agriculture and Hydraulic Resources (1976-1989): Water management and agricultural production are managed by a single ministry. Mexican Institute of Water Technology (1986-2014): The institute is a decentralized organism of the Ministry of Agriculture and Hydraulic Resources. Its goal is to develop solutions to preserve water quality and to use it efficiently. Ministry of Human Settlements and Public Works (1976-1982): It was in charge of the provision and management of drinking water in the whole country. Ministry of Urban Development and Ecology (1976-1982): Initially, urban water issues linked to ecological problems were address by the federal government. However, since 1983, the obligation to provide water services and sanitation was transferred to municipalities.	Federal Law of Rights (1982) Reform to Article 115 of the Constitution. (1983) Federal Law of Waters (1986) Reform to the Law of Federal Rights (1986) Creation of the General Law of Ecological Equilibrium and Environmental Protection (1988)	Water and economic policy: Economic policy focused on the overall economic growth. With regard to water uses, they had to be subjected to water conservation criteria. Environmental policy: Increased concern to address water pollution issues through the Ministry of Agriculture and Hydraulic Resources

Source: Elaborated with information from Birrichaga (2009); Escobar (2009) and Aboites et al. (2010).

The changes introduced in this period marked a turning point for the future of water management in Mexico, since water pollution problems were addressed more seriously for the first time. As shown before, many changes in policy and institutions were introduced in order to address water management resources. Moreover, the first steps were undertaken toward the decentralization of water services by transferring them to municipalities.

2.2.5 The period of 1989-1994

The process of decentralization continued to deepen with the support of the liberalization of water markets in Mexico. However, the most important feature of this period was the creation of the National Commission of Water (Conagua), which nowadays remains a key player in water management. Also, the efforts to promote the decentralization of water services were increased by the federal government.

In 1989, President Carlos Salinas de Gortari created Conagua in order to provide council to municipalities and create financially sustainable water utilities (Aboites et al., 2010). Conagua was also responsible for providing specialized technical support and promoting more active citizen participation (Sandoval, 2010). The Law of National Waters in 1992 provided the legal framework for the duties and tasks of Conagua. The Law of National Waters established the obligation of citizenship participation in the form of Basin Councils, the use of water and issues about quality and pollution (Birrichaga, 2009). The institutional changes of this period are shown in Table 2.4

Table 2.4: Institutional framework of water management from 1989-1994

Federal organisms linked to water and their tasks	Changes in the legal framework	Policy considerations
Water National Commission (1989-2014.): Conagua is a federal organism created in the framework of decentralization. The tasks of Conagua were to promote the liberalization of water markets, promote the private sector involvement and create a Public Record of Water Rights.	Reform to the Federal Law of Rights (1991) Creation of the Law of National Waters (1992) Rules of procedure of the Law of National Waters (1994)	Water and economic policy: Economic policy focused on the overall economic growth. With regard to water uses, they had to be subjected to water conservation criteria. Environmental policy: Increased concern to address water pollution issues through Conagua. Focus on specialized support and more active participation of users to reduce water pollution.

Source: Elaborated with information from Birrichaga (2009); Escobar (2009) and Aboites et al. (2010).

Of the changes described, the most important regards the creation of Conagua, which will be a key player in the entire country's water management. Moreover, the institutional framework for environmental protection was improved with the creation of Semarnat and the reforms undertaken in the legislation.

2.2.6. The period of 1994-2014

During this period, the tasks of CONAGUA were not very different from those of the last years. However, the awareness of the environmental degradation led to the creation of the Ministry of Environment, Natural Resources and Fisheries, which, since 2000, would be known as the Ministry of Environment and Natural Resources (Semarnat).

The role of Semarnat is to design and propose the environmental policy for the country. Regarding the relation among Conagua and Semarnat, they are mutually decentralized organisms, although they cooperate to address the environmental issues linked to the sustainable use of water management (Escobar, 2009). The problem of the increasing water scarcity and pollution could turn the water resources into a national security issue (Birrichaga, 2009). This situation has been acknowledged in the National Development Plans of water problems that were described in the "Policy Dimension" subchapter.

Table 2.5 shows the latest institutional and legal changes since the modernization of water management.

Table 2.5 Institutional framework of water management from 1994-2014

Federal organisms linked to water and their tasks	Changes in the legal framework	Policy goals
Water National Commission (1989-2014): In addition to the tasks previously described, in this period, Conagua sought to organize water management in basins and hydrological-administrative regions. Ministry of Environment, Natural Resources and Fisheries (1994-2014): Since the year 2000, it changed its name to the Ministry of Environment and Natural Resources (Semarnat).	Modifications to the rules of procedure of the LAN (1997) Reform to the constitutional Article 115 (1999) Federal Law of Rights in Water Issues (2001) Reform to the Law of National Waters (2004) Reform to the Law of National Water and the General Law of Ecological Equilibrium (2008) Reform to the LAN (2014)	Water and economic policy: Economic policy focused on the overall economic growth. With regard to water uses, they had to be subjected to sustainable development criteria. Environmental policy: Conagua and Semarnat determined the strategies for sustainable water management.

Source: Elaborated with information from Birrichaga (2009); Escobar (2009) and Aboites et al. (2010).

The changes described above aim to introduce a more comprehensive water management by the inclusion of more relevant actors in this activity. Nevertheless, the institutional and legislative reforms have a lack of effectiveness in their application and are having considerable impacts on water resources development.

The potential effects of economic policy and institutional changes will be better explained in the subchapters of the physical and economic dimensions. However, despite the progress in some areas of water management, Mexico is still far from achieving a sustainable use of water resources.

2.3 The physical dimension

This dimension refers to the spatial distribution of water in a given territory that could restrict water availability depending on the difficulty to access it; also, this is directly linked to demographic factors. In Mexico, water resources are featured by strong territorial and seasonal differentiation; also, they encounter a contradiction with population concentration and generation of the GDP (Perevochtchikova, 2010).

In 1950, the total population was 25.8 million people, and since then up until 2010, it has increased its size by five times, and the population of Mexico today is 112.3 million people (INEGI, 2015). Also, the rainfall is spatially distributed unequally, since South and Southeast Mexico receive most of the precipitation in comparison with the central and north regions of the country. Nevertheless, the latter regions have the largest share of the population and produce 87% of the GDP, but they also have arid or semi-arid weather that limits their water supply sources; thus, they are more prone to suffer water scarcity (Saltiel, 2008; Seckler et al., 2009). The differences between both regions are shown in Table 2.6.

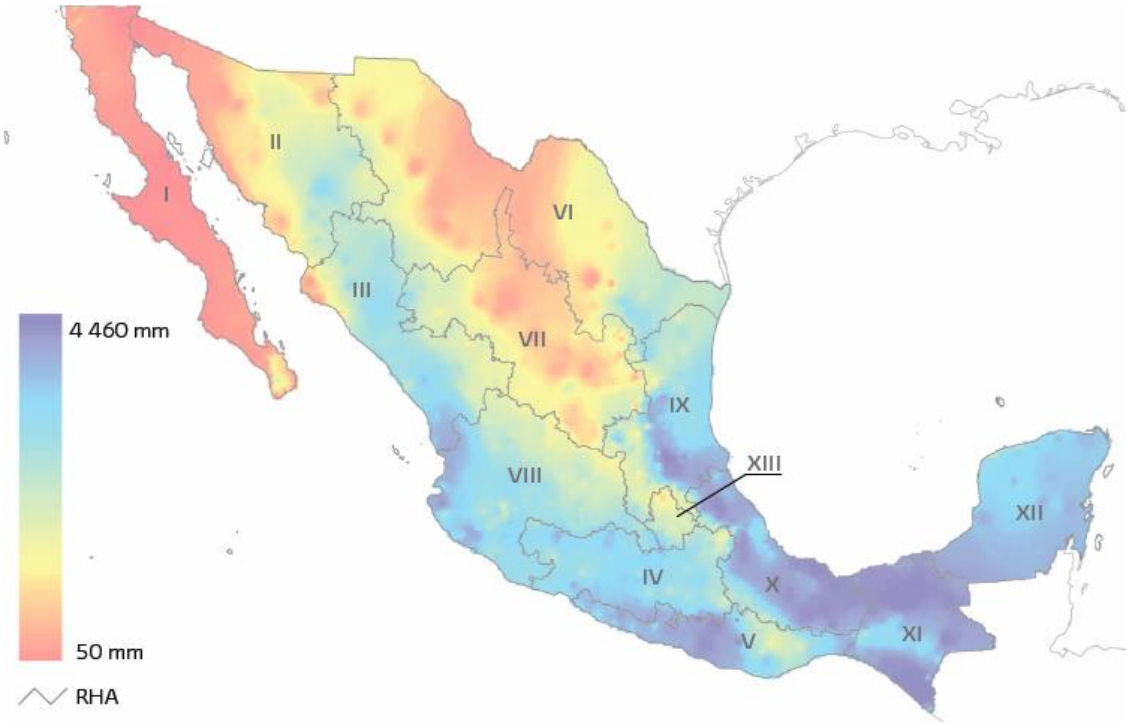
Table 2.6. Regionalization of the natural availability of water population and GDP in Mexico (percentage)

Regions	Rainfall	Availability	Population	GDP
Central and North	20	31	77	87
South and Southeast	80	69	23	13

Source: La problemática del agua: revisión de la situación actual desde una perspectiva ambiental (2010, p. 67).

The differences in renewable water availability are shown in Figure 1.

Figure 1. Annual rainfall distribution 1971–2000



Source: Estadísticas del Agua en México (EAM, 2014, p. 7).

Additionally, since 1950 there has been a transfer of population from rural to urban areas, which is where most of the population is concentrated nowadays. In 2013, the urban population reached 93.9 million, and although the number of rural settlements is still high, the growth and concentration of the population in urban areas put a lot of pressure on the environment and the provision of water and associated services; also, the population is expected to increase to 19 million by the year 2030 (AAG, 2014). Also, Mexico has a large share of the urban areas in its central and northern regions where the water availability is less; thus, their economic development and social wellbeing could be compromised in the near future. The distribution of the main population centers is shown in Figure 2.

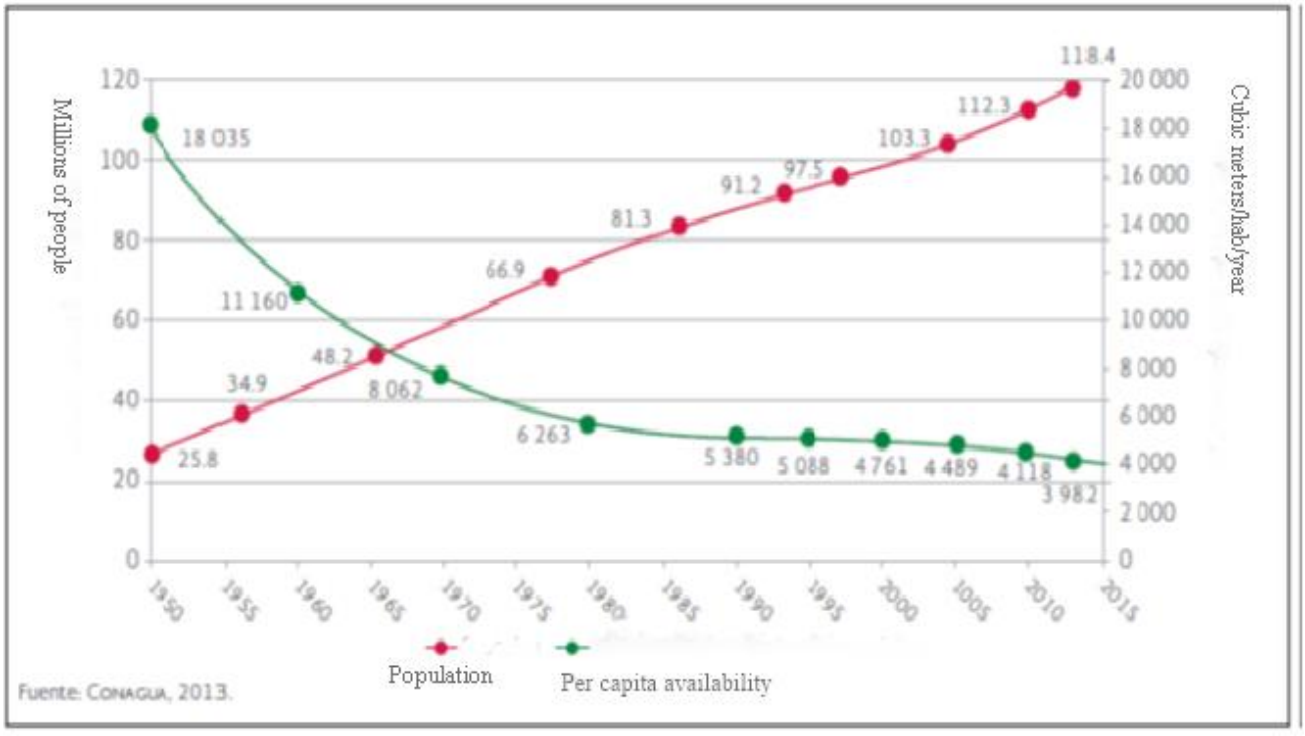
Figure 2. Main population centers in 2013

Source: AAG (2014, p. 15)

In the last 60 years, water availability per capita decreased due to population growth; however, water consumption increased. According to Agua y medio Ambiente: un prontuario para la correcta toma de Decisiones (AMAD, 2015) in 1955, water consumption was estimated in 40 liters per capita, but it reached 280 liters per person every day in 2012. Also, according to the National Water Program (WNP) the average natural water availability dropped from 18,035 cubic meters per person to 3,983 cubic meters in 2013, and it is expected to be only 3,430 cubic meters per person by the year 2030 (WNP, 2013; AMAD, 2015).

The relation between water availability and population is shown in Figure 3.

Figure 3. Population evolution and average natural availability per capita 1950-2013



Source: WNP (2013, p. 26)

The drop in water availability must be seriously considered, especially at the regional level, given that water resource availability per capita in the south/southeast

part of the country is 13,487 m^3, which is eight times higher in comparison to the 1,750 m^3 for the inhabitants of the central and northern area of Mexico (Perevochtchikova, 2010a).

In this regard, water stress is crucial in determining policy outcomes, and this problem will be analyzed in more detail in the "Economic Dimension" subchapter.

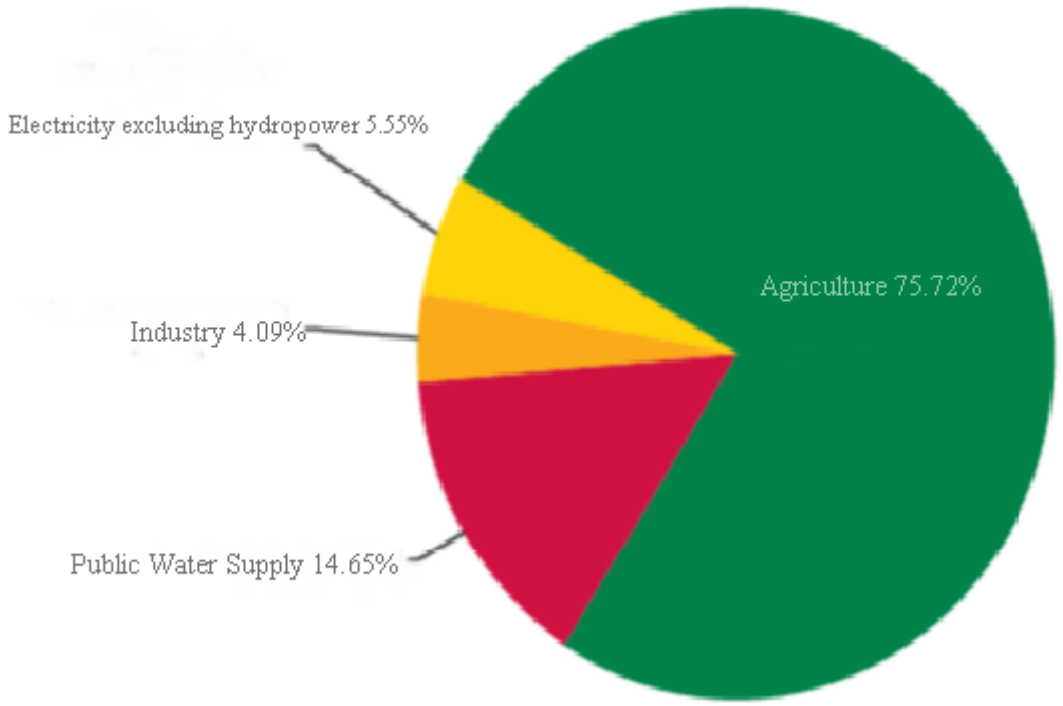
2.4 Economic dimension

It is universally accepted that water is a crucial resource for economic development and adequate performance of ecosystems that provide the environmental services that support human survival (AMAD, 2015). Thus, water resource development has served historical functions in supporting the world, which is now experiencing an increase in population and expanding economic activities while attempting to make sustainable use of water (Saleth & Dinar, 2004). In Mexico, water is considered a limited resource essential for public health, the ecosystems, agriculture, industry and economic development; therefore, water is strategic for national security and social and political stability (NWP,2013).

The Law of National Waters (2014) includes two broad categories of water uses: consumptive uses and nonconsumptive uses. Consumptive uses refer to the uses of water where the resource is withdrawn and does not return to the source; these include activities such as agriculture or drinking water. In contrast, according to ("Agua, medio ambiente y sociedad: hacia la gestión integral de los recursos hídricos en México" (AMAS, 2005) nonconsumptive uses refer to those activities such as tourism, fishing and electricity generation where the water withdrawn is returned to the source with no sensible loss of quantity, although it might show changes in the water's physical, chemical and biological conditions (AMAS, 2005).

According to EAM (2014), in 2013, the extracted water volume was estimated to be 81.65 billion m^3, of which 62.8% came from superficial waters and 37.2% from aquifers. Also, the most important consumptive uses were agriculture, with the largest share, followed by public water supply, industry and energy. The shares of water consumption of each activity are shown in Figure 4.

Figure 4. Percentage of water consumption by most relevant consumptive uses in 2013.

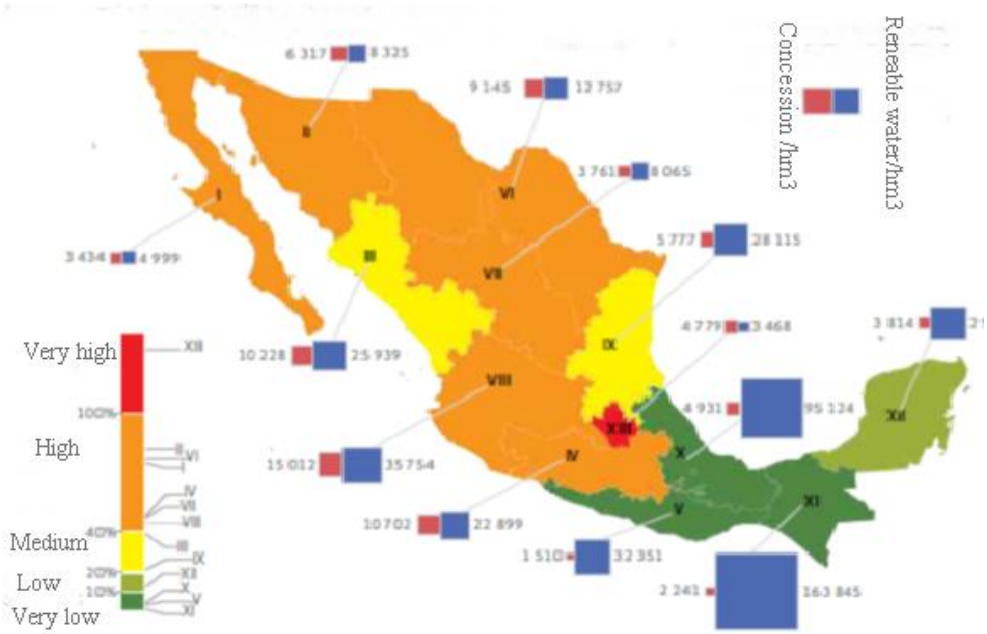


Source: EAM, 2014, p. 61

Given the regional differences physically, this information provides evidence of the economic policy priorities and their possible impact in regions that suffer water stress.

The central and northern regions of Mexico have large irrigation districts, most of the industrial activity and the urbanized areas of the country; moreover, they have the largest share of cases involving poor water quality caused by the degree of stress over water resources (Perevochtchikova, 2010a). In this regard, EAM (2014, p. 230) defines the degree of stress as the percentage obtained from the quotient of the concessions' volume divided by the renewable water. The degree of stress over water resources throughout the country is shown in Figure 5.

Figure 5. Degree of stress over water resources in 2013



Source: EAM, 2014, p. 75

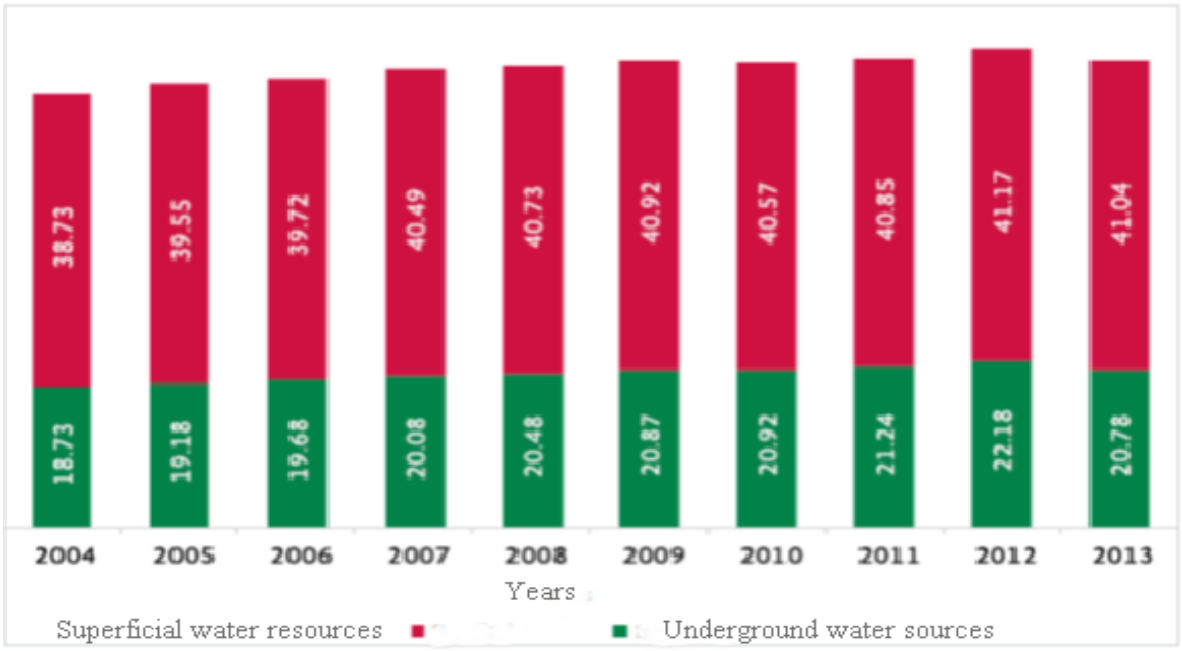
The degree of stress over water resources is linked to the distribution of the economic activities and the distribution of water in the country. In the following subchapters, water uses will be discussed to provide a more comprehensive perspective of the current situation of stress over water resources.

2.4.1 Agriculture

In Mexico, as in the rest of the world, agriculture is water intensive; moreover, Mexico is ranked seventh among all countries in regard to irrigation infrastructure. Mexico has 30.2 million hectares dedicated to agriculture, of which 6.4 million hectares are prepared with irrigation infrastructure that exhibits water use efficiency between 76% and 86% depending on the technology. The rest of the land is used for seasonal crops. Moreover, the output per hectare with irrigation technology is 2.2 to 3.3 times higher than the output of seasonal agriculture (EAM, 2014; NWP, 2013).

With regard to the sources of water, most of the resource comes from superficial sources; however, there has been a small increase in the amount of water coming from aquifers. This is shown in Figure 6.

Figure 6. Evolution of the concession's water volume for agriculture by type of source 2004-2013 (billion m^3).



Source: EAM, 2014, p. 68

The problem in agriculture is that if irrigation starts to depend on underground water sources, it could lead to overexploitation of aquifers due to drilling activities to increase the number of boreholes (AMAS, 2005).

2.4.2 Public water supply

The demand on the public water supply has been increasing in the past few years, especially in the urban areas of Mexico that require larger volumes of water to cover domestic and industrial uses.

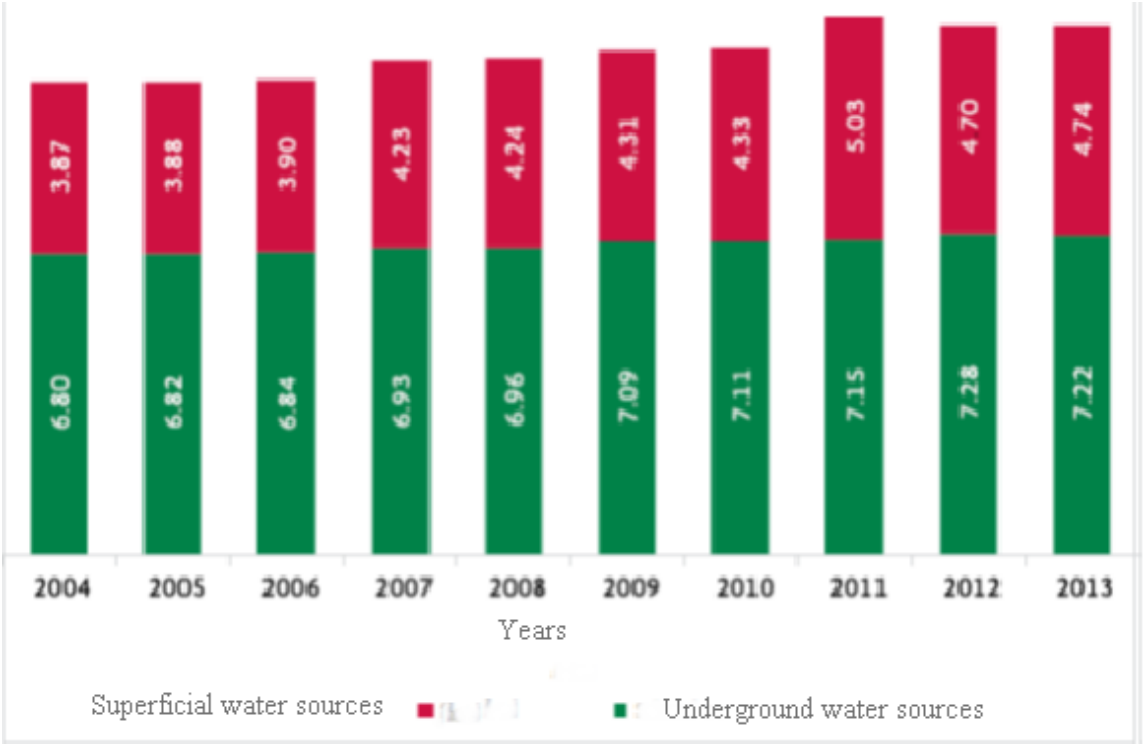
The public water supply refers to water distributed through the networks to domestic users, some industries and services. Who has recognized that the provision of sufficient water of good quality for human consumption is necessary to maintain the health of the population and its general welfare (EAM, 2014).

In Mexico, municipalities are responsible for the services of water supply, sewage, wastewater disposal and wastewater treatment. The tasks related to these services are assumed by municipal water companies (MWCs) that nowadays amount to approximately 2,500 companies; also, most of them are public owned. However, their performance has been poor due to reasons that will be explained in more detail in Chapter 3. Thus, municipalities are incapable of fulfilling their duties associated with water due to shortage of funds, technology and know-how as well as lack of planning for the long run (Rodríguez, 2008).

According to Contreras (2006), of the total water produced by MWCs, 40% is physically lost in the network during the distribution process, and 25% of the billed water is not collected from the users; therefore, approximately only 30% of the produced water generates an income for municipalities. In this regard, the main losses during the distribution process are caused by a high incidence of leaks in the infrastructure, which are estimated to plague around 30% to 50% of the network. (AMAS, 2005). This topic will be described in more detail in Subchapter 3.21.

More importantly, the main water sources for public supply are aquifers, which have been providing approximately 60% of the public water supply in the past years. This is shown in Figure 7.

Figure 7. Evolution of the concession's water volume for public supply by type of source 2004-2013 (billion m^3).



Source: EAM, 2014, p. 69

Given the regional differences in water availability and the increase in the urban population, sustainable water use must be fostered; otherwise, the stress over water resources will continue to increase.

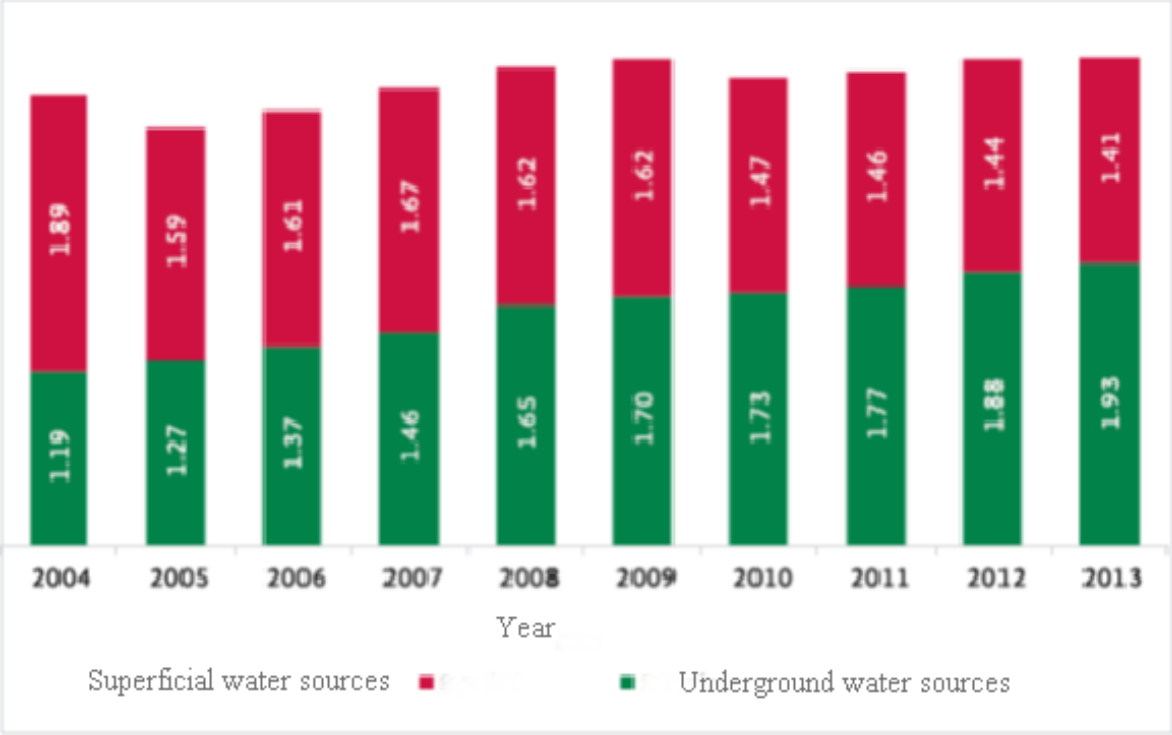
2.4.3 Industrial water consumption

The industrial water demand is less than the volume required to cover the needs of the public water supply; nevertheless, industrial wastewater contributes considerably to water pollution. Industrial water use refers to the water taken directly from superficial

and underground aquifers for activities such as mining, electricity generation, construction and manufacturing (EAM, 2014). Nonetheless, the pollution that is produced generates a biochemical oxygen demand (BOD) three times higher than the one produced by 100 million people; also, the industrial sector competes for the use of water with other sectors, especially agriculture, which could be a source of conflict (AMAS, 2005). In this regard, the BOD is a pollution indicator that shows the quantity of organic matter in the water bodies originated mostly by municipal and non-municipal residual water discharges (EAM, 2014, p. 50).

Also, since 2001, the industry switched from using superficial water sources to underground sources, with a growth of 59.2% in the concessions' volume. The industrial water use by type of source is shown in Figure 8.

Figure 8. Evolution of the concession's water volume for industrial use by type of source 2004-2013 (billion m^3)



Source: EAM, 2014, p. 70

The increase of the proportion of use of underground water resources by the industry must be considered seriously as well; otherwise, in the central and northern regions, it could even compromise the water supply for human consumption, given that several industries are located in those regions.

2.5 Implications of the relationship between the policy, institutional, physical and economic dimensions

As shown before, the main uses of water in Mexico could bring more complications, given that most of the country is already experiencing water stress. Therefore, the issues involving sustainable development must become a priority since the water demand has been increasing due to population and economic pressures. Moreover, the contextual features of water availability in the country could lead to the outbreak of water scarcity, which could be aggravated if the degree of stress is not reduced.

Therefore, it is necessary to think about a strategy that could provide a realistic balance among progress and the environmental situation in Mexico. Nevertheless, there are several restrictions to overcome to achieve sustainable water management. This situation will be developed in detail in Chapter 3.

CHAPTER 3: WATER SCARCITY AND ENVIRONMENTAL PROBLEMS OF URBANIZATION IN MEXICO

As mentioned in the previous chapters, due to changes in the economic policy in the 1950s, Mexico became mostly an urban country. After decades of disordered urbanization, and due to regional differences in water availability, the problems of water scarcity and pollution started to increase, and nowadays, they represent the greatest challenges for water management.

This chapter will seek to provide the evidence to support the arguments developed in Chapter 2 about the institutional path taken to change water management. Also, it will provide proof of the hypothesis concerning the institutional resistance that developed due to the long application of a public administration approach focused mainly on economic development. As will be shown in the following subchapters, this has increased the water pollution problems and water scarcity with higher social, economic and environmental costs.

3.1 Urbanization, water scarcity and pollution

The consequences of urbanization on water resources in Mexico have been serious. The growth in population and the increase of industrial activities are increasing the levels of pollution, which are affecting water resources due to the authorities' lack of response to address the challenge.

According to CVA (2015), water is the center of sustainable development and is crucial for socioeconomic development, healthy ecosystems and human survival. In this regard, water is crucial for preserving different benefits and services provided by manmade and natural capital. Moreover, water is critical to maintain human health and to improve social welfare and make economic development more inclusive.

However, Rojas (2013) argued that since the 1950s, the population growth and the industrial activities have increased the water demand, and due to these reasons, water scarcity is a problem that has worsened. The challenges in the provision of drinking water are due to the increasing users in urban areas and industry, low use efficiency in agriculture and industry, and mistakes in urban planning (Roman et al., 2010). These factors became a source of pollution, and nowadays, 96% of the superficial water bodies have some degree of contamination, mainly due to the lack of municipal and industrial wastewater treatment (Saltiel, 2008). Between 1985 and 2007, there was an increase of 34% in municipal wastewater discharges due to population growth; also, between 1992 and 1996, the volume of industrial wastewater tripled in size (Jiménez et al., 2010).

In Mexico, 90% of the population has access to water, but around 60-70% of the wastewater volume lacks proper treatment (Contreras, 2008). According to Arreguín et al. (2010), in 2008, there were 2,174 treatment plants but only 2,082 in operation that treated 33,778 m^3/s, which is equivalent to 60% of the installed capacity. Cities are also facing increasing pollution problems in groundwater resources since approximately 40 million people live close to recharge areas and are also a cause of overexploitation of aquifers. The water quality of the underground aquifers is decreasing as well. Mexico owns 653 aquifers, of which 106 are overexploited in a way that water reserves decrease every year. This is important since 55.2% of the water for all types of uses comes from this source (AAG, 2014, p. 58). Aquifers' overexploitation is shown in Table 3.

Table 3. Number of overexploited aquifers in the period 1975-2013

Year	Overexploited aquifers
1975	32
1981	36
1985	80
2004	104
2007	101
2010	105
2013	106

Source: Elaborated with data from AAG, 2014, p. 58, and INEGI, available at http://cuentame.inegi.org.mx/territorio/agua/sobreexplota.aspx?tema=T#.

Also, the stress on groundwater resources is causing springs, bases of rivers and ecosystems to disappear, and the costs of extraction are increasing, while quality is decreasing (Arreguín, 2010). As stressed by Carillo et al. (2008), the overexploitation of aquifers is having impacts on inland water bodies such as lakes: In the state of Jalisco, the surfaces of the lakes San Marcos and Sayula reduced considerably in the late 20th century. Also, in the state of Cohahuila, a lagoon system was desiccated as a result of excessive boreholes.

Additionally, the semi-arid regions of Mexico cover almost half of the country; they contain about 45% of the total population and produce 55% of the GDP. In this regard, groundwater resources provide around 70% of the water supply of drinking water for the total population (Carrillo et al., 2008). According to these authors, one reason for the pollution of aquifers is linked to the lack of proper sewerage in the recharge transit areas. Therefore, groundwater pollution occurs due to the industrial

and municipal wastewater that leaks directly into the ground and is a persistent problem in many Mexican states.

Jimenéz et al. (2010) mentioned another cause of aquifer pollution linked to urbanization issues. Solid waste landfills that sometimes are located in places near the recharge areas often are responsible for increasing the levels of pollution due to an inadequate design or due to the presence of clandestine landfills, from which leached pollutants filter into underground water resources. Also, excessive pumping to extract water from aquifers is increasing their pollution. This has been increasing the concentration of dangerous elements such as fluoride and arsenic in aquifers, risking the health of the population. This is happening in many aquifers; however, the most common problem of aquifer pollution addressed by the authorities is saline intrusion.

One more factor that affects water quality is the performance of water services in the cities. However, this topic deserves special attention, and it will be discussed in the next subchapter; the literature suggests that they suffer mostly from lack of funds for infrastructure and necessary human resources.

3.2 Municipal water companies' features and problems

As stressed in the previous sections, the decentralization process in Mexico was aimed at modernizing water management to face the challenges of water pollution and scarcity. The changes in water management described in Chapter 2 were mostly focused on solving the federal government's financial problems than on sustainable practices, by transferring the provision of water services to municipalities. However, the reforms have not yet even fostered financial stability of MWCs; also, the reforms have had even less impact on progress in environmental and social aspects (Romero, 2007). In this regard, MWCs are the entities in charge of providing drinking water, sanitation and treatment services for localities (EAM, 2014, p. 231). However the

restrictions faced by these entities have retarded the implementation of the correct strategies to directly tackle the rising problems of pollution and water scarcity in urban areas.

From 1943 to 1983, water management was centralized and water resources were controlled through federal boards that were administrated by the General Direction of Operation of Water Systems and Sewage (Pineda and Salazar, 2008). The General Direction of Operation of Water Systems and Sewage was composed of 34 delegations, 873 federal boards and 146 municipal committees, and by 1973, it had installed 695,000 domestic connections to distribution networks. However, only 55% of water connections were equipped with water meters.

According to Rodríguez (2008, p. 40), the federal government administered three types of water companies during this period. The federal boards of drinking water and sewage were a common type of water company in areas with large populations, in which states and municipal governments agreed to transfer water management to federal authorities. Another type was the municipal committees of drinking water and sewage, which were commonly used in regions with small populations and lacked representatives of the state's authority. The last type was direct federal administrations, under which the federal government had absolute control in water management decisions.

With the decentralization of water services in 1983, water companies were supposed to improve their operational performance in diverse areas; however, many municipalities lacked the technical and financial capacities to assume these new duties (Saltiel, 2008). Thus, the decentralization of water services was only partial, since nowadays the federal government still has the best capacity to invest within the water sector (Caldera & Torregosa, 2010).

Mexico is organized as a federal republic composed of 31 states and a federal district. The country has 2,438 municipalities that must attend to the needs of 3,190

urban locations and around 185,000 rural localities. Currently, only 2,356 MWCs are distributed throughout the country, the majority of which are publically owned (Sandoval, 2010). Given the size of the figures, the challenges of providing sustainable water services under the decentralization scheme seem very difficult to surpass.

Since 1989, the National Water Commission (CONAGUA) was created to foster sustainable water management and provide support to successfully decentralize water services.

According to Pineda et al. (2010, p. 120), Conagua defined five fundamental lineaments of the new water management:

1. Strengthening the autonomy of the MWPs based on their legal capacity and the ownership of their patrimony to become decentralized public enterprises.
2. Democratization of administrative councils, with citizen inclusion in the administration procedures.
3. Reinvestment of financial resources collected from the users in the public company.
4. Setting of tariffs by the directive councils and not by the states' legislatures, like in the past.
5. Financial autonomy and larger technical and administrative capacities to strengthen their business nature.

According to Rodríguez (2008, p. 40), the types of MWCs broadened after the decentralization process. One type is centralized operational state boards, which belong to the state governments and provide water supply and sanitation services. The coordination boards of services are another type that is operated by the state government and provide water supply and sanitation service to the population through

franchises along their territory. The local operational organisms of a state nature are a type of MWC with full autonomy to choose how to provide water and sanitation services; moreover, they respond the states' governments. State boards are a type of MWC that are fully controlled by state governments and take all of the decisions linked to water services provision. Regional water companies are a type of MWC that operates within the states in the different municipalities, with the main goal to achieve self-sufficiency in providing water services. Finally, all of the previous types of MWCs are allowed to be combined to create the most suitable option for water services provision in any given region.

As shown before, the types of MWCs have increased; however, given their restrictions, it has not been possible to exploit the advantages offered by decentralization. In the following subchapters, the restrictions faced by WMCs will be addressed to show that the transfer of responsibilities to municipalities has been partial, at best.

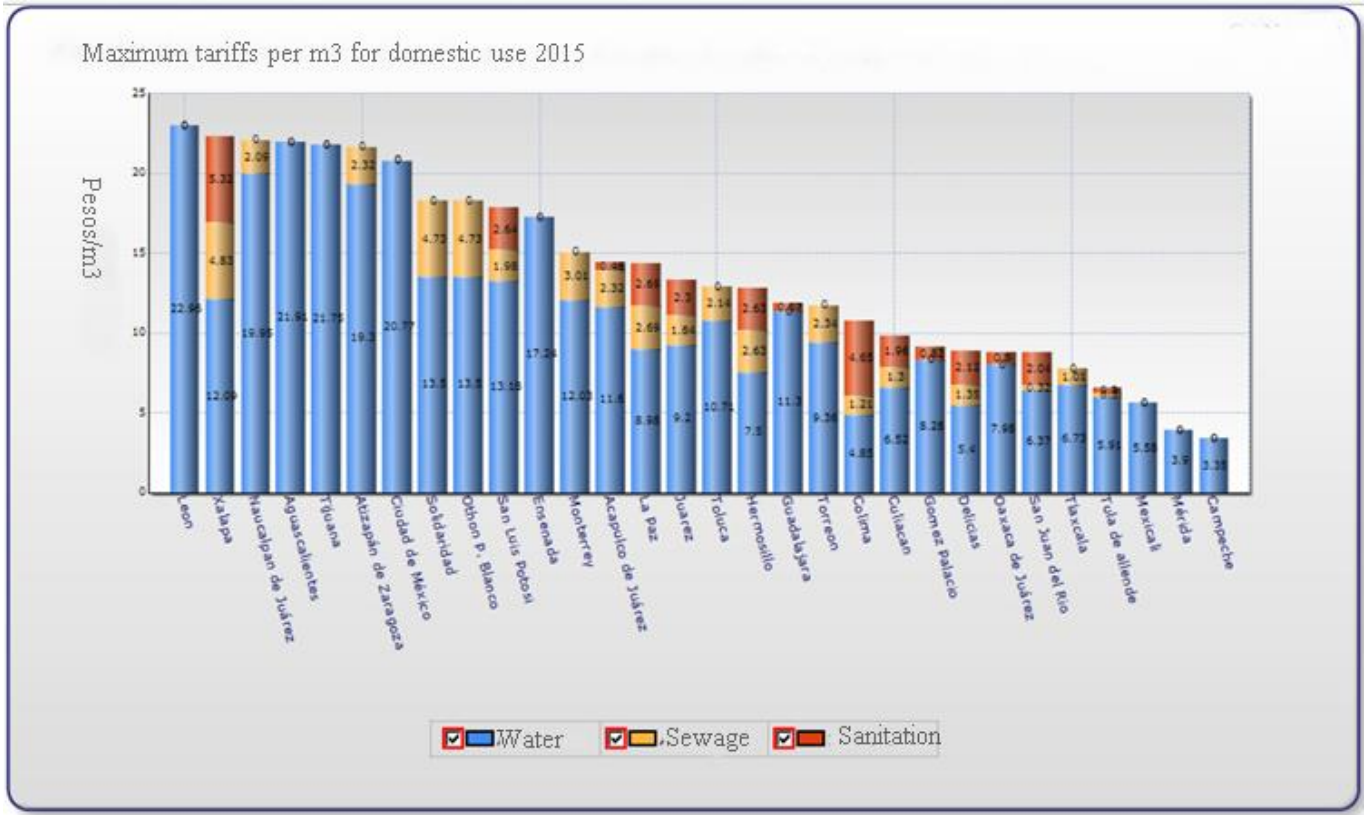
3.2.1 Financial capacity of municipal water companies

The MWCs face considerable financial restrictions due to the low tariffs they charge for water services; thus, according to Contreras (2008), the tariffs should cover at least the operational and maintenance costs of water production. As referred by Hájek and Petružela (2016), complications can arise from promoting a cost recovery approach, if the demand conditions lead to increased water prices. This is the case in the Czech Republic, where reduced water demand among households has increased water prices, in some cases beyond the socially acceptable price.

Nonetheless, the conditions of water services and drinking water consumers in Mexico have not yet reached a sufficient level of development for this problem to occur. In 2007, the average cost of producing a cubic meter of water in Mexico was

€0.32, without considering the treatment costs, whereas the average tariff charged by the MWCs was €0.24 per cubic meter. In this regard, tariffs are supposed to consider the costs of drinking water production and sewage and wastewater treatment. However, the compositions of tariffs in Mexico often disregard cost recovery criteria, as shown in Figure 9.

Figure 9. Maximum water tariffs for domestic use (Pesos/ m^3)



Source: EAM, 2014; p. 80

Two crucial factors affecting the financial capacity of MWCs are physical efficiency, which is defined as the proportion of the produced water that reaches the users, after calculating the water losses along the distribution network, and commercial efficiency, which is defined as the proportion of the total water billing that is actually collected (Pineda et al., 2010). Both issues are very important to

address, given that water consumption per capita in Mexico is high and reaches approximately 380 liters per person every day.

Pineda et al. (2010) found that the physical efficiency in 21 cities with populations greater than 50,000 was 57%, on average, whereas their commercial efficiency was estimated to be 79%. Thus, there are several problems that, if corrected, could increase the financial resources of MWCs to cope with their investment needs. The issues of physical and commercial efficiency could improve the performance of MWCs to achieve sustainability goals. Pineda et al. (2010) elaborated three different scenarios to assess the potential impacts on water scarcity abatement and the finances of MWCs, based on population growth forecasts by 2030. The first scenario was the status quo, to assess the situation if no changes were introduced to improve the finances of MWCs. In this regard, if population growth and the levels of efficiency and tariffs remain the same, the cities will demand 55% more water in the future than they already do. This will put stronger pressure on MWCs in the providing water services. The second scenario involves physical efficiency increasing to at least to 80%; if this occurs, then some cities will be able to cope more comfortably with public water supply challenges. The third scenario involves physical efficiency increasing to at least 80% and commercial efficiency increasing to at least 95%. In this case, the changes would help to reduce water scarcity due to avoiding the addition of new water sources. Also, this will improve the financial situations of MWCs, which is crucial for cost recovery and the development of new sustainable water projects.

However, water tariffs are currently subjected to political and electoral interests, since they are fixed in the state legislatures and not by the MWCs (AGA, 2011, pp. 46–47). Also, an additional challenge to improving the financial situations of MWCs is the population's reluctance to pay for the services. According to Colmex (2015), most of the population lacks a culture of paying for drinking water provision and sanitation services, given several deficiencies in the services. Then, it is not surprising that MWCs mostly depend on federal subsidies to maintain their operations

and to invest in new projects (Contreras, 2008). The investment structure in the water sector is shown in Table 3.1.

Table 3.1. Investment in the water sector in 2013 (millions of pesos)

	Federal government investment (Conagua)	**States investment**	**Municipalities investment**	**Private sector investment**	**Total investment**
Investment	22,984.4	5,880.5	3,296.1	4,952.0	37,113.1
Share of the total investment	61.9%	15.8%	8.9%	13.4%	100%

Source: Elaborated with data from EAM, 2014; P.129

This situation is reflected in the modernization projects promoted by Conagua. For example, 60% of the funds for projects such as Potable Water, Sewage and Treatment in Urban Areas and the Modernization Program of Water Operating Organisms come from the federal government.

Overall, MWCs lack the incentives and the institutional framework to improve their efficiency; however, there are some successful experiences, like the case of the state of Guanajuato. According to Saltiel (2008), the State Water Commission of Guanajuato (CEAG) shows that is possible to set a path to improve MWCs' efficiency. The CEAG takes decisions based on information and the cooperation of experts with different specializations in water issues, with the goal to increase the coverage of water services to low-income groups. Also, the CEAG generates several indicators related to physical and commercial efficiency to reward the MWCs

distributed throughout the state: Any MWC that can increase both efficiencies by 10% will receive a bonus of US$160,000.

Thus, one option to incentivize efficiency would be to link the federal subsidies to the operating performance of MWCs, although this would require several changes to reshape the structure of water companies. The strengthening of MWCs' finances will be crucial to improve water management by introducing more sustainable practices to promote water conservation as well.

3.2.2. Human resources of the municipal water companies

In addition to their financial restrictions, the MWCs are not able to count with the specialized human resources necessary to achieve a decentralized and sustainable water management.

Overall, MWCs do not have a permanent training program for their managerial, administrative and technical staff (AGA, 2011, p. 44). Another key problem is that staff turnover is high, due to the municipal elections every 3 years and state elections every 6 years (Contreras, 2008).

According the GCOM (2014), the constant staff turnover has many consequences. The report states that this leads to a lack of human and financial capacities among MWCs, since very few personnel have the necessary profiles to perform specific technical and administrative duties necessary to run the MWCs.

Another issue is that key personnel are replaced at the end of every local administration. This happens with almost every change of the municipal administration, which leads to constant changes in the staff of MWCs.

According to Rodríguez (2008), the directors of the MWCs are often assigned through acts of nepotism. The elected mayors usually name a close friend or a person with whom they have political links to take the director position. The administrative and technical staff members are more likely to keep their positions if they are members of a labor union. Nevertheless, there could be conflicts among the unionized workers and the directors of the MWCs due to losses in the negotiation power of labor unions to develop professionalization among the water companies' staff. Also, the directors often hire private companies to do work that could be done by their own staff, which is leading to declining job positions and the loss of human capital in the MWCs.

Because of this issue, long-term planning is not very frequent, given the three-year time horizon of a municipal administration, versus six years for a governmental administration. It is not common to propose plans with a longer time horizon than that of a new administration. Finally, MWCs lack the employees to improve their technological stock to increase their commercial and physical efficiency, which are crucial for MWCs' financial sustainability.

The lack of necessary human resources is a serious problem, since staff specialization is crucial in long-term planning to abate water scarcity. In this regard, Lípa and Hájek (2014) showed the relevance of counting high-quality human resources. The authors studied the efficiency of the organizational arrangements for environmental protection in the city of Prague. They found that the efficiency of achieving sustainable development goals in small municipalities was low due to incompetence and a lack of education among some of the elected representatives; also, a very broad agenda can impose many responsibilities on a reduced number of workers. Moreover, the authors showed the relevance of long-term planning. Although environmental policy in the Czech Republic depends on the political representation generated each election and on subsequent coalitions, such policies have been stable, since they have been very similar from 2001 to 2014. These results

could be considered if there is the political will to improve the performance of water companies in Mexico to achieve sustainable development goals.

3.3 The relevance of municipal water companies in the future of urbanization

This chapter showed some results of the decentralized approach of water management in Mexico. In this regard, the need for economic growth has led to the uncontrolled spread of urbanization, which could potentially sharpen the problems of water pollution and scarcity in the near future. As population and economic activities are expected to be concentrated in urban centers, it will be important to find strategies to strengthen MWCs' capacities.

This is crucial to avoid a deeper overexploitation of water resources, which could also result in increased pollution and acute water scarcity. The strengthening of water companies' capacities depends on their dissociation from political and electoral issues to improve their financial situation and technical stock, and the quality of human resources necessary for sustainable water management. Moreover, self-sufficient local or regional water companies will facilitate the inclusion of more actors to improve water management.

CHAPTER 4: AN ASSESSMENT OF THE POLICY AND INSTITUTIONAL CHANGES FOR WATER QUALITY AMONG THE MOST PRODUCTIVE HYDROLOGICAL-ADMINISTRATIVE REGIONS

In this chapter, the problems of HAR XIII Waters of the Valley of Mexico, HAR VI Río Bravo and HAR VIII Lerma Santiago Pacific will be quantitatively and qualitatively evaluated. These regions share similarities that can provide more comprehensive information about the impacts of urbanization, economic growth and institutional responses on abating water scarcity.

4.1 Previous studies about water management modelling

The literature regarding sustainable water management focuses on different topics linked to water scarcity, such as addressing water scarcity abatement based on economic criteria and in developing institutions to promote sustainable development.

De Maria and Carvalho (2014) studied the price elasticities of water in the city of Fortaleza given spatial differences in income, average, price, the number of residents and the number of bathrooms to assess the sensitivity of different segments of the population to price changes. The authors estimated three economic models with data from a 2007 survey of household consumption: the spatial error model (SEM), the spatial autoregressive model (SAR) and the spatial autoregressive moving average model (SARMA). Based on the results, the authors concluded that ignoring spatial differences in terms of economic, social, geographical and demographic factors is a key specification error that could lead to miscalculating price elasticities.

Destandau and Garcia (2014) estimated econometric models to assess the relation of the quality of the water services and water production. The authors

integrated multi-dimension output into the cost function and considered the volume and quality of service as endogenous factors in United States. They also tested private against public ownership to evaluate the impact on costs. The results showed that public ownership is more capable of improving the delivered volume and water service quality; thus, the type of property has to be considered to understand the trade-offs of both issues.

Krause, Chermak and Brookshire (2003) studied the water provision by public and private suppliers under scarcity conditions and taking into account the heterogeneity in consumer response to regulatory policy. The authors estimated water demand for different groups econometrically by considering a potentially exhaustible source. The study's outcomes can be useful for regulators to design a compatible pricing system based on disaggregated demand. The authors concluded that such estimations will minimize the enforcement costs and welfare loss.

Walter, Kloos and Tsegai (2011) stressed the need for development planners to understand the economic value of water and the usefulness of information systems. The authors studied the Middle-Olifants sub-basin located in the Olifants Basin, which is the third-most water-stressed basin in South Africa. The region has three main competing uses: large-scale irrigation, mining and domestic use. Walter et al. (2011) identify the demand functions and water price elasticities for the large-scale agricultural sector, urban households and the mining sector. The authors used the WSAM hydrological model, which assumes that water is an economic good, for which efficiency is decisive for allocation to high-value uses. However, the model ignores water quality issues, distribution and transportation costs. The simulations assessed different scenarios with different changes in tariffs, subsidies to aid the poor and increases in population and urbanization for the year 2050. The main findings were that increasing population and urbanization can sharpen water scarcity in the future. Moreover, they concluded that efficiency must be addressed to achieve the country's sociopolitical objectives and to make water availability sustainable.

Although efficiency increases are easy to introduce in theory, they are difficult to implement in practice due to legal and institutional barriers.

Cocos, Cocos and Sarbu (2012) studied the impacts of global warming on the hydrological cycle and precipitation regime that have caused water scarcity, especially in developing countries. Most of the less-developed countries lack the financial, technical and human resources to effectively abate water scarcity. According to the authors, scarcity is induced by factors such as environmental problems and poor water management focused on serving economic interests rather than on improving efficiency. Also, the authors stress that developing countries overuse their environmental capital to the point of environmental degradation to serve other interests, rather than invest in conservation. The study focuses on the Calnistea area in Romania, which shelters three distinct aquifers. The methodology consists of estimating water demand based on quantitative and qualitative data on the hydrological parameters of the region's surface water and groundwater.

Cocos et al. (2012) showed that pollution has affected river stretches and ponds, and that pollution is already affecting the performance of some public utility services in the region. Also, the authors showed that water stress in the region increases when extraction is higher than the recharge. Moreover, the findings show that discharges from domestic uses and industrial and agriculture activities pollute aquifers due to the lack of a proper sewage system. The authors concluded that the overexploitation of groundwater resources will lead to more acute water scarcity; therefore, they recommend strengthening the financial capacity of local authorities to improve water supply systems and increase wastewater treatment capacity. Finally, they stress the need to increase people's awareness and construct water reservoirs.

Wutich (2009) analyzed the situation of water provision in Cochabamba, Bolivia, where the public water company SEMAPA supplies water from borehole fields and reservoirs. SEMAPA faces the pollution of surface water resources and

overexploitation of the aquifer system; moreover, the water system distributes water inequitably. The analyses were performed in the settlement of Villa Israel, Cochabamba, between 2003 and 2005, with a follow-up visit in 2008. The data collected came from preliminary research and survey research. The authors conducted in-depth interviews with key informants; afterward, 96 households were contacted, of which 72 households participated in the survey. The interviews were useful for gathering information about how institutional governance affects water distribution in Villa Israel, a poor area where nearly 90% of the inhabitants participate in the informal sector; thus, households struggle to cover their basic needs. Villa Israel also lacks public infrastructure linked to the municipal water supply.

The hypothesis is that if people live close to the subsistence level, all kinds of cheating will be expected, such as theft and overuse, which would become serious problems. However, the survey results showed that underreporting incidents to the authorities was common, but residents were more willing to share stories about violations among them; additionally, people showed more interest in preserving water resources during the dry season. The author concluded that common pool resources such as water have contingency rules that enhance their sustainability during severe water stress.

Hearne (2007) developed an institutional comparative study of the Red River Basin, which is devoted to agricultural production and rangeland. The region faces challenges, since water is shared among the Canadian province of Manitoba and the American states of North Dakota, South Dakota and Minnesota, which use water for different purposes. These political units have different economic activities as well as different physical and geographical characteristics; thus, their institutions should reflect the diversity of needs within the basin.

Hearne (2007) compared the provincial and federal institutional frameworks to assess institutional performance. In some cases, there was tension between provincial

agencies and federal protocols established by the United States Environmental Protection Agency under the Clean Water Act. However, federal programs were more broadly promoted to achieve economies of scale. The author concluded that despite the tensions in the Red River Basin, local actors have promoted laws and changes, thus enhancing dynamic institutional changes.

Lara (in press) studied determinants of water scarcity in the Hydrological-Administrative Region (HAR) XIII Waters of the Valley of Mexico to assess the impacts of stress factors such as economic and population growth. Given the region's features, the research aim was to assess the impacts of demographic, economic and financial factors on the quality of water resources, which are crucial to manage water scarcity. Thus, the goal was to weigh the contributions of relevant factors affecting water quality to determine which should be prioritized in water policy. The methodology consisted of documentary research about water scarcity and the estimation of a regression model to assess water stress factors' on water quality from 2003 to 2012. The results showed that wastewater management had a crucial contribution to maintaining water quality, whereas GDP showed a negative impact on water quality.

Some contradictions were found when assessing changes in population and public water supply, since increases in both showed to improve water quality. Finally, an increased collection of federal funds does not necessarily mean more investment into infrastructure improvements. Lara (in press) concluded that economic policy must be designed with environmental criteria, whereas wastewater treatment needs to be improved to manage water scarcity more efficiently. Both actions need to be embraced by all stakeholders and not only by the federal government.

Colmex (2015) assessed alternatives to abate water pollution in the Coatzacoalcos River Basin, which disembogues into the Gulf of Mexico. This is important, since pollutants are affecting environmental services and marine

ecosystems. The study identifies the water management problems in the area, including a lack of water supply infrastructure and sewage and wastewater treatment, as well as low water quality in the main stream and its branches. Although the water quality is still acceptable, it is subjected to stress factors such as population growth and industrial and petrochemical activities.

More important, Colmex (2015) highlighted the lack of infrastructure to handle municipal wastewater discharges and demographic pressures. Two possible policy instruments were introduced to analyze how to improve the situation: the introduction of a market of water quality bonds and a tax for wastewater treatment. The results showed that the introduction of a bond market would have limited reach, since only a small number of participants could intervene, whereas the tax could have broader benefits for most municipalities. The tax showed lower political feasibility; however, it would take less time to be implemented and have better environmental outcomes. Based on the results, the authors concluded there is very little concern for sustainable water use along the Coatzacoalcos Basin, due the reluctance of people to pay for water services.

Hájek and Petružela (2016) studied water services in the Czech Republic and highlighted water services as a means of maintaining ecosystem functions and a key output from public governance. In this regard, water services such as public water supply and sewerage systems have a crucial role in sustainable societal development. The path to sustainability depends on public regulation; a combination of social, economic and environmental goals; and the means to achieve them. Based on supply and demand, the authors aimed to quantify the most important issues of sustainable water supply and sanitation firm management with regard to the current regulations. The methodology consisted of examining behavior indicators interpreted from water bills to compare household expenditures in the Czech Republic.

The results showed that the prices of water and sanitation services increased in the past few years, so more consumers invested in water-saving equipment at home. This led to increased costs to provide water services, making it difficult for companies to recover their costs and keep providing affordable services. Thus, the expenditures on water services in the Czech Republic are approaching—and exceeding, in some cases—the limit of what is considered socially acceptable. The authors conclude that decreasing water consumption has negative economic and social impacts.

4.2. Normative criteria and monitoring of water quality in Mexico

Quality is often given very little relevance in the water scarcity literature, although its relevance has been increasing in recent years. Water quality can be an abstract concept, since the parameters for quality change according the consumptive use. According to Jiménez, Durán and Méndez (2010), water requires constant monitoring and scientific knowledge to identify pollutants and their tolerable concentrations.

At least since the National Development Plan of 1989–1994, water quality has been addressed by the federal government to abate water scarcity. However, some deficiencies must be solved. In Mexico, the data about water quality are obtained through the National Monitoring Network, which were counted from 389 permanent stations in 2008. Of these stations, 207 are located in superficial water bodies, 52 are on the coasts, 130 are in aquifers and 285 are mobile. Also, the stations are located near important industrial and urban areas; thus, they provide useful information about the effects of urbanization.

However, most of the information produced about water quality is related to superficial water resources. This is an important obstacle to the elaboration of good-quality data, since there have been few efforts to measure water quality of groundwater resources.

This should be addressed, given the relevance of aquifers in providing drinking water throughout the arid and semi-arid areas of the country; also, many urban settlements are near the aquifers' recharge zones (Carrillo, Cardona, Huizar, & Ganiel, 2008). According to NOM 127-SSA1-1994, water has to fulfill 48 parameters to be considered safe for human consumption. In this regard, aquifers are the cheapest source from which to produce drinking water, since they normally only require chlorine for disinfection (Jímenez et al., 2010). However, quality is not guaranteed after the application of chlorine, since the efficiency of water chlorination is 90%, on average. Also, drinking water quality is affected by sporadic distribution, which incentivizes the use of domestic tanks to store the liquid when water quality changes.

For the water quality assessment that will be developed in the next section, it would have been preferable to use information about the quality of groundwater resources. However, the statistical information available on superficial water resources is more abundant.

4.2.1 Description of the problem and key features of the most productive hydrological-administrative regions

A hydrological-administrative region (HAR) is defined as a territorial area based on hydrological criteria that is formed by one or several streams of a particular basin (EAM, 2014, p. 232). In this case, as in other legal instruments, the municipality is the smallest link at the management level.

HAR XIII Waters of the Valley of Mexico, HAR VI Bravo River and HAR VIII Lerma Santiago Pacific are regions that exhibit the factors that affect water quality. These regions together have more than half the national population and almost 60% of the GDP. Also, as shown in Figure 5 and Table 4, they have considerable levels of water stress.

Table 4. Economic, demographic and water stress features in HAR XIII, HAR VI and HAR VIII 2003–2012

	Average GDP (%)	Average population (millions of people)	Water stress degree
HAR XIII Waters of the Valley of Mexico	24.675	21,442,025.8	Very high
HAR VI Bravo River	14.016	10,935,523.3	High
HAR VIII Lerma Santiago Pacific	18.07	21,296,012.22	High
Total	56.761	53,673,561.32	

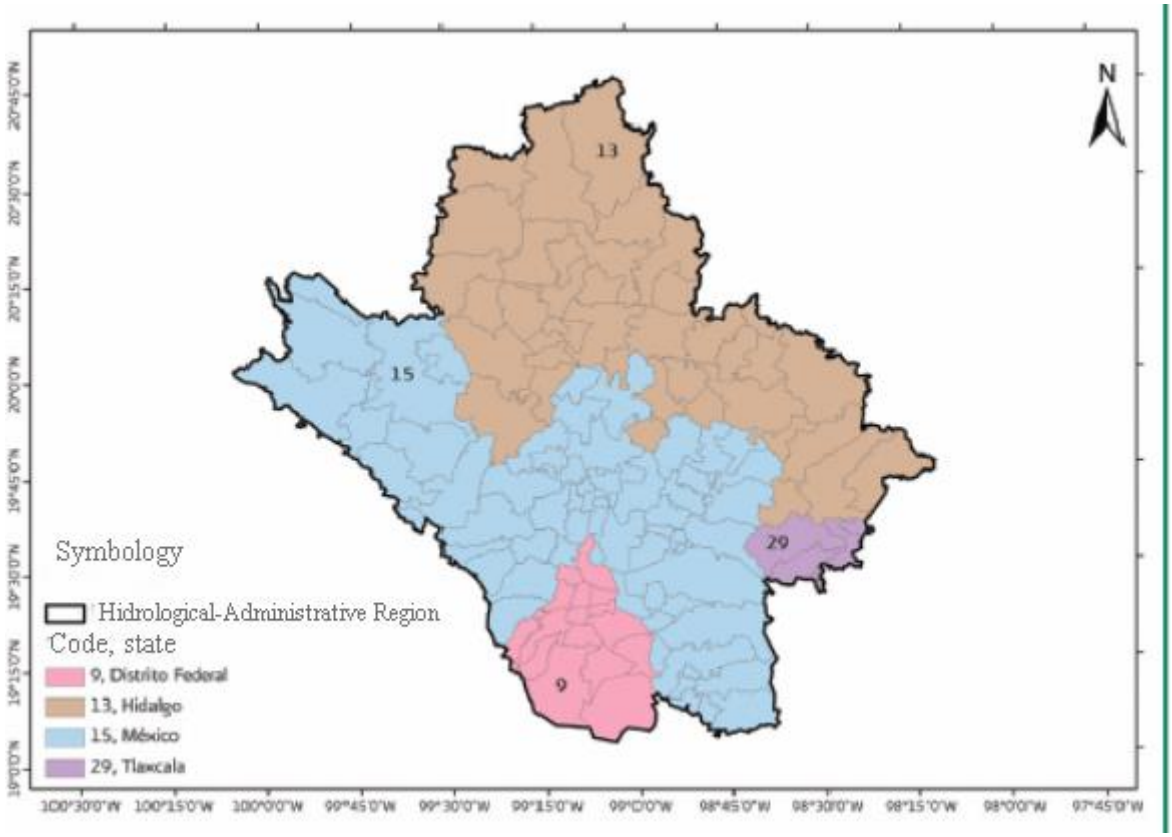
Source: Elaborated with EAM (2014) and SINA (2015)

Also, the respective Water Regional Program 2030 of each HAR acknowledges the problems associated with water pollution.

HAR XIII Waters of the Valley of Mexico (WRP, 2013c, pp. 10–22, 39)

HAR XIII Waters of the Valley of Mexico is located in the center of Mexico and is composed of the totality of Mexico City and parts of the Mexican states of Hidalgo and Tlaxcala. It covers an area of 18,228 km^2, which is equivalent to .09% of the national territory, and accounts for 121 municipalities. The distribution of municipalities is shown in Figure 10.

Figure 10. Distribution of municipalities in HAR XIII Waters of the Valley of Mexico



Source: WRP, 2013c, p. 16

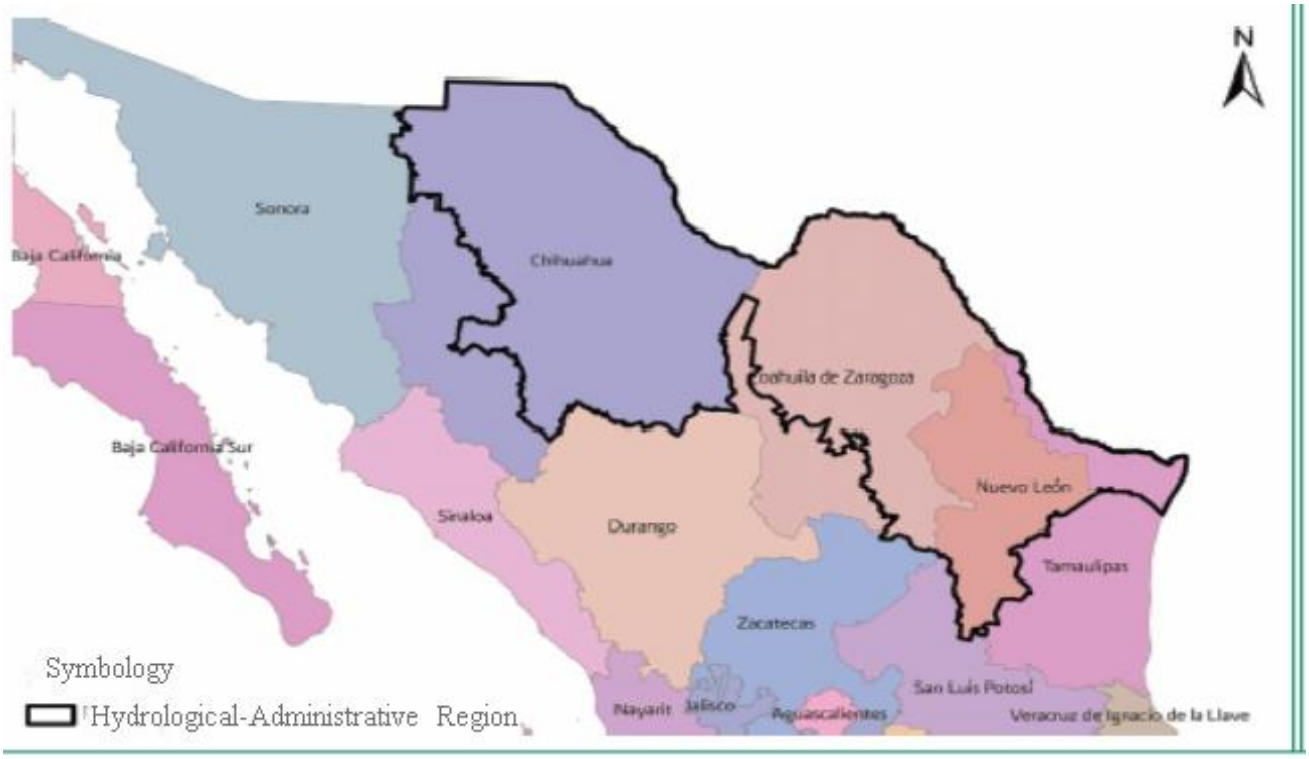
Also, the region includes 12 hydrological basins and three main aquifers. According to the water quality monitoring stations, based on biochemical oxygen demand (BOD), one station had excellent water quality, three were acceptable and 12 were strongly polluted.

The population in 2010 was 21.8 million people, of which 94.7% lived in cities; also, the region has 4,077 settlements, of which 403 are urban and the remaining are rural. Also, most of the urban population is located in three metropolitan areas. Within the region, problems linked with the population concentration and the large share of GDP have been acknowledged as factors of water pollution, due to low levels of water treatment. Some forecasts show that if industrial and municipal wastewater treatment fail to improve, then it will be necessary to bring water from more distant basins.

HAR VI Rio Bravo (WRP, 2013a, p.7-21)

HAR VI Rio Bravo is located in the north of Mexico, next to the border with the United States, with which it shares the basin. The area spans 388,810 km^2 and covers the totality of the state of Nuevo León as well as parts of the states of Coahuila, Chihuahua and Tamaulipas, and comprises 144 municipalities. This is shown in Figure 11.

Figure 11. Limits of HAR VI Río Bravo



Source: WRP, 2013a, p. 17

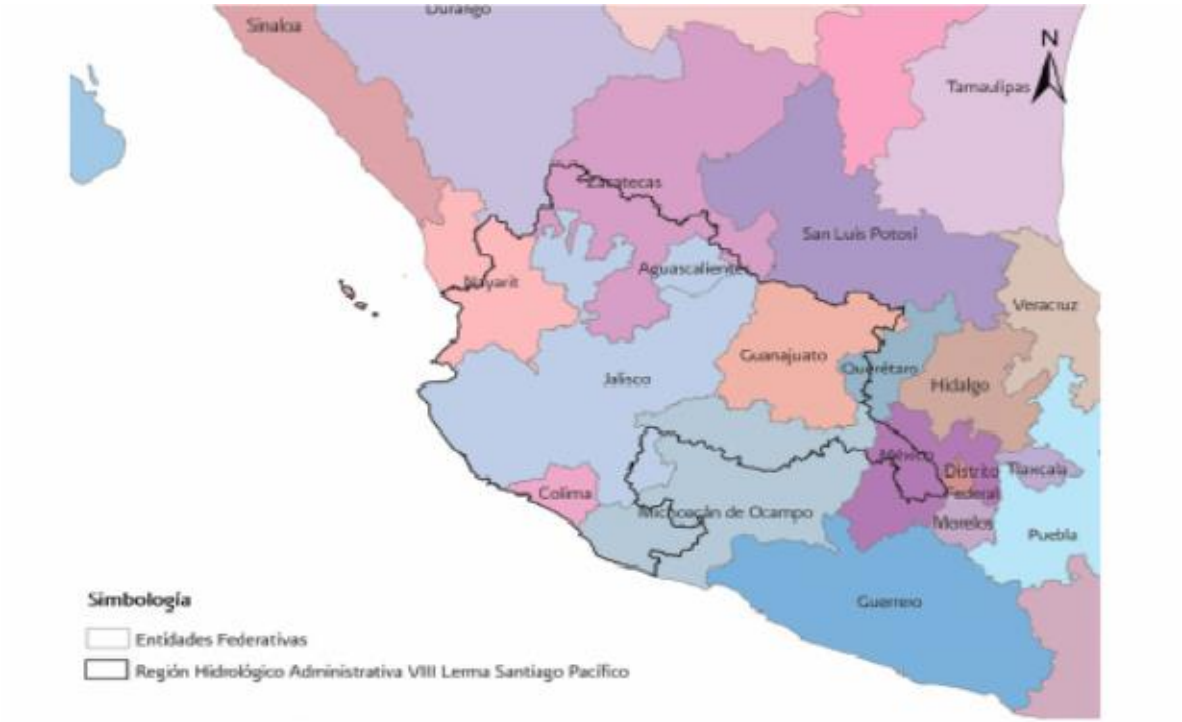
The main problem is the overexploitation of the basin and aquifers due to urban population growth and industrial activities, which are concentrated in nine metropolitan areas in which 80% of the regional population lives. However, according to the monitoring stations, the BOD parameter showed good water quality overall.

The population growth and the manufacturing industry are considered factors of water pollution to account for, especially given the region's vulnerability to droughts.

HAR VII Lerma Santiago Pacific (WRP, 2013b, p. 19-38)

HAR VII Lerma Santiago Pacific is located in central western Mexico and extends for 191,500 km^2. The region comprises the full states of Aguascalientes and Colima, and parts of the states of Guanajuato, Jalisco, Estado de México, Michoacán, Nayarit, Querétaro and Zacatecas; also, it includes 332 municipalities. The limits of HAR VIII Lerma Santiago Pacific are shown in Figure 12.

Figure 12. Limits of HAR VIII Lerma Santiago Pacific



Source: WRP, 2013a, p. 18

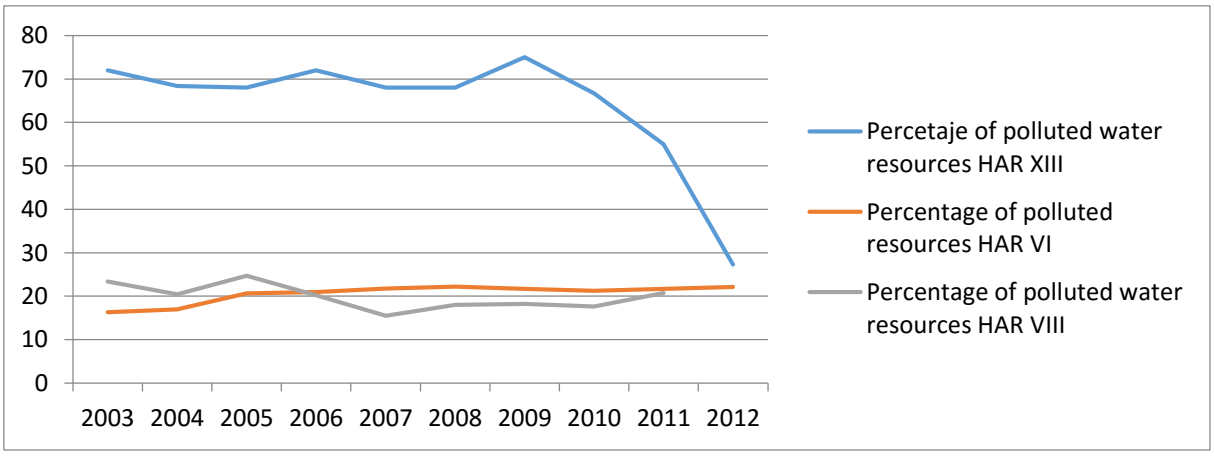
Water stress has been significant, since bans for water exploitation were decreed in several areas due to the population and industrial activities, which are both stress factors. The region contains 15 metropolitan areas that contain 53% of the urban population. Also, industry produces more of regional GDP than all other sectors, but it is one of the largest sources of water pollution in the area.

As shown before, these regions provide useful cases for the study to show how the effects of urbanization and economic activities affect water quality in similar regions. Nevertheless, the regions have several differences in their factors of water scarcity.

Heavily polluted and polluted water resources

The degrees of pollution in each HAR differed and, in some cases, changed during the analyzed period. Figure 13. shows the evolution in the percentage of polluted superficial water resources.

Figure 13. Percentages of heavily polluted and polluted water resources in HAR XIII, HAR VI and HAR VIII, 2003-2012 (percentages of polluted superficial water resource bodies)



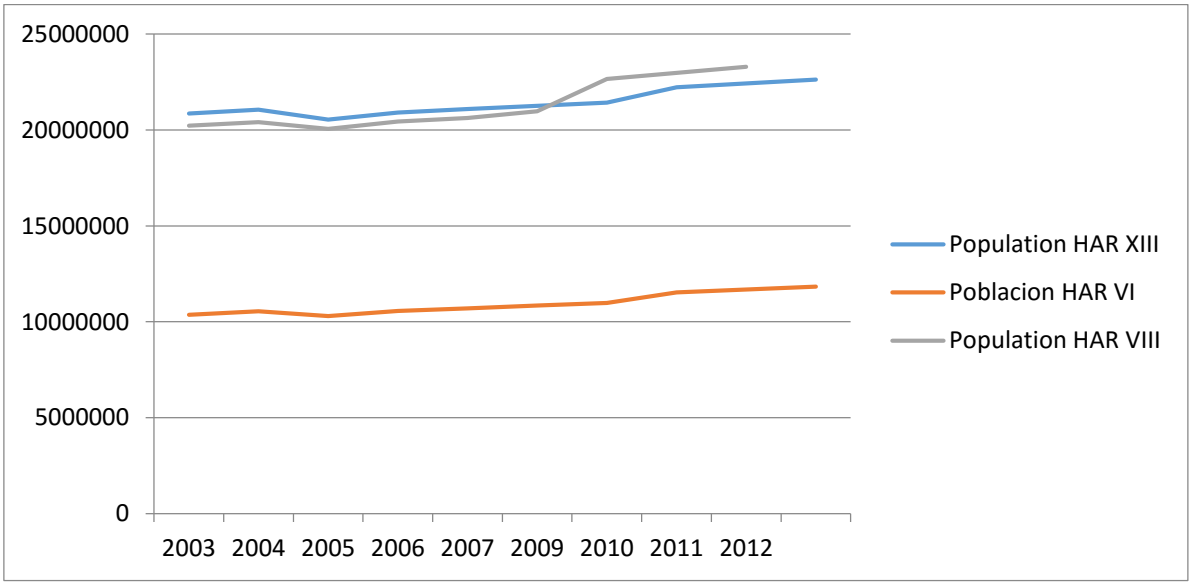
Source: SINA (2015), available at http://201.116.60.25/sina/

The most remarkable trend is the behavior of water pollution in HAR XIII. From 2003 to 2012, the region passed from a continuous and steady level of pollution to a dramatic drop in 2009. HAR VI and HAR VIII have had more stable behavior in water pollution

Population

The most interesting trend is that the population growth stabilized in all of the HARs considered in the study. Figure 14. shows the evolution in population growth.

Figure 14. Population growth from 2003 to 2012 in HAR XIII, HAR VI and HAR VIII (millions of people)



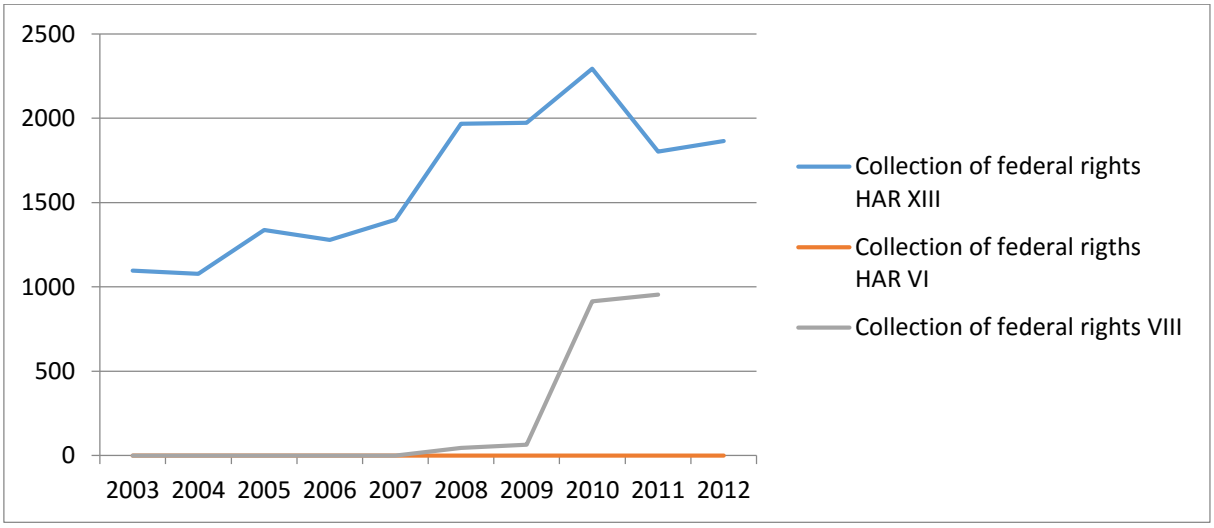
Source: Elaborated with statistics of the SINA (2015), available at http://201.116.60.25/sina/

After the boom in population growth since the 1950s, the population was still growing in the analyzed sample but a slower pace than in the past. Although the population growth was slower in all of the studied HARs, it must still be considered to assess its impact on water quality.

Collection of water rights

The collection of water rights is a source of income for the federal government. This is crucial for investment into infrastructure for sustainable water management, since most of the investment comes from federal funds. However, their collection varies among these regions, as shown in Figure 15.

Figure 15 Collection of water rights in HAR XIII, HAR VI and HAR VIII in 2003-2013 (millions of pesos)



Source: Elaborated with statistics of SINA (2015), available at http://201.116.60.25/sina/

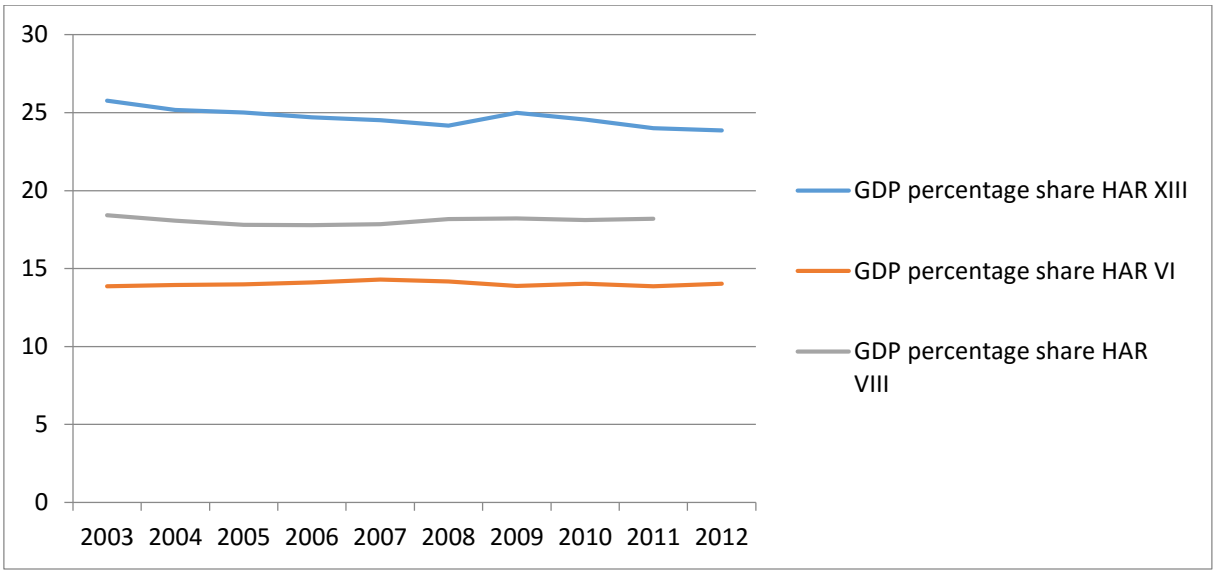
This variable shows a large regional gap. According to the information, only HAR XIII showed more constant collection since 2003. In HAR VIII, the federal

government's resources only started to increase in 2008; moreover, the collection of these rights in HAR VI has been close to zero.

Share of the GDP

As explained previously, the three regions create almost 60% of the national GDP; also, they maintained their competitiveness during the studied period. Figure 16. shows the variation in GDP.

Figure 16. Changes in the GDP of HAR XIII, HAR VI and HAR VIII in 2003-2012 (percentage by HAR of the national GDP)



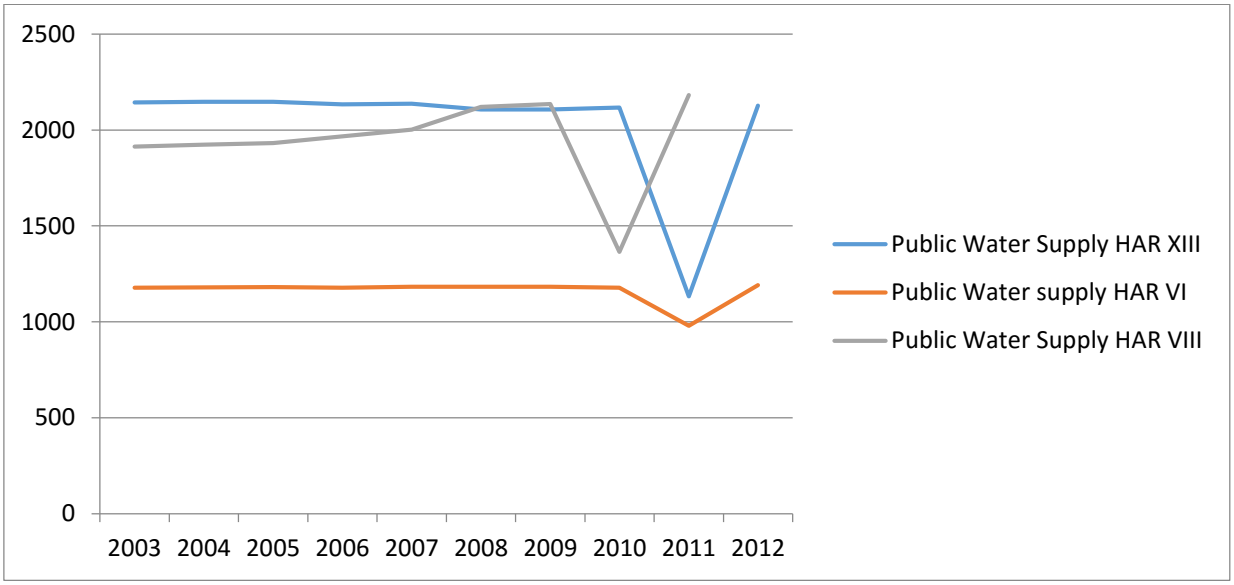
Source: Elaborated with statistics of SINA (2015), available at http://201.116.60.25/sina/

Each HAR's percentage of the national GDP was almost constant in the studied period. However, the implications of changes in economic growth must be considered to analyze the changes in the status of water resources in these regions.

Public water supply

The public water supply behaved erratically in all of the studied HARs, as shown in Figure 17.

Figure 17. Changes in the volume of the concessions of public water supply in HAR XIII, HAR VI and HAR VIII in the period 2003-2012 (Volume in cubic hectometers)



Source: Elaborated with statistics of SINA (2015), available at http://201.116.60.25/sina/

The steady trend since 2003 and until 2008 changed due to a historical drought that restricted the volume of urban water supply. In 2011, Mexico had its worst draught in the past 70 years. This affected 20 of the 32 states of Mexico, which limited the water supply for human consumption more strictly.

4.3 Methodology, data and model specification

The previous subchapters set the basis to develop the analysis for the selected HARs; more importantly, the estimation of quantitative models is justified given the lack of this type of research about Mexico. Thus, such study concerning the assessment of the specific aspects of urbanization will contribute to a better understanding of how to improve water management.

As already shown in the introduction, the hypothesis is the following: The impacts of economic activities and increasing urbanization have a negative impact on water quality in the HARs with the largest GDP. Thus, this may contribute to increased water scarcity.

The methodology consists of the estimation of OLS regression models to weigh relevant factors of water quality and scarcity acknowledged in the literature. The data to perform the analysis of all HARs was obtained from the National System of Water Information (SINA) and consists of a time series of the period 2003-2012. The information includes variables of pollution of water resources, size of population, GDP share, wastewater treatment and economic resources for investment. In this regard, the pollution variable will be biochemical oxygen demand (BOD). Conagua uses several indicators of water quality, such as Total Suspended Solids, which measures the quantity of suspended solids from different origins in water that cannot be dissolved, and the indicator chemical oxygen demand, which estimates the amount of organic matter in water degraded by chemical means. However, the selection of the indicator BOD better suits the needs for analyses, and its relevance is justified in WWAP (2016, P.20): "It is estimated that the number of people living in environments with high water quality risks due to excessive biochemical oxygen demand (BOD) will affect one-fifth of the global population in 2050…"

A description of the variables, model specification and their expected impact independent variables for all HARs is given in Table 4.1.

Table 4.1. Description of the variables and model specification

Variable Type	Name of Variable	Variable Description	Expected Result
Dependent variable	Polluted water resources (PWR)	Percentage of polluted and heavy polluted water resources based on the biochemical oxygen demand (BOD)	
Independent variables	Collection of water rights (CWR)	Millions of pesos collected by the federal government from water concessions.	$\beta 1_{<}0$
	Public water supply (PWS)	Volume of water used for public supply in cubic hectometers	$\beta_2<0$
	Gross Domestic Product (GDP)	Share in the percentage of GDP	$\beta_3>0$
	Wastewater treatment (WWT)	Volume in m^3/s of treated wastewater	$\beta_4<0$
	Population (POP)	Millions of inhabitants	$\beta_5>0$

A first round of modelling was performed to test the whole set of independent variables for each HAR. After obtaining the results, some statistically insignificant variables were removed in order to improve the results of a second round of modelling. However, it must be stressed that still, after the second round of modelling in all HARs, the models showed problems of heteroscedasticity and stability due to the size of the sample and probably due to the quality of data.

4.3.1. Estimation and interpretation of results for the Hydrological-Administrative Region XIII Waters of the Valley of Mexico

The results of the second estimation of the OLS regression for HAR XIII are shown in Table 4.2.

Table 4.2. Regression results for HAR XIII Waters of the Valley of Mexico

Variable	**Coefficient**	**Significance**
Constant term	214.797	Statistically not significant
Population (POP)	-1.023	Significant at 10%
Collection of water rights (CWR)	.724	Significant at 10%
Public water supply (PWS)	-.466	Statistically not significant
Gross Domestic Product (GDP)	.555	Significant at 10%
Wastewater treatment (WWT)	-.129	Statistically not significant
R^2	.868	

The set of selected variables explains 86.8% of the variation of water quality. The non significant variables were kept because they are acknowledged as factors that affect water quality, although there are some contradictory results.

4.3.2 Estimation and interpretation of results for the Hydrological-Administrative Region VI Bravo River

In the case of HAR VI, the variables excluded are the collection of federal rights and the public water supply; however, the model conserves fundamental variables that affect water quality. The results of the estimation of the regression for HAR VI are shown in Table 4.3

Table 4.3. Regression results for HAR VI Río Bravo

Variable	**Coefficient**	**Significance**
Constant term	10.764	Statistically not significant
Population (POP)	.356	Statistically not significant
Wastewater management (WM)	-.835	Statistically not significant
Gross Domestic Product (GDP)	.014	Statistically not significant
R^2	.289	

The set of selected variables explains only 28.9% of the variation of polluted water resources in HAR VI. Also, none of the variables was statistically significant, but their impact is consistent with the factors of water scarcity.

4.3.3. Estimation and interpretation of results for the Hydrological-Administrative Region VIII Lerma Santiago Pacific

In the case of HAR VIII, the variable public water supply was excluded in the estimation. As in the case of HAR VI, the model conserves fundamental variables that affect water quality. The results of the estimation of the regression for HAR VI are shown in Table 4.4.

Table 4.4. Regression results for HAR VI Lerma Santiago Pacific

Variable	**Coefficient**	**Significance**
Constant term	-108.857	Statistically not significant
Population (POP)	-.341	Statistically not significant
Wastewater treatment (WWT)	.199	Statistically not significant
Gross Domestic Product (GDP)	.305	Statistically not significant
Collection of water rights (CWR)	.114	Statistically not significant
R^2	.225	

This set of variables explains only 22.59% of the variation of polluted water resources in HAR VIII. Also, none of the variables was statistically significant, and the model is the most contradictory of the three regions.

4.4 Discussion of the results

The selection of variables and regression results were presented through a questionnaire to three experts with different profiles in the field of water management to learn their opinions about the research outcome. However, it must be mentioned that it was possible to discuss the results in person with at least one of the experts.

Expert No. 1 was the former director of social communication and water culture of Conagua in the state of Zacatecas and currently works as a consultant in the private sector, Expert No. 2 is responsible for the water quality department at Conagua in the state of Zacatecas and Expert No. 3 is a well-known academic and researcher in the field of environmental economics and trans-boundary water issues. These experts provided a general evaluation of the relevance of the research and some specific insights about the results of each HAR, which will be mentioned when discussing the regression results for each region. Table 4.5 shows the questions and answers about the general aspects of the regression results.

Table 4.5. General opinion about the research and results

	What is your professional opinion about independent variables used to explain the variation in water quality?	**Does there exist a better database different than the SINA?**	**What is your professional opinion about the quality of the data provided by the National System of Water Information (SINA)?**
Expert No. 1	Overall, the variable selection criterion is a good approach to study the changes in water quality.	The SINA is almost the only comprehensive source of water statistical information, although at states' level, it could be possible to find additional information.	There is no more consistent database in the country.
Expert No. 2	Overall, the variable selection criterion helps to study the changes in water quality.	Each basin administrative organism has its own database.	Did not provide an answer about the quality of SINA´s data.
Expert No. 3	Overall, they are relevant; however, for future research, more work has to be done about the statistical information on wastewater discharges.	There is no better database than SINA.	The data provided by the SINA, overall, is good. However, the data is insufficient to assemble time series to perform more precise studies.

Although the regions had features that made them comparable, the outcomes of the regression are very different for each case. The main difference is the gap among the R^2 coefficients of each HAR to explain the variations in water quality. In this regard, the selected explanatory variables performed better in HAR XIII by explaining 86.8% of the variation in water quality, whereas respectively in HAR VI and HAR VIII, only 28.9% and 22.59% of the variation is explained by the set of explanatory variables. This fact stresses the need to develop more reliable statistical information to perform quantitative studies. Overall impacts of wastewater treatment, GDP and population are consistent with the literature review. However, it is necessary to discuss particular results of each HAR.

Also, according to Expert No. 2's recommendations, a search was performed in order to consult the database of each basin administrative organism in order to consult more specific data. Nonetheless, no statistical information is available at their respective websites; thus, so far, SINA has the most reliable information for water statistics in the country.

As a final remark, the study of De Maria and Carvalho (2014) showed that ignoring spatial effects could lead to calculation mistakes. In this regard, the analyzed HARs have different territorial extensions, with HAR VIII being the largest and HAR XIII the smallest. Therefore, it is possible to assume that although SINA stores the best statistical information, it also fails to capture all necessary information as the size of HARs increases.

Discussion and interpretation of results for HAR XIII Waters of the Valley of Mexico

In this region, the variables of wastewater treatment and GDP had the expected results, and it seems that water quality is particularly vulnerable to increases in economic activities. In this regard, wastewater treatment is consistent with the studies of Cocos et al., (2012), Colmex (2015) and Hájek and Petružela (2016), who highlighted the crucial role of water services in sustainable water management.

The variable GDP matches the results of Walter et al. (2011), since increases in economic activities could negatively affect sustainability issues. In both cases, the professional opinions of Expert No. 1 and Expert No. 2 converge with the results, given that both agree that a more dynamic economy could decrease the levels of water quality, whereas Expert No. 3 did not provide insights about such a variable.

The main contradiction was population, since in this case population growth would improve water quality. However, Wutich (2009) stressed that in areas with water scarcity, the population contributes to water preservation. In this regard, Expert No. 1 stressed that in some Mexican regions with high water stress, people are more likely to save and preserve water resources. In this regard, Perevochtchikova (2010b**)** showed that there has been some progress in the region. At least in the case of Mexico City, there has been an increase in the interest of the society in responsible use leading to the creation of civil associations or non-governmental organizations to participate more actively in sustainable water management.

Collection of water rights and public water supply showed contradictory impacts as well; however, this could happen because they are related. Under the presence of corruption, the collected resources might not be invested in the water sector, whereas an increase in the water supply could be motivated by a rent-seeking behavior. Another insight was provided by Expert No. 1, who stressed that given the

share of the GDP of HAR XIII in the region, there is a constant request for water concessions from industry and municipal authorities. This matches the information published in WRP (2013c, p. 39), which shows that by the year 2030, industrial and municipal water demand will increase 55%.

Discussion and interpretation of results for HAR VI Rio Bravo

In the region of HAR VI Rio Bravo, the variable of wastewater treatment could reduce pollution substantially. This is consistent with the findings of Cocos et al., (2012), Colmex (2015) and Hájek and Petružela (2016) that highlighted the crucial role of water services in sustainable water management.

The variable population was the main factor of water pollution. This corresponds with the findings of Walter et al. (2011) and with the opinion of Expert No. 2, although it draws attention to the fact that the variable GDP does not significantly decrease water quality. According to WRP (2013a, p. 26), general pollution problems are linked to wastewater discharges of economic activities. Nevertheless, according to Expert No. 3, there are benefits that the region borders the United States. Although the basin is overexploited, HAR VI is located downstream in the basin; thus, it receives water previously treated in the United States.

Discussion and interpretation of results for HAR VIII Lerma Santiago Pacific

This region showed the most contradictory results of all the studied HARs and had many statistical problems. However, as explained in the beginning of this subchapter, it seems that the SINA has problems creating good quality data for large territorial areas, which is the case of HAR VIII.

In this case, the variables wastewater treatment, population and collection of water rights had the opposite expected effect. With regard to wastewater treatment, there are no valid arguments to support such results; however, the results might change if there was better quality data with which to estimate the regressions.

The variable population matches the results of Wutich (2009), which stressed that in areas with water scarcity, the population contributes to water preservation. Also, Expert No. 1 stressed that in some regions with high water stress, people are more likely to save water resources. This could occur given that exploitation of water is banned in some areas of the basin. However, according to WRP (2013b), in the region there is a lack of water users' participation in using water efficiently. Thus, efforts have been undertaken by the authorities to raise consciousness and to inform the society about the relevance of participating more actively in water management.

Only GDP is consistent in its negative impact on water quality. This is consistent with the findings of Walter et al. (2011), since the economic values of water are linked also to sustainability issues. Also, the professional opinion of Expert No. 1 and Expert No. 2 converge with this result.

CHAPTER 5: CONCLUSIONS, POLICY RECOMMENDATIONS AND CONSIDERATIONS FOR FUTURE RESEARCH

It is well-known that Mexico is a region with problems of water scarcity and quality as well. This has been a result of the economic policy decisions from the past that did not consider the environmental dimension and were planned only to fulfill short-term economic growth goals. This was the main outcome of the centralistic policies applied at least since the early 1920s that promoted irrigation programs in the dry areas of the country.

Moreover, this was the cause of the late development of water management in urban areas. Additionally, the industrialization strategy promoted in the 1940s was also not planned with environmental criteria. Thus, it is not surprising that the reforms toward decentralization services did not significantly contribute to this cause. In fact, decentralization is useful in promoting the efficiency and sustainability of water management; however, in the case of Mexico, the process of decentralization responded mostly to fiscal and international pressures rather than to a true consensus about the improvement of water management. Moreover, the process of decentralization of water lacked a rigorous institutional diagnosis, which nowadays has significant social, economic and environmental costs.

The transfer of the responsibilities to the municipalities partially releases the federal government burden; however, there is still much work to be done regarding the provision of good water services and the rational use of water resources, which are sustainability goals among MWCs.

Most of the water companies face several financial and technical restrictions that limit their influence and performance. A real tariff adjustment must be enforced in almost the whole country; however, this should be differentiated in order to avoid the increase of the inequality gap. Also, this tariff must be fixed by the MWCs and

not by the states' legislatures in order to reflect the actual costs of water production, sewage and wastewater treatment.

In terms of human resources, it is necessary to develop training programs and grant continuity to the staff of the municipal water companies in order to enforce a long-term water policy. In order to reverse this path, it is necessary to disassociate the administrative structure of MWCs from political interests and grant them autonomy. By these means, MWCs will be able to decide based on technical parameters about the levels of water tariffs and the staff necessary for administrative and technical duties; also, this will allow them to maintain experienced staff and even develop specific training programs to improve their skills.

It is important to mention that most of the MWCs are publicly owned and have a different vision than private water concessionaires, which operate with profitability criteria. However, as shown before, they face several financial restrictions that affect their performance. In this regard, incentives must be developed to use more efficiently the federal funds received by the MWCs in order improve their response capacity for water management problems. These incentives could be linked to long-term planning of water projects and the attainment of specific goals. In this regard, one more alternative could be to form alliances with the private sector to improve the quality of water services by anticipating the effects on welfare of water users.

Overall, the current status of the decentralization of water services in Mexico is that history has had a strong influence on the reforms undertaken in the political arena. Thus, it is necessary to raise awareness about the situation and develop an alternative form of institutional change.

With regard to the results of the analyses of water quality in the hydrologic administrative regions in Mexico, they showed that it is important to address more comprehensively the challenge to improve water quality.

The lack of wastewater treatment and overexploitation of the underground resources is decreasing water quality on a regular basis. Wastewater treatment must be increased because the coverage of sewage in the country is much higher than the capacity of wastewater treatment of the installed plants. In this regard, investment programs must be created or improved in order to increase the availability of funds for the strengthening of wastewater treatment capacity. Also, MWCs are crucial for this purpose, which gives one more reason to develop strategies for the financial self-sufficiency of these companies in charge of providing water and sanitation services. The improvement of wastewater treatment capacity is crucial given the hydrological conditions in the dry areas of Mexico that cover most of the territory.

Moreover, it is necessary to study and increase monitoring activities in aquifers because they are the main sources of the water of the country, with a share of 70% of the total of water resources, especially in the dry areas of Mexico. This would be crucial to count with consistent data for decision makers to introduce the necessary changes to foster sustainable water development. Although in the case of superficial water resources there is more statistical information about their quality and factors of stress, the quality of the data is not good. Thus, the authorities also have to improve the quality of this information to know with precision which problems to address. This will require the intervention of the municipal, state and federal government to introduce improvements in the statistical information. Also, currently the data of water resources is more concentrated at the federal level; thus, the states and municipal government need to develop their own databases to increase the efficiency of their managerial decisions in the water sector.

Some of the regression results were contradictory and not very stable, but they partially proved the impacts of urbanization and economic policy on water pollution in the country. The findings confirm that although problems of water quality are acknowledged in all the National Development Plans from 1983-2013, economic

growth always has been a top priority that regarded partially the sustainable use of water resources.

Thus, a true implementation of a sustainable development strategy would need a radical change to pass from a liberal economic model based on exhaustive natural resources exploitation to a sustainable scheme with a realistic approach to environmental problems.

Considerations for future research

Water pollution and scarcity problems in Mexico are not very common topics among the scientific community. Nevertheless, that the topics must be tackled before they become a more serious problem, especially given the situation in the arid areas of the country.

In this regard, future research should focus on how to enhance the cooperation among local, regional and federal authorities; this will be crucial for the improvement of quantitative and qualitative aspects of water management in Mexico.

Given the results of this thesis, future research should focus on more punctual areas of the hydrological-administrative regions or in developing better methodologies to address better the regional differences between HARs. In this regard, contextual differences in HARs in terms of demographic, economic, social and environmental features must be considered to propose strategies to improve regional water management. Thus, future research should focus on the improvement and development of indicators that actually reflect the reality of HARs in order to assess the progress of water management.

With regard to water companies and decentralization, more qualitative and quantitative studies could be performed to detect their potential improvement areas, by also considering contextual differences. As shown before, HARs normally encompass a large number of municipalities that belong to different Mexican states; therefore, future research should focus on how to improve the communication and exchange of information among them to address water problems more comprehensively. Therefore, future research could find the key topics to enhance cooperation among MWCs to develop improvements in water management.

REFERENCES

Aboites, A. L., Birrichaga, G. D., & Garay, T. J. A. (2010). El manejo de las aguas mexicanas en el siglo XX. *El Agua en México: Cauces y encauces*, 21–46. Retrieved from http://www.conagua.gob.mx/CONAGUA07/Contenido/Documentos/elaguaenmexico-caucesyencauces.pdf

Acemolgu, D., & Johnson, S. (2005). Unbundling institutions. *Journal of Political Economy*, *113*(5), 949–995.

Allina-Pisano, J. (2009). Property: What is it good for?, *Social Science Research, 76*(1), 175–202.

Ang, F., & Van Passel, S. (2012). Beyond the environmentalist's paradox and the debate on weak versus strong sustainability. *BioScience, 62*, 251–259.

AGA. (2011). Agenda del Agua 2030, Comisión Nacional del Agua, 14, 18, 30–32,44–47, 2011. Retrieved from http://www.conagua.gob.mx/CONAGUA07/Temas/AgendadelAgua2030.pdf

AAG (2014). Atlas del Agua en México. (2014). 1–30, 50, 65–90. Retrieved from http://www.conagua.gob.mx/CONAGUA07/Publicaciones/Publicaciones/SGP-17-14.pdf

AMAS (2005). Agua, medio ambiente y sociedad: Hacia la gestión integral de los recursos hídricos en México. (2005). 14–39, 55–70, 90–112. Retrieved from http://www.bibliotecavirtual.info/recursos/agua_medio_ambiente_y_sociedad.pdf

AMAD (2015). Agua y medio ambiente un prontuario para la toma de decisiones, *Centro Virtual de Información del Agua*. Retrieved from https://www.agua.org.mx/index.php/biblioteca-tematica/geografia-del-agua/1320-agua-en-mexico/34645-prontuario-del-agua

Arreguín, C. F. I., Alcocer, Y. V., Marengo, M. H., Cervantes, J. C., Albornoz, G. P., & Salinas, J. M. G. (2010). Los retos del agua. *El Agua en México: Cauces y encauces*, 51–74. Retrieved from http://www.conagua.gob.mx/CONAGUA07/Contenido/Documentos/elaguaenmexico-caucesyencauces.pdf

Azari, R. J., & Smith, K. F. (2012). Unwritten rules: Informal institutions in established democracies. *Perspectives on Politics*, *10*(1), 37–55.

Barbier, B. E. (1999). Endogenous growth and natural resource scarcity. *Environmental and Resource Economics*, *14*, 51–68.

Basurto, J. (2010). La crisis económica en la Revolución mexicana y sus repercusiones sociales (1913-1917), UNAM, Instituto de Investigaciones Sociales, ISBN 978-607-02-2062-3, p.37-70. Retrieved from:

http://ru.iis.sociales.unam.mx/jspui/bitstream/IIS/4392/1/La%20crisis%20economica%20en%20la%20Revolucion%20Mexicana.pdf

Birrichaga, D. (2009). Legislación en torno al agua siglos XIX y XX. *Semblanza Histórica del Agua en México*, 44–59. Retrieved from http://www.conagua.gob.mx/CONAGUA07/Publicaciones/Publicaciones/SGP-28SemblanzaHist%C3%B3ricaM%C3%A9xico.pdf

Bonevac, D. (2010). Is sustainability sustainable?. *Academic Questions*, *23*, 88–101.

Byrch, C., Milne, M., & Morgan, R. (2007). Sustainable "what"?: A cognitive approach to understanding sustainable development. *Qualitative Research in Accounting & Management*, *4*(1), 26–52.

Caldera, O. A. R., & Torregosa, A. M. L. (2010). Procesos políticos e ideas en torno a la naturaleza del agua: un debate en construcción en el orden internacional. *El Agua en México: Cauces y encauces*, 317V342. Retrieved from http://www.conagua.gob.mx/CONAGUA07/Contenido/Documentos/elaguaenmexico-caucesyencauces.pdf

Cerda, L. (1991). ¿Causas económicas de la Revolución mexicana?. *Revista Mexicana de Sociología*, *53*(1), 307–347.

Carrillo, R. J. J., Cardona, Huizar, A. R., & Ganiel, E. (2008). Response of the interaction between groundwater and other components of the environment in México, *Environmental Geology, 55*, 303–319.

Castro, E. C. (2008). Neoliberal water and sanitation policies as a failed development strategy: Lessons from developing countries. *Progress in Development Studies, 8*, 63–83.

Chilcote, H. R. (1967). Cambio estructural y desarrollo: La experiencia mexicana. *Desarrollo Económico*, *7*(25), 859–875.

Cocos, A., Cocos, O., & Sarbu, I. (2012). Coping with water scarcity: The case of the Calnistea catchment (Romania). *Environment Earth Science, 67*, 641–652.

Colmex. (2015). ¿Cómo gobernar la contaminación en México? Alternativas de política pública ambiental. El Colegio de México, Centro de Estudios Internacionales, ISBN: 978-607-462-865-4, 211–248.

Contreras H. (2008). La última generación de proyectos de participación pública privada en sistemas de agua en México: Quince años de experiencias. *El agua potable en México: Historia reciente, actores, procesos y propuestas, ejemplos y propuestas*, 105–121. Retrieved from http://www.aneas.com.mx/contenido/EL%20AGUA%20POTABLE%20EN%20MEXICO.pdf

Culas, J. R. (2006). Deforestation and the Environmental Kuznets Curve: An Institutional Perspective**.** *Ecological Economics*, *61*(2), 429-437

EAM (2014). Estadísticas del Agua en México (2014). 20–70, 120–164, 210–220. Retrieved from http://www.agua.org.mx/index.php/biblioteca-tematica/estadisticas/34253-estadisticas-del-agua-en-mexico-2014

Daiger, G. T. (2009). Evolving urban water and residuals management paradigms. *Water Environment Research*, *81*(8), 809–820.

Dau, F. E. (2008). El agua potable en México: Historia reciente, actores, procesos y propuestas, ejemplos y propuestas, México, Asociación Nacional de Empresas de Agua y Saneamiento A.C., p. 97–104. Retrieved from http://www.aneas.com.mx/contenido/EL%20AGUA%20POTABLE%20EN%20MEXICO.pdf

De María, A. D., & Carvalho, J. R. (2014). Spatial determinants of urban residential water demand in Fortaleza, Brazil. *Water Resource Management*, 2401–2412.

Destandau, F., & Garcia, S. (2014). Service quality, scale economies and ownership: An econometric analysis of water supply costs. *Journal of Regulatory Economics*, *46(1), 152–182.*

Duit, A. (2005). Understanding environmental performance of states: an institution-centered approach and some difficulties, *QOG Working Paper Series.*

Dutta, V. (2009). Water pricing, affordability, and public choice: An economic assessment from a large Indian metropolis. *International Journal of Economics and Finance*, *1*(2), 238–252.

EAM. (2014). Estadísticas del Agua en Mexico 2014, Comisión Nacional del Agua, Retrieved from http://www.conagua.gob.mx/CONAGUA07/Publicaciones/Publicaciones/EAM2014.pdf

Escobar, O. A. (2009). Manejo del agua en México: Bosquejo de la evolución institucional federal 1926-2008. *Semblanza Histórica del Agua en México,* 62–73. Retrieved from http://www.conagua.gob.mx/CONAGUA07/Publicaciones/Publicaciones/SGP-28SemblanzaHist%C3%B3ricaM%C3%A9xico.pdf

Eurostat. (2015). Sustainable development in the European Union 2015 monitoring report of the EU Sustainable Development Strategy. *European Statistical Office.* Retrieved from http://ec.europa.eu/eurostat/documents/3217494/6975281/KS-GT-15-001-EN-N.pdf

Foa, R. (2009). Social and governance dimensions of climate change: Implications for policy. *Social Development Working Papers.*

GCCOM. (2014). Guía para la creación de organismos operadores metropolitanos de agua potable y saneamiento en México, 15–25. Retrieved from http://imco.org.mx/wp-content/uploads/2014/03/AguaPotable.pdf

Getzner, M. (1999). Weak and strong sustainability indicators and regional environmental resources. *Environmental Management and Health*, *10*(3), 170–176.

Grissom, T. V. (2014). The use of strong and weak form sustainability to assist in rate development for the valuation of exhaustible resources (part I). *Property Management*, *32*(3), 256–277.

Gruszewska, E. (2014). Changes in informal institutions in Poland and transition countries. *Equilibrium: Quarterly Journal of Economics and Economic Policy*, *9*(1), 39–55. doi:http://dx.doi.org/10.12775/EQUIL.2014.003

Grzymala-Busse, A. (2010). The best laid plans: The impact of informal rules on formal institutions in transitional regimes. *Studies in Comparative International Development*, *45*, 311–333.

Hájek, M., & Petružela, L. (2016). Sustainability of the public water supply and sewerage services operating system: A case study on the example of the Czech Republic. *Scientia Agriculturae Bohemica*, *47*(1), 32–39.

Harris, J.M. (2003). Sustainability and sustainable development. *International Society for Ecological Economics.*, 1-12

Hearne, R.H. (2007). Evolving water management institutions in the Red River Basin. *Environmental Management*, *40*, 842–852.

Hediger, W. (1999). Reconciling "weak" and "strong" sustainability. *International Journal of Social Economics*, *26*(7), 1120–1144.

Hodgson, G.M. (2006). What are institutions?. *Journal of Economic Issues*, *40*(1), 1–21.

Iacob, E. S. (2014). Controversies concerning the concept of sustainable development. *Valahian Journal of Economic Studies*, *5*(2), 91–98.

Jiménez, C. B., Durán, A. J. C., Méndez, C. M. J. (2010). Calidad. *El Agua en México: Cauces y encauces*, 265–290. Retrieved from http://www.conagua.gob.mx/CONAGUA07/Contenido/Documentos/elaguaenmexico-caucesyencauces.pdf

Kates, W. R., Parris, M. T., & Leiserowitz, A. A. (2005). What is sustainable development? Goals, indicators, values and practice. *Science and Policy for Sustainable Development*, 47(3), 8–12.

Keiner, M. (2003). Re-Emphasizing sustainable development: The concept of "Evolutionability" on living changes, equity, and good heritage. *Environment, Development, and Sustainability*, *6*, 379–392.

Krause, K., Chermak, J. M., & Brookshire, D. S. (2003). The demand for water: Consumer response to scarcity. *Journal of Regulatory Economics*, *23*(2), 167–191.

Kirskey, W. (2010). Thinking outside the waterworks: Transitioning to a decentralized water system model. *American Water Works Association Journal*, *102*(4), 34–35.

Knight, A. (1986). La revolución mexicana: ¿Burguesa, nacionalista, o simplemente "gran rebelión"?. *Cuadernos Políticos*, *48*, 5–32.

Knight, A., & Urquidi, M. (1989). Los intelectuales en la Revolución mexicana. *Revista Mexicana de Sociología*, *51*(2), 25–65.

Lara, C. F. R. (2016). Economic development and water scarcity in Mexico. *Actual Problems of Economics*, *8*, Forthcoming August 2016.

Lara, R., & Hak, T. (2009). Environmental Economics and Management Young Scholars Perspective, Prague, Litomys Seminar Publishing, ISBN 978-80-86709-15-4, pp.129-124.

Lara, R., Hlavacek, J., & Sauer, P. (2013). Natural resources and violent conflicts: Quantitative analyses for African countries. *Actual Problems of Economics*, *9* (147), 268–377.

Laxmirayan, R., & Fischer, C. (2005). Sequential development and exploitation of an exhaustible resource: Do monopoly rights promote conservation?. *Journal of Environmental Economics and Management*, *49*(3), 500–515.

Lípa, J., & Hájek, M. (2014). Organizational arrangement of environmental protection in the city of Prague. *Scientia Agriculturae Bohemica*, *4*(45), 238–246.

Lobina, E., & Hall, D. (2000). Public sector alternatives to water supply and sewage privatization: Case studies. *International Journal of Water Resources Development*, *16*, 35–55.

Lysnyak, S., & Sharipov, I. (2015). Exploring the formal and informal institutions as a key tool for enhancing economic resilience. *CES Working Papers*, *2*(4), 891–898.

Mantzavinos, C., North, C. D., & Shariq, S. (2004). Learning, institutions, and economic performance. *Perspectives on Politics*, 2(1), 75–84.

Meadowcroft, J. (1999). The politics of sustainable development: Emergent arenas and challenges for political science. *International Political Science Review*, *20*(2), 219–237.

Mehlum, H., Moene, K., & Torvik, R. (2006). Institutions and the resource curse. *The Economic Journal*, *116*(508), 1–20.

Nuñez, M. L. (1960). Un balance objetivo de la Revolución Mexicana. *Revista Mexicana de Sociología*, *22*(2), 529–542.

Meyer, S. Konisky, M., & David, M. (2007). Adopting local environmental institutions: Environmental need and economic constraints. *Political Research Quarterly*, *60*(1), 3–13.

Mohr, W. J., & White, C. H. (2008). How to model an institution. *Theory and Society*, *37*(5), Special Issue on Theorizing Institutions: Current Approaches and Debates, 485–512.

Mukheibir, P. (2010). Water access, water scarcity, and climate change. *Environmental Management, 45*, 1027–1039.

OECD. (2008). *Measuring sustainable development.* Organization for Economic *Cooperation and Development.* Retrieved from http://www.oecd.org/greengrowth/41414440.pdf

Oran, R. Y. (2003). Environmental governance: The role of institutions in causing and confronting environmental problems. *International Environmental Agreements: Politics, Law and Economics*, *3*(4), 377–390.

NOM 127-SSA1-1994. Official Mexican Norm NOM 127-SSA1-1994, Secretaría de Salud, 2016. Retrieved from http://www.salud.gob.mx/unidades/cdi/nom/127ssa14.html)

Olivares, R. (2008). Las reformas al 115-una reflexión prospectiva, *El agua potable en México: Historia reciente, actores, procesos y propuestas, ejemplos y propuestas*, 49–74. Retrieved from http://www.aneas.com.mx/contenido/EL%20AGUA%20POTABLE%20EN%20MEXICO.pdf

Pacheco-Vega, R., & Vega, O. (2008). Retos y perspectivas en materia de política de tratamiento de aguas y saneamiento den México, *El agua potable en México: Historia reciente, actores, procesos y propuestas, ejemplos y propuestas*, 173–185. Retrieved from http://www.aneas.com.mx/contenido/EL%20AGUA%20POTABLE%20EN%20MEXICO.pdf

Perevochtchikova, M. (2010). Nueva cultura del agua en México: avances, limitaciones y retos, *Revista Latinoamericana de Recursos Naturales 6* (2), 77-92.

Perevochtchikova, M. (2010a). Los grandes problemas de México: Medio ambiente Vol.4, México D.F., El Colegio de México, ISBN 978-607-462-112-9, p. 61-105 , Retrieved from http://2010.colmex.mx/16tomos/IV.pdf

Phillips, N., Lawrence, B. T., & Hardy, C. (2004). Discourse and institutions. *The Academy of Management Review*, 29(4), 635–652.

Pineda, P. N, Salazar, A. A., & Buenfil, R. M. (2010). Para dar de beber a las ciudades mexicanas: El reto de la gestión eficiente del agua ante el crecimiento urbano. *El Agua en México: Cauces y encauces*, 117–139. Retrieved from http://www.conagua.gob.mx/CONAGUA07/Contenido/Documentos/elaguaenmexico-caucesyencauces.pdf

Prado, M., & Trebilcock, M. (2009). Path dependence, development, and the dynamics of institutional reform. *The University of Toronto Law Journal*, *59*(3), 341–379.

Raymond, L., Weldon, S. L., Kelly, D., Arriaga, B. X., & Clark, A. (2014). Making change: Norm-Based strategies for institutional change to address intractable problems. *Political Research Quarterly*, *67*(1), 197–211.

Rodríguez, B. E. (2008). Agua y saneamiento en México: Avances, errores y alternativas. *El agua potable en México: Historia reciente, actores, procesos y propuestas, ejemplos y propuestas*, 29–47. Retrieved from http://www.aneas.com.mx/contenido/EL%20AGUA%20POTABLE%20EN%20MEXICO.pdf

Roland, L., & Cárdenas, Y. V. (2010). La gestión del agua en México. *Polis*, *6*, 155–158. Retrieved from http://www.juridicas.unam.mx/publica/librev/rev/polis/cont/20102/art/art6.pdf

Román, C. J. A., Cortez, L. A. A., Soto, O. R., Escobar, G. F., & Viramontes, O. O. A. (2010). El agua en el noreste. *El Agua en México: Cauces y encauces*, 479–504. Retrieved from http://www.conagua.gob.mx/CONAGUA07/Contenido/Documentos/elaguaenmexico-caucesyencauces.pdf

Romero, L. P. (2007). Descentralización y retiro del Estado: ¿Mecanismos para gestionar sustentablemente el agua?. *Gestión y Política Pública*, *1*, 29–59.

Rojas, R. J. J. P. (2013). Dilemas del desarrollo regional hidráulico al interior de México: Conflictos en la gestión regional del agua y la nueva fórmula política en la Cuenca Lerma-Chapala. *Historelo Revista de Historia Regional y Local*, *9*, 318–352.

Ross, A. (2009). Modern interpretations of sustainable development. *Journal of Law and Society*, *36*(1), 32–54.

Saleth, R. M., & Dinar, A. (2004). *The Institutional Economics of Water: A Cross-Country Analysis of Institutions and Performance*. The World Bank, 10–185.

Saltiel, G. (2008). Problemática del sector de agua, alcantarillado y saneamiento mexicano- análisis, *El agua potable en México: Historia reciente, actores, procesos y propuestas, ejemplos y propuestas*, 229–236. Retrieved from http://www.aneas.com.mx/contenido/EL%20AGUA%20POTABLE%20EN%20MEXICO.pdf

Sánchez, R. M. (2009). De la tradición a la modernidad. Cambios técnicos y tecnológicos en los usos del agua. *Semblanza Histórica del Agua en México*, 28–41. Retrieved from http://www.conagua.gob.mx/CONAGUA07/Publicaciones/Publicaciones/SGP-28SemblanzaHist%C3%B3ricaM%C3%A9xico.pdf

Sandoval, M. R. (2010). La evolución del marco institucional del agua potable y saneamiento urbanos en México: Un análisis cognitivo preliminar. *El Agua en México: Cauces y encauces*, 625–643. Retrieved from http://www.conagua.gob.mx/CONAGUA07/Contenido/Documentos/elaguaenmexico-caucesyencauces.pdf

SAYEN. (2007). Sustainable development: An introduction, South Asia Youth Environment Network. Retrieved from http://www.sayen.org/volume-i.pdf

Seckler, D., Barker, R., & Amarashinge, U. (1999). Water scarcity in the twenty-first century. *International Journal of Water Resources Development*, *15*, 29–41.

SINA. (2016). Sistema Nacional de Información del Agua. Data retrieved from http://201.116.60.25/sina/

Soubbotina, P. T. (2004). Beyond economic growth: An introduction to sustainable development. *The World Bank*, 82–100. Retrieved from http://www.worldbank.org/depweb/english/beyond/beyondco/beg_all.pdf

Skoog, E. G. (2005). Supporting the development of institutions: Formal and informal rules an evaluation theme basic concepts. *Swedish International Development Agency*, 5–33. Retrieved from http://www.sida.se/contentassets/502276753e2c429b9c4e066ae0c16872/20053-supporting-the-development-of-institutions---formal-and-informal-rules.-an-evaluation-theme-basic-concepts_1886.pdf

Spicer, A., McDemott, G. A, & Kogut, B. (2000). Entrepreneurship and privatization in Central Europe: The tenuous balance between destruction and creation. *The Academy of Management Review, 25*(3), 630–649.

Tauheed, F. L. (2013). A critical institutionalist reconciliation of "contradictory" institutionalist institutions: What is an institution?. *Journal of Economic Issues, 47*(1), 147–165.

Tlaiye, L., & Biller, D. (1994). Successful environmental institutions: Lessons from Colombia and Curitiba, Brazil. *The World Bank Latin America Technical Department Environment Unit*, 12, 1-42

Tortajada, C. (1998). Water supply and wastewater management in Mexico: An analysis of the environmental policies. *International Journal of Water Resources Development*, *14*, 327–337.

UN. (2010). Sustainable development: From Brundtland to Rio 2012. *United Nations*. Retrieved from http://www.un.org/wcm/webdav/site/climatechange/shared/gsp/docs/GSP1-6_Background%20on%20Sustainable%20Devt.pdf

UNESCO. (2005). UNESCO and sustainable development. Retrieved from http://unesdoc.unesco.org/images/0013/001393/139369e.pdf

Vásques,W. F., Franchesci, D., & Van Hecken, G. T. J. A. J. (2011). Household preferences for municipal water services in Nicaragua. *Environment and Development Economics*, *17*, 105–126.

Viesca de la Garza, J. E. (2008). Política pública en materia de agua potable, drenaje, alcantarillado, tratamiento y disposición de las aguas residuales. *El agua potable en México: Historia reciente, actores, procesos y propuestas, ejemplos y propuestas*, 123–139. Retrieved from http://www.aneas.com.mx/contenido/EL%20AGUA%20POTABLE%20EN%20MEXICO.pdf

Walter, T., Kloos, J., & Tsegai, D. (2011). Options for improving water use efficiency under worsening scarcity: Evidence from the Middle Olifants Sub-Basin in South Africa. *Water SA*, *37*, 357–367.

Willams, C. C., Millington, C. A. (2004). The diverse and contested meanings of sustainable development. *The Geographical Journal*, 170(2), 99–104.

Williamson, R. C., & Berekes, B. C. (2011). Securing private property: Formal versus informal institutions. *The Journal of Law & Economics*, *54*(3), 537–572.

WNP. (2013). Programa Nacional Hídrico 2013-2018, Comisión Nacional del Agua, 15–60. Retrieved from http://www.conagua.gob.mx/conagua07/contenido/documentos/PNH2014-2018.pdf

WRP. (2013a). Programa Hídrico Regional Visión 2030 Región Hidrológico-Administrativa VI Río Bravo, Comisión Nacional del Agua, 5–90. Retrieved from http://www.pronacose.gob.mx/pronacose14/contenido/documentos/VI%20PHOCRB.pdf

WRP. (2013b). Programa Hídrico Regional Visión 2030 Región Hidrológico-Administrativa VIII Lerma-Santiago-Pacífico, Comisión Nacional del Agua, 8–45. Retrieved from http://www.pronacose.gob.mx/pronacose14/contenido/documentos/VIII%20PHOCLSP.pdf

WRP. (2013c). Programa Hídrico Regional Visión 2030 Región Hidrológico-Administrativa XIII Aguas del Valle de México, Comisión Nacional del Agua, 14–60. Retrieved from http://www.pronacose.gob.mx/pronacose14/contenido/documentos/XIII%20PHOCAVM.pdf

WWAP (United Nations World Water Assessment Programme). (2016). *The United Nations World Water Development Report 2016: Water and Jobs.* Paris: UNESCO, 20–23, 85–87. Retrieved from http://unesdoc.unesco.org/images/0024/002439/243938e.pdf

WWFMD. (1997). Marrakech Declaration of the First World Water Forum. *World Water Council.* Retrieved from http://www.worldwatercouncil.org/fileadmin/wwc/Library/Official_Declarations/Marrakech_Declaration.pdf

WWFMD. (2000). Hague Ministerial Statement. Retrieved from http://www.worldwatercouncil.org/fileadmin/world_water_council/documents/world_water_forum_5/WWF5_Final_Report_ENG.pdf

WWFMD. (2003). Final Report of the 3rd World Water Forum, 2003. Retrieved from http://www.worldwatercouncil.org/fileadmin/world_water_council/documents/world_water_forum_3/3d_World_Water_Forum_FinalReport_BD.pdf

WWFMD. (2006). Final Report of the 4th World Water Forum (2006). Retrieved from http://www.worldwatercouncil.org/fileadmin/world_water_council/documents/world_water_forum_4/Final_Report_4th_Forum.pdf

WWFMD. (2009). Istanbul Ministerial Statement. *World Water Council*. Retrieved from http://www.worldwatercouncil.org/fileadmin/wwc/World_Water_Forum/WWF5/Ministerial_Statement_22_3_09.pdf

WWFMD. (2012). Marseille Ministerial Statement. *World Water Council*. Retrieved from http://www.worldwaterforum6.org/en/news/single/article/the-ministerial-declaration-of-the-6th-world-water-forum/

WWFMD. (2015). Gyeongju Ministerial Statement. *World Water Council*. Retrieved from http://www.worldwatercouncil.org/fileadmin/wwc/World_Water_Forum/WWF5/Ministerial_Statement_22_3_09.pdf

Wutich, A. (2009). Water scarcity and the sustainability of a common pool resource institution in the urban Andes. *Human Ecology*, *37*, 179–192.

Yamia, M., Voglb, C., & Hausera, M. (2009). Comparing the effectiveness of informal and formal institutions in sustainable common pool resources management in Sub-Saharan Africa. *Journal of Conservation and Society*, *7*(3), 153–164.

Zak, M., & Vymetal, P. (2006). Institucionální aspekty nové komparativní ekonomie: ČR a EU. *Politická ekonomie*, *6*, 583–609.

APPENDIX

A1. First regression results for HAR XIII Waters of the Valley of Mexico

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	público volumen concesionado hm3," Recaudación suministros urbanos e industria-cobro derechos millones de pesos , Caudal tratado (m^3/s) , Aportacion al PIB %, Población/millones de habitantes[b]	.	Enter

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.932[a]	.868	.703	7.650

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1537.924	5	307.585	5.256	.067[b]
	Residual	234.076	4	58.519		
	Total	1772.000	9			

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	214.797	234.749		.915	.412
	Recaudación suministros urbanos e industria-cobro derechos millones de pesos	.024	.009	.724	2.598	.060
	Población/millones de habitantes	-1.989E-005	.000	-1.023	-2.217	.091
	Aportacion al PIB %	12.306	5.840	.555	2.107	.103
	Caudal tratado (m^3/s)	-4.043	11.188	-.129	-.361	.736
	público volumen concesionado hm3”	-.021	.011	-.466	-1.971	.120

a. Dependent Variable: % de acuíferos contaminados y fueremente contaminados

A2. First regression results for HAR VI Río Bravo

Variables introducidas/eliminadas[a]

Modelo	Variables introducidas	Variables eliminadas	Método
1	Caudal tratado (m^3/s) , público volumen concesionado m3,” Suministro de agua en bloque a centros urbanos e industriales (Recaudacion cobro de derechos millones de pesos), Aportacion al PIB %, Población/millones de habitantes[b]	.	Introducir

Resumen del modelo

Modelo	R	R cuadrado	R cuadrado corregida	Error típ. de la estimación
1	.474[a]	.225	-.744	5.7671888

ANOVA[a]

Modelo		Suma de cuadrados	Gl	Media cuadrática	F	Sig.
1	Regresión	38.599	5	7.720	.232	.930[b]
	Residual	133.042	4	33.260		
	Total	171.641	9			

a. Variable dependiente: % de acuíferos contaminados y fueremente contaminados

Coeficientes[a]

Modelo		Coeficientes no estandarizados		Coeficientes tipificados	t	Sig.
		B	Error típ.	Beta		
1	(Constante)	-108.190	264.553		-.409	.704
	Suministro de agua en bloque a centros urbanos e industriales (Recaudacion cobro de derechos millones de pesos)	40.369	259.249	.103	.156	.884
	público volumen concesionado m3”	-2.542E-006	.000	-.327	-.388	.718
	Aportacion al PIB %	9.182	19.158	.297	.479	.657
	Caudal tratado (m^3/s)	.415	1.420	.202	.292	.785

a. Variable dependiente: % de acuíferos contaminados y fueremente contaminados

A3. First regression results for HAR VIII Lerma Santiago Pacific

Variables introducidas/eliminadas[a]

Modelo	Variables introducidas	Variables eliminadas	Método
1	Caudal tratado (m^3/s) , público volumen concesionado m3," Aportacion al PIB %, Suministro de agua en bloque a centros urbanos e industriales (Recaudacion cobro de derechos millones de pesos), Población/millones de habitantes[b]	.	Introducir

Resumen del modelo

Modelo	R	R cuadrado	R cuadrado corregida	Error típ. de la estimación
1	.727[a]	.529	-.060	2.8416546

ANOVA[a]

Modelo		Suma de cuadrados	Gl	Media cuadrática	F	Sig.
1	Regresión	36.281	5	7.256	.899	.557[b]
	Residual	32.300	4	8.075		
	Total	68.581	9			

a. Variable dependiente: % de acuíferos contaminados y fueremente contaminados

Coeficientes[a]

Modelo		Coeficientes no estandarizados		Coeficientes tipificados	t	Sig.
		B	Error típ.	Beta		
1	(Constante)	40.242	84.085		.479	.657
	Suministro de agua en bloque a centros urbanos e industriales (Recaudacion cobro de derechos millones de pesos) público volumen concesionado m3”	.007	.005	1.046	1.377	.241
		-8.150E-008	.000	-.036	-.033	.975
	Aportacion al PIB %	-.790	5.547	-.063	-.142	.894
	Caudal tratado (m^3/s)	-.972	.758	-1.272	-1.282	.269

a. Variable dependiente: % de acuíferos contaminados y fueremente contaminados