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Identifying challenges in drinking water supplies: assessment of boil water advisories in Norway (2008–2019)

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ABSTRACT

The issuing of boil water advisories (BWAs) is a widely used response to microbiological contamination events in drinking water supply systems, and may therefore serve as an indicator for the access to safe drinking water. To supplement data source on the overall status of water supply systems (WSSs) in Norway, we analysed public media reports published in Norway to assess trends, causes, geographical and seasonal distribution of BWAs issued during the period 2008–2019. We identified 1,108 BWA events increasingly reported over the study period but characterised by a decreasing trend in time with respect to duration. The two main frequent causes for BWA were detection of faecal indicator bacteria (42.6%) and risk of contaminants intrusion in the distribution system (21%). We observed higher reporting rates in summer and autumn compared with winter, and higher reporting rates in Northern and Eastern Norwegian regions compared with the Central region. The results of this study could serve as supplementary information to better understand the overall status among WSSs in Norway, particularly in case of recurrent BWA's events, as well as suggest the relevance of BWAs' monitoring in identifying risk factors and planning targeted interventions.

Key words: boil water advisories, drinking water, media, microbiological contamination, public health

HIGHLIGHTS

- Trends of boil water advisories.
- Assessment of risks in drinking water supplies.
- Media reports as data source for drinking water status.

GRAPHICAL ABSTRACT

INTRODUCTION

Despite precautionary actions, such as protection of source waters, development in water treatment measures and regulations, in high-income countries, waterborne outbreaks still occur (Moreira & Bondelind 2017) and remains a recurrent threat to public health (Hrudey & Hrudey 2007). In urban areas, typical water supply systems (WSSs) have several residents connected and the general hygiene level is high. On the other side, the drinking water supplies also run the risk of contamination during distribution and become a vehicle for transmission, thus exposing many residents in a short time span served by the water supplies (Hunter *et al.* 2010). Among others, the issuing of boil water advisories (BWAs) is a widely used measure to prevent further cases when waterborne outbreaks are detected (Mac Kenzie *et al.* 1994; O'Connor 2002; Nygard *et al.* 2006; Pitkanen *et al.* 2008; Laine *et al.* 2011; Widerstrom *et al.* 2014; Hyllestad *et al.* 2020). In addition, BWAs are commonly used in situations where events – such as severe main breaks or flooding – represent a risk of microbiological contamination (Wang *et al.* 2013).

Drinking water may be contaminated if the treatment process fails or becomes overwhelmed, or there is an intrusion of polluted water during distribution caused, for example, by pressure loss in pipelines or at points where the system is not protected by pressure (reservoirs, pump stations, etc.) (Havelaar 1994; Ercumen *et al.* 2014; Moreira & Bondelind 2017). Thus, unsafe drinking water represents an important public health issue. A focus on the management of risks in drinking water systems to protect public health has increased (World Health Organization 2005), such as regulatory instruments and applying a multi-barrier approach, although the risks will never be eliminated (Hrudey *et al.* 2011). Routinely monitoring of drinking water quality is essential in the efforts to ensure safe drinking water and to oversee the effect of safety measures implemented. However, when assessing the outcome of faecal indicator bacteria in isolation, little information is provided about the system as it does not alone create an understanding of the hazards, hazardous events and control measures in the WSS (WHO-ROE 2019). In this regard, BWAs have been used as a proxy to identify risks in drinking water supply systems and disproportionate access to safe drinking water, particularly in Canada, by assessing for trends, causes and geographical distribution (Galway 2016; Thompson *et al.* 2017) or as a measure for lack of operational management and to understand how drinking water advisories can inform alternative water management (Lane & Gagnon 2020). Both of the latter references have assessed the nature of BWAs in the light of being indicative of operational problems, which further represent a risk, in particular linked to poor operation among small drinking water systems. This approach adds to a general concern of an observed increasing number of BWAs *per se* (Baird 2011; Bradford *et al.* 2018).

In Norway, since the middle of the 1990s, several hygienic barriers have been implemented to ensure safe drinking water in a targeted programme to improve the quality of the drinking water. Today, only a small proportion of the consumers of the public drinking water supply receive water that is not disinfected (Norwegian Institute of Public Health 2014). However, despite the contextual benefits in Norway, studies reveal that waterborne outbreaks occur each year (Guzman-Herrador *et al.* 2015, 2016). The risk of contamination in the distribution system has become a growing concern in Norway in recent years, along with an awareness that an ageing pipe infrastructure is vulnerable to backflow of contamination during the loss of pressure (Nygård *et al.* 2007). In Norway, in line with other areas of the world, the effects of changing climatic factors are expected to act as stressors to vulnerable drinking water supply systems and health consequences (Hedlund *et al.* 2014; United States Global Change Research Program 2016). The ability of small WSSs to manage a water crisis for effective public health protection is also a concern (WHO-ROE 2016).

There are approximately 1,500 publicly registered WSSs in Norway serving approximately 88% (4.7 out of 5.3 million citizens) of the Norwegian population (Norwegian Institute of Public Health 2019). These WSSs serve more than 50 persons, and in addition, there are several very small-scale WSSs serving fewer than 50 persons (Lovdata 2017)[1]. Water supply utilities serving more than 50 persons (or 10 m^3 produced water) are obliged to register and seek approval from the Norwegian Food Safety Authority, and other WSSs serving schools, kindergartens, serving places and so forth fall under the same obligation. All the regulated WSSs need to comply with drinking water standards, hazard assessment and handling of risks, preparedness planning and responses (water safety plans). It is the responsibility of the water supplier to monitor and provide necessary response to breaches in the water supply, hereunder the issuing of BWAs. Incorporated in the preparedness plans are the routines for handling deviations, including how to issue and lift a BWA, along with a communication strategy. The Norwegian Food Safety Authority conduct inspections of the regulated WSSs to monitor the compliance to the Drinking water Regulation. A BWA is regarded as a notifiable event to the Norwegian Food Safety Authority, at least if it is a response to a severe event. In Norway, national guidelines for issuing and lifting BWAs have not been developed, yet some generic advice is published online (Norwegian Institute of Public Health 2018).

The WSSs submit an annual report of water quality and administrative data to the Norwegian Food Safety Authority, however, the issuance of a BWA is not a part of the routine reporting nor do the Norwegian Food Safety Authority (NFSA) systematically collect information on BWAs from the notifiable events reported, and hence information on the practice and trends on the issuance of BWAs is not available. Nonetheless, some previous studies shed light on the issuance of BWAs in Norway. In 2009, Robertson *et al.* (2009) reported on a water contamination event and highlighted the need for discussion on boil water notices and potential post-treatment contamination of parasites. In 2018, a Norwegian study investigating the number of BWAs, their causes and the routines and attitudes among the water suppliers and health authorities revealed different practices in preparedness routines, despite the obligation to comply with the same drinking water legislation (Kjørsvik & Hyllestad 2020). Examples of different practices when it comes to issuing BWAs are those BWAs reported to be conducted as a precautionary measure following a water outage due to the event itself because it is regarded as representing a risk for contamination without detecting faecal bacteria (Hyllestad *et al.* 2019), whereas another water supplier would issue a BWA because of the detection of faecal bacteria and would not have a routine for issuing precautionary BWAs (Franer *et al.* 2020). The compliance to BWA was assessed in both of the latter situations and was found to be sub-optimal in the case where the BWA had been issued as a precautionary measure due to low awareness and time span studied, while in the emergency situation, there was a high compliance due to a high awareness (media attention among other communication modes).

In the current study, we retrieved and assessed data on BWAs media reports from 2008 to 2019 to gain information on their causes and trends in Norway, in order to supplement data on the overall status of WSSs in Norway, particularly in case of recurrent BWA's events.

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[1] Comment to reference: Lovdata was established as a private foundation on 1 July 1981 by the Ministry of Justice and the Faculty of Law at the University of Oslo. The purpose of Lovdata is to establish and operate legal information systems on a non-profit basis. The Norwegian laws and regulations are normally not translated into English.

MATERIALS AND METHODS

Data source and collection

We retrieved data on BWAs from the Norwegian database for monitoring of media reports (Retriever 2020), which contains historical and uncensored information released to the public. The media reports recorded in *Retriever* include all news published in local media such as newspapers, broadcasted reports over radio/TV that have been reported as a news article or on the municipal internet website. Media reports issued only on radio or television were not included.

The searching criteria in the database Retriever were designed to cover and retrieve different types of BWA media reports from 2008 to 2019 by using the keywords 'boil' and 'drinking water'. We screened data on BWAs, excluding media reports of single wells serving, for example, private cabins or single households. We also excluded news reports on BWAs due to national or international events that could not be linked to an identifiable WSS in Norway. In addition, media reports on the same BWA event published in different newspapers were considered only once to avoid event duplication.

The retrieved media reports on BWAs were assessed and the following information was collected: date of media report, date of issuing (if different from the media report), date of lifting, municipality or location, name of water supplier and reported cause of the BWA.

In addition, we linked the retrieved data from the media reports with the administrative database of water supplies in Norway (Norwegian Institute of Public Health 2019) to integrate the information on the size and ownership of the water suppliers issuing the BWAs.

Data analysis

We described BWA events in terms of time, place, cause and duration. The BWA events were grouped by water supply size, ownership, geographical region and season. Northern hemisphere seasons were used (spring: March–May; summer: June–August; autumn: September–November; winter: December–February).

We also categorised the BWAs into nine main causes (where each BWA was grouped into a unique category): (a) detection of faecal contamination, (b) risk of intrusion in the distribution system, (c) malfunction disinfection, (d) use of a reserve water source, (e) upgrading of treatment process, (f) pollution of raw water source, (g) deteriorated water quality, (h) detection of waterborne outbreak and (i) other causes. If several causes were identified concurrently, only the one referred as the main cause on BWA triggering the media report was coded as the main cause and the underlying factors were coded as reasons. Data on the reason for the BWA was retrieved where available, for example, a BWA triggered by a main break due to land slide, the BWA would fall into the category of 'risk of intrusion to the distribution system', with an explanatory reason 'weather event'. The category 'unknown causes' includes events where a BWA is reported with no further information in the media report, along with some BWAs with unclear causes, such as 'trouble in the water supply'.

The category detection of faecal contamination includes variations of reporting of BWAs because of a deviation in the monitoring programme on microbiological parameters (mainly as *E. coli* and intestinal enterococci, but sometimes termed 'unwanted', 'gut' and 'harmful' bacteria by either the reporter or the water supplier).

Time-series analysis

We conducted a time-series analysis to examine the trends, the associations between season and geographical region and the occurrence of BWAs for the different types of WSS.

We conducted a time-series analysis, adjusting for trend, seasonality (for the four seasons) and geographical region and then calculating the adjusted rate ratios (aRRs) with 95% confidence intervals (95% CIs) using a negative binomial regression on monthly data for the period 2008–2019 (time set: month year). We conducted the above analysis for all BWAs issued at first and then repeated the analysis for BWAs issued in (i) large water supplies and (ii) small water supplies. A water supply was defined as large when supplying water to more than 5,000 inhabitants.

We performed all statistical analyses using Stata version 16 (Stata Corporation, College Station, Texas, USA). We considered a *p*-value of $\leq$0.05 as statistically significant.

Ethical considerations

The current study did not require ethical approval because we did not collect any sensitive personal data or health information. The analysis included only reports from the media and data on WSSs from historic and administrative databases.

RESULTS

In the period 2008–2019, we reviewed 11,087 media reports, resulting in 1,108 unique BWA events being identified. The BWAs were issued in 299 (70.9%) out of 422 administrative municipalities registered in Norway by 31 December 2019 (The Norwegian Association of Local & Regional Authorities 2020). The total number of residents in the affected municipalities with one or more BWAs was approximately 4.4 million residents, while the mean proportion of residents served by registered WSSs was approximately 73%, the retrieved data thus cover approximately 3.2 million residents (Statistics Norway 2020).

Trends, characteristics and geographical distribution of BWA events

The total number of 1,108 BWAs that was reported through media per year ranged from 53 to 144. There was an increase in the first studied years and a peak in 2011 ($n = 113$), followed by a stable period (2012–2017) before the numbers started increasing again over the last 2 years (2018–2019) (Figure 1). For the BWAs that both the date of issuing and lifting was identified ($n = 522$, 47%), the median length of the BWA was 6 days (IQR: 3–10). The mean length of the BWA was 13 days with a range of 1 to 518 days (9 BWAs had duration more than 100 days and 21 BWAs had a duration more than 50 days). The median length of the BWAs was decreased during the studied period (Figure 1).

The cumulative monthly distribution of BWAs for the entire period showed a seasonal variation, with fewer BWAs during winter months (December–February), increasing BWAs during the spring months (March–May), increasing in summer and autumn with a peak in August. BWAs caused by the detection of faecal contamination varied throughout the year, with most of the increases of BWAs observed from June ($n = 47$) and the following months, peaking in August ($n = 93$) before decreasing in September. In the months of December to May, the number of BWAs caused by the detection of faecal contamination were found to be more stable with less than 20 BWAs reported by media. The group of BWAs issued because of unknown reasons was furthermore slightly higher in number in the same period as the previously mentioned cause. Other causes, such as BWAs due to the risk of intrusion in the distribution system and because of the malfunction disinfection process, were stable during the year, and other causes varied slightly with no clear trend (Figure 2).

The two main causes for issuing a BWA were the detection of faecal contamination ($n = 472$, 42.6%), which had a median duration of 8 days (range: 1–518), and the risk of contaminants' intrusion into the distribution system ($n = 247$, 22%), which had a median duration of 3 days (range: 1–140). The origin of faecal contamination was mostly unknown ($n = 378$, 80%), while pipe breakage was the main reason for BWA events issued because of the risk of intrusion to the distribution system ($n = 163$, 70%). The third main category of BWAs was reported without any clear causes (unknown causes), yielding 18.5% of the total BWAs identified (Table 1).

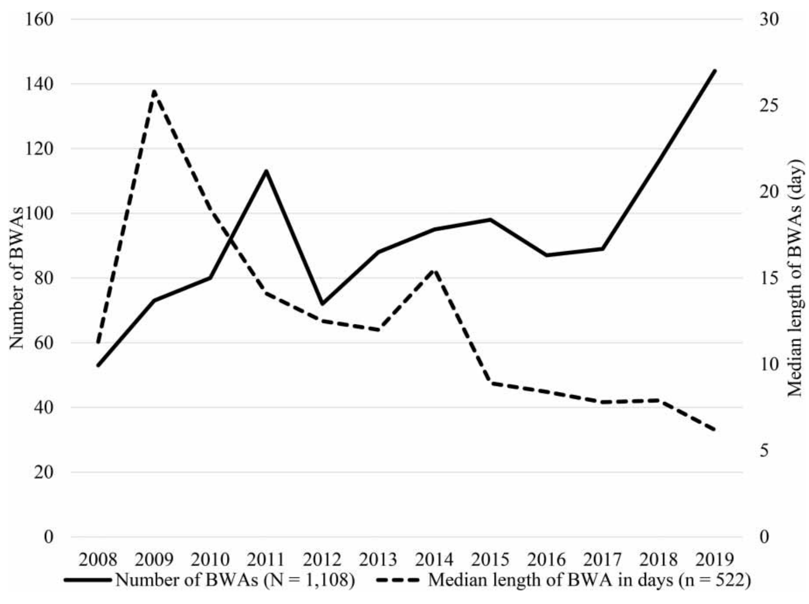

Figure 1 | Number of BWAs ($N = 1,108$) and median length of a BWA in days ($n = 522$) identified from media reports in Norway over the period 2008–2019.

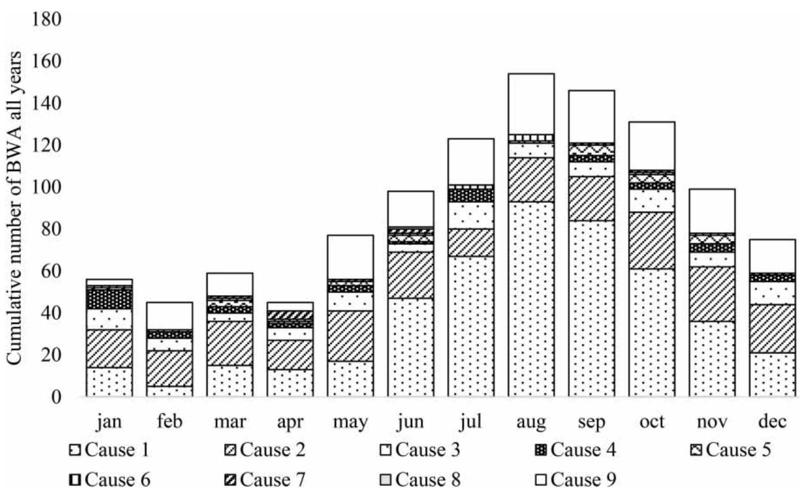

Figure 2 | Cumulative number of BWAs by causes per month reported through media in Norway (2008–2019) (n = 1,108). Note: Cause 1: Detection of faecal contamination; Cause 2: Risk of intrusion in the distribution system; Cause 3: Malfunction disinfection; Cause 4: Use of reserve water source; Cause 5: Upgrading of treatment process; Cause 6: Pollution of raw water source; Cause 7: Deteriorated water quality; Cause 8: Detection of waterborne outbreak; Cause 9: Other causes.

Table 1 | Main causes with reasons for BWAs reported through media in Norway, (2008–2019) (N = 1,108)

Main cause for issuing a BWA	Number of BWAs, n (%)	Duration, median days (min–max)[a]	Reason	Number of BWAs, n (%)	Duration, median days (min–max)[a]
Detection of faecal contamination	n = 472 (42.6)	n = 236, 8 (1–518)	Technical malfunction	n = 37 (7.8)	n = 16, 9 (4–36)
			Weather event	n = 28 (5.9)	n = 18, 8 (4–62)
			Pressure loss because of maintenance work	n = 4 (0.8)	n = 2, 20 (12–28)
			Pipe break	n = 10 (2)	n = 6, 7.5 (2–12)
			Large water outtake	n = 2 (0.4)	n = 2, 5 (3–7)
			Intrusion of contaminated water on critical points	n = 13 (2.8)	n = 11, 8 (2–31)
			Unknown	n = 378 (80)	n = 181, 7 (1–518)
Risk of intrusion in the distribution system	n = 247 (21)	n = 135, 3 (1–140)	Technical malfunction	n = 6 (2.4)	n = 6, 5.5 (1–22)
			Weather event	n = 33 (13.4)	n = 18, 8 (2–50)
			Pressure loss because of maintenance work	n = 38 (15.4)	n = 23, 2 (1–14)
			Pipe break	n = 163 (66)	n = 84, 3 (1–140)
			Large water outtake	n = 1 (0.4)	N/A
			Intrusion of contaminated water on critical points	n = 1 (0.4)	N/A
			Unknown	n = 5 (2)	n = 4, 4 (2–4)
Unknown causes	n = 205 (18.5)		N/A	N/A	n = 76, 5.5 (1–220)

Note: N/A, not applicable.

[a]Data, the date of issuance and lifting of BWA, were not reported for all identified BWAs. In 1,108 cases of the BWA, 522 (47%) had both start and end date.

In addition to the most frequent causes presented in Table 1, less frequent causes of BWAs were malfunction disinfection process events ($n = 95$, 8.6%) with a median duration of 6.5 days ($n = 34$), use of reserve water source (without adequate treatment) ($n = 40$, 3.6%), with a median duration of 7 days ($n = 17$), upgrading of water treatment process ($n = 25$, 3.5%), with a median duration of 4 days ($n = 14$), pollution of raw water source ($n = 11$, 1%), with a median duration of 8 days ($n = 6$) and deteriorated water quality ($n = 11$, 1%). One BWA was caused by a large waterborne outbreak; the source of contamination was a polluted drinking water reservoir in the distribution system, and the BWA lasted for 43 days. When assessing the difference among large- and small-scale WSSs and main causes, there is a difference of higher proportion (80%) of BWAs related to the detection of faecal indicator bacteria where among the small-scale WSSs, while the proportion of BWAs related to the risk of intrusion to the distribution is slightly higher among the large WSSs (56%).

Regarding the size of the water supplies, 753 BWAs were linked to 390 small water supplies (ratio: 1.9) serving 5,000 persons or less, and 275 BWAs were linked to 87 large water supplies (ratio: 3.2) serving more than 5,000 persons. In 80 of the BWAs identified, the link to the size of the water supply was not found as the information was a part of the media report or the water supply was not registered in the national administrative database of WSSs. The percentage of small size WSSs linked to BWA events reported by media was higher in the Northern region (23%) and the lowest in the Eastern region (6%), while for large size WSSs, the highest percentage was recorded in the Northern region (60%) compared with the Western region (38.7). Regarding the ratio between the BWAs events reported by media and the number of concerned WSSs, the highest ratio for small size WSSs was recorded in the Northern (2.2) compared with the Southern region (1.2), while for large size WSSs, the highest ratio was in the Western (5.1) compared with the Northern and Southern regions (2.0). More details on BWAs characteristics per region are available in Table 2.

The geographical distribution of BWAs per year differs by region, with lower numbers of BWAs in the Southern region ($n = 28$; range = 0–5) compared with the higher numbers recorded in the Northern region ($n = 347$; range = 10–44), followed by the Eastern ($n = 279$; range = 8–45), Western ($n = 245$; range = 12–41) and Central regions ($n = 209$; range = 13–24). In 2019, the highest number of BWAs was registered in the Eastern and Western regions (Table 2). Considering the population served by WSSs triggering a BWA event, the most affected region for small size WSSs is the Northern followed by the Central, Western, Eastern and Southern regions. While the most affected regions per large size WSSs are the Eastern, Northern and Central followed by Southern and Western regions (Figure 3).

Time-series analysis of BWA reporting rates

We observed an increasing monthly trend (per month, aRR = 1.005; CI 95% 1.003–1.006) with higher BWA reporting rates in summer (aRR = 2.10; CI 95% 1.73–2.56) and autumn (aRR = 2.08; CI 95% 1.71–2.54) compared with winter. In addition, we observed higher reporting rates in the Eastern (aRR = 1.33; CI 95% 1.09–1.63) and Northern (aRR = 1.67; CI 95% 1.37–2.02) regions and lower rates in the Southern (aRR = 0.13; CI 95% 0.09–0.20) region compared with the Central region (Table 3, analysis a). We observed similar results for the BWAs issued in large water supplies and small water supplies regarding the trend and seasonality (Table 3, analysis b and c); however, small differences were found regarding the regions. We observed that the reporting rates of BWAs in large water supplies were higher in Eastern and Western regions and lower in the Southern region compared with the Central region. The reporting rates of BWAs in small water supplies were lower in Eastern and Southern regions, and higher in the Northern region compared with the Central region.

DISCUSSION

In the present study, we analysed published media reports to assess BWAs issued in Norway during the 11-year period from 2008 to 2019. We identified a total of 1,108 BWAs, providing new information regarding the nature of BWAs in Norway, such as frequency and duration, trends, seasonality, causes and their spatio-temporal distribution.

We observed an increasing trend of BWAs during the study period (monthly trend aRR 1.005) but with a decreasing trend in duration. The peak observed in 2011 was likely due to a particularly long period of BWAs caused by the long-term use of a reserve water source lacking adequate disinfection. The highest number of BWA events in 2019, as observed in the present study, was likely due to a large waterborne *Campylobacter* outbreak that occurred in June (Hyllestad *et al.* 2020). This outbreak may have influenced the level of preparedness among the water suppliers, following national interest and media coverage of the outbreak. The observed overall increase is in line with a Canadian study on trends of BWAs also reporting an increasing number of BWAs in the period 2004–2013 which may reflect an increased effort in drinking water monitoring (Galway 2016). Water sampling and analysis are widely conducted among the water supplies in Norway according to the

Table 2 | Summary of BWAs characteristics per region and size of water supply system in Norway, 2008–2019

BWA characteristics per region and size	Centre	East	North	South	West	Norway
Small size Water Supply System (WSS)[a]						
Total number of small WSSs[b] (%)	482 (18%)	1,028 (38%)	582 (21%)	98 (3.6%)	526 (19%)	2,716
Number of WSS linked to BWA events (%)	93 (24%)	64 (16%)	136 (35%)	12 (3%)	85 (22%)	390
Percentage of WSSs linked to BWA events	19%	6%	23.4	12.2	16.2	14.4
Number of BWA events	159	108	303	14	169	753
Number of BWA events/number of WSSs linked to BWA events	1.7	1.7	2.2	1.2	2.0	1.9
Number of BWA events/number of total WSSs	0.3	0.1	0.5	0.1	0.3	
Number of recurrent BWA events						
1	57	39	72	10	46	224
2–3	29	21	40	2	30	122
4–6	5	4	18	–	6	33
7–10	2	–	4	–	2	8
>10	–	–	2	–	1	3
Large size Water Supply System (WSS)[c]						
Total number of large WSSs[b] (%)	23 (14%)	83 (50%)	15 (9%)	14 (8.4%)	31 (18.7%)	166
Number of WSSs linked to BWA events (%)	12 (7%)	47 (54%)	9 (10.3%)	7 (8%)	12 (7%)	87
Percentage of WSSs linked to BWA events	52.2	56.6	60	50	38.7	52.4
Number of BWA events	28	154	18	14	61	275
Number of BWA events/number of WSSs linked to BWA events	2.3	3.3	2.0	2.0	5.1	3.2
Number of BWA events/number of total WSSs	1.2	1.6	1.2	1.0	2.0	
Number of recurrent BWA events						
1	4	18	4	2	4	32
2–3	5	12	5	5	5	32
4–6	3	11	–	–	–	14
7–10	–	4	–	–	1	5
>10	–	2	–	–	2	4

[a]Water supply systems serving equal or less than 5,000 inhabitants, including small systems serving less than 50 persons.
[b]Data on size of water supply systems are collected from the administrative database of water supplies in Norway (Norwegian Institute of Public Health 2019).
[c]Water supply serving more than 5,000 inhabitants.

regulation; therefore, the increasing trend cannot explicitly be explained by monitoring alone. The increase of numbers of BWAs, with shorter duration, may reflect a growing practice of issuing precautionary BWAs, particularly because of pipe breaks with a suspected risk of contamination. In Norway, attention to the drinking water distribution system as a risk factor for gastrointestinal illness has increased, in particular after an early study on the risk of gastrointestinal illness after breaks and maintenance of the distribution system (Nygård *et al.* 2007). As a consequence, the recent update of the Norwegian Drinking Water Regulation, which was enforced in 2017, clearly states that the public shall be notified when suspecting contaminated drinking water that may jeopardise human health, and proper action should be taken (Lovdata 2017).

We also cannot exclude that change in climatic factors, such as increasing events of extreme precipitation, could have played a role, yet this alone does not explain the number of BWAs. Changes in climate parameters, such as rainfall, are predicted to become more frequent and extreme (Kelemen *et al.* 2009). Studies have shown that the microbial load such as faecal indicator bacteria increase in water bodies after rainfall (Kistemann *et al.* 2002; Tryland *et al.* 2011). For example, the Central and Eastern regions of Norway are remarkably drier areas in terms of rainfall than the Western region. In the Western region, the yearly precipitation is higher than the other region, while extreme rainfall may occur also in the dry areas. In Norway, surface water such as lakes are widely used for source water to drinking water production. Studies indicate that the source water will be affected by extreme weather events by an increase in faecal indictor bacteria, while on the other side,

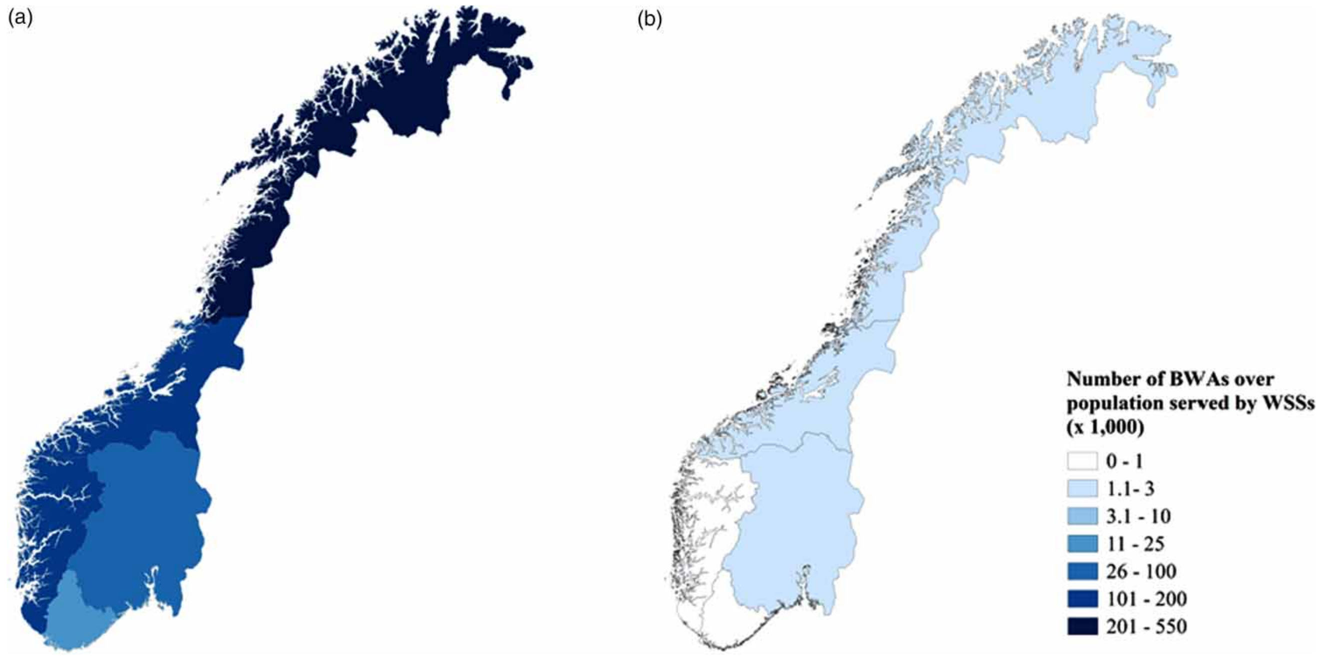

Figure 3 | Cumulative number of BWAs events per region over the average population served by small (a) and large (b) WSSs triggering the BWA event reported by media, Norway, 2008–2019.

Table 3 | Time-series analysis of BWAs reported through the media in (a) all types of water supplies, (b) large water supplies and (c) small water supplies, Norway, 2008–2019

	(a) All water supplies (*N* = 1,108)		(b) Large water supplies (*n* = 273)		(c) Small water supplies (*n* = 775)	
Variables	**Number of BWAs (%)**	**aRR (CI 95%)**	**Number of BWAs (%)**	**aRR (CI 95%)**	**Number of BWAs (%)**	**aRR (CI 95%)**
Trend (month year)	1,108 (100%)	**1.005 (1.003–1.006)**	273 (100%)	**1.01 (1.01–1.01)**	755 (100%)	**1.002 (1.000–1.004)**
Seasons						
Winter	176/1,108 (16%)	Ref	48/273 (18%)	Ref	119/755 (16%)	Ref
Spring	181/1,108 (16%)	1.02 (0.82–1.28)	48/273 (18%)	1.02 (0.67–1.55)	114/755 (15%)	0.95 (0.72–1.25)
Summer	375/1,108 (34%)	**2.10 (1.73–2.56)**	**79/273 (29%)**	**1.65 (1.12–2.41)**	267/755 (35%)	**2.24 (1.77–2.83)**
Autumn	376/1,108 (34%)	**2.08 (1.71–2.54)**	**98/273 (36%)**	**2.03 (1.40–2.94)**	255/755 (34%)	**2.11 (1.67–2.68)**
Geographic location – Regions						
Centre	209/1,108 (19%)	Ref	28/273 (10%)	Ref	162/755 (21%)	Ref
East	279/1,108 (25%)	**1.33 (1.09–1.63)**	152/273 (56%)	**5.48 (3.61–8.33)**	114/755 (15%)	0.68 (0.53–0.89)
North	347/1,108 (31%)	**1.67 (1.37–2.02)**	18/273 (7%)	0.65 (0.35–1.18)	309/755 (40%)	**1.90 (1.53–2.36)**
South	28/1,108 (3%)	**0.13 (0.09–0.20)**	14/273 (5%)	**0.50 (0.2–0.96)**	14/755 (2%)	**0.09 (0.05–0.15)**
West	245/1,108 (22%)	1.16 (0.95–1.43)	61/273 (22%)	**2.18 (1.38–3.46)**	176/755 (23%)	1.05 (0.83–1.33)

Note 1: aRR, adjusted rate ratio; CI, Confidence interval. aRRs in bold were statistically significant (p-value <0.005).

Note 2: There are 1,090 BWAs concerning a single water supply, 16 BWAs concerning two water supplies and two BWAs concerning three water supplies. Thus, the total of 1,108 unique BWAs affected a total of 1,128 water supplies.

Note 3: Based on the media reports, we were unable to determine the ownership of 71 of the affected water supplies, and here, 955 were publicly owned and 102 privately owned.

Note 4: Based on the media reports, we were unable to determine the size of 80 of the affected water supplies, and here, 273 were large and 775 small.

the drinking water treatment systems are anticipated to cope with this increase (Guzman-Herrador *et al.* 2021). The same assumption of uncertain weather patterns representing stressors to WSSs has been previously reported (Levy *et al.* 2016), in particular in relation to ageing drinking water reservoirs (Renwick *et al.* 2019). However, the hypothesis of a combination of weather conditions resulting in an increased number of contamination events triggering BWAs has not yet been studied in a Norwegian setting. We consider that the differences in the geographical regions can mostly be attributed to the distribution of water supplies (size and population covered), but this needs to be explored further.

We observed a seasonal pattern of BWAs, both in the descriptive and time-series analysis of BWA reporting ratios, with increasing numbers starting of BWAs from May with a peak in August and decrease to December, caused by detection of faecal indicator bacteria, which also accounts for the most frequent cause for issuing a BWA, while the other reported reasons remain more stable during the year, such as the risk of intrusion of the distribution system. In Norway, the water bodies are affected by snow thaw in the spring and rainfall during fall which is causing runoff from surfaces. The more frequent issuing of BWAs due to detection of faecal indicator bacteria may be linked to such weather conditions challenging the water treatment capacity (Levy *et al.* 2016) or intrusion to leaky parts of the drinking water distribution system (Ercumen *et al.* 2014) and installation such as water storages which are normally not protected by positive pressure. The drinking water distribution system in Norway is ageing and vulnerable to sudden pipe breaks and pressure loss situations, and there is a growing concern directed at an ageing distribution system with a low renewal rate, among other issues, has a leakage proportion of more than 30% (Norwegian Institute of Public Health 2019), which may explain the high number of BWAs linked to risk of intrusion of the distribution system.

The most frequently reported known reasons for the main frequent cause for BWAs, detection of faecal indicator bacteria (42.6%), were weather event and technical malfunction. While for risk of intrusion to the distribution systems (21%), the most frequently reported reasons were pipe break, maintenance work and weather events. The high number of unknown reasons for the category detection of faecal indicator bacteria is somewhat expected since during routine monitoring water sampling the findings not necessarily will be revealed despite efforts for troubleshooting. In contrast, only a few of the BWAs issued due to the risk of intrusion to the distribution system had unknown reasons reported by the media. The proportion of BWAs where no cause or reason were reported in the media report, represent a void in the understanding of the underlying problems in the drinking water supplies. To close this knowledge gap, reporting on BWAs could benefit from being a formal obligation of the drinking water supplier to NFSA (for example, during the annual reporting) which could have secured accurate and complete information on BWAs in Norway.

Overall, we observed higher reporting rates of BWAs in the Northern region, both for large and small WSSs, which is challenging to explain. It might be that the WSS is more prone to BWAs or it could, on the other hand, be a result of more robust emergency response capacity. In the latter, this would be in contrast to assessments where smaller WSSs have a common challenge when it comes to managerial and financial resources making them more vulnerable (WHO-ROE 2016). At the same time, there is a low ratio of BWAs for large WSSs meaning fewer recurrent BWAs for the same large WSS. Although for large size WSSs, the Western region had the lowest percentage of WSSs linked to BWAs (38.7%), it was also characterised by the highest ratio (5.1), meaning that more recurrent episodes concerning the same WSSs occurred during the study period. While the South region had the lowest ratio both for small and large size, meaning fewer recurrent episodes per WSS. Regarding issued BWAs based on population served (Figure 3), the number of BWAs were more concerning small WSSs than large size WSSs, particularly for the North region. Even though the large size WSSs recorded lower BWA events, they could potentially affect a large number of individuals; therefore, the importance should not be underestimated.

This study highlights the use of publicly available media reports to assess the nature of BWAs in Norway without the use of traditional and usually resource-heavy, surveys or questionnaires. However, there are several limitations to the present study. First, the assessment of BWAs based on media reports only includes BWAs where the water suppliers have chosen to use the (local) media newspaper to alert the public. Second, the classification of causes for the issued BWAs may be prone to misclassification while assessing the media report for information because this part of the analysis was conducted manually for each media report. Moreover, the media may describe the events that have led to a BWA event not necessarily using a scientific language or technical terminology. This implies that when extracting data, there might be challenges to classify the event. In addition, we report the main cause for the issued BWA, but it might be also some bias there if two causes were equally important factors. This is a common feature within water supply, which is a dynamic system and it is not likely to a clear-cut explanation for every operational deficiency. We believe that this may have affected the precision regarding the cause and reasons for BWAs, particularly for the classification containing low numbers of BWAs.

It is also worth highlighting that the interpretation of the results can be challenging. For example, having more BWAs could mean that there are more worrying issues in the WSSs, while on the other hand it could also imply that the precautionary principle on prevention is more used, hence being more proactive in protecting the served population against potential exposure. In addition, the mode of communication over the internet favours an effective distribution of BWAs, which in itself could have played a role in the increase of BWAs. Finally, the findings on numbers of BWAs based on population served might have been influenced by different population density in urban and suburban areas in each region. Such phenomena could be further explored in future studies.

Despite deficiencies in using BWAs as a proxy (such as inconsistent reporting) for the reliable access to safe drinking water, such as inconsistent reporting of BWAs, information may support regulatory agencies and water safety planners in their strategies to ensure safe drinking water. To ascertain effective public compliance to BWAs, although a limited studied area, but that highlight the importance of awareness and perception impacting the effectiveness of BWAs (Vedachalam *et al.* 2016), the World Health Organization (WHO) encourages water suppliers to develop clear protocols, in conjunction with local health authorities, for when to issue and lift BWAs (World Health Organization 2011).

In Norway, a general interest in looking into the issuance of BWAs increased among water suppliers, risk assessors and media in recent years, particularly after a large waterborne outbreak in 2019 in Norway (Hyllestad *et al.* 2020). In addition, a discussion on the use – and possible need – of precautionary BWAs after low-pressure situations in the drinking water distribution systems is currently ongoing among the water suppliers in Norway. Data from this study serve in that respect as documentation for trends, such as an observed increase in the total number of BWAs. The study also highlights that future monitoring of drinking water quality data should include minimum characteristics for BWAs and such data could potentially form a basis for the development of national guidelines on the issuance and lifting of BWAs, which is currently lacking in Norway.

CONCLUSION

In this study, we have described the nature and trends of BWAs in Norway based on media reports. The study demonstrates an increasing trend of BWAs in Norway, most frequently used as a response to detection of faecal indicator bacteria in the water distribution system typically during summer months. While the second most frequent cause for issuing BWAs was the risk of intrusion of contaminants into the drinking water distribution system. There are geographical differences in the ratio in issuing BWAs, more concerning small WSSs and populations. Future studies exploring the issuance of BWAs in case of pipeline breakages and its correlation with environmental and/or weather conditions including extreme precipitation events might add to the discussion on the reasons for the increase of BWAs, particularly in the Northern Norwegian region. Finally, this study could serve as supplementary information to better understand the overall status of Norwegian WSSs particularly in case of recurrent BWA's events, as well as suggest the relevance of BWAs' monitoring in identifying risk factors and planning targeted interventions. Reporting on BWAs should be obligatory in the annual reporting to the Norwegian Food Safety Authority to ensure accurate and complete information on the BWAs for future assessments.

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AUTHORS' CONTRIBUTIONS

S.H. designed and led the study and retrieved the empirical corpus. S.S.K. screened the media reports and collected data for the study. E.A., L.V. and S.K.K. analysed the data. S.H. drafted the first version of the manuscript. All authors critically reviewed the manuscript and approved its final version.

COMPETING INTERESTS

The authors claim no competing interest in the study.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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