water

Article

Public Water Service Disruptions: A Descriptive Analysis of Boil Water Advisories

Fahad Alzahrani * and Rady Tawfik

Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Hofuf 31982, Al-Ahsa, Saudi Arabia
* Correspondence: falzahrani@kfu.edu.sa

Abstract: Water is the essence of life. It possesses profound spiritual and cultural importance, and serving as an indispensable requirement for the achievement of sustainable development. Access to safe, sufficient, affordable, and reliable drinking water is a human right. Water advisories can be used as an indicator of the reliability of access to safe drinking water. The objective of this article is to explore the trends and characteristics of boil water advisories (BWAs) and the reasons behind them. Visual and statistical tools were employed to describe the drinking water advisory data in Kentucky (USA). The dataset covers all counties in Kentucky for 17 years from 2004 to 2020 and contains 378 water systems and 36,673 BWAs. The average duration of BWAs was 5 days. The number of BWAs issued increased, while the average duration decreased during the study period. More BWAs occurred in the summer months (29%), in surface water (92%), and in large systems (54%). The leading factor for issuing a BWA was because of a line break or a leak (87%). It is imperative for governments, organizations, and communities to collaborate to address these issues effectively. Investing in sustainable and resilient water infrastructure is crucial to ensure access to safe water.

Keywords: boil water advisory; water service disruptions; drinking water contamination; water infrastructure; health risk communication

check for updates

Citation: Alzahrani, F.; Tawfik, R. Public Water Service Disruptions: A Descriptive Analysis of Boil Water Advisories. *Water* **2024**, *16*, 443. https://doi.org/10.3390/w16030443

Academic Editor: Guocheng Zhu

Received: 26 December 2023
Revised: 20 January 2024
Accepted: 26 January 2024
Published: 29 January 2024

1. Introduction

Access to safe and reliable drinking water is a necessary aspect of modern life. However, public water systems (PWSs) in many parts of the United States are still struggling to provide this basic service [1]. Aging infrastructure, limited finances, and impaired water sources are some of the challenges that impact the reliability and safety of public water service in the United States [2].

Water distribution systems are designed to meet the specific needs of each country. For example, water systems in the United States rely on looped systems with large pressure zones to serve customers in regions of varying elevation, while District Metered Areas (DMAs) are used to improve water leakage control and water pressure management in the United Kingdom [3]. The proper division of a water distribution system into DMAs offers several significant management benefits, particularly in terms of reducing the potential movement of contaminants throughout the system. These benefits include improved water quality monitoring, better identification and containment of contamination sources, enhanced response to incidents or emergencies, and targeted maintenance and repair efforts. Additionally, DMAs enable better control and management of water flow, pressure, and consumption within specific areas, which can help optimize system efficiency and reduce potential losses [4].

When a water system issues a boil water advisory to its customers, it is an indicator of underlying problems in the public water service. A BWA is a tool to communicate health and environmental risks related to drinking water quality. Therefore, BWAs play an important role as a precautionary measure or as a first line of defense meant to protect public health. A BWA is typically issued in response to the identification or suspicion of the presence of microbial contaminants within the water distribution system. The BWA instructs water system customers to boil all water used for three to five minutes before drinking, cooking, preparing food, brushing teeth, and making ice [5]. PWSs can use various communication methods to notify individuals in the impacted areas about BWAs, including local news outlets, radio broadcasts, newspapers, email notifications, text messages, official websites, and door tags. In general, water service disruptions related to BWAs are considered short-term problems and are resolved within a few days [6].

Previous studies have shown that disruptions in public water service related to BWAs result in large health and economic costs for residents, businesses, and communities [7–16]. Therefore, a better understanding of the frequency, duration, and causes of BWAs is required to help decision-makers (i.e., governmental agencies, public water systems, or customers) weigh the benefits and costs of BWAs. For example, understanding and analyzing historical data of BWAs can be an important source of information for governmental agencies to help them allocate their limited financial resources available to support public water systems or to identify high health-risk areas in order to aid health officials with program planning and evaluation. Water customers can also benefit from such information when making life-impacting decisions, such as where to buy a house [8]. Finally, such information may help public water systems with managing their assets and identify the causes of the advisories, so they can be safely reduced to ensure the sustainability of the water system.

Few studies have analyzed the frequency, duration, and causes of BWAs in Canada and Norway [17–24]. Six of the Canadian studies examined various factors related to BWAs in drinking water systems serving rural and First Nations communities in different parts of Canada. Various factors were found to be associated with total number of BWAs, status, and/or duration. For example, Edwards et al. [17] found that governing structure (the entity responsible for running the water system, such as local government or utility) is the most important factor associated with BWA status for small and rural residential water systems in British Columbia. McLeod et al. [22] compared Indigenous and non-Indigenous small drinking water systems in Saskatchewan for the period 2012–2016 and found that season and region (north vs. south) and type of community (Indigenous, villages, or towns) were significant for the number of BWAs. Galway [18] and Thompson et al. [23] examined the trends and characteristics of BWAs by analyzing the frequency, duration, and causes. Similar results were found in both studies, where systems that rely on surface water and have uncertified operators experienced more and longer BWAs. Using a decision tree model (a data mining method), Harvey et al. [19] and Thompson et al. [24] found that drinking water system operator' training is the important predictor of the status of BWAs (i.e., whether the water system is under a BWA or not) in small drinking water systems.

Lane and Gagnon [21] explored BWAs characteristics in Atlantic Canada, and, unlike the previous studies, they focused more on municipal and private water systems. They found that BWAs were issued largely because of operational or process-related concerns, and most of the BWA burden is on small and rural water systems.

Finally, Hyllestad et al. [20] analyzed public media reports published in Norway to assess trends, causes, geographical, and seasonal distribution of BWAs issued during the period 2008–2019. They found that the most frequent causes for BWAs are the detection of fecal indicator bacteria and risk of contaminant intrusion in the distribution system. Also, they found that summer and fall months had a higher number of BWAs compared to other seasons.

However, we did not find such studies in the United States. To gain a better understanding of this issue, we examine a unique and large dataset on BWAs in Kentucky to explore the trends and characteristics of BWAs and the reasons behind them.

The rest of this article is organized as follows. The following section describes the materials and methods used in this study, where we provide information of the study area and data used in the analysis. Then, results are presented and discussed. Next, the article ends with conclusions and future research.

2. Materials and Methods

2.1. Study Area

The study area for this research encompasses the state of Kentucky, situated in the southeastern region of the United States. Kentucky offers a diverse range of geographical features, including rolling hills, plateaus, and the Appalachian Mountains in the eastern part of the state. Figure 1 shows a map illustrating Kentucky counties located in the Appalachian region and rural counties. The state capital is Frankfort, and its most populous cities are Louisville and Lexington. As of the year 2022, Kentucky had a population of approximately 4.5 million. In the same year, its per capita personal income (PCPI) stood at USD 51,921, ranking 47th in the country, and 16.5% of the residents lived under the poverty threshold. The total land area of the state spans around 40,408 square miles (104,656 square kilometers), and its largest cities are Louisville and Lexington. The manufacturing industry is the primary employer, contributing about 20% of the state's GDP. Regarding housing, 68.1% of houses in Kentucky are owned, with a median value of USD 177,000, according to the Census Bureau's 2022 data. The state has 434 public water systems serving drinking water to 4,512,310 residents. The largest public water system in Kentucky is the Louisville Water Company, which serves nearly one million people. Kentucky State was chosen for this study because it stands out as one of the few states that consistently gather and update BWA data covering the entire state.

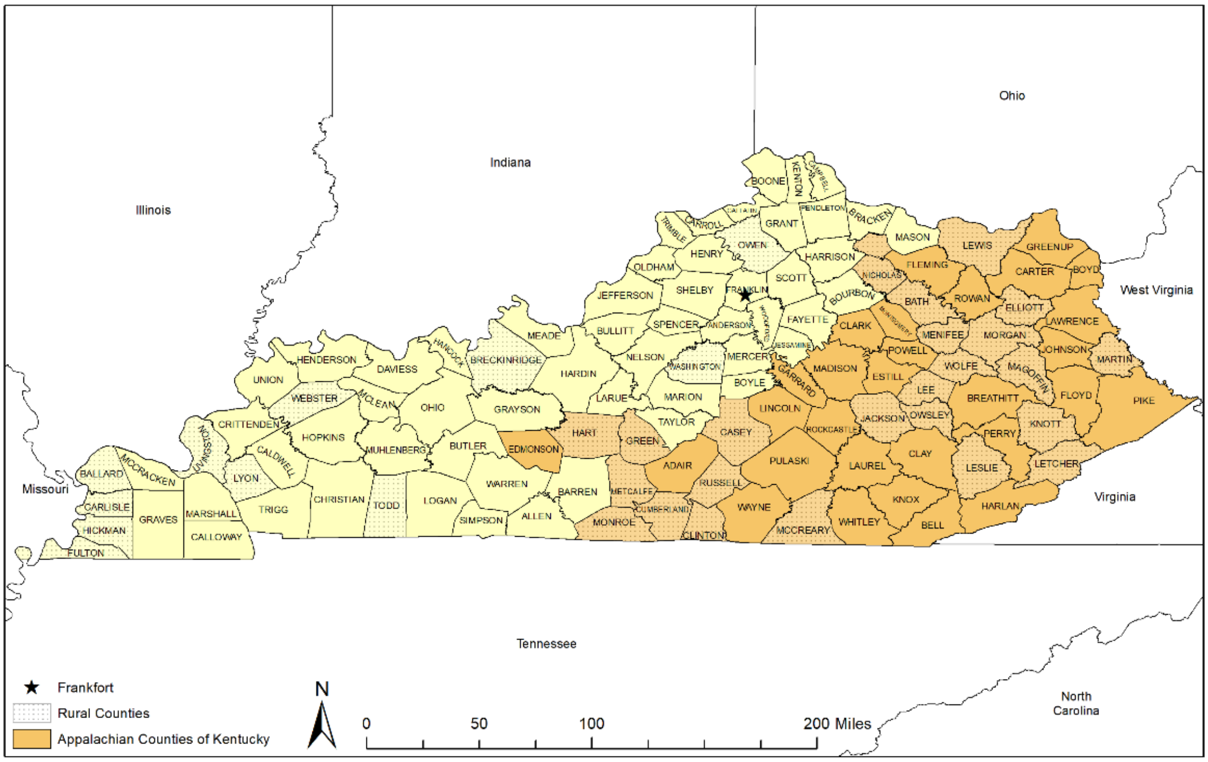

Figure 1. Study Area.

2.2. Data

We utilize two primary sources of data: (1) Kentucky's Energy and Environment Cabinet (KEEC) for data on drinking water-related incidents, and (2) the Environmental Protection Agency (EPA) Safe Drinking Water Information System (SDWIS) Federal Reporting Services for data on PWSs characteristics. Our analysis covers all 120 counties in Kentucky from 1 January 2004 to 31 December 2020.

The KEEC dataset provides details for each incident, including the water system name, the affected county and municipality, incident type (the cause of the incident), a description of the incident, the incident start and end dates, and the number of customers impacted.

One important information provided by the incident description is whether there was a BWA issued for the incident or not. Therefore, we only consider observations for water incidents that resulted in the issuance of a BWA. The dataset contains 51,616 water incidents with 36,673 being related to BWAs.

The SDWIS data provide information about PWS characteristics, including system type (i.e., community water system vs. non-community water system) and population served to determine the PWS size. In our analysis, we include all water incidents that occurred only in active community water systems (CWSs), which are defined as public water systems that supply water to the same population year-round and serve at least 25 people at their primary residences or at least 15 residences that are primary residences. Those systems represent about 87% of all water systems in Kentucky (378 out of 434).

PWS data were merged with the water incidents data to explore the relationships between BWAs and system characteristics such as size, water source, and ownership. The systems in each dataset were manually aligned, since water incidents data did not encompass the system ID employed by SDWIS, and there were many inconsistencies in the naming conventions between the data sources. We did this by using PWSID (i.e., identifying code that begins with the state's initials followed by seven digits). These codes provide the means to retrieve additional data regarding the PWSs, such as the city and county served or the primary water source in the SDWIS/Federal Warehouse. Table 1 shows the variable used in the study and their description and sources.

Table 1. Variables used in the study.

Variable	Description	Calculation	Source
BWAs	Total number of boil water advisories	Summing the number of all water incidents that resulted in boil water advisories. It can be calculated at the public water system or the county level.	KEEC
Average BWA duration	Average boil water advisory duration	Subtracting the end date from the start date of water incident and then calculating the average number of this difference across public water systems or counties.	KEEC
Customers affected	Estimated total number of customers affected by boil water advisories	Available in the description of the water incidents in the dataset.	KEEC
Notification method	Method used to alert water customers about boil water advisories	Available in the description of the water incidents in the dataset.	KEEC
Size	Public water system size	Used population served as a proxy for system size as employed by the SDWIS.	SDWIS
Water source	Primary water source used by public water system	Available in SDWIS dataset.	SDWIS
Ownership	Who is responsible for running the public water system	Available in SDWIS dataset.	SDWIS
Type	Type of public water system (community vs. non-community)	Available in SDWIS dataset.	SDWIS

3. Results

3.1. Frequency of BWAs

Of the 378 CWSs in Kentucky, 352 (93%) issued one or more BWAs between 2004 and 2020. The total number of BWAs issued by CWSs was 36,673 during the study period. The leading factor for issuing a BWA was because of a line break or leak (87%). The number of BWAs in a single CWS varied from 1 to 1361 separate occurrences, with most of them being in the lower frequencies, as shown in Figure 2. Fourteen CWSs experienced only one BWA, while 49 systems had more than 200 separate BWAs between 2004 and 2020.

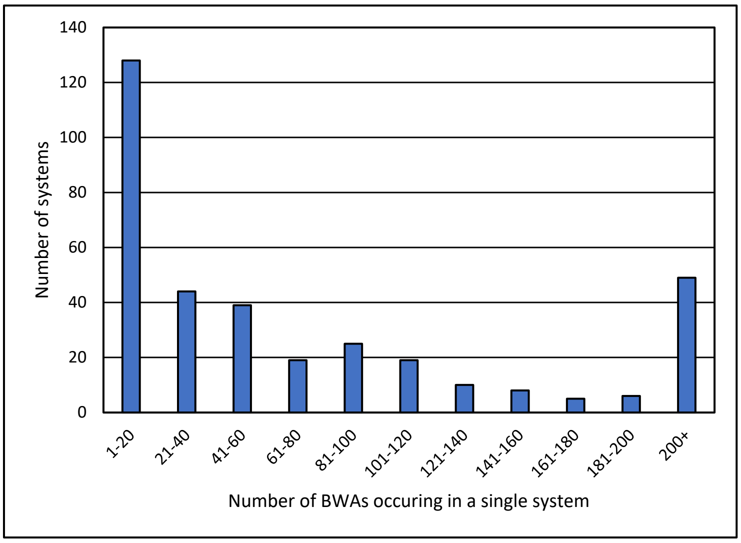

Figure 2. Frequency of boil water advisories (BWAs) in a single community water system in Kentucky (2004–2020).

Regional distribution of PWSs and BWAs varied significantly. Figure 3 provides a map with the average number of BWAs at the county level. PWSs in counties in the eastern part of the state issued about 58% of the total number of BWAs in Kentucky. These counties are in Appalachia, a region known for its long history of poverty and lack of funding. In addition, 31 out of the 49 PWSs that issued more than 200 BWAs are located in the same region. The yearly average number of BWAs in Appalachian Kentucky was 391, while the yearly average in non-Appalachian Kentucky was 236 BWAs (p-value = 0.019). The highest three counties in terms of the total number of BWAs are Boyd, Carter, and Bell with 1859, 1602, and 1476 BWAs, respectively. On the other hand, the lowest counties are Crittenden, Owen, Hickman, and Ballard with fewer than 12 BWAs each.

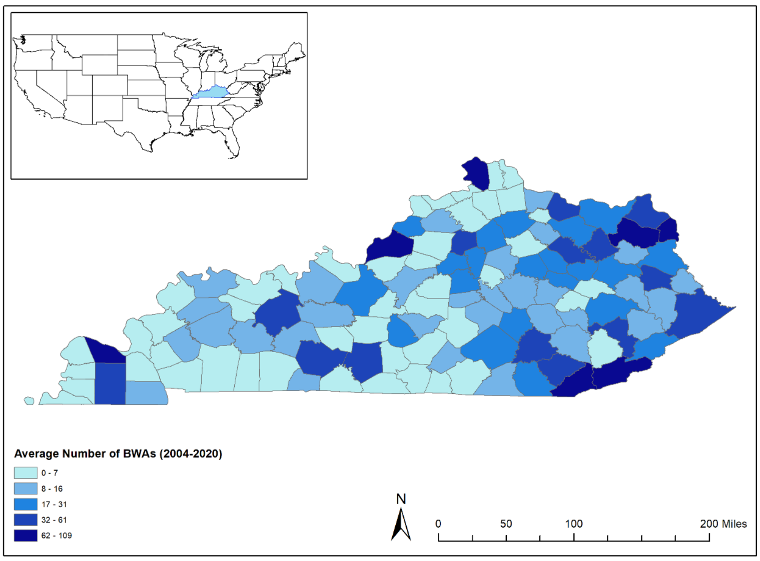

Figure 3. Average number of boil water advisories (BWAs) by county in Kentucky (2004–2020).

Seasonal variation in BWAs suggests higher occurrences of BWAs during the summer season compared to spring, fall, or winter as shown in Figure 4. Moreover, Figure 5 shows that across Kentucky, the number of BWAs issued by CWSs increased between 2004 and 2020.

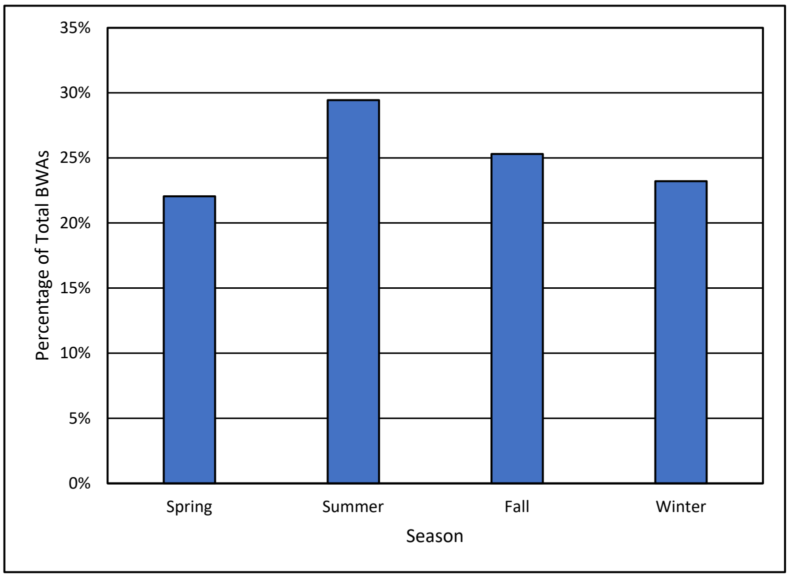

Figure 4. Percentage of total number of boil water advisories (BWAs) by season (2004–2020).

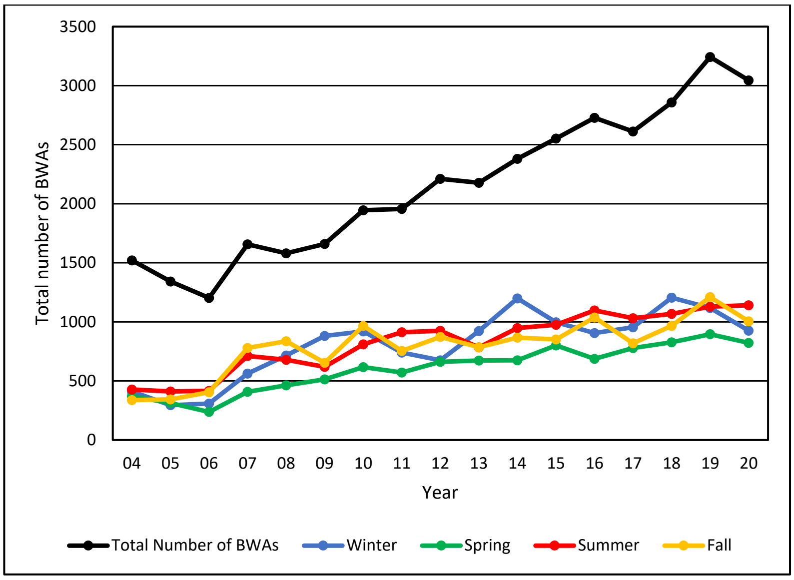

Figure 5. Number of boil water advisories (BWAs) in Kentucky (2004–2020).

3.2. System Attributes

BWAs can also be explored relative to the CWSs attributes. Factors that commonly affect the performance of a drinking water system include, but are not limited to, the size of the system, type of source water, and ownership of the system. Table 2 shows the number of CWSs and BWAs related to each of these categories. One-third of the systems in Kentucky were small systems responsible for about 11% of the total number of BWAs, and another third were medium systems responsible for about 29% of the total number of BWAs. There are also 90 large systems responsible for the majority of BWAs (54%) in Kentucky. According to one-way ANOVA results, the difference between PWS size was statistically significant (F = 26.625, p-value = 0.000). In terms of water source, surface water was the most common source type used by CWSs (80%) and it was associated with the majority of

BWAs (92%) (F = 2.335, p-value = 0.04). For ownership, most of the systems in Kentucky were owned by the local governments (86%), which were responsible for about 84% of the BWAs. The difference between ownership groups was not statistically significant (F = 2.549, p-value = 0.054).

Table 2. Distribution of public water systems (PWSs) and boil water advisories (BWAs) by system size, water source, and ownership (2004–2020) in Kentucky.

Public Water System Attributes	PWSs	% of Total PWSs	BWAs	% of Total BWAs	Average BWA Duration (Days)	Std. Dev.
PWS Size *						
Very Small	21	6.0	388	1.1	6.6	21.9
Small	117	33.2	3978	10.8	9.1	47.5
Medium	121	34.4	10,750	29.3	5.8	35.1
Large	90	25.6	19,859	54.2	3.8	29.0
Very Large	3	0.9	1698	4.6	2.3	19.2
Source						
Groundwater	49	13.9	2247	6.1	4.0	23.4
Groundwater purchased	18	5.1	398	1.1	3.0	10.9
Groundwater under influence of surface water	2	0.6	109	0.3	8.7	18.4
Purchased groundwater under influence of surface water	1	0.3	43	0.1	7.5	5.0
Surface water	124	35.2	22,172	60.5	4.6	35.6
Surface water purchased	158	44.9	11,704	31.9	5.6	29.8
Ownership						
Federal government	2	0.6	120	0.3	0.3	0.7
Local government	301	85.5	30,754	83.9	5.1	33.1
Private	48	13.6	5758	15.7	4.0	27.5
State government	1	0.3	41	0.1	1.9	1.2
Total	352		36,673			

Notes: * System size is defined by the population served as follows: Very small ($\leq$500); Small (501–3300); Medium (3301–10,000); Large (10,001–100,000); Very Large (>100,000).

3.3. Customers Affected and Notification Method

Other important information also includes the number of customers affected by BWAs and how the PWS or the health department notified those customers. Most of the incidents' descriptions (94%) provide information about customers affected; however, only 43% provide information about the notification method. Figure 6 provides a map with the average number of customers affected at the county level in Kentucky between 2004 and 2020. The figure shows the stark difference between Appalachian and non-Appalachian regions in terms of number of customers affected by BWAs. On average, people living in eastern counties are more likely to be affected by BWAs than the other counties. In terms of notification methods, there are various ways PWSs or health departments can notify water customers about a BWA. Table 3 shows each notification method and the associated number of BWAs. In-person visits are the most used method of customer notification (43%), followed by using multiple methods (22%) and door tags (13%).

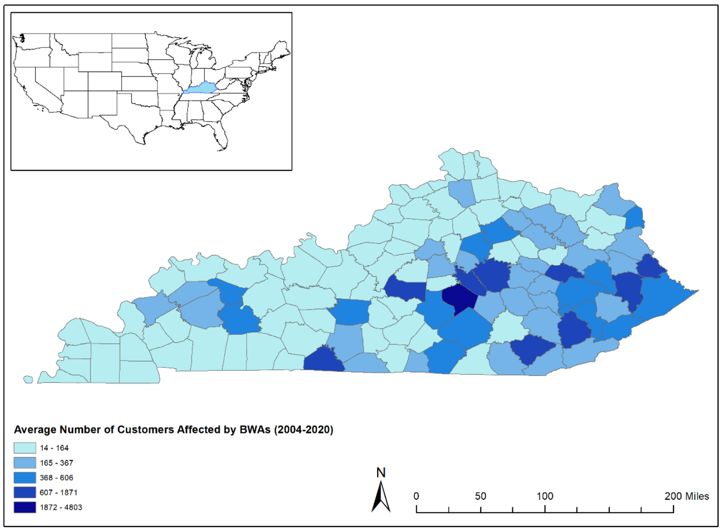

Figure 6. Average number of customers affected by boil water advisories (BWAs) in Kentucky (2004–2020).

Table 3. Number of BWAs by notification method.

Notification Method	BWAs	Average Number of Customers Affected	% of Total BWAs
In person	6833	135	43.4
Door tags	1961	32	12.5
Traditional media (radio, television, billboards, flyers, and newspaper)	2634	231	16.7
New media (Facebook and websites)	472	159	3.0
Emergency notification systems (Code red, one call, and reverse 911)	385	156	2.4
More than one method	3450	348	21.9
Total	15,735	264	100

3.4. BWA Duration

The average duration of all BWAs issued during the study period was about 5 days, with the longest lasting 2588 days, or over 7 years. The vast majority of PWSs (244) had an average duration between 0 and 5 days. The longest BWA average for a PWS was 78 days.

Similar to the number of BWAs, there was also a disparity between counties in terms of BWA duration. Figure 7 shows the average duration of BWAs at the county level in Kentucky between 2004 to 2020. The county with the shortest duration was Ohio, with an average BWA duration of less than a day (0.4 day), whereas Kenton County had the longest duration, with an average of 36 days. Moreover, there was a statistically significant difference between counties in the Appalachian and those in the non-Appalachian region, where Appalachian counties had longer durations (6.4 days) compared to counties in the non-Appalachian region (3.6 days) (p-value = 0.000).

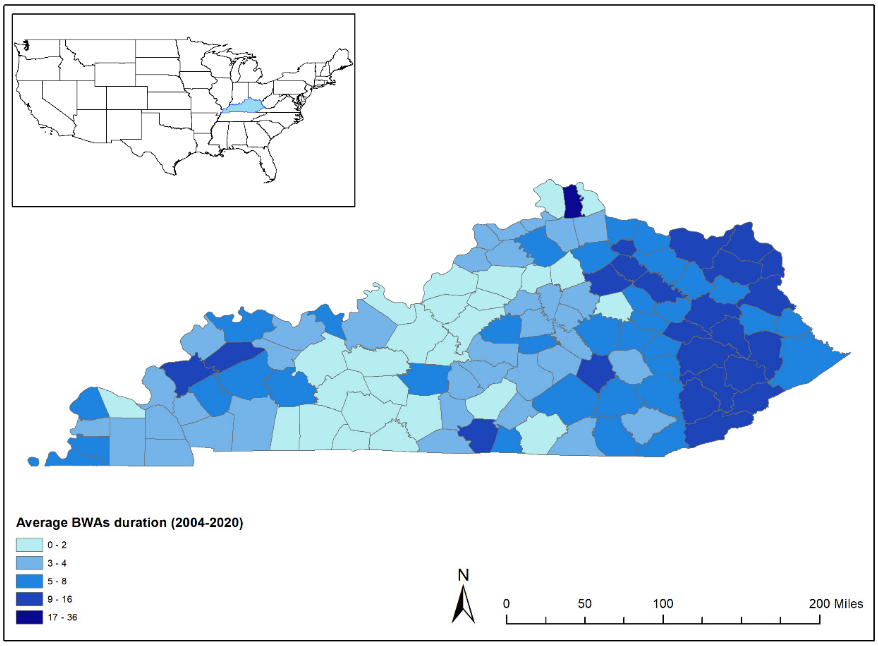

Figure 7. Average boil water advisory (BWA) duration in days in Kentucky (2004–2020).

Figure 8 shows the average BWA duration in days by season in Kentucky for the period 2004–2020. BWAs that were issued in the winter season had the highest average duration, followed by those in the spring, fall, and summer. Among the winter months, January had the highest average duration, which was about 12 days. We see some improvements in terms of average duration on the state level between 2004 and 2020, where the average duration of BWAs in 2004 was about 7 days, but it decreased to about 3 days in 2020, as shown in Figure 9.

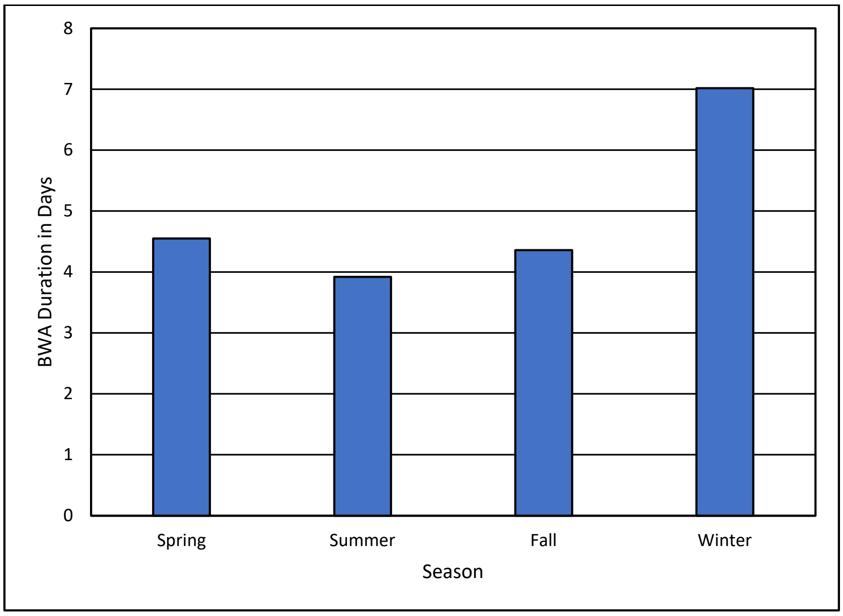

Figure 8. Average boil water advisory (BWA) duration in days by season in Kentucky (2004–2020).

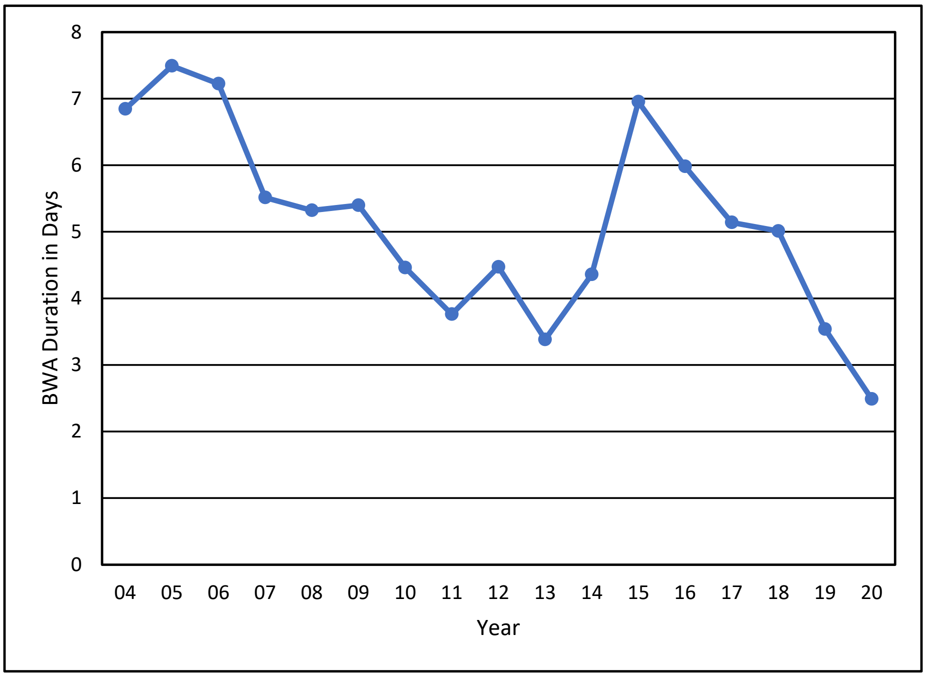

Figure 9. Boil water advisory (BWA) average duration in days in Kentucky (2004–2020).

Relationships between CWS attributes and the average duration of BWAs are also shown in Table 2. Small water systems experienced longer BWAs on average (9 days) compared to the other systems. In addition, water systems that use groundwater had longer BWA duration compared to those that use surface water. In terms of ownership, water systems owned by the local governments had the longest durations.

4. Discussion

Public water service disruptions, in the form of boil water advisories, are a significant issue that can severely impact communities. These disruptions can arise from various factors such as contamination events, aging infrastructure, extreme weather conditions, funding shortfalls, and population growth. Without access to clean and safe drinking water, public health, economic development, and local resilience are all at risk. Water supply unreliability presents substantial challenges for communities and municipal services. These challenges include managing dilapidated water infrastructure systems, facing water scarcity and contamination events, addressing high expectations and dealing with the impacts of population dynamics and demographic changes. Regions that have experienced boil water advisories and water shortages have shown an increase in bottled water consumption during advisory periods [9] and a decline in residential property prices [8].

This study covers all counties in Kentucky for 17 years from 2004 to 2020. Of the 378 CWSs in Kentucky, 93% issued one or more BWAs during the study period. In total, there were 36,673 BWAs. Thompson et al. [23] used a database for 776 CWSs in which 66% experienced at least one BWA during the study period (11 years from 2004 to 2015) and included 1470 BWAs. Galway [18] investigated 402 advisories during the period from 2004 to 2013 and reported that 70% of the CWSs issued at least one BWA during this period. Collecting a comprehensive database of community water systems and advisories is vital for informed decision-making, efficient water resource management, swift emergency response, monitoring water quality, ensuring public health, and enhancing the overall resilience of water systems in the face of challenges. It provides a systematic overview and organized repository of information and assists in the identification of status, characteristics, trends, patterns, and potential issues.

The number of BWAs issued shows an increasing trend throughout the study period. The same trend was noticed in other studies in Canada [18,23]. The average duration of BWAs included in our study was 5 days, with the longest lasting 2588 days (above 7 years). The average duration on the state level decreased during the study period. The average duration was 169 days, with the longest lasting 3956 days (over 10 years) in Thompson et al. [23], while the average advisory duration was 294 days in Galway [18], with 14% being long-term advisories (more than 1 year).

The frequency and duration of BWAs differ based on factors such as spatial and temporal characteristics, source type, and system size. Counties in Appalachia in the eastern part of the state issued more BWAs and had longer durations than other counties. The correlation between the high number of BWAs and low-income communities was evident in other studies as well (e.g., Canadian First Nations communities [18,19,23,24]). More BWAs occurred in the summer months (29%), but the highest average durations were in the winter months (about 12 days in January). Surface water (92%) and large systems (54%) were associated with the majority of BWAs, whereas groundwater under the influence of surface water (8.7 days) and small water systems (9 days) had longer BWAs. Thompson et al. [23] found that more BWAs were issued in summer, with surface water (51%), and in systems without fully trained operators, whereas the long BWAs were associated with summer months, groundwater under the influence of surface water, small systems, and remote areas. Galway [18] reported that the majority of BWAs were issued in summer months (32%) and in surface water systems (78%). BWAs are often more prevalent in summer due to factors like increased temperatures fostering microbial growth, higher water demand stressing treatment systems, and extreme weather events. In addition, they are more common in surface water systems due to the vulnerability of these sources to contamination from runoff, storms, and human activities.

The leading factor for issuing a BWA was because of a line break or leak (87%). Other studies reported similar findings (e.g., this reason represented 80% in Marion County [8], and 58% in First Nations communities in Ontario [18]). The deterioration of water infrastructure contributes to higher occurrences of main breaks, causing issues with both water quantity and quality. Leaks and the introduction of contaminants into the water supply result from these breaks, leading to the escalation of BWAs. According to the American Society of Civil Engineers (ASCEs), numerous pipes and main lines responsible for distributing water throughout the country are over a century old, making them susceptible to a range of stressors [25]. Approximately 240,000 water main breaks occur annually, leading to the loss of over two trillion gallons of treated drinking water [25]. Around 40 percent of valves within the water distribution network in the United States are estimated to be malfunctioning [26]. The expenses linked to upgrading obsolete water infrastructure are substantial. According to the American Water Works Association, approximately USD 1 trillion is required for water infrastructure to sustain existing levels of water service in the next 25 years [27]. USD 4.2 million, an aggregated willingness-to-pay, was estimated for a single-day reduction in the annual occurrence of boil water notices across Marion County [8].

The results show that there are spatial and temporal variations in the data, prompting future studies to employ a comprehensive integrated framework to assess the effect of the political, economic, social, technological, environmental, and legal factors on CWSs and BWAs in different regions.

5. Conclusions

The reliability and safety of public water services in the United States encounter obstacles such as outdated infrastructure, financial constraints, and impaired water sources. Investing in sustainable and resilient water infrastructure is crucial to ensure access to safe drinking water for all communities, especially in the face of adverse water quality events and other challenges. The proper division of a water distribution system into DMAs offers several significant management benefits. It is evident that public water service disruptions, such as boil water advisories, pose significant challenges for local utilities in Kentucky. With the increasing occurrences of water scarcity, contamination events, and extreme weather conditions, the need for proactive infrastructure management is more important than ever. Not only are the communities affected by these disruptions at risk of adverse health effects, but the economic development and local resilience of these areas are also threatened. The health and economic consequences of BWAs result in substantial costs for residents, businesses, and communities, highlighting the need for a deeper understanding of the frequency, duration, and causes of such disruptions and emphasizing the importance of addressing these issues to provide accessible, clean drinking water for all. Collaboration among governments, organizations, and communities is crucial in order to pave the way for a healthier, more resilient water infrastructure for present and future generations.

Author Contributions: Conceptualization, F.A.; methodology, F.A.; software, F.A. and R.T.; validation, R.T.; formal analysis, F.A.; data curation, F.A.; writing—original draft preparation, F.A. and R.T.; writing—review and editing, F.A. and R.T.; visualization, F.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Deanship of Scientific Research, Vice Presidency for Graduate Studies and Scientific Research, King Faisal University, Saudi Arabia, Grant Number 5336.

Data Availability Statement: Data are available upon request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Mueller, J.T.; Gasteyer, S. The Widespread and Unjust Drinking Water and Clean Water Crisis in the United States. *Nat. Commun.* **2021**, *12*, 3544. [CrossRef] [PubMed]
2. Allaire, M.; Wu, H.; Lall, U. National Trends in Drinking Water Quality Violations. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 2078–2083. [CrossRef]
3. Grayman, W.; Murray, R.; Savic, D. Effects of Redesign of Water Systems for Security and Water Quality Factors. In Proceedings of the World Environmental and Water Resources Congress 2009: Great Rivers, Kansas City, MO, USA, 17–21 May 2009; pp. 504–514.
4. Ciaponi, C.; Murari, E.; Todeschini, S. Modularity-Based Procedure for Partitioning Water Distribution Systems into Independent Districts. *Water Resour. Manag.* **2016**, *30*, 2021–2036. [CrossRef]
5. Water Quality Research Foundation Boil Water Notices: What Are They, Why Are They Issued and What Are You Supposed to Do If You Receive One? 2018. Available online: https://wqa.org/wp-content/uploads/2022/09/Boil_Water_Notice_Study_Brochure.pdf (accessed on 25 November 2023).
6. Vedachalam, S.; Spotte-Smith, K.T.; Riha, S.J. A Meta-Analysis of Public Compliance to Boil Water Advisories. *Water Res.* **2016**, *94*, 136–145. [CrossRef] [PubMed]
7. Ailes, E.; Budge, P.; Shankar, M.; Collier, S.; Brinton, W.; Cronquist, A.; Chen, M.; Thornton, A.; Beach, M.J.; Brunkard, J.M. Economic and Health Impacts Associated with a Salmonella Typhimurium Drinking Water Outbreak-Alamosa, CO, 2008. *PLoS ONE* **2013**, *8*, e57439. [CrossRef]
8. Alzahrani, F.; Collins, A.R. Impact of Public Water Supply Unreliability on Residential Property Prices in Marion County, West Virginia. *Agric. Resour. Econ. Rev.* **2022**, *51*, 105–129. [CrossRef]
9. Alzahrani, F.; Erfanian, E.; Collins, A.R. Drinking Water Contamination and Avoidance Behavior: Do Bottled Water Sales Adequately Measure the Cost of This Behavior? *Urban Water J.* **2023**, *20*, 112–122. [CrossRef]
10. Anadu, E.C.; Harding, A.K. Risk Perception and Bottled Water Use. *J. Am. Water Work. Assoc.* **2000**, *92*, 82–92. [CrossRef]
11. Des Rosiers, F.; Bolduc, A.; Thériault, M. Environment and Value: Does Drinking Water Quality Affect House Prices? *J. Prop. Invest. Financ.* **1999**, *17*, 444–463. [CrossRef]
12. Dupont, D.P.; Jahan, N. Defensive Spending on Tap Water Substitutes: The Value of Reducing Perceived Health Risks. *J. Water Health* **2011**, *10*, 56–68. [CrossRef]
13. Harrington, W.; Krupnick, A.J.; Spofford, W.O. The Economic Losses of a Waterborne Disease Outbreak. *J. Urban Econ.* **1989**, *25*, 116–137. [CrossRef]
14. Heflin, C.; Jensen, J.; Miller, K. Understanding the Economic Impacts of Disruptions in Water Service. *Eval. Program Plan.* **2014**, *46*, 80–86. [CrossRef]
15. Kim, M.; de Vito, R.; Duarte, F.; Tieskens, K.; Luna, M.; Salazar-Miranda, A.; Mazzarello, M.; Showalter Otts, S.; Etzel, C.; Burks, S.; et al. Boil Water Alerts and Their Impact on the Unexcused Absence Rate in Public Schools in Jackson, Mississippi. *Nat. Water* **2023**, *1*, 359–369. [CrossRef]
16. Laughland, A.S.; Musser, L.M.; Musser, W.N.; Shortle, J.S. The Opportunity Cost of Time and Averting Expenditures for Safe Drinking Water. *J. Am. Water Resour. Assoc.* **1993**, *29*, 291–299. [CrossRef]
17. Edwards, J.E.; Henderson, S.B.; Struck, S.; Kosatsky, T. Characteristics of Small Residential and Commercial Water Systems That Influence Their Likelihood of Being on Drinking Water Advisories in Rural British Columbia, Canada: A Cross-Sectional Study Using Administrative Data. *J. Water Health* **2012**, *10*, 629–649. [CrossRef] [PubMed]

18. Galway, L.P. Boiling over: A Descriptive Analysis of Drinking Water Advisories in First Nations Communities in Ontario, Canada. *Int. J. Environ. Res. Public Health* **2016**, *13*, 505. [CrossRef]
19. Harvey, R.; Murphy, H.M.; McBean, E.A.; Gharabaghi, B. Using Data Mining to Understand Drinking Water Advisories in Small Water Systems: A Case Study of Ontario First Nations Drinking Water Supplies. *Water Resour. Manag.* **2015**, *29*, 5129–5139. [CrossRef]
20. Hyllestad, S.; Kjørsvik, S.S.; Veneti, L.; Amato, E. Identifying Challenges in Drinking Water Supplies: Assessment of Boil Water Advisories in Norway (2008–2019). *J. Water Health* **2021**, *19*, 872–884. [CrossRef]
21. Lane, K.; Gagnon, G. Evaluating the Use and Intent of Drinking Water Advisories in Atlantic Canada. *Water Policy* **2020**, *22*, 908–924. [CrossRef]
22. McLeod, L.; Bharadwaj, L.A.; Daigle, J.; Waldner, C.; Bradford, L.E.A. A Quantitative Analysis of Drinking Water Advisories in Saskatchewan Indigenous and Rural Communities 2012–2016. *Can. Water Resour. J.* **2020**, *45*, 345–357. [CrossRef]
23. Thompson, E.E.; Post, Y.L.; McBean, E.A. A Decade of Drinking Water Advisories: Historical Evidence of Frequency, Duration and Causes. *Can. Water Resour. J.* **2017**, *42*, 378–390. [CrossRef]
24. Thompson, E.; Post, Y.; McBean, E. Data Mining to Identify Attributes Associated with Drinking Water Advisories in First Nations Communities. *J. Water Resour. Plan. Manag.* **2019**, *145*, 04019050. [CrossRef]
25. American Society of Civil Engineers Infrastructure Report Card: Drinking Water. Available online: https://www.infrastructurereportcard.org/wp-content/uploads/2017/01/Drinking-Water-Final.pdf (accessed on 1 September 2023).
26. Baird, G.M. Fasten Your Seat Belts: Main Breaks and the Issuance of Precautionary Boil-Water Notices. *J. AWWA* **2011**, *103*, 24–28. [CrossRef]
27. American Water Works Association Buried No Longer—Confronting America's Water Infrastructure Challenge—McWane Ductile—Iron Strong. 2012. Available online: https://www.awwa.org/Portals/0/AWWA/Government/BuriedNoLonger.pdf?ver=2013-03-29-125906-653 (accessed on 10 October 2023).