research paper

ENVIRONMENTAL HAZARDS
Human and Policy Dimensions

Exploring the risks of ineffective water supply and sewage disposal: A case study of Mexico City

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This study proposes a method to evaluate the effectiveness of water management in providing a safe water supply and adequate sewage discharge and treatment for residents of Mexico City. This method also assesses the vulnerability of the city and its capacity to face or cope with potential threats generated by insufficient water supply and sewage extraction. Indices for analysing these parameters were estimated and the spatial distribution of the groups most affected was identified. According to the results of the models used, Mexico City inhabitants are mainly exposed to risk because of economic limitations rather than ineffective water management. However, some practices implemented by city authorities are increasing the population's exposure to risk. Consequently, in the future it may be necessary to modify the way water is supplied and how sewage is transferred from the city to the sea.

Keywords: risk assessment; sewage discharge; vulnerability; water management assessment; water quality; water supply

1. Introduction

Water issues have become one of the most significant worldwide concerns. Over the last several decades, the scarcity of water and its unequal distribution have been increasing. Water-related risk mitigation and prevention have become a modern day challenge that demands innovative perspectives in water management.

There has been some effort from the international community to create a safer water world. These efforts, which have advanced water supply and sanitation in various countries, constitute part of the Millennium Development Goals (MDGs) strategies. The seventh MDG aims to halve, by 2015, the proportion of the world's population without access to safe drinking water and basic sanitation. Improvements in water supply and sanitation services have already had positive impacts such as the decrease of famine and child mortality, the eradication of diseases such as malaria and tuberculosis, the elimination of social inequalities and the preservation of environmental resources (WWAP, 2006).

The lack of a safe water supply and proper sanitation services constitutes a threat to human health, the environment and city development. This is due to the fact that individuals without access to a direct water supply are forced to look for alternative sources such as wells, rivers, springs, cistern cars or illegal connections to water networks. These sources do not guarantee safe water for consumption and in some cases are more expensive. Furthermore, lack of proper sewage treatment results in the improper use of septic tanks and latrines. This may lead to the pollution of existing aquifers, as well as of air and soil.

In this context, this case study evaluates the effectiveness of water management as a risk that can threaten human health and well-being when individuals do not have the capacity to face or cope with such water management problems. Indices for explaining these phenomena were designed and tested based on accepted

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definitions of the concept of risk and vulnerability. In this respect, risk can be defined as a product of threats and vulnerability; vulnerability was conceptualized as the fragility of human condition that limits our capacity to face and cope with threats (Renn, 1992; Blaikie et al., 1994; Crichton, 1999; Alexander, 2000; IPCC, 2001; Cardona, 2003; ISDR, 2004; UNDP, 2004).

Both risk and vulnerability are not evenly distributed among social groups, spatial units or over time. Consequently, it was necessary to identify the distribution and location of the most vulnerable groups using ad hoc geographical information systems, disaggregated by neighbourhoods. Additionally, the indices proposed in this paper, estimated by principal component analysis, were normalized and transformed into decimal units to simplify the data into a language that decision makers can easily understand.

2. Water management in Mexico City

2.1. Water supply

Mexico City receives 35.1 m^3/s of water from various internal and external sources. Groundwater from the aquifers of the Mexico Basin is the main source, providing nearly half the total supply. However, the amount of water extracted from the aquifers (20.7 m^3/s) is almost three times the natural recharge capacity of this basin (7.9 m^3/s) (Perló and González, 2005; Conagua, 2007).

One consequence of groundwater overexploitation is soil subsidence. This phenomenon has caused the collapse of buildings, breakage of water and sewage pipelines, wastewater flooding and leakages. A recent risk study examined the occurrence of cracks in the subsoil of these aquifers. Through these cracks, groundwater is directly exposed to pollution caused by wastewater and garbage leaching (Mazari, 1996). Additionally, subsoil moisture losses have been judged to amplify the intensity of earthquakes (Simon, 1997).

The Cutzamala and Lerma Systems are the second most important water sources in Mexico City and represent 43 per cent of the total supply (Perló and González, 2005; Conagua, 2007). Water from these external sources must be transported almost 127 km and pumped up nearly 1,100 m to reach the city. This process requires a large amount of electricity, which increases the cost of water extraction and distribution (Conagua, 2002).

It is expected that the dependency of Mexico City on external sources of water will increase and make the city authorities less capable of satisfying water demand. Additionally, the absence of economic compensation mechanisms for those communities located in areas from which water is extracted has caused strong opposition. This has created conflicts among users and sometimes limits water transferred to the city.

According to the Mexican National Institute of Statistics and Geographical Information (INEGI), approximately 86 per cent of homes within the city have access to water directly from pipelines. The other 14 per cent acquire this resource mainly by car tanks (88 per cent of that total), but also via wells, rivers, streams and springs (INEGI, 2005). It is estimated that 1.25 million people are exposed to several risks generated by the lack of safe water supply and this number does not include those affected by a non-permanent water provision.

Although city authorities have made considerable efforts to improve the detection and control of water leakage, the results obtained prove contrary. The Mexican Ministry of Environment (Semarnat) and the National Water Commission (Conagua) have reported that Mexico City is still losing 38 per cent of the total amount of water it receives (13.3 m^3/s). This volume is greater than the supply of water that comes from any one of the above-mentioned sources (Conagua and Semarnat, 2006).

2.2. Water quality

As dictated by the Mexican National Water Law, water provided to residents must be free from microorganisms and any substance that could produce adverse physiological effects and cause harm to human health. In this respect, parameters such as residual chlorine or fecal coliform bacteria are the most commonly used indicators for evaluating water quality (EPA, 2005).

In Mexico, conforming to the national norm NOM-127-SSA1-1994, the amount of residual chlorine accepted as safe fluctuates from 0.2 to 1.50 mg/litre (Semarnat, 2007). Nevertheless, due to the decline of water source quality, the use of chlorine as the only disinfection mechanism is no longer sufficient for providing safe water. For example, bacteria such as *Helicobacter pylori*, total coliforms, fecal coliforms, *Streptococci* and *Vibrio* spp. have been found in some samples of city water (Mazari-Hiriart et al., 2005).

As reported by the Mexico City Water System (SACM), in 2007, some 2 per cent of samples analysed did not satisfy residual chlorine standards. For fecal coliform analysis, pathogenic microorganisms were identified in 12 per cent of the samples. In both cases, the most affected areas were in the south and southeast of Mexico City (SACM, 2008). Since 1997, the analysis of samples has been reduced from 160,000 per year to less than 30,000 per year (SACM, 2008). This has increased the exposure to risks that could adversely affect the health of city residents because local authorities are less capable of identifying water quality problems.

2.3. Sewage discharge and treatment

Mexico City generates 25 m^3/s of wastewater, of which 71 per cent is its total water supply. Only 7 per cent of this volume receives some kind of treatment while the remaining 93 per cent is discharged without any treatment, thereby polluting rivers used for transferring effluent from the city to the sea (SACM, 2008).

Conagua has stated that city wastewater that has been treated for disinfection is mainly used for the artificial recharge of aquifers (25 per cent of the total), the irrigation of agricultural lands (7.8 per cent of the total) and green areas (37 per cent of the total), the filling of lakes and channels (20 per cent of the total), and some industrial and commercial activities (15 per cent of the total) (Conagua and Semarnat, 2006).

Although artificial infiltration of treated water into aquifers has reduced the risk associated with soil subsidence, the Mexico Basin may be exposed to pollution if the water does not meet quality standards. Today, the Mexican National Congress is examining some norms, such as NOM-014-CONAGUA-2007 and NOM-015-CONAGUA-2007, that could be used to regulate the treatment of water used for infiltration. These norms define the quality standards that infiltrated treated or rain water must meet in order to be environmentally secure and subsequently suitable for human consumption.

Some agricultural areas located in the Valley of the Mezquital and the Valley of Tula use this wastewater for farming activities (Conagua and Semarnat, 2006). This practice has had severe impacts on the health of producers and consumers of these crops (i.e. sorghum, barley, oat, wheat, corn, tomato, carrot, onion and coriander). Furthermore, it is also known to pollute the soil of the areas where these crops are grown (Romero, 1994). Evidence of this has been a documented increase of waterborne diseases. For example, the morbidity rate caused by *Ascaris lumbricoides* in children between 0 and 4 years old increases from 2.7 to 15.3 per thousand children in areas where wastewater is used to irrigate crops. Similarly, the morbidity rate caused by *Entamoeba histolytica* increases for individuals between 5 and 14 years of age, from 12.0 to 16.4 per thousand (Esteller, 2000).

As with drinking water pipelines, the sewage network has been considerably affected by soil subsidence. This has made it necessary to construct several pumping plants to evacuate wastewater generated in the city and has increased the risk of wastewater floods. However, this problem originates not only from soil subsidence. Other components include population growth leading to greater sewage discharge, and sewage pipeline breakage and poor maintenance. For example, the Great Channel, which is a Mexico City sewage network, has reduced its flow extraction capacity from 90 to 12 m^3/s. For this reason, several pumping plants have been built whose operational costs in terms of electrical power are over US$3.4 million per year (Conagua and Semarnat, 2006).

The INEGI reported that 93 per cent of homes in Mexico City are connected to the sewage network. Of the remaining 7 per cent, 5.5 per cent dispose of their sewage by alternative mechanisms (mainly septic tanks) and 1.5 per cent do not have access to this service (INEGI, 2005). Therefore, approximately 605,000 city residents do not have adequate sanitation services to guarantee their health.

In this context, this study proposes an experimental method to assess the risks generated by the above-mentioned water management problems. Through the indices estimated, the distribution and location of the most vulnerable groups were identified.

3. Water management risk assessment model

There is no universally accepted definition of risk and vulnerability. Also, there is no unique method for measuring these parameters. The absence of consensus among scientists, experts and governments about what can be defined as risk and how it should be evaluated is evidence that its comprehension and recognition are determined by both political and cultural factors (Jasanoff, 1995).

As indicated above, in this study, risk is seen as the product of threats and vulnerability; vulnerability is conceived as the human condition that limits our capacity to cope with threats. Based on these definitions, three indices were estimated by principal component analysis to determine to what extent water management in Mexico City has been capable of reducing the exposure of its inhabitants to risk from insufficient water supply, low quality of water and inadequate sewage discharge and treatment.

In these three indices, the models summarized several variables that were measured with different units, simplifying their understanding and interpretation. The input variables used by these models were selected based on their capacity to explain the effectiveness of water management in providing a safe water supply and proper sewage disposal system for residents of Mexico City; to calibrate these models, variables with low capacity to explain the variations in the sample were eliminated.

An advantage of principal component analysis is that it avoids problems such as multicolinearity and heteroscedasticity. Both problems make the parameters of models biased. In the case of multicolinearity, the close correlation that some variables exhibit can make the identification of the individual effect that each variable has on the behaviour of the sample more difficult. Regarding heteroscedasticity, which is attributed to non-constant variations in the residuals of a model, the variance of the parameters estimated increases.

These indices were normalized and transformed into decimal units, using the same 'pass'/'fail' criteria and scores as in the Mexican Educational System for evaluating the performance of students. This was done to simplify the results for decision makers. The accuracy and reliability of this method in other spatial and temporal contexts must still be evaluated because the information was based on 2005 data. It is expected that the functional form of these models would also need to be modified depending on the place analysed. The database built for estimating these models was based on information reported by national and local governments in Mexico, disaggregated by neighbourhoods.

3.1. Water Management Effectiveness Index

The Water Management Effectiveness Index (*WMEI*) measures the success in providing a safe water supply and adequate sewage discharge and treatment. This index is made up of three sub-indices. First, the Supply Index (*WSI*) evaluates the performance of authorities in providing residents with the minimum amount of water required for satisfying basic needs. Second, the Water Quality Index (*QI*) measures the effectiveness of authorities in providing safe water. Third, the Sewage Index (*SI*) estimates the extent to which the sewage network is evenly distributed among inhabitants, and whether this service is effective in extracting wastewater from the city to the sea. The equation that represents the *WMEI* model is

$$WMEI = \phi_1\overline{SI} + \phi_2\overline{QI} + \phi_3\overline{SI} \tag{1}$$

An effective supply of water means that authorities provide a volume from the water network that permanently satisfies basic needs. Effective safe water supplies must be free of any pathogenic microorganism, metals and toxic substances so that outbreaks of waterborne diseases are prevented. Finally, effective sewage discharge and treatment is related to fast, safe and environmentally friendly extraction and disinfection of the generated wastewater.

The input variables of the *WSI* index include water consumption per person (*Cons*), access to water from pipelines (*Accwpip*), water pipeline network coverage (*Wpipe*) and also volume lost and number of water leakages in the pipeline network (*Leaks*). The *QI* index is made up of the following variables: concentration of residual chlorine (*RChlor*) and presence of fecal coliform bacteria in water samples (*Fecalbac*), and both the total mortality (*Totalmort*) and infant mortality (*Infantmort*) caused by waterborne diseases. Lastly, the *SI* index is composed of access to sewage networks (*Accdpip*), drainage pipeline network' coverage (*Dpipe*), residential area floods (*Uflood*) and avenue floods (*Vflood*). Because of their low capacity to explain the variance in the sample, variables such as access to water from other houses, water pipeline network pressures, water pumping and treatment plants, sewage treatment plants, and biochemical oxygen demand and chemical oxygen demand in surface water were eliminated from the *WMEI* principal component model.

3.2. Water Management Vulnerability Index

The lack of capacity of residents to cope with problems related to water management was estimated by the Water Management Effectiveness Vulnerability Index (*WMVI*). This index analyses the extent to which the physical condition (*PCI*), economic capacity (*ECI*), social characteristics (*SCI*) and political representation (*PRI*) of people inhibit them from finding an alternative safe water supply and means of sewage discharge and treatment. The equation that represents the *WMVI* is the following:

$$WMVI = \gamma_1\overline{PCI} + \gamma_2\overline{ECI} + \gamma_3\overline{SCI} + \gamma_4\overline{PRI} \tag{2}$$

The physical components that increase vulnerability are closely related to location, which can be affected by flooding, landslides or lack of public services (i.e. water supply, sewage discharge or electricity). Segregation and obstacles that populations face with access to education, health services, safe housing and other public services are social components that reduce their capacity to deal with water management problems. Economic components can be associated with income, employment and working hours; therefore, they determine whether people have enough funds to find an alternative water supply and sanitation system. Finally, political components can be explained by the capacity of government in satisfying the demands of citizens and the participation of residents in the water management decision-making process.

The *PCI* index includes variables such as slope (*Slope*), pluviometry (*Pluv*), soil subsidence (*Ssub*), soil permeability (*Perm*), proximity to rivers (*Rivers*), flood areas (*Aflood*) and dams (*Dams*). The *SCI* index is composed of population density (*PCon*); people without access to water (*Ww*), sanitation services (*Ws*), electricity (*We*) and gas (*Wg*); illiteracy (*Illiter*); people without or incomplete elementary (*Weled*) and secondary (*Wsed*) education; people without radio (*Wrad*) and television (*Wtv*); houses with unsafe floors (*Floor*), roofs (*Roof*) and walls (*Walls*); people without health services (*Wahs*); people with disabilities (*Disab*); elderly people (*Elder*): and children (*Child*). The *ECI* index is made up of per capita income (*Incom*), the number of entrepreneurs (*Entrep*), salary (*Sal*) and working hours (*Hrs*). Finally, the variables that constitute the *PRI* index include the number and characteristics of social (*Sorg*) and political (*Porg*) organizations, the electoral roll (or register) (*Eroll*) and the number of voters (*Vot*). Variables such as population growth, employment by economic sector, medical expense and flood insurance coverage, and political party preference were excluded from the *VWVI* multi-component model due to their low capacity for explaining the variance in the sample.

3.3. Water Management Ineffectiveness Risk Index

Problems in providing a safe water supply and adequate sewage discharge and treatment do not generate nor intensify, by themselves the risks to which people are exposed. Exposure to these risks also depends on physical, social, economic and political limitations to face or cope with these problems.

Risk caused by water management problems was estimated by the Water Management Ineffectiveness Risk Index (*WMIRI*). This index has a probabilistic distribution ($0 \le WMIRI \le 100$), where n is the total number of neighbourhoods. Therefore, when $WMIRI \approx 100$, the inhabitants of the neighbourhood analysed face the maximum risk possible generated by the above-mentioned water management problems. However, if $WMIRI \approx 0$, their exposure is minimal.

The equation that represents *WMEI* is the following:

$$WMIRI = \frac{\overline{WMEI} \otimes \overline{WMVI}}{n} \qquad (3)$$

4. Water management assessment model results

4.1. Water Management Effectiveness Index

Using the same criteria as the Mexican Educational System, the results of the *WMEI* model were normalized and transformed into decimal units. Therefore if $WMEIi = 10$, the water management in the neighbourhood i is effective. If $WMEIi \ge 6$, then problems related to water management do not constitute serious threats to the well-being and health of the residents of the neighbourhood *i*. However, if this index is smaller than this value ($0 \le WMEIi < 6$), these problems become urgent, and need to be addressed immediately, as they may present great risk to the most vulnerable groups.

According to the normalized and transformed results of the *WMEI* model for Mexico City, water management is not a major threat to its inhabitants because the evaluation of its authorities' effectiveness in providing a safe water supply and adequate sewage disposal was 7.0. This outcome is a pass mark in the Mexican Educational Grading System, although it is associated with an average performance. Consequently, it is a mistake to argue that water management in Mexico City is ineffective, and constitutes the main cause of people's exposure to risks generated by water management problems. The most affected neighbourhoods, that is, those characterized by a lack of water supply, low quality of water provided, and inadequate sewage discharge and treatment, were located in the south and southeast regions of Mexico City (Figure 1).

Based on the results from principal component analysis (Tables 1 and 2), the functional form of the *WMEI* model is

$$WMEI = 0.3136WSI + 0.3358QI + 0.3506SI \qquad (4)$$

In this context, a concentration of infrastructure for water supply and sewage treatment and disposal improves water management efficiency in Mexico City. However, water supply through pipelines does not necessarily increase water consumption, because the volume provided to people could be inconsistent. Improvements in the water supply can lower rates of infant mortality. Furthermore, advances in sewage discharge and treatment reduce mortality rates from waterborne diseases in this city. There is no evidence to conclude that the use of chlorine guarantees the elimination of pathogenic microorganisms.

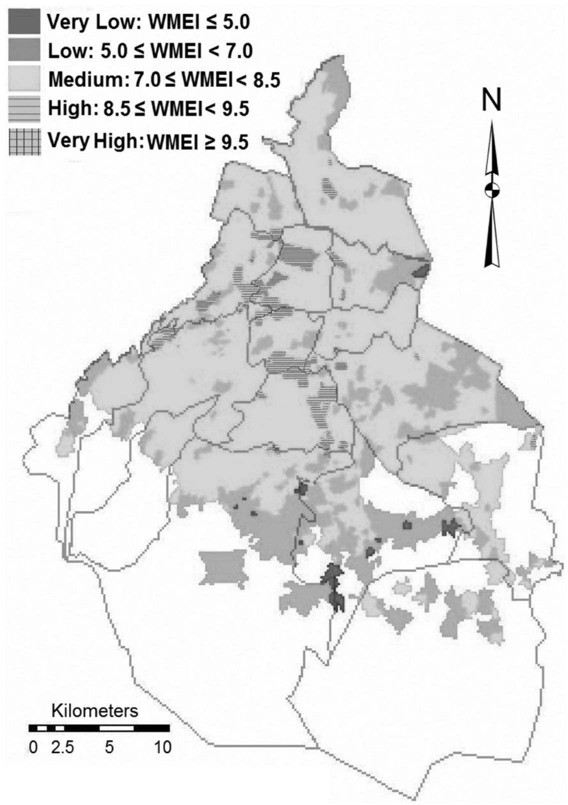

FIGURE 1 Water Management Effectiveness Index
Source: Results of the *WMEI* model.

Finally, the participation of Mexico City residents in water management decision making has improved their access to safe drinking water; nevertheless, it has not influenced sewage discharge and treatment. Despite the impact that the lack of this service has on people's quality of life and health, advances in this service area do not appear to constitute a priority in the current demands of citizens.

4.2. Water Management Vulnerability Index

The results of the *WMVI* were also normalized and transformed into decimal units. If $WMVIi = 10$, the residents of neighbourhood *i* are not vulnerable to problems related to water supply, low quality of water, or inadequate sewage discharge and treatment. If $WMVIi \geq 6$, living conditions allow citizens to identify alternative safe water sources and ways to dispose of their sewage; however, if this index is smaller than this value ($0 \leq WMVI < 6$), residents are not capable of dealing with these water management problems, thus they are highly exposed to associated risks.

Based on the normalized and transformed results of the *WMVI* model for Mexico City, living conditions of its inhabitants inhibit their capacities to cope with insufficient water supply, low quality of water and inadequate sewage disposal because the evaluation of their vulnerability was 5.7. This score corresponds to a failing (unsatisfactory) mark according to the Mexican Educational Grading System; therefore, their living conditions limit them from finding an alternative safe water supply and means of sewage discharge and treatment, making them more vulnerable (Figure 2).

Economic limitations, represented by a non-equitable distribution of income and unemployment, are the first component that makes Mexico City inhabitants vulnerable to water management problems. Indeed, in all the neighbourhoods of the city, groups of people can be found

TABLE 1 *WMEI* total variance explained

Component	Initial eigenvalues			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
SI	1.65893432	55.2978108	55.2978108	1.05198342	35.0561142	35.0561142
QI	0.9896106	32.98702	88.2848308	1.00059591	33.5819705	68.6380846
WSI	0.35145508	11.7151692	100.000000	0.94088421	31.3619154	100.000000

Extraction method: Principal component analysis.

TABLE 2 *WMEI* component score coefficient matrix

Component *WSI*		Component *QI*		Component *SI*	
Cons	0.0324	*Infantmort*	−0.12889	*Accdpip*	0.50141
Accwpip	0.50838	*Totalmort*	−0.0887	*Vflood*	−0.02773
Wpipe	0.50886	*Rchlor*	0.60687	*Uflood*	−0.0464
Leaks	−0.02484	*Fecalbac*	0.61705	*Dpipe*	0.5001
Total variance explained	75.6478045	Total variance explained	60.9478045	Total variance explained	80.9578045

Extraction method: Principal component analysis. Rotation method: Varimax with Kaiser normalization.

whose vulnerability is explained principally by these economic limitations. The second component that explains citizen vulnerability concerns the physical characteristics of the environment where people live – since many reside in areas affected by floods, landslides or lack of basic services (i.e. water, sewage, electricity or gas). The third component is the lack of political representation and the insufficient participation of citizens in the water management decision-making process. Finally, the fourth component affecting vulnerable city residents regards the social conditions in which they live, related to the restrictions they face in terms of access to education, health services, safe housing and other basic services. Similar to the *WMEI* model, the most vulnerable groups of people are concentrated in the south and southeast of Mexico City.

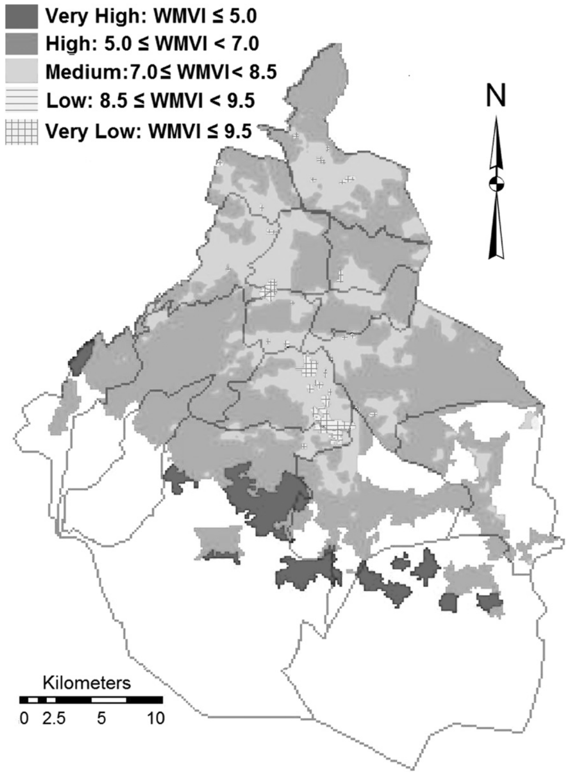

FIGURE 2 Water Management Vulnerability Index
Source: Results of the *WMVI* model.

The functional form of the *WMVI* model in agreement with the results obtained from principal component analysis (Tables 3 and 4) is the following:

$$WMVI = 0.2545PCI + 0.1403SCI + 0.3743ECI + 0.2309PRI \qquad (5)$$

Greater concentrations of the infrastructure for water supply and sewage disposition are mainly located in the zones that are physically less vulnerable. However, populations with lower average income levels (and no access to education, health or public services) live principally in danger zones that are often affected by floods, sinkholes, landslides and soil subsidence. Because of this, the ability of poor parts of the population in Mexico City to contend with water management problems is limited.

When people receive an adequate income, they have sufficient economic resources to find alternative ways to access a safe water supply, and to access efficient and environmentally friendly sewage removal and treatment, which is usually more expensive. Moreover, people with less favourable economic conditions live in

TABLE 3 *WMVI* total variance explained

Component	Initial eigenvalues			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
ECI	1.49704603	65.5988906	65.5988906	1.00179056	37.4320013	37.4320013
PCI	1.01819642	15.3617777	80.9606683	1.00128401	25.4438918	62.8758931
PRI	0.92392843	13.9108484	94.8715167	0.99728027	23.0920067	85.9678998
SCI	0.56082912	5.12848327	100.000000	0.94368027	14.0321002	100.000000

Extraction method: Principal component analysis.

areas that are affected by floods, landslides, sinkholes or the lack of public services. Here the price per m^2 or ha of land is lower, because it needs to compensate for its disadvantages. However, waterborne diseases affect all economic sectors, because they are closely related to problems in sewage discharge and treatment, which are widespread across Mexico City.

4.3. Water Management Ineffectiveness Risk Index

Water management risks are unevenly distributed within Mexico City. As the results of the *WMEI* and *WMVI* models indicate, the most exposed neighbourhoods to risks generated by water management problems are concentrated at the south and southeast. Nevertheless, few of these neighbourhoods experience high exposure to these risks (Figure 3).

Risks generated by the low quality of water are widespread in the city, and they affect more neighbourhoods than the risks caused by problems in water supply and sewage. However, people from the middle and upper classes have greater political power to negotiate for their own interests. In contrast, the demands and requests from the poorest people in the city are less represented in the political arena, making them more vulnerable to water management problems.

5. Policy implications

Water management in Mexico City has partially contributed to the mitigation and prevention of

TABLE 4 *WMVI* component score coefficient matrix

Component *ECI*		Component *PCI*		Component *PRI*		Component *SCI*			
Incom	0.44809	*Slope*	0.32422	*Sorg*	−0.55118	*Pcon*	0.24929	*Wtv*	0.13746
Entrp	−0.32771	*Pluv*	0.34434	*Porg*	−0.53918	*Ww*	0.21014	*Floor*	0.2074
Sal	0.33848	*Perm*	0.26971	*Eroll*	−0.63156	*Ws*	0.20605	*Roof*	0.13289
Hrs	0.25907	*Ssub*	−0.27132	*Vot*	−0.22333	*We*	0.16201	*Walls*	0.24002
		Rivers	−0.02525			*Wg*	0.15001	*Wahs*	0.15885
		Aflood	−0.10491			*Illiter*	0.14997	*Disab*	0.09423
		Dams	−0.11187			*Weled*	0.12688	*Elder*	0.12721
						Wsed	0.06775	*Child*	0.25563
						Wrad	0.06352		
Total variance explained									
78.67765		70.38247		68.02189		74.70532			

Extraction method: Principal component analysis. Rotation method: Varimax with Kaiser normalization.

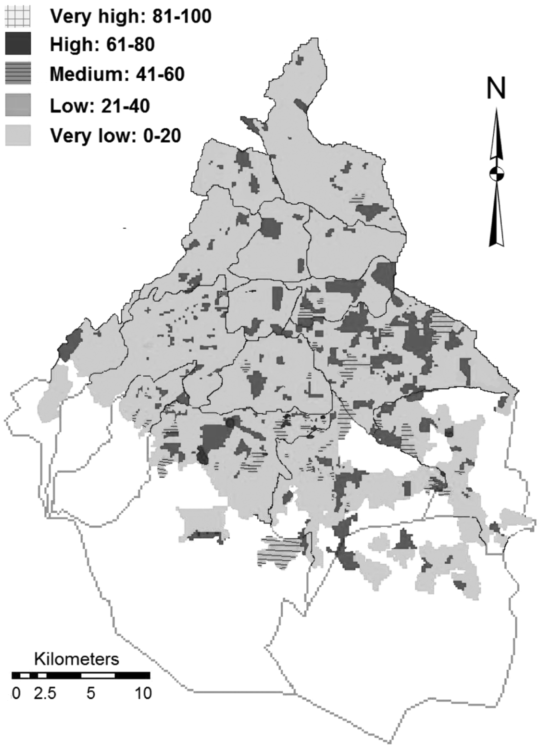

FIGURE 3 Water Management Ineffectiveness Risk Index
Source: Results of the *WMIRI* model.

some risks; however, government actions and strategies continue to increase people's exposure to risk. Even though some measures taken to provide water to Mexico City – and discharge the sewage generated by its inhabitants – have had a negative impact, they are well known. Nevertheless, authorities responsible for water management perpetuate them. For example, instead of recovering the volume lost by water leaks, which is more than the volume supply from any other source, current strategies are focused on looking for new sources of water farther away (Perló and González, 2005). This policy will not only increase the associated risks associated with a greater dependence on external sources, but it will also intensify water-related conflicts.

The city is transferring some of the risks caused by water management problems to other locations beyond its political-administrative limits; more water is being extracted from sources farther away. Most of the sewage discharged to rivers or other bodies of water does not receive any kind of disinfection treatment. In this context, authorities must consider as a major priority guaranteeing the quality of the water supply to the population, instead of focusing exclusively on increasing the volume of the water supply. Moreover, it is necessary to treat the total volume of sewage generated in Mexico City, so as not to pollute the rivers used to extract it from the city and send it to the sea.

The results of the *WMIRI* model show that in order to reduce the Mexico City inhabitants' exposure to water management risks, the people's vulnerability should be reduced. Therefore, building infrastructure for water supply and sewage discharge and treatment is not sufficient to mitigate or prevent the negative impact of water management risks. It is necessary to strengthen the ability of the citizenry to better handle and withstand water management problems. This can be done by improving equitable income distribution, by increasing well-paid employment, by guaranteeing people's access to basic services and safe housing, and by encouraging greater organization and participation on the part of those sectors underrepresented in the water management decision-making process (Blaikie et al., 1994; ISDR, 2004; UNDP, 2004).

It is also fundamental to be critical and reflective about current urban development in Mexico City, because it is becoming more vulnerable every day. For this reason, plans and policies must be redefined with a more sustainable perspective. Programmes that address and promote sewage treatment, rainwater treatment and reuse, and water rights payments for sewage discharge and water extraction, must be updated and implemented. Additionally, the failure to obey existing laws, or to carry out current policies, must have its consequences; there must be accountability. This may require improving monitoring and evaluation systems. Evidently, the approval of policies, laws and plans is not sufficient to guarantee mitigation and prevention of risks; they need to be translated into specific actions.

Furthermore, the cost of first-used and treated water must be adjusted in order to encourage consumers to use treated water in activities that do not require high quality. It is contradictory that water supplied directly from the network is cheaper than treated water. This explains why the demand for treated water has not been enhanced during last decades. In addition, it is necessary to approve water rights based on the amount of water that can be extracted, considering the natural recharge capacity of the source bodies of water (i.e. aquifers, springs, rivers, etc.). This strategy could also be helpful for consolidating water markets with the aim of allocating any water surplus efficiently (CEPAL, 1995, 2005).

6. Conclusions

Institutional efforts to reduce risks generated by water management problems face new challenges; these challenges make the task more complex. They include climate change, increase in water demand, emergence of conflicts (to access this resource) and the deterioration of the sources where it is extracted.

Since people are affected differently, and their ability to cope with water management problems is not the same, risks caused by these problems are unevenly distributed socially and spatially. These differences must be considered when implementing successful measures that can mitigate and prevent the negative effects caused by the lack of a safe water supply and adequate sewage discharge and treatment. In this context, water management problems constitute risks that have negative impacts on people's quality of life, the environment and the operation of cities.

In order to improve the decision-making and planning process to mitigate and prevent the negative impacts related to water management problems, it is fundamental to develop methods that support and guide the identification, selection and management of these risks. The development of more sophisticated methods is not a simple task, due to the lack of reliable and timely information – and the methodological difficulties associated with modelling uncertainty.

Recently, models have been used to support the decision-making process in water and risk management. They are a useful tool, although they also are a simplification of the real world. Without this simplification, however, it would be harder – if not extremely difficult – to understand and explain reality. Nevertheless, actions implemented for reducing people's risk exposure should not be based exclusively on the results of models, because they depend on the interpretation of decision makers. The use of advanced technological tools, such as geographical information systems, can be very helpful for facilitating the analysis of these phenomena. These tools allow the identification of those areas most exposed to risks, and the location of the most vulnerable groups of people.

In this context, the method proposed constitutes a useful example for assessing water management, and for monitoring people's vulnerability and risk exposure. Nevertheless, it is still necessary to evaluate their accuracy and reliability in other spatial and temporal contexts – to determine their sensitivity to changes. One of the most important limitations of these models is that they do not identify uncertainty; they are focused on a single time period, due to insufficient reliable and temporal information. Due to this lack of information, these indices do not capture the dynamic nature of risks and vulnerability generated by water management problems. The next step is therefore to design and test alternative models, in order to improve further on the assessment of risks generated by water management problems.

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