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Occurrence of citizen complaints concerning drinking water: a case study in Quebec City

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ABSTRACT

Understanding complaints regarding tap water is a useful tool for improving management of water quality. This paper presents an analysis of the spatio-temporal occurrence of citizen complaints concerning drinking water in three distribution systems of Québec City (Canada). The study is based on an analysis of complaint data by census unit within the territory under study (spatial dimension) and by week over a period of three years (temporal dimension). Spatial and temporal complaint variability was associated through Poisson regression analysis to parameters of water quality (at the source and within the distribution system), meteorological factors and socio-economic characteristics of the population. The results show that variability of complaints is associated with distributed water quality. Modelling results highlighted the fact that the socio-economic portrait of the population has a great influence on the spatial distribution of complaints. Also, the study demonstrates that the temporal variability of complaint occurrence is affected by the variability of raw and distributed water quality. Recommendations are provided to enhance the analysis of drinking water complaints for future studies.

Key words | complaints, drinking water, perception, spatial analysis, temporal analysis, water quality

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INTRODUCTION

Among other actions, compliance with regulations regarding drinking water includes routine monitoring of water quality in municipal distribution systems. Monitoring allows municipal managers to adjust their operation and management strategies with respect to water quality. The examination of citizen (customer) complaints regarding water quality is also an important tool for the surveillance of distributed water (Wen *et al.* 2001). Consumer complaints are usually the result of their poor perception of tap water.

Perception of tap water has been routinely associated with its organoleptic attributes (Grondin *et al.* 1995; Jardine *et al.* 1999). As mentioned by Jardine *et al.* (1999), drinking water odour can lead people to believe it poses a risk. Young *et al.* (1996) and Turgeon *et al.* (2004) associated the drinking water taste to concentration of residual chlorine in tap water. Consumers exposed to drinking water with abnormal organoleptic qualities can file a complaint to the water utility. If they do so, this information may prove very useful for management of distributed water quality (Rodriguez *et al.* 1994).

In drinking water management, recent research has demonstrated the usefulness of analysing population complaints (Nare *et al.* 2006; Pizarro *et al.* 2007; Whelton *et al.* 2007). Many potential causes for complaints are not

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easily identified. Complaints as an indicator of perception of water quality can be associated with different groups of factors such as raw water quality and treatment process (Suffet *et al.* 1996), the physical nature or hydraulic characteristics of the distribution system (Wen *et al.* 2001; Besner *et al.* 2001, 2003; Tomboulian *et al.* 2004); or the socio-economic and demographic profile of the population (Turgeon *et al.* 2004).

The objective of this study is to gain a better understanding of the occurrence of drinking water complaints by carrying out a descriptive analysis of the spatial and temporal distribution of the complaints and hypothesizing the factors influencing the distribution.

STUDY METHODOLOGY

Case study

In Québec City, Canada, a field and laboratory team is responsible for verifying water quality through collection of samples (twice a week) at 141 monitoring points located throughout the nine distribution systems. The monitoring includes samples from raw water and treatment plants. Once collected, water samples are analysed to determine their physicochemical and microbiological properties. This same team receives citizen complaints concerning their tap water. Complaints are received directly by telephone during regular office hours or through voice messaging out of hours. The call is catalogued by an operator who records all the characteristics of the complaint. When necessary, the team visits the claimants, collects samples of their drinking water and conducts water quality analyses in the laboratory. A complete status report regarding the complaint is then filed (recording the type of complaint and analysis of the water quality) and kept for a period of five years.

Compilation of information on complaints

For this study, all reports on drinking water complaints in Québec City for 2003, 2004 and 2005 (three years) were reviewed to determine the date and location of each complaint. Using the residential address of the claimants, each complaint was assigned a unique identifier number corresponding to an address. Using a geographic information system, MapInfo™ (MapInfo Corporation 2005), it was possible to geo-reference each complaint within the municipal territory. These data were compiled in a computerized database. Only complaints from residences were considered in this investigation (during the period under study, there were no customers that logged more than one complaint). Complaints filed by businesses and institutions were excluded due to the very small sample size. The same procedure was used to compile and geo-reference the sampling locations for routine surveillance of water quality.

Specific systems under investigation

Of the nine distribution systems in Québec City, the Désilet, Sainte-Foy and Québec systems have special characteristics (Table 1). These are the largest systems, serving over 80% of the population of Québec City, and are the target of a large proportion of complaints filed by residents–about 75%. Moreover, these three systems receive their water supply from three different surface water sources. During the period under study, 770 complaints were filed on these three systems. The complaints were classified into four categories: taste, odour, colour and other. Other complaints included those linked to the presence of particles in the water, appearance of a whitish film in the water (degassing), health problems that applicants attributed to water and all other kinds of trouble linked to tap water.

Study components

To achieve the study objectives, two separate dimensions for complaint analysis were considered: (1) spatial and (2) temporal. The first dimension consists of studying the spatial distribution of the number of reported complaints and identifying factors that explain their presence (frequency) over the study area. Among these potential factors are the spatial variability of the quality of distributed water, socio-economic characteristics of the population and characteristics of the building environment. Some authors have argued that these factors may influence public perception of water quality (Rodriguez *et al.* 1994; Arens *et al.* 1996; World Health Organization 2000; Turgeon *et al.* 2004). The second dimension is analysis

Table 1 | Description of the systems under study and sampling locations

System	Source	Population served	Water treatment	Number of monitoring points*
Désilet	Montmorency river	72,000	Natural filtration	32
			Pre-ozonation	
			Post-chlorination	
Sainte-Foy	St Lawrence river	99,000	Pre-ozonation	20
			CPCT†	
			Post-ozonation	
			Post-chlorination	
Québec	St Charles river	237,000	Pre-chlorination	52
			CPCT	
			Post-ozonation	
			Post-chlorination	

*From the 141 locations monitored by the municipality, 104 are located within the three systems under study.
†Complete physicochemical treatment including coagulation, flocculation, sedimentation and filtration.

of temporal variability of the complaints filed and identification of factors associated with their distribution. This dimension uses information on the temporal variability of the quality of both raw and distributed water. To these variables are added meteorological factors, also considered an important factor affecting the quality of raw water (Rose *et al.* 2000; Curriero *et al.* 2001). Factors that might explain the presence or number of complaints in time and space considered for this study are presented in Tables 2 and 3.

Spatial dimension

For the spatial dimension, the unit of analysis is the dissemination census area. A dissemination area is a small area composed of one or more neighbouring blocks, with a population of 400 to 700 persons. All territory in Canada is divided into dissemination areas (Ministry of Industry 2004). Once complaints were geo-referenced, they were placed in 741 dissemination areas covering the Désilet, Sainte-Foy and Québec distribution systems. For the purpose of this study, each dissemination area was characterized by number of complaints according to type, as well as factors that could influence their spatial variability such as quality of the distributed water, socio-economic characteristics of the population and building environment. The specific variables describing each attribute are presented in Table 2.

Data on the distributed water for each dissemination area was generated from 104 routine sampling points located throughout the three systems (see Table 1). For each dissemination area, an average value for each water quality parameter (turbidity, residual chlorine, temperature, etc.) was computed according to information available for the sampling points. For each parameter, a value was obtained by calculating the average value of the two monitoring points closest to the centroid of each dissemination area (Euclidian distance within the same system). The existence of a hydraulic association was confirmed between the two selected points and the section of the water distribution system within the dissemination area.

The socio-economic profile of the dissemination areas included: average level of education, average household income, average age of the population and level of availability of the population. This last variable was adapted on the basis of the work of Joerin *et al.* (2005). The availability level is a combination of the proportion of professions, activity rate and the proportion of each type of household (single-parent, couple, etc.).

For the building environment, both average age of the building and type were used in the assessment. The age of the building is an explanatory factor that indirectly considers the level of obsolescence of internal piping in buildings that could give rise to complaints about tap water. The type of building was used to assess the impact

Table 2 | Potential factors for explaining spatial distribution of complaints

Variable (per dissemination area)	Definition
Distributed water quality	
Heterotrophic plate count bacteria (HPC)	Average value of aerobic and facultative anaerobic heterotrophic bacteria at 35°C (number of colonies per ml)
Turbidity	Average value of measured water turbidity in nephelometric turbidity units (NTU)
Colour	Average value of apparent colour of water measured in units of apparent colour (UAC)
Free residual chlorine	Average concentration of free residual chlorine in water ($mg\,l^{-1}$)
Temperature	Average water temperature (°C)
Socio-economic characteristics of population	
Education	0: majority of persons with less than 12 years of academic standing 1: majority of persons with 12 years or more of academic standing
Income	Average of population income in 2001 (Canadian dollars)
Availability*	Grade of 1 (minimum availability) to 10 (maximum availability)
House tenancy	0: majority of tenants
	1: majority of landlords
Age	0: majority of persons less than 40 years old
	1: majority of persons more than 39 years old
Building environment characteristics	
Building age	0: majority of buildings constructed before 1979
	1: majority of buildings constructed in or after 1980
Building type	0: majority of buildings with less than 5 dwelling units
	1: majority of buildings with 5 or more dwelling units

*See explanation in the text.

of time taken for water to travel through the internal piping of buildings. Water travel time in pipes has been previously linked to complaints about tap water (Tomboulian *et al.* 2004).

Temporal dimension

For the temporal dimension, the number of complaints made on a weekly basis was compiled for 156 weeks of information. The factors that may explain the distribution of complaints considered in the analysis are presented in Table 3. Raw water quality and meteorological factors were considered, since both may alter the quality of drinkable water (Rose *et al.* 2000; Coulibaly & Rodriguez 2003) and the potential occurrence of complaints. Socio-economic characteristics are not taken into account because they are considered constant during the three years. To associate a water quality status to each week, the weekly averages of water quality and environmental parameters were calculated for raw and distributed water. For each system, the average of all monitoring locations was used. Meteorological data from the Environment Canada weather station at Jean Lesage International Airport, northwest of the city, was used to correlate climatological factors. In particular, the weekly averages of precipitation and temperature were used.

STATISTICAL ANALYSIS OF COMPLAINTS

An exploratory analysis was completed to identify factors most closely related to the occurrence of complaints and potential correlations between attributes (Tables 2 and 3). A multivariate Poisson modelling technique was applied to identify factors influencing the breakdown of complaints in space and time. Poisson regression models were developed to explain the variability of the total number of complaints. Models were developed separately for spatial and temporal dimensions. In these models, dissemination area and week were used to analyse the spatial and temporal dimensions, respectively.

Table 3 | Potential factors for explaining temporal distribution of complaints

Variable (per week)	Definition
Distributed water quality factors	
Heterotrophic plate count bacteria (HPC)	Average value of aerobic and facultative anaerobic heterotrophic bacteria at 35°C (number of colonies per ml)
Turbidity	Average value of measured water turbidity in nephelometric turbidity units (NTU)
Colour	Average value of apparent colour of water measured in units of apparent colour (UAC)
Free residual chlorine	Average concentration of free residual chlorine in water ($mg\,l^{-1}$)
Temperature	Average water temperature (°C)
Raw water quality factors	
Heterotrophic plate count bacteria (HPC)	Average value of aerobic and facultative anaerobic heterotrophic bacteria at 35°C (number of colonies per ml)
Turbidity	Average value of measured water turbidity in nephelometric turbidity units (NTU)
Colour	Average value of apparent colour of water measured in units of apparent colour (UAC)
Temperature	Average water temperature (°C)
Total coliforms	Average of total coliform count in water (number of colonies per 100 ml)
Conductivity	Average conductivity of water ($\mu mhos\,cm^{-1}$)
Meteorological factors	
Rainfall	Average of total rainfall (mm)
Ambient temperature	Average of air temperature (°C)

In spatial analysis, the number of complaints per dissemination area was considered a count random variable, Y_i, following a Poisson distribution (Cameron & Trivedi 1998; Winkelmann 2003). This assumption concurs with the relatively low occurrence of complaints per spatial analysis unit. For model definition, y_i represents the observed value of the variable outcome Y_i, where y_i is the reported number of complaints during the analysis period for each dissemination area, i. Assuming that complaints at n dissemination areas are independent and that the number of complaints in a dissemination area i, Y_i, follows a Poisson distribution with a mean per time unit of μ_i, then

$$Y_i|\mu_i \sim \text{Poisson}(\mu_i), \quad \text{for} \quad i = 1, \ldots, n \text{ and } \mu_i > 0 \tag{1}$$

μ_i can be specified as an exponential function of area-specific attributes or covariates, that is,

$$\mu_i = E_i \cdot \exp(\beta_0 + \beta_1 x_{1i} + \ldots + \beta_1 x_{ki}) \tag{2}$$

where $\beta = (\beta_0, \ldots, \beta_k)$ is a vector of regression parameters to be estimated from the data and $x_i = (x_{1i}, \ldots, x_{ki})$ is a vector of explanatory variables representing area-specific attributes. Finally, E_i is a measure of population exposure consisting of the number of inhabitants per dissemination area. The model analysis allowed placing the number of complaints in the dissemination areas into perspective with the number of inhabitants in each area.

In temporal analysis, Poisson regression adapted for time-series data was also applied to estimate the changes in the number of complaints over time. Temporal models allow association of explanatory factor variability with the variability of occurrence of complaints for the same time frame. Models with delayed information on explanatory variables (one week's delay compared to complaints) were also attempted, but without improved modelling results. To detect potential problems of collinearity between variables in the statistical models, correlation matrices were computed using SPSS (SPSS Inc. 2004).

RESULTS AND DISCUSSION

Portrait of the spatial distribution of complaints

The distribution of complaints according to type (in %) was quite similar in the three systems (Table 4). In all systems,

Table 4 | Distribution of complaints according to population and spatial dissemination area (DA)

Systems	Types of complaint	Number of complaints*		Number of complaints per 1,000 inhabitants	Average number of complaints per DA†	
Désilet (DE)						
	Taste	29	(13%)	0.40	0.21	(0.50)
	Odour	37	(17%)	0.51	0.27	(0.48)
	Colour	127	(57%)	1.76	0.93	(1.23)
	Other	31	(14%)	0.43	0.23	(0.50)
	Total	224	(100%)	3.11	1.65	(1.63)
Sainte-Foy (SF)						
	Taste	28	(15%)	0.28	0.15	(0.41)
	Odour	28	(15%)	0.28	0.15	(0.44)
	Colour	99	(51%)	1.00	0.55	(0.98)
	Other	39	(20%)	0.39	0.22	(0.49)
	Total	194	(100%)	1.95	1.07	(1.38)
Québec (QC)						
	Taste	52	(15%)	0.21	0.12	(0.42)
	Odour	48	(14%)	0.20	0.11	(0.34)
	Colour	183	(52%)	0.77	0.43	(1.01)
	Other	69	(20%)	0.29	0.16	(0.44)
	Total	352	(100%)	1.48	0.83	(1.34)
DE + SF + QC						
	Taste	109	(14%)	0.26	0.15	(0.43)
	Odour	113	(15%)	0.27	0.15	(0.40)
	Colour	409	(53%)	1.00	0.55	(1.06)
	Other	139	(18%)	0.34	0.19	(0.46)
	Total	770	(100%)	1.88	1.04	(1.44)

*In parenthesis, the relative proportion of each type of complaint for each system.
†Standard deviation of the number of complaints per DA in parenthesis.

the most frequent complaints were related to distributed water colour. The analysis of complaints by dissemination area led to a better understanding of spatial distribution. Of the three systems, the Désilet system had the highest level of complaints per inhabitant and by dissemination area. The overall complaint level was the highest in this system which may be attributed to the age of the Désilet system water treatment plant (Villeneuve *et al.* 2002). The Désilet system averaged the highest levels of apparent colour and turbidity (Table 5) with apparent colour often being higher than the aesthetic drinking water criteria (Health Canada 2006). The Sainte-Foy system had a higher number of complaints by groups of inhabitants than the Québec system despite the higher average values of apparent colour, turbidity and HPC (heterotrophic plate count) bacteria in the Québec system. Analysis of these two systems indicated that an increase in complaints regarding water appearance is not solely related to lower quality of the distributed water as defined by commonly measured indicators.

Portrait of the temporal distribution of complaints

The seasonal analysis of complaints shows that the three systems experienced more complaints during spring and summer (Figure 1). Interestingly, complaints about water colour were the most frequent, irrespective of season, for all systems. However, colour complaints were not received in the same season for each system. For Désilet, the highest number of colour complaints occurred in summer; for Sainte-Foy, during spring; and for Québec, during autumn and spring. This result suggests that events of discoloured water do not have the same origin in the three systems. In fact, it is likely that the complaints are related to specific system incidents (e.g. changes on hydraulic patterns, cleaning programmes).

The seasonal portrait of complaints regarding taste and odour in both the Désilet and Québec systems were quite comparable (seasonal differences between one system and the others not statistically significant) (Figure 1). In the Sainte-Foy system, the number of complaints regarding taste and odour of the water did not vary as much with the seasons. The Désilet and Québec water sources were potentially more vulnerable to taste and odour precursors than that for Sainte-Foy (i.e. St Laurence River). Moreover, it is possible that the appearance of seaweed in the Désilet and Québec systems during warmer periods influences the number of taste and odour complaints.

Regression results for the complaint distribution

Regression Poisson models (Equations (1) and (2)) were calibrated to determine the association of the factors in Tables 2 and 3 with the spatial and temporal variability of the number of complaints.

Table 5 | Quality parameters in the distributed waters of the studied systems

	Désilet		Sainte-Foy		Québec	
	Average	SD*	Average	SD*	Average	SD*
HPC (colonies per ml)	11	22	14	8	16	29
Free residual chlorine (mg l^{-1})	0.82	0.30	0.58	0.15	0.55	0.27
Colour (UAC)	10.3	0.88	1.7	0.37	4.5	0.71
Temperature (°C)	9.9	0.74	12.5	0.53	10.5	0.79
Turbidity (NTU)	0.68	0.09	0.19	0.07	0.35	0.08

*Standard deviation.

Spatial dimension

The results from the regression models show that the distribution of complaints is as easily explained by the distribution of water quality parameters as by socio-economic variables and the building environment. In all systems, the spatial distribution of the total number of complaints might be explained by at least three variables of the distributed water quality, three socio-economic variables and the building environment.

Among the variables of distributed water quality, temperature was the most frequently significant variable for each system (Table 6). Free available chlorine

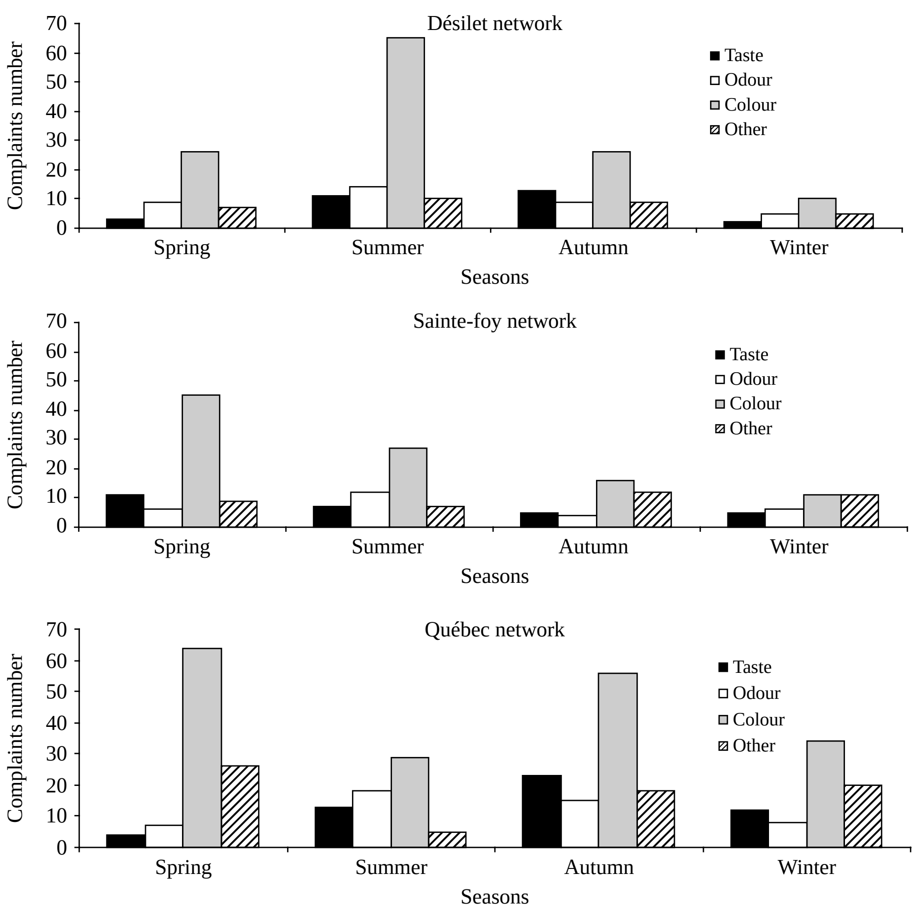

Figure 1 | Seasonal distribution of complaints in the systems under study.

concentration was also a highly significant variable, but presented a negative relationship with the number of complaints in the Québec system. This may be explained by a degradation of water quality along the peripheral areas of the network where the level of residual chlorine is usually low and thus HPC bacteria are highest. The relatively high standard deviations (Table 5) for water quality parameters support this explanation. The colour of the distributed water did not emerge as a significant variable underlying the number of complaints in the systems. However, turbidity and HPC were often significant and appeared to have an impact on complaints.

Of the socio-economic and building environment variables, the latter is a significant variable, showing a negative correlation (Table 6) meaning that buildings with fewer than five dwellings account for more registered complaints. This does not support the hypothesis set forth regarding residence time of water within buildings. Other variables, such as income and age of population, indicate that older people with higher incomes are generally more likely to file complaints. To a lesser extent, variables like education, level of availability and age of building show positive relationships. Therefore, and in general, people with higher education, the most availability and who live in newer buildings are more likely to file complaints about tap water quality.

Temporal dimension

Temporally weekly number of complaints, according to type of complaint ($n = 156$) were examined. The explanatory variables are expressed on a weekly basis (Table 3). In all systems, the temporal variability of the number of complaints was explained by at least two variables of distributed water quality, as well as by at least four variables of raw water quality and precipitation (Table 6). The results suggest that the temporal variability of raw water quality has a large impact on complaint distribution. This result may be due in part to a high temporal variability of raw water quality. It is

Table 6 | Regression model results for total number of complaints

Spatial dimension				**Temporal dimension**			
Dependent variables	**Desilet**	**Sainte-Foy**	**Quebec**	**Dependent variables**	**Desilet**	**Sainte-Foy**	**Quebec**
DS water quality parameters				Raw water quality parameters			
HPC	0.003	−0.029*	0.003*	Rainfall	0.010	−0.021	0.034*
Residual chlorine	1.219†	1.130	−0.645†	HPC	0.4×10^{-3}†	8.6×10^{-5}	0.18×10^{-3}†
Turbidity	−1.396‡	1.898‡	−0.033	Colour	0.044†	0.0067*	–
Temperature	0.378†	−0.223‡	−0.322†	Temperature	0.049†	0.023*	−0.060†
				Turbidity	−0.425†	–	0.040‡
				Total coliforms	-0.2×10^{-3}	-0.71×10^{-4}*	-0.39×10^{-3}†
				Conductivity	–	−0.004*	−0.002*
Socio-economic characteristics				DS water quality parameters			
Education	−0.102	0.386†	0.153	HPC	0.0008	−0.007	0.004†
Income§	0.012*	−0.010†	0.006†	Residual chlorine	1.072†	−1.727*	−0.380
Availability	0.120	−0.071	0.137†	Colour	–	0.153*	0.156†
Population age	−0.134	0.195	0.198‡	Temperature	–	0.081†	−0.018*
Building age	−0.366†	0.281*	−0.159	Turbidity	0.677†	−0.694	0.114
Building type	−0.573†	−0.908†	−0.375†				

*Significance < 10%.
†Significance < 5%.
‡Significance < 15%.
§Income in thousands of dollars.
DS, distribution system; Definition of variables in Tables 2 and 3.

possible that some routine parameters of raw water quality (e.g. turbidity, colour, HPC) have a comparable temporal variation pattern as compound precursors of taste and odour. Even if the levels and the variability of the measured parameters in the distributed water are relatively low (because of the drop of the levels of these parameters by the water treatment), it is possible that the taste and odour precursors in the distributed water remain high and perceptible by the population (since those compounds are not necessarily removed by the treatment).

Among the variables representing the distributed water quality, free residual chlorine was a frequent significant variable. However, regression coefficients did not indicate any direct relation to complaints (Table 6). This did not allow determination of whether or not a low or high concentration level of free residual chlorine leads to complaints. The measured colour in the distributed water was frequently significant in models and its regression coefficient indicated that a high value of this parameter can lead to complaints. HPC represents the variable with the lowest frequency as a significant variable in models. Rainfall, turbidity and temperature were variables that, to a lesser extent, also explained complaints filed by the population.

CONCLUSIONS

This study highlighted historical data on complaints about drinking water and information about potential factors explaining their spatial and temporal distribution. The results of this study demonstrated that various factors can successfully explain the frequency of complaints regarding drinking water. These factors may vary from one water distribution system to the other and depend on water supply system characteristics (source, treatment process, distribution) and the socio-demographic profile of the population.

In future work, it will be important to consider the possibility of improving complaint databases by individualizing characteristics instead of generalizing them in spatial and temporal units. Thus, ideally, the complaint management process should systematically document socio-economic characteristics of individuals filing complaints and water quality characteristics at claimants' homes. Also, it would be relevant to document the presence of substances responsible for taste and colour in raw or distributed water (which are not part of routine monitoring of water quality) in order to associate them with the occurrence of complaints.

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