Statistical approaches for analyzing customer complaint data to assess aesthetic episodes in drinking water

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ABSTRACT

Customer complaints and concerns about their drinking water quality provide valuable information for assessing potential risks when utilities routinely analyze these data. This research presents strategies to evaluate complaint patterns for diversity and frequency of descriptors and to apply exceedance frequencies to evaluate when the complaints were indicative of a water quality problem. Mean complaint frequency ranged between 0.2 and 2.6 complaints per 1,000 customers per year for different utilities. The most common temporal pattern was a shift to lower complaint frequencies on weekends. Weekday and seasonal patterns were slight and varied by utility. Autocorrelation analysis indicated little predictive ability in the number of complaints from one day to the next. Exceedance probabilities, however, could be used to set alarm values indicating atypical complaint frequencies. A combination of high frequency of complaints together with consistency of descriptors, that is, low diversity, was indicative of episodic water quality problems.

Key words | customer complaints, exceedance probabilities, Shannon diversity index, water quality

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INTRODUCTION

An element in the drinking water industry's effective delivery of safe drinking water is a dialogue between utilities and their customers, as exemplified by publications such as consumer confidence reports, public service announcements, and utility-based customer call centers (Meyer-Emerick 2004). Customer complaints and concerns about water quality provide utilities with valuable information that can be applied to assess risks of poor quality water or contaminated water (Burlingame & Mackey 2007). This feedback can and has been used to identify problems in the distribution system, treatment plant, and source water that sometimes have gone undetected by utility staff. Customers and their human senses are excellent and constant water quality sensors for changes in taste, odor, and appearance because they are distributed throughout the system and sample the water at all hours (Dietrich *et al.* 2004).

Customers around the world equate aesthetic qualities of their drinking water with its perceived safety and quality (Meyer-Emerick 2004; McGuire *et al.* 2005; Dietrich 2006; Doria *et al.* 2009; Doria 2010). When an intense episode results in large and noticeable numbers of customer complaints, a utility is usually prompted to respond quickly. Examples of this are: (1) complaints of 'olive oil' flavor affected millions of customers in Brazil and initiated the shut-down of the water treatment plant (Bruchet *et al.* 2007); (2) intermittent but repeated customer complaints of 'sweet' and 'strawberry' flavored water in a large Spanish city allowed the utility to identify industrial contamination as the source of the flavor (Martín-Alonso *et al.* 2007); (3) customer complaints prompted implementation of emergency water treatment measures for two million people in China who received sulfur-smelling drinking water (Zhang *et al.* 2010). While many utilities generally try to respond individually to water quality complaints (Lauer 2004; Ömür-Özbek 2012), few collectively and systematically assess an individual complaint as one in a longer-term record of complaints. Systematic tracking and statistical analysis of water quality complaints can aid utilities in identifying water quality problems that are serious but not intense or widespread enough to be readily noticeable.

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Since the early 21st century, USEPA has encouraged utilities to perform customer complaint surveillance as a part of the Water Security Initiative (USEPA 2008, 2011). The numbers of utilities that track customer complaints is not known as these data are not routinely gathered or maintained at a national level. In 2012, utility personnel participated in a Virginia Department of Health Continuing Education program which focused on aesthetic issues in drinking water. Of the 59 respondents, 37% reported using paper copies to record and track customer complaints; 19% reported using electronic records, and the rest either did not record or were not aware of the system used. Twenty-four percent of respondents reviewed complaints on a daily basis, 17% on a weekly or monthly basis, and the rest yearly or the frequency was not known. In a global survey of 392 water utilities, 42% reported using only paper copies to record customer complaints and 67% reported using electronic databases (more than one answer could be selected) (Ömür-Özbek 2012). Only 67% of the utilities reported reviewing the customer complaints on a routine basis. Many of the respondents indicated that they would like more guidance on how to routinely track this type of data but were unfamiliar with the approaches suggested by Whelton *et al.* (2007) or the Alarm Estimation Tool (USEPA 2011).

Utilities need an awareness of the typical complaint reporting frequency and the descriptions used by their customers. While many utilities reviewed complaints on a monthly basis, this is not enough to detect water quality problems or possible disasters as documented by Hrudey & Hrudey (2007), who reported that several waterborne disease outbreaks in affluent countries were preceded or accompanied by drinking water taste, odor, or color/turbidity episodes. Unfortunately, these customer-reported water quality problems were not always extensively investigated in a timely fashion by water utility personnel. As a result, the waterborne disease outbreaks proceeded until public health officials intervened and in all these cases, public confidence in the water supply decreased. The authors concluded that 'the failure of a water utility to be concerned about aesthetic factors makes such water supplies an inherently greater health risk for their customers' (Hrudey & Hrudey 2007).

Since many utilities do not systematically track, review, or analyze customer complaint data, they are missing an opportunity to use sensory and health data provided by customers to determine short-term indicators of water quality or long-term indicators of water quality, customer concerns, and customer confidence. To effectively utilize customer complaint data, an understanding of what defines 'typical' or 'background' conditions in terms of customer complaints is required in order to determine when complaint levels are higher than usual. The analysis of complaint frequency in a historical context would allow a utility to better track water quality at the customers' taps and determine when customers are reporting unusual and potentially serious water quality problems.

The goal of this current work was to review historical customer complaint data from a diverse set of utilities, then to make recommendations for assessing when the complaints indicate a significant water quality problem. The specific objectives were to: (1) apply statistical techniques of standard summary statistics, autocorrelation, and exceedance probabilities to water quality customer complaint data to describe common patterns and frequencies; (2) demonstrate that understanding and evaluating both complaint frequency and descriptor diversity are useful for assessing distributed water quality and potential risks.

METHODS

Customer complaint data

Six utilities across the United States supplied historical data pertaining to customers who contacted the utility to report concerns, complaints, and alerts related to operations, water quality, suspicious activity and other concerns/inquiries. These data were blinded to remove any identifying customer information. Only customer records related to water quality were analyzed. Operations related issues (facilities and pressure) as well as billing, meter reading and suspicious activities were filtered from the data prior to analysis. Based on utility and customer descriptors, the water quality complaints were categorized as appearance, taste and odor, illness, and other. Appearance complaints were subcategorized as cloudy/milky, colored, filmy, particles, rusty, and other/blank. Taste and odor were subcategorized based on the Taste and Odor Wheel which is depicted in Standard Method 2170 (Khiari *et al.* 2002; APHA 2012) and included six odor groups (metallic, earthy-musty, septic-sulfur, chemical-medicinal, chlorine-bleach, gasoline), four tastes (sweet, sour, salty, bitter), and other/blank. Not all subcategories were present in the observed complaints: 'Dirty water' complaints due to particulates, which can be caused by hydraulic transients such as flushing or changes in water chemistry in the source, treatment or distribution systems, were generally included in the analysis since they related to the water's appearance. All statistical analyses were conducted in R version 2.15.2 (R Development Core Team 2009). Frequency analysis consisted of summary statistics for each utility by day of the week, season of the year, and total number of complaints per day.

Autocorrelation analysis for complaint frequencies

Autocorrelation analysis was performed to determine how well the number of complaints from the previous day (lag 1 autocorrelation) would predict the following day's number of complaints. High magnitude correlations (near ±1) would indicate to a utility that once today's complaint count is known, the utility can make a reasonably accurate prediction for tomorrow's count. Autocorrelations near 0 indicate there is no such relationship.

Exceedance probabilities for complaint frequencies

For each utility that provided individual water complaints by date, running totals of the number of complaints per weekday, week (7 day) and 4 week (28 day) time periods were calculated. The weekly and monthly values always had the same number of weekend days (2 for weekly, 8 for monthly) and thus normalized the weekday/weekend variability discussed below. The running totals were used to generate empirical cumulative density functions in R. Exceedance probabilities for a given number of complaints were determined as 1 minus the cumulative probability to that number.

Diversity analysis for complaint descriptors

The diversity of descriptors can assist in determining when a significant change in water quality has taken place by evaluating how consistently descriptors are used. The Shannon diversity index (H') (Shannon 1948; Magurran 1988), commonly used by ecologists to measure how diverse species occurrence is at a given site, was adapted to describe diversity of complaints. For each day, the index was calculated as

$$H' = -\sum_{i=1}^{D} p_i \ln p_i$$

where H' is the Shannon diversity index, D is the number of categorized descriptors used for complaints that day, and p_i is the relative abundance of each descriptor for that day, that is, $p_i = n_i/N$ where n_i is the number of complaints with a given descriptor and N is the total number of complaints that day. The minimum diversity index H' is 0, when all the complaints use the same descriptor, and the maximum possible diversity occurs when all descriptors are present in equal numbers. A relatively high diversity indicates that a wide variety of descriptors is being used, and therefore no consistent pattern to the type and nature of the complaints. A low diversity indicates that customers perceive and describe a common problem, suggesting a true water quality episode or loss or process control. Utilities should thus be concerned for days that have both a high number of complaints and a low diversity within the context of what is typical.

RESULTS AND DISCUSSION

Customer complaint data

Summary statistics

Table 1 summarizes the size, source waters, and treatment used by each of the participating utilities. In addition to multiple source waters, the larger utilities also had multiple treatment facilities and service areas, but the blinded data did not include geographic information. Table 2 analyzes the complaint data provided. Results show that record length ranged from 1 to 7 years. Analysis of customer reported water quality issues revealed the mean number of

Table 1 | Properties of utilities

Utility ID	Service population	Source water type	Treatment	Disinfectant
A	330,000	Surface water	Clarification, filtration, carbon	Chlorine
B	250,000	Ground, surface and desalinated water	Clarification, filtration	Chlorine, Chloramines, ozone
C	250,000	Surface water	Clarification, filtration	Chlorine
D	200,000	Surface water	Filtration	Chlorine
E	657,000	Ground water	None	Chlorine
F	600,000	Ground, surface and desalinated water	Clarification, filtration	Chlorine, ozone

Table 2 | Summary statistics for number of complaints

			Mean daily complaint frequency				
Utility ID	Length of record (days)	Total WQ complaints	Overall (std. deviation)	Week-day	Week-end	Max number of WQ complaints in single day	Mean complaint frequency per 1,000 customers per year
A	2,557	1,421	0.56 (0.88)	0.74	0.09	7	0.61
B	1,461	1,631	1.12 (1.35)	1.49	0.18	8	1.62
C[a]	801	1,424	1.78 (3.38)	2.07	1.04	28	2.60
D[b]	584	63	0.11 (0.49)	0.15	0.00	9	0.20
E	455	768	1.69 (2.57)	2.35	0.04	19	0.91
F[c]	2,190	5,793	2.64	NA	NA	NA	1.61

[a]Utility C data taken from their 'dirty water' database. Dirty water descriptors frequently cross over to include hydraulic issues.
[b]Utility D kept paper records only. A portion of these were transcribed to a database by the authors.
[c]Utility F only kept summary counts by month, not daily data. NA = Not available.

concerns ranged from 0.11 to 2.64 per day, while the maximum number ranged from 7 to 28 per day. Normalized to customer base, the complaint frequency ranged from 0.2 to 2.6 complaints per 1,000 customers per year. The finding that neither the mean nor maximum customer reporting frequency correlated with service population underscores the complexity of comparing data across utilities. This finding may be because utility service population size, demographics, geographic location, source, treatment, and distribution infrastructure varied considerably. Complaint/concern frequency is caused by many factors: source water quality, engineering operations and infrastructure, economic status of the customers, how educated the customers are in noticing water quality changes, how easy it is to contact the utility, and how well the utility records the information. Montenegro *et al.* (2009) found that older, more affluent customers were more likely to register drinking water complaints. Utility D, for example, had the fewest customer water quality records, but used paper files rather than electronic files (e.g. spreadsheet or database) to store concerns. The practice of storing customer concerns on paper files instead of electronic records may have contributed to the lower number of records.

Complaint time patterns

The frequency of reported customer concerns varied daily, but within weekdays there was little variation. Variability between daily customer concerns between utilities can be partly attributed to their customer feedback infrastructure. For example, most utilities used call centers to receive customer feedback and inquiries. All of these call centers were closed on weekends (Saturday and Sunday), and the number of water quality related complaints dropped significantly (Table 2). The only utility to show moderate complaint frequency on weekends is Utility C, whose records include the 'dirty water' calls, which may be related to hydraulics as well as water quality. Based on this result and discussions with utility personnel, customers appear more willing to call during off hours for hydraulic issues, but typically wait for business hours to call concerning water quality.

The seasonal comparisons for utilities with more than 3 years of record did not show a consistent pattern (Figure 1). Utilities A and F exhibited a bimodal pattern, with peak frequencies in late winter and again in summer. Utility B had the highest number of complaints during summer. Based on discussion with Utility A, freezing and burst pipes, with subsequent release of rust and particulates, were an occasional problem that led to complaints during the winter, with a subsequent higher water quality complaint frequency.

Episodic events

Two water quality events were first detected by customers reporting water quality issues to Utilities A and D. Figure 2 presents the customer reported water quality records several weeks surrounding these events. Figure 2(a) represents Utility D, which never had more than two complaints per day, and usually none, except for 9/15/2004 when the complaint count jumped to nine. This was a very short-term event. There was no prior indication or increase in the number of customer reported issues in the data, and the event did not last past the 1 day. An alarm mechanism based on the number of calls in 1 day would easily detect

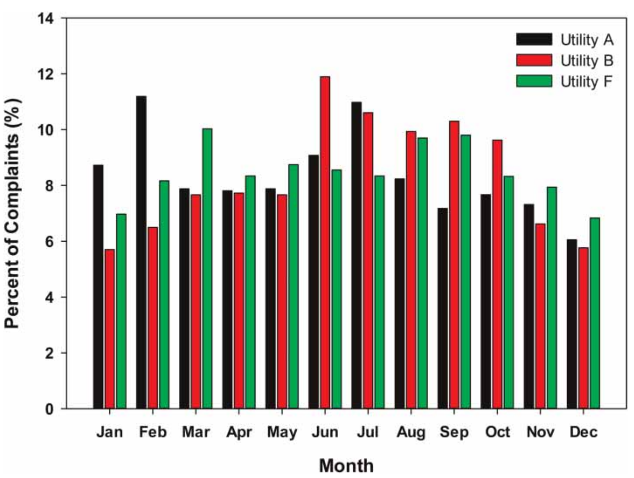

Figure 1 | Percentage of complaints by month.

such an event. Utility D relied on paper files as records, and unfortunately there was no water quality description provided. Figure 2(b) depicts Utility A which recorded a spike of earthy/musty complaints that occurred over a 2–3 week period. The data show that the number of daily complaints gradually increased as did the consistency of the complaint descriptor, and some calls were even placed on weekends. Also interesting is that the background level of miscellaneous complaints and descriptors continued during this episode. While an alarm based on complaints each day would likely eventually detect the problem, a running count of complaints over a longer time period (e.g. 7 or 28 days) would likely detect the gradual increase in complaints earlier. For example, four complaints in 1 day may not be too unusual, but four complaints for several days in a week could be very unusual. Figure 2 illustrates the nature of the problems that utilities can undergo and how customers respond. Sudden and dramatic changes in water quality are easily seen by evaluating complaint frequency. Other water quality problems develop more gradually and can be more difficult to detect early, especially above background levels. A combination of alarms based on short and long-term counts should be considered.

Figure 2 also emphasizes the importance of recording the nature of the complaint. Part of the assessment of a possible water quality problem is to look for common complaint descriptors. This could easily be done for the earthy/musty outbreak, because such information was recorded. The descriptors of the complaints for Utility D were not. This additional information would help laboratory, operations, management staff more quickly ascertain if customer reported water quality issues are a sign of a growing previously undetected water quality issue.

Autocorrelation analysis for complaint frequencies

Long-term clusters of customer reported water quality problems were rare and previous day water quality records were not good predictors of the following day's customer reported water quality issues. Autocorrelation analyses, with perfect correlations at ± 1, revealed the lag 1 day correlations were 0.08 (Utility A), 0.13 (Utility B), 0.66 (Utility C), 0.05 (Utility D), and 0.34 (Utility E). While all the autocorrelations except for Utility D were statistically significant, only

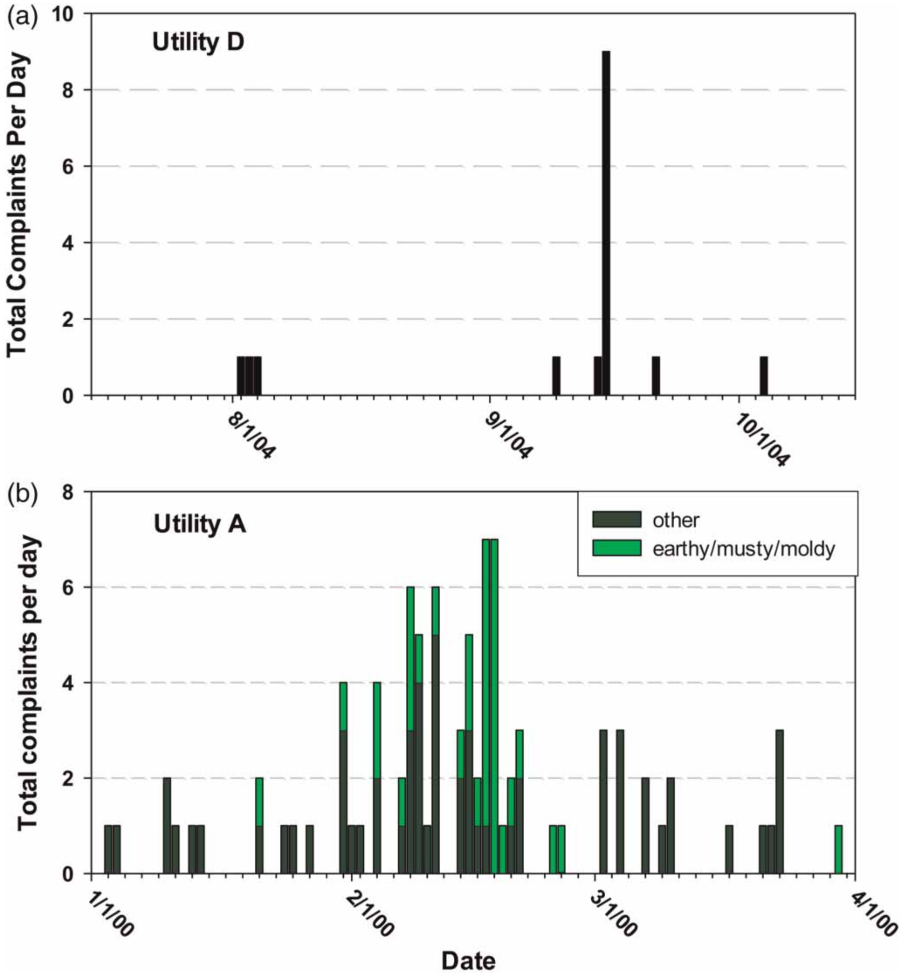

Figure 2 | Example water quality events found through customer complaints for (a) Utility D and (b) Utility A. (a) Represents an example of a very sudden short term event. (b) Represents a gradually worsening earthy-musty event above normal background complaint levels.

the autocorrelation for Utility C appeared to have a high enough magnitude to provide useful expectation from one day to the next. The lag 1 day autocorrelations were all slightly lower if only weekdays were considered. A strong lag 7 day autocorrelation was seen for all the utilities, corresponding to the low number of calls on weekends (i.e. 7 days apart) as previously discussed. The drop in calls from Friday to Saturday and the increase in calls from Sunday to Monday was repeated with some consistency.

Exceedance probabilities for complaint frequencies

An exceedance plot depicts the probability of exceeding a given number of complaints within a specific time period. Such data are useful to utilities for establishing preliminary alarms or triggers that help identify unusual events. Exceedance plots for the number of complaints for weekday, week, and 4 week time periods are shown in Figure 3. Since the number of complaints is discrete, the number of complaints to exceed would be one or more higher than the value plotted. For example, Utility A has one or more complaints on 51% of weekdays (i.e. the exceedance probability at 0 complaints is 0.51), has six or more total complaints on 20% of weeks (weekly exceedance probability at 5 is 0.20), and has 19 or more complaints in 21% of 4 week periods (monthly exceedance probability at 18 is 0.21).

As expected, as the time period becomes longer, the number of complaints for a fixed probability of exceedance becomes higher. This is why the curves shift to the right (higher complaints) when moving from weekday (Figure 3(a))

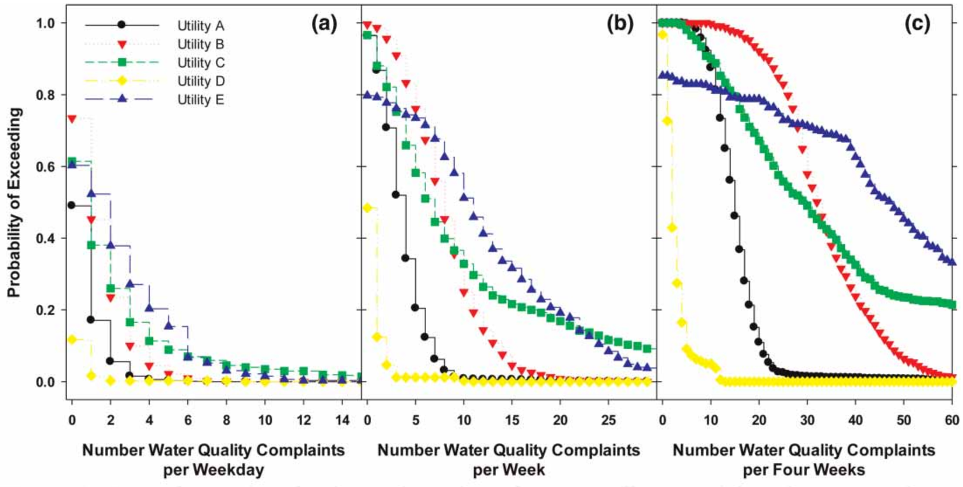

Figure 3 | Exceedance plots for the total number of water quality complaints that occurred per day, week (7 day), and month (28 days).

to week (Figure 3(b)) to 4 week (Figure 3(c)) time periods. Of more interest are the differences among the utilities. Utility D, for example, only had a mean weekday frequency of 0.15 complaints per day, while Utility E had a mean weekday frequency of 2.35 complaints per day (Table 2). So within each time period, Utility E's curve is to the right of Utility D's curve. Over a 4 week period, for example, Utility D would only exceed 10 complaints approximately 5% of the time, while Utility E would exceed 10 complaints over 80% of the time.

The plots can thus be used to set preliminary alarm values (number of complaints per time period) for short-term (daily), mid-term (weekly), and long-term (4 weekly) periods. Table 3 illustrates the number of complaints exceedance values for different exceedance probabilities, that is, risk, for the water utilities. Utilities that are more risk adverse could set alarms based on the higher exceedance probabilities with lower number of complaints needed to trigger an alarm, while those utilities that are more risk tolerant could set alarms based on lower exceedance probabilities with correspondingly higher number of complaints needed to trigger an alarm.

The advantage of an exceedance plot for a utility is that it quantifies and provides context for typical versus unusual situations. While the curves are monotonically decreasing by definition, their shapes distinctively define the typical pattern of complaints for a utility. The very sharp decline illustrated in the curves for Utility D indicates complaints are rare and there is little variability. The longer tails and more gradual decreases indicate a greater variability for Utilities C and E.

Table 3 | Number of water quality complaints for given exceedance probability and time period

		Number of complaints				
Time period	**Exceedance probability**	**Utility A**	**Utility B**	**Utility C**	**Utility D**	**Utility E**
Weekday	0.20	1	3	3	0	5
	0.10	2	3	5	1	6
	0.05	3	4	8	1	7
Week	0.20	6	11	17	1	20
	0.10	7	14	28	2	25
	0.05	8	15	38	2	27
4 week	0.20	19	42	68	4	80
	0.10	21	43	131	5	94
	0.05	23	53	152	9	100

Reliabilities of the exceedance plots in Figure 3 are a function of the length of historical record for each utility. Thus, the confidence intervals about the curve would be narrower for Utility A (2,557 days) than for Utility E (455 days). The plots are also confounded by the mixture of routine complaint frequencies during routine operation as well as during water quality episodes. A more accurate and conservative alarm value, that is, an alarm based on fewer complaints, would be obtained if only routine operation periods were considered, but this was not feasible using the historical data provided.

Diversity analysis for complaint descriptors

The diversity of descriptors can assist in determining when a significant change in water quality has taken place by evaluating how consistently descriptors are used. The Shannon diversity index was calculated for each day using Utility A and B records. Figure 4 shows the mean diversity consistently increased with complaint frequency for Utility B, that is, on days with more complaints, more different descriptors were used. This implies that the complaints could not be attributed to a single cause. However, for Utility A when the complaint frequency reached 7/day, most of the customers were using similar descriptors. This occurred during the earthy/musty outbreak discussed above. The daily diversity calculations for this event are shown in Figure 5, with

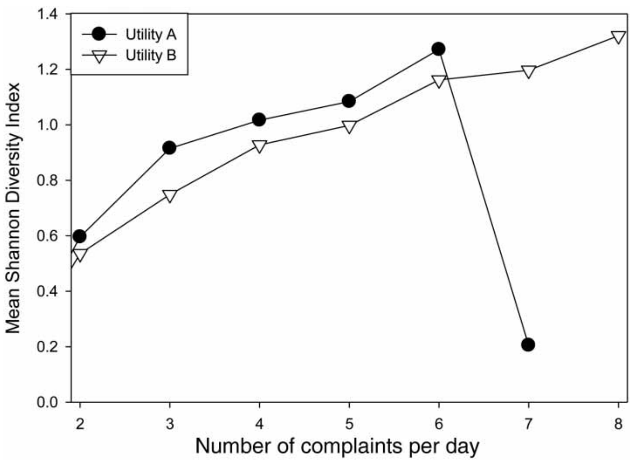

Figure 4 | Comparison of Mean Shannon diversity index. The low diversity (0.2) and high number of complaints ($n = 7$) for Utility A indicate a likely water quality episode.

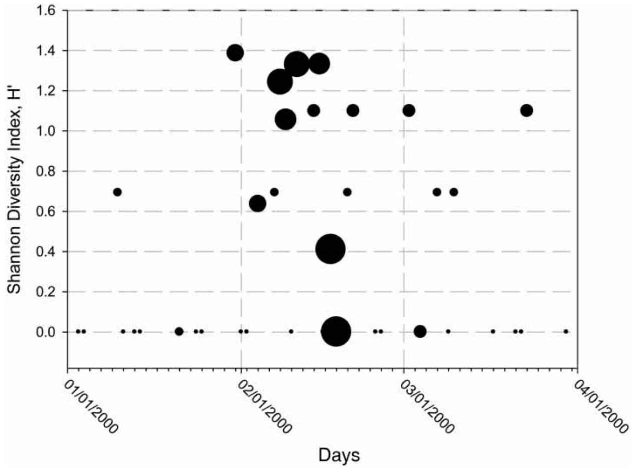

Figure 5 | Daily Shannon diversity index for Utility A during earth/musty outbreak. The size of the point indicates the total number of complaints that day. Large points with low diversity indicate potential water quality problems.

the size of the data point indicating the total number of complaints that day. The rise in the total number of complaints in early February is visible. Also apparent from this graph is the sudden drop in diversity on February 16 and 17 from a diversity in the range of 1.0–1.4 to a 0.4 on the 16th and a 0.0 on the 17th. All seven complaints on February 17 were related to earthy/musty descriptors. The combination of many complaints and low diversity is indicative of a strongly perceived specific water quality problem. In summary, Shannon diversity index results show that a combination of evaluating complaint frequency and the diversity of descriptors is useful in isolating true utility water quality problems from the normal background level of complaints.

IMPLICATIONS

The current research demonstrates the usefulness of statistical analyses for determining complaint patterns for diversity and frequency. Tools for customer complaint surveillance are a key component of maintaining customer satisfaction (European Communities 2007) and drinking water safety (USEPA 2008). USEPA is currently facilitating development of integrated software surveillance systems that focus on processing customer complaints as water quality indicators (Mix & Pickard 2012). While integrated surveillance systems are still under development, their success will be based on statistical methods to establish baseline complaint levels and alarm thresholds based on the number, type, and frequency of complaints in a real-time system.

CONCLUSIONS

Tracking, categorizing, and routinely assessing customer water quality complaints provide a means of assessing water quality throughout the distribution system. Utilities that consistently collect and analyze customer complaints are more likely to identify and understand upsets and process changes. A high customer complaint frequency, in and of itself, should not be taken as an indication of a poorly run utility; rather, it should be an indicator of a utility that takes customer feedback seriously. Utilities should have a systematic and long-term program for recording customer complaints on each of the 7 days of the week and throughout the year. A set of standardized descriptors should be part of this program. In order to determine if customer complaints represent day to day variation in water quality or a serious risk, it is necessary to categorize and tally complaints on at least a short-term, e.g. daily, and long-term, e.g. weekly or monthly, basis. A serious water quality problem is indicated by both a higher number of complaints compared to background and also a low diversity in the complaint descriptors. By routinely integrating customer feedback with other distribution system water quality data such as chlorine residual, turbidity, and coliform counts, utilities will have a more comprehensive early warning system for detecting and resolving water quality problems to improve water safety and security.

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