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Articles

Econometric analysis of water demand in Tijuana, Mexico

Análisis econométrico de la demanda de agua en Tijuana, México

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Abstract

The scarcity of water and the strong growth of the population and the industrial sector in the City of Tijuana make it necessary to use this resource properly. The aim of this article was to determine the factors that affect the demand for water in the residential and industrial sectors of Tijuana, and to analyze the effect that an increase in the prices of water and electricity has on the consumption of water in both sectors. A model of simultaneous equations of the demand for water was estimated and annual data from 1991 to 2019 were used. The results indicate that the demand for water in the residential and industrial sectors responds inelastically to their respective prices. The price of water would have to increase by 53.1 and 57.7 %, to decrease the demand for water by 10 % in the residential and industrial sectors, respectively; and the price of electricity would have to increase by 17.0 and 64.3 % to achieve the same effect on consumption in both sectors. The shortage of water in the city justifies the increase in the previous prices to reduce the consumption of the vital liquid.

Keywords: Tijuana, water demand, prices, residential sector, industrial sector, elasticity coefficients, simultaneous equations.

Resumen

La escasez de agua, y el fuerte crecimiento de la población y del sector industrial en la ciudad de Tijuana hace necesario un uso adecuado del recurso. El objetivo de este artículo fue determinar los factores que afectan la demanda de agua en los sectores residencial e industrial de Tijuana, y analizar el efecto que un aumento en los precios del agua y energía eléctrica tienen sobre el consumo del líquido en ambos sectores. Se estimó un modelo de ecuaciones simultáneas de la demanda de agua y se usaron datos anuales de 1991 a 2019. Los resultados indican que la demanda de agua en el sector residencial e industrial responde de manera inelástica a sus respectivos precios. El precio del agua tendría que aumentar en 53.1 y 57.7 % para disminuir la demanda de agua en 10 % en los sectores residencial e industrial, respectivamente; y el precio de la energía eléctrica tendría que aumentar en 17.0 y 64.3 % para lograr el mismo efecto en el consumo en ambos sectores. La escasez de agua en la ciudad justifica el aumento en los precios anteriores para lograr disminuir el consumo del vital líquido.

Palabras clave: Tijuana, demanda de agua, precios, sector residencial, sector industrial, coeficientes de elasticidad, ecuaciones simultáneas.

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Introduction

Population growth, urbanization, industrialization, increased production, and consumption generate an ever-increasing demand for freshwater. Such a context leads to the question of whether there is enough water to meet the world's growing demands. A solution could lie in the way water is used, managed, and shared (UNESCO, 2015).

The water availability is limited by geographical and hydrological characteristics. In these, Mexico is highly heterogeneous, since two-thirds of its territory is arid and semi-arid. In these areas, 77 % of the total population concentrate and contributes the most to the national total GDP (Gross Domestic Product). Yet, in terms of water, contains only 28 % of the natural runoffs. In contrast, the southeast of the country, with ten times more precipitation than the arid areas in the north of the country, has a lower GDP. This situation encourages competition for water, its pollution, and the overexploitation of aquifers (Sectur, 2018).

The municipality of Tijuana borders to the north with the United States and the municipality of Tecate, to the east with the municipalities of Tecate and Ensenada, to the south with the municipalities of Ensenada and Playas de Rosarito, and Playas de Rosarito municipality and the Pacific Ocean to the west (Sectur, 2018) (Figure 1). Due to its geographical location, it is in an area with a high degree of pressure on the water resources (Conagua, 2016). To supply water to the city, approximately 131 hm^3 per year are required. However, only 80 hm^3 of water is assigned from the Mesa Arenosa aquifer at San Luis Río Colorado, Sonora (by agreement the water is taken from the Colorado River instead of allocated from the aquifer). There is a 51 hm^3 deficit covered by the Tijuana aquifer (local source) and thanks to water rental negotiations with farmers of the DR-014 irrigation district. The assigned volume of the aquifer and the water income is conducted through the Colorado River-Tijuana Aqueduct (ARCT) (Comisión Estatal del Agua de Baja California, 2018). The Tijuana aquifer is not very useful due to its quality and deterioration, caused by contamination of the city itself. Despite this, an annual volume of 14.5 hm^3 is extracted from which 9.3 hm^3 (64.1 %) are for public-urban use (residential), 1.4 hm^3 more (9.7 %) for agriculture, 1.4 hm^3 (9.7 %) for services, 1.3 hm^3 (9.0 %) for livestock-domestic activities, and 1.1 hm^3 (7.6 %) for industrial use (Conagua, 2015; Sectur, 2018). The water infrastructure present is the Abelardo L. Rodríguez and El Carrizo dams, as well as an aqueduct carrying water from the Colorado River, from Mexicali to Tijuana city for public-urban supply (Sectur, 2018).

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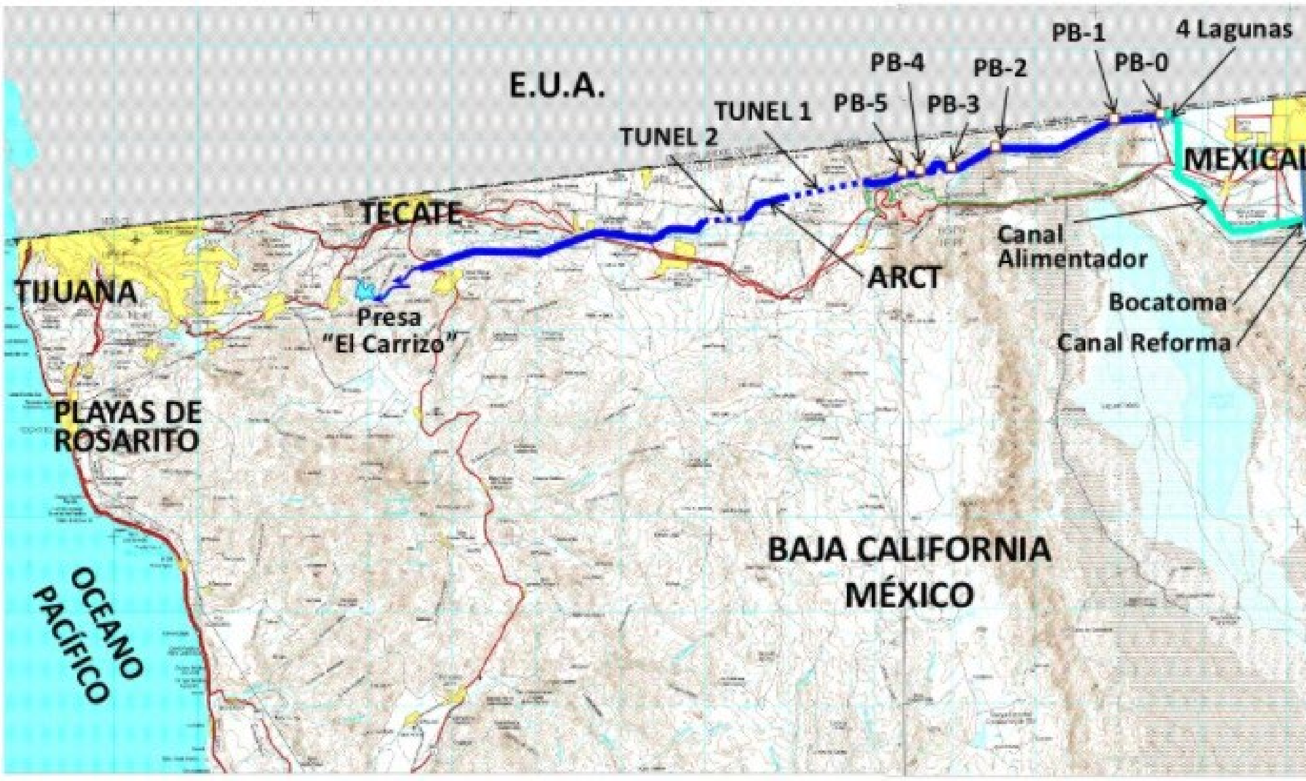

Figure 1. *Location of Tijuana and the Colorado River-Tijuana Aqueduct (ARCT).* PB-0 to PB-5 are pumping plants 0 to 5. Source: Comisión Estatal del Agua de Baja California (2011).

The population in Tijuana city in 2019 was 1.8 million people and is projected to grow 19.5 % during the 2019 to 2030 period (Conapo, 2018). This will increase the pressure on the city´s water resources, which justifies the rational and efficient use of it in all productive sectors.

Regarding the industrial growth in Tijuana, data from the State Public Services Commission from Tijuana, acquired through the national transparency platform (CESPT, 2020: Personal communication, May 8, 2020), indicate an average annual growth rate of the drinking water intakes for industrial use of 9.6 % from 1991 to 2000. For the 2000 to 2010 period this rate grew 0.6%, and in the 2010 to 2019 period had a 2.4 % annual growth. The foregoing indicates that the industry is a dynamic sector in Tijuana (extractive industry, electricity, manufacturing, and construction), and has shown a growing trend during the last decade. Therefore, these sectors' growth implies greater water demand.

The National Survey of Occupation and Employment (ENOE), published by the INEGI (2020a), indicates that in Tijuana city 97.2 % of the EAP (Economically Active Population) was employed and only 2.8 % were unemployed during the second quarter of 2019. From the employed population, 59.4 % worked in the tertiary sector, which included commerce, restaurants, lodging services, transportation, communications, mail, storage, professional, financial and corporate services, social services, various government services, and international organizations. 34.3 % worked in the secondary sector, which included extractive industries, electricity, manufacturing, and construction; the remaining 6.2 % corresponded to workers with not specified economic activity sector.

For a long time, the city of Tijuana has had to deal with water supply problems. From 1950 to 1980 this city had water shortages caused by migratory factors and by industrial and population growth; by 1987, five years after the Río Colorado-Tijuana aqueduct opened, it was necessary to increase its capacity from 1 500 to 2 660 l/s, and by 1993 to 4,000 l/s. In 1999, the capacity was again increased to 5 300 l/s, thought to cover the requirements until 2017; however, this did not happen as expected, because the population and economic activity continued to grow. Even today, to supply the city's water demand it is necessary to negotiate and buy more than 1 395 l/s of additional water (equivalent to 44 hm^3 per year) from the 014 (DR-014) Irrigation District (Navarro-Chaparro, Rivera, & Sánchez, 2016; Comisión Estatal del Agua de Baja California, 2018).

Electrical energy is directly linked to water consumption. In residential areas, it is associated with using dishwashers, washing machines, bathrooms, and showers, while in the industrial sector it relates to dishwashers, pressurized water in sinks, laundries, water in industrial processes, machinery cooling, water heating, ice makers, and pumps, among others. For this reason, it is important to analyze the electrical energy linked to water management (Wolf, 2010).

Given the above context, it is important to analyze the factors that determine the demand behavior in arid areas, with water supply problems, such as the City of Tijuana in this case. The scarcity of water resources is increasingly critical due to population and industry growth.

Water scarcity has been the subject of multiple research projects. The factors that determine water consumption have been studied by Guzmán, García, Rebollar and Hernández (2011); Gómez-Ugalde, Mora-Flores, García-Salazar and Valdivia-Alcalá (2012); Torres-Sombra *et al*. (2013); Castro and Sisto (2015); Romano, Salvati and Guerrini (2016); Martínez-Santos (2017), and Ojeda, Alvarez-Chavez, Ramos-Corella and Soto-Hernandez (2017), among others. The water market (supply and demand) has been analysed by Koutiva and Makropoulos (2016); Ashoori, Dzombak and Small (2017); Jiménez, Orrego, Cossio, Vásquez and Ponce (2017); Montesillo-Cedillo (2017), and Noya and Hernández (2018), among others, and the competition for water usage has been studied, among others, García-Salazar, Guzmán-Soria and Fortis-Hernández (2006), and Torres-Sombra and García-Salazar (2015).

Considering the water´s social and economic importance, in addition to the dependence that the city of Tijuana has on the Río Colorado-Tijuana aqueduct as its main source for water supply, the pollution of aquifers, scarce rainfall, and the population and industrial growth, the objective of this research is to estimate the elasticity coefficients of some factors that determine water demand for the residential and industrial sectors of Tijuana, and determine the necessary price of water and electricity to reduce water demand in these sectors through predictive scenarios. The hypothesis has been that a decrease in water demand in Tijuana would occur if water and electricity prices increase.

Materials and methods

To meet the proposed objectives and hypothesis, a simultaneous equations model was formulated, consisting of two water demand equations and three identities, symbolized by the different water consumers (residential, industrial) for Tijuana. Annual data was in the variables considered in the 1991 to 2019 model. The estimation was carried out through the ordinary least squares method in two stages using and the SAS econometric software (SAS, 2013). The estimated model was as follows:

$$CARP_t = \propto_0 + \propto_1 PARR_t + \propto_2 PERR_t + \propto_3 INGR_t + \propto_4 TEMP_t + \propto_5 PP_t + \varepsilon_1 \quad (1)$$

$$QDAR_t = 385940 * CARP_t \quad (2)$$

$$CAIP_t = \propto_0 + \propto_1 PAIR_t + \propto_2 PEIRL_{t-1} + \propto_3 PIBAS_t + \propto_4 TEMP_t + \propto_5 PP_t + \varepsilon_2 \quad (3)$$

$$QDAI_t = 2329 * CAIP_t \quad (4)$$

$$QDARI_t = QDAR_t + QDAI_t \quad (5)$$

Where, $CARP_t$ is the average annual consumption per drinking water intake for residential use at year t, as m^3 per intake; $PARR_t$ is the average price (in monetary terms) of drinking water in the residential sector for year t, in pesos per m^3; $PERR_t$ is the real weighted price of electricity for residential use at year t, in pesos per kilowatt-hour; $INGR_t$ is the real *per capita* income (general minimum wage at the economic zone A, the municipalities of Baja California all included) in year t, in pesos per month; $TEMP_t$ is the mean annual summer temperature in Tijuana in year t, in °C; PP_t is the rainfall in year t, in mm; $QDAR_t$ is the demanded quantity of water in the residential sector in year t, in m^3; $CAIP_t$ is the average annual consumption per drinking water intake in the industrial sector in year t, in m^3 per intake; $PAIR_t$ is the real price of drinking water for industrial use in year t, in pesos per m^3; $PEIRL_{t-1}$ is the weighted real price of energy for industrial use in year t^{-1}, in pesos per kilowatt-hour; $PIBAS_t$ is the PIB of the secondary activities in the state of Baja California in year t, in millions of pesos; $QDAI_t$ is the demanded water quantity in the industrial sector in year t, in m^3; $QDARI_t$ is the total amount of water demanded by residential and industrial sectors in Tijuana in year t, in m^3; for equations (1) and (3), the $\propto_0$ represents the intercept in the corresponding equation, the $\propto_1,\ldots,\propto_5$ in each case are the estimated coefficients of the parameters that associate the exogenous variables with the average annual consumption per drinking water intake, for residential and industrial use, respectively; the ε_1 and ε_2 represent the random error terms.

The model is theoretically justified with empirical evidence. In theory, a good´s demand is a function of its price (inverse functional relation), the substitute and complementary goods (direct and inverse functional relationship, respectively), the consumers' income (a direct functional relation if it is a normal good, an inverse functional relation if it is an inferior good), the population, and consumer expectations of the price and future quantities (Barkley & Barkley, 2013). Based on this, the prices of water and electricity are considered as complementary goods and income.

The empirical evidence for the formulation of the different proposed equations in this research was based on the research of other authors. In this way, Equation (1) contemplates the price of water and electricity for residential use, income, temperature, and precipitation as explanatory variables of the water consumption for drinking water intake in the residential sector (Guzmán *et al*., 2011; Gómez-Ugalde *et al*., 2012; Noya & Hernández, 2018). Equation (2) is an identity indicating that the demanded water quantity in the residential sector is obtained by multiplying the average number of drinking water intakes (1991 to 2019) by the water consumption per drinking water intake in the residential sector (Guzmán *et al*., 2011).

To formulate Equation (3), the price of water and electrical energy for industrial use, the PIB of the secondary activities in the state of Baja California, temperature, and precipitation were considered as explanatory variables of the water consumption by intake in the industrial sector (Torres-Sombra *et al*., 2013; Renzetti, 2015). Equation (4) is an identity indicating that the quantity of demanded drinking water in the industrial sector is obtained by multiplying the average number of drinking water intakes in the industrial sector for the evaluated period (1991 to 2019) by the water consumption per intake in this sector (Guzmán *et al*., 2011). Equation (5) establishes that the total amount of demanded water is equal to the demand of the residential and industrial sectors (Guzmán *et al*., 2011).

Once the model was estimated in its structural and reduced restricted forms, the elasticity coefficients that relate some determining factors of the water consumption demand in the residential and industrial sectors of Tijuana (price and cross elasticity of demand) were estimated. The average values of the variables and the parameters of the structural and reduced forms of the model allowed calculating the elasticities.

The two analysed scenarios aim to reduce the water demand in the short term by 10 and 20 %; to achieve this, the estimated elasticities and prices changes of water and electricity necessary to reduce the water demand by the set magnitude are used. It is assumed that only the water and electricity prices change, leaving constant other variables affecting the demand.

The volume consumed and the number of drinking water intakes for residential and industrial use were obtained from the Tijuana State Public Services Commission *via* the national transparency platform (CESPT, personal communication, May 8, 2020). As a proxy variable for the water and electricity prices for residential and industrial use, the rates charged per m^3 by the water operator in the city of Tijuana, and per kilowatt per hour by the Federal Electricity Commission (CFE), were used. This information came from CESPT (2020) and INEGI (2020b). To obtain said rate per m^3, the following procedure was followed: the average annual residential and industrial consumption was divided by the number of drinking water intakes for residential and industrial use, respectively, then the calculator provided by the CESPT in its website to estimate the rate corresponding to consumption per outlet.

The information on temperature and precipitation was obtained from the National Meteorological Service (SMN, 2020). Finally, to deflate the water and electricity price, the Implicit Price Index for Electricity, Gas, and Water (IPIEGA) and the National Consumer Price Index (INPC) were used to deflate the income, both were obtained from the INEGI (2020c).

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Results and discussion

Statistical results are interpreted according to the coefficient of determination R^2, Fisher's F test, and Student's t-statistic. Table 1 shows that the coefficient of determination for consumption per water intake in the residential sector is 0.80 and 0.73 for the industrial sector. These coefficients indicate acceptable goodness of fit. The F test was significant at a probability level of less than 1 % ($P \leq 0.01$), this means that all the parameters of the estimated regressions are different from zero at a global level. The Student's t statistic indicates the individual significance of the estimated parameters in each of the equations, these were significant, since most of the coefficients are greater than the unit in absolute terms.

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Table 1. Estimated coefficients of the structural form of the model.

Exogenous Variables	Endogenous Variables						R^2	Prob. *F*
	Intercept	***PARR***	***PERR***	***INGR***	***TEMP***	***PP***		
	(m^3)	**($/$m^3$)**	**($/kW/h)**	**($/month)**	**(°C)**	**(mm)**		
CARP (m^3)	224.48	-0.67	-53.77	0.02	1.95	-0.00	0.80	0.0001
Standard Error	109.94	0.41	15.86	0.01	4.06	0.04		
t statistic	2.04	-1.65	-3.39	0.86	0.48	-0.1		
	Intercept	*PAIR*	*PEIRL*	*PIBAS*	*TEMP*	*PP*		
CAIP (m^3)	943.37	-7.98	-271.12	0.0006	127.1	-0.12	0.73	0.0001
Standard Error	1 418.35	4.56	179.6	0.0002	66.68	0.7		
t statistic	0.67	-1.75	-1.51	3.17	1.91	-0.18		

The economic results are examined according to the expected signs according to the economic theory, and with the obtained elasticities. In this way, the signs of the parameters relating the exogenous variables to their respective endogenous variables in each of the equations are correct.

Table 2 presents the coefficients of the restricted reduced form of the model, which indicate the relationships that exist between the endogenous variables only with the exogenous variables of the model. This allowed identifying the interrelations that derive from the simultaneous equations system.

Table 2. Estimated coefficients of the reduced form of the model.

Exogenous Variables	Unit of Measurement	Endogenous Variables				
		CARP (m³)	***CAIP*** (m³)	***QDAR*** (m³)	***QDAI*** (m³)	***QDARI*** (m³)
Intercept	(m³)	224.4	943.3	86 636 091	2 197 124	88 833 214
PARR	($/m³)	-0.67		-260 622		-260 622
PERR	($/kW/h)	-53.77		-20 750 000		-20 750 000
INGR	$/month	0.01		6 067.83		6 067.83
TEMP	°C	1.95	127.1	753 349.2	296 024.8	1 049 374
PP	mm		-0.12	-1 652.2	-291.76	-1 944.03
PAIR	($/m³)		-7.98	0	-18 588.2	-18 588.2
PEIRL	($/kW/h)		-271.1	0	-631 457	-631 457
PIBAS	Millions of $		0.0006	0	1.61	1.61

Table 3 shows the descriptive statistics of the variables used in the model, these are useful to estimate the elasticities of the water demand in the residential and industrial sectors. It should be noted that the *TOMAR* and *TOMAI* variables are the number of drinking water intakes in the residential and industrial sectors, each, since they do not explicitly appear in the model as indicated, but were used to estimate the previously described *CARP* and *CAIP* variables.

Table 3. Descriptive statistics of the evaluated variables, 1991-2019.

Variables	Unit of Measurement	Average	Standard Error	Minimum	Maximum
CARP	m^3	173	35.3	132.3	236.3
PARR	$/$m^3$	48.21	13.2	29.5	69.6
PERR	$/kW/h	1.9	0.4	1.2	2.7
INGR	$/month	2 586.7	313.2	2 332.6	3 374.3
TEMP	°C	21.5	0.9	19.7	23
PP	mm	187.2	79.4	85	357
CAIP	m^3	2 994.8	502.9	2 196.1	4 308.5
PAIR	$/$m^3$	65	21.1	36.6	100.8
PEIRL	$/kW/h	1.7	0.5	1.1	2.8
PIBAS	Millions of $	449 409.8	317 475.0	207 811.1	1 279 958.5
TOMAR	Intakes	385 939.9	162 195.7	120 103.0	619 111.0
TOMAI	Intakes	2 328.7	641.5	1 022.0	3 106.0
QDAR	m^3	66 767 620.0	13 605 935.3	51 059 862.0	91 197 622.0
QDAI	m^3	6 974 800.9	1 171 148.5	5 114 716.9	10 034 496.5
QDARI	m^3	73 742 420.9	14 660 547.4	56 637 351.2	100 051 781.0

Table 4 shows the coefficients of the price of water and electricity demand elasticity. In the residential sector, the elasticity of the price of water demand was -0.188 and -0.588 for electricity. These values indicate that a 10 % increase in the real prices of water and electricity decrease by 1.88 and 5.88 %, respectively, the demand for water in these sectors. These results suggest that water and electricity are essential in residential activities, given that, even with significant changes in the price, the water demand in the residential sector responds less than proportionally to the price change. The foregoing suggests that to obtain a significant decrease in the water demand in the residential sector, the water and electricity prices should increase.

Table 4. Price of water and electricity elasticities.

Endogenous Variables	**Water Price**		**Electricity Price**	
	PARR	***PAIR***	***PERR***	***PEIRL***
	($/m³)	**($/m³)**	**($/kW/h)**	**($/kW/h)**
QDAR (m³)	-0.188		-0.588	
QDAI (m³)		-0.173		-0.156
QDARI (m³)	-0.170	-0.016	-0.533	-0.015

The above elasticities are similar to those reported by other authors. Noya and Hernández (2018) found a coefficient of the price elasticity of water demand for residential use of -0.24 for Cúcuta city, Colombia; Castro and Sisto (2015) reported an elasticity of -0.18 for México; Jimenez *et al*. (2017) report a -0.10 coefficient for Manizales, Colombia.

While Torres-Sombra *et al*. (2013) found an elasticity coefficient of -0.22 that relates residential water demand to electricity. However, it is observed that there are differences in the magnitude of the coefficients, due to factors such as the spatial and temporal dimension of the different studies, the used methodology, but beyond all that, it has to do with the greater or lesser use of the water in the sector; that is, a more inelastic coefficient indicates that the use of water in the sector is more essential and vice versa.

Regarding the industrial sector, in this research, an elasticity coefficient is estimated to relate the prices of water and electricity with the water demand in this sector, of -0.173 and -0.156, respectively. This means that a 10 % increase in real term prices will decrease water demand in this sector by -1.73 and -1.56 %, respectively. In this sense, the price elasticity coefficient of water and electricity in the industrial sector found by Torres-Sombra *et al*. (2013) for Sinaloa state was -0.82 and -0.9, respectively. These coefficients are higher than the one reported here, this is probably due to Sinaloa´s industrial sector using large amounts of water derived from low water and electricity prices, compared to Tijuana which pays higher prices for these goods.

As mentioned above, a higher inelastic demand indicates that the water resource is more essential. Renzetti (2015) argues that water is used as an input in industrial production processes and water usage in this sector is very diverse; For example, it is used to cool machines, produce steam, move and clean raw materials, electricity production, cleaning work areas, and watering gardens. Given the above, it can be thought that the water demand in the industry is considerable, which is why the coefficients are high.

The price increase is justified by the scarcity and water contamination in Tijuana; however, this action is debatable. On one hand, the price increase encourages efficient and rational use of this resource, because it allows better planning of the water service in the city of Tijuana; further, it would create social discontent because it would affect people with limited economic resources.

Regard the total quantity of water demanded by the residential and industrial sectors (QDARI), this inelastically responds to water prices in the residential and industrial sectors, given that the elasticity coefficients are -0.170 and -0.016, respectively. In the same mode, responds to the prices of electricity in the residential and industrial sectors, with coefficients of -0.533 and -0.015, respectively. These coefficients indicate that with a 10 % increase in the water prices real terms, the total water demand in Tijuana, from these two sectors, fall by 1.70 and 0.16 %, each. A 10 % increase in the price of electricity will cause the total demand of both sectors to decrease by 5.33 and 0.15 %, respectively.

The drop of the total water demand is more noticeable when the water price increases in the residential sector than in the industrial, this is attributable to the number of water users; that is, there are more residences (houses) than industries in the city of Tijuana, so the effect of the increase in the water price in the residential sector is greater on the total water demand. On the contrary, the total demand (QDARI) decreases in greater proportion when the price of electricity increases in the industrial sector, this is due to the elasticity coefficient of electricity and means this sector is sensitive to energy price changes, which in turn impacts water consumption because both goods are complementary. In this area, Guzmán *et al*. (2011) report that the total demand (residential and industrial) of Guanajuato inelastically responds to changes to water prices in residential and industrial sectors, with coefficients of -0.018 and -0.0082, respectively. In this sense, Torres-Sombra *et al*. (2013) report that the total water demand in northern Sinaloa state also responds inelastically to the prices, with -0.0009 and -0.00002 elasticities, respectively.

Table 5 shows the elasticity coefficients that relate the water demand in Tijuana with the rest of the determining factors of consumption. The coefficient values indicate that with a 10 % increase in real income the water demand increased by 2.35 % in the residential sector and by 2.13 % in the total demand (QDARI). These results are like those described by Gómez-Ugalde *et al*. (2012), where the coefficient was 0.40. Considering the value of the income of demand elasticity, water behaves like a normal good, which indicates that when income rises so does the water demand.

Table 5. Cross elasticity of water demand in Tijuana.

Exogenous variables	Endogenous variables		
	QDAR	*QDAI*	*QDARI*
	(%)		
INGR (%)	0.235		0.213
TEMP (%)	0.242	0.911	0.306
PP (%)	-0.005	-0.008	-0.005
PIBAS (%)		0.104	0.01

A 10 % increase in real PIBAS will cause water consumption in the industrial sector to increase by 1.04 and 0.10 % in total demand. In this case, Guzmán *et al*. (2011) report a coefficient that relates the GDP per capita with the total water demand for residential and industrial sectors of 0.024, similar to that reported here. A 10 % increase in temperature will cause the water demand to increase by 2.42 % in the residential sector, 9.11 % in the industrial sector, and 3.06 % in total demand. Noya and Hernández (2018) found a temperature elasticity coefficient of 0.3259 for a residential sector in Colombia. Guzmán *et al*. (2011) indicate a temperature coefficient related to the total water demand in the residential and industrial sectors of Guanajuato state of 0.1404. The result of this research is similar to that reported by Noya and Hernández (2018), but higher compared to that of Guzmán *et al* (2011). This makes sense since Tijuana has a hotter climate than Guanajuato, therefore, as the temperature increases the impact on water consumption is greater for Tijuana.

Similarly, a 10 % increase in precipitation will cause water demand to decrease by 0.05 % in the residential sector, 0.08 % in the industrial sector, and 0.05 % in total demand. It is also perceived that temperature influences water demand to a greater extent than precipitation, this is consistent with the climatic situation that exists in Tijuana, given that it has high temperatures and rainfall is scarce. It should be noted that it is difficult to influence some variables such as temperature and precipitation, due to their merely stochastic nature since they depend on environmental conditions.

Table 6 shows the model validation, which consists of comparing the observed values against the model predictions. There is a good fit since there is little percentage difference between the observed and estimated values. In this same table, the two proposed scenarios are presented, of reducing demand by 10 and 20 %, and the required change in the price to reduce demand.

Table 6. Water demand decrease in Tijuana.

Scenarios	Sector	
	Residential	**Industrial**
	hm³	
Model validation		
Observed	61.4	6.7
Estimated	66.4	6.9
Difference	4.9	0.2
Difference in %	8.0	2.4
Scenario 1 (decreases 10 % the water demand)		
Demand	59 .7	6 .2
Change	-6.6	-0.7
Change in %	-10	-10
Change in % required in the price		
Water price	53.1	57.7
Electricity price	17.0	64.3
Scenario 2 (decreases 20 % the water demand)		
Demand	53 .1	5.5
Change	-13 .3	-1.4
Change in %	-20	-20
Change in % required in the price		
Water price	106.3	115.4
Electricity price	34.0	128.6

Scenario 1 analyses the price changes that would be necessary to reduce the water demand in the residential and industrial sectors by 10 %. The drop in the water demand for the residential sector would go from 66.4 to 59.7 hm^3, a 10 % decrease compared to the estimated value. Considering the inverse relations between the price and the water demand, and the electricity price as a complementary good to the water demand, it is necessary that the price of water and electricity in the residential sector increase by 53.1 and 17.0 %, respectively.

The water demand in the industrial sector would go from 6.9 to 6.2 hm^3, representing a decrease of 10 % compared to the estimated value. This fall makes it necessary for the price of water and electricity in the industrial sector to increase by 57.7 and 64.3 %. These results show that it is feasible to implement a price increase in water and electricity to reduce demand in the residential and industrial sectors, considering the water shortage suffered by the city of Tijuana.

In scenario 2, a 20 % decrease in water demand is analyzed with respect to the value estimated by the model. Residential water demand goes from 66.4 to 53.1 hm^3 and industrial from 6.9 to 5.5 hm^3. To obtain these reductions it is necessary that the water and electricity price in the residential sector increase 106.3 and 34.0 %, the mentioned prices in the industrial sector must increase by 115.4 and 128.6 %. Reducing demand by these magnitudes would be beneficial for better water planning in Tijuana. In addition to the prices increase, this objective could be complemented with water consumption habits, investments in water-saving technology, and advertising on water care is procured.

It is worth mentioning some limitations of the model used. The model only considered residential and industrial sectors, the assessment would have been more complete if it had considered other consumer sectors, such as agriculture and livestock. These sectors were not included in the model because their contribution to the Gross Domestic Product of the Region is not relevant for the region. A strong limitation that hinders the inclusion of other sectors is obtaining a relatively long time series to carry out an econometric estimation. Also, the model did not consider a function for the regional supply of water in the City of Tijuana, since this variable does not respond to variations in price, and its behavior depends on the growth in the demand of the residential and industrial sector. The proposed model can be used in other cities in the country with water scarcity problems similar to those of Tijuana City. Knowing the factors that determine the demand behavior is important because the elasticities derived from this type of study are important in making price policy decisions focused on reducing water consumption and avoiding aquifers over-exploitation, where the large cities of northern Mexico are usually supplied.

Conclusions

The model of simultaneous equations system and the coefficients of the estimated elasticities allowed us to observe that the water demand in the residential and industrial sectors of Tijuana City inelastically responds to their respective prices. Increasing the prices of water and electricity causes decreases in the water demand, accepting the proposed hypothesis.

The growth of population and industry implies greater water consumption, this is complicated in places with a water deficit such as Tijuana, therefore, economic tools such as increasing the water and electricity price can help to achieve efficient usage of this scarce resource.

The elasticity coefficients of the water and electricity prices indicate that the demand for the liquid inelastically responds to changes in the respective prices; therefore, these prices would have to significantly increase to reduce water consumption in both sectors. Other factors coefficients that determine the demand indicate that it also responds inelastically, except for temperature, which presented a higher coefficient and makes sense due to the climatological conditions. The coefficients of other factors that determine demand indicate that it also inelastically responds, except for temperature, which reported a higher coefficient. This makes sense given Tijuana´s prevailing weather conditions.

The estimated values of the model variables, close to the observed values, allowed for scenarios consisting of reducing the water demand in residential and industrial sectors by 10 and 20 %. The scenarios reveal that it is possible to increase water and electricity prices as a measure to reduce the water demand. Although the increasing water and electricity prices negatively affect consumer spending. Yet, it is justified by the severe scarcity of the resource in Tijuana City.

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