Community Dental Health (2022) **39**, 106–112
Received 4 October 2021; Accepted 6 November 2021
© BASCD 2022
doi:10.1922/CDH_00267Nyakutsikwa07

Water fluoride concentrations in England, 2009-2020

Blessing Nyakutsikwa, Tanya Walsh, Iain Pretty and Deborah Moore

Division of Dentistry, The University of Manchester, UK

Objectives: Contemporary research, surveillance and monitoring of water fluoridation requires an understanding of the population coverage of this intervention. The aims of this research are to create the first publicly available record of water fluoride concentrations in England and to describe and visualise the observed variation in water fluoride concentrations and optimal fluoridation (>/= 0.7 mg F/L) between 2009-2020. ***Basic research design***: Routine water quality sampling data were requested from water companies in England from 2009-2020 under the provisions of the Environmental Information Regulations 2004. Fluoride concentrations of Water Supply Zones (WSZs) were assigned to Lower Super Output Areas (LSOAs) using population-weighted centroids. ***Results***: Between 2009-2020 4247 LSOAs (12.9%) had an annual mean water fluoride concentration of >/= 0.7 mg F/L in at least one year, and 3019 LSOAs (9.1%) had a grand mean fluoride concentration of >/= 0.7 mg F/L. Coverage of optimal fluoridation varied over time; from 10.9% of LSOAs in 2014 to 6.3% in 2016. ***Discussion***: This study confirms previous work identifying variability in the coverage and achieved concentrations of water fluoridation programmes. The current provision for accessing, collating and utilising these data are a barrier to essential monitoring, surveillance and research. An annually maintained and publicly accessible database of water fluoride concentrations is urgently required.

Keywords: *Oral health, water quality, public health, Fluoridation*

Introduction

Water fluoridation has been highlighted as one of the greatest success stories in 20th century public health (Centers for Disease Control and Prevention, 2018). The ability of fluoride to prevent dental caries, or tooth decay, was first identified in a series of US epidemiological studies conducted throughout the 1930s and 40s (Dean *et al.*, 1950). These studies found that in communities where the drinking water naturally contained 1.0 to 1.2 milligrams of fluoride per litre (mg F/L), the prevalence of dental caries was around 50% lower (Dean *et al.*, 1950). As a result of this work, the first public health programme to increase the fluoride concentration of drinking water was implemented in Grand Rapids, Michigan, in 1945. Programmes to adjust the fluoride levels of drinking water to prevent caries have subsequently been implemented in 25 countries around the world. Coverage is highest in North America and Australia, where schemes reach 74% and 89% of the population respectively (British Fluoridation Society, 2012).

Despite the long history and recognised success of water fluoridation, it is important that research remains applicable. The context in which water fluoridation is operating has changed dramatically in the years since it's inception. Fluoride containing toothpastes have been widely available since the mid 1970s, and other highly effective topical fluoride products such as varnishes, mouthwashes, and higher-strength prescription only toothpastes have now been added to the range of fluoride delivery options. Increased availability of topical fluorides is widely considered to be the major factor behind the dramatic improvements that have been observed in population oral health in the last four decades (Bratthall *et al.*, 1996). The need for more contemporary research on the health effects and economic case for water fluoridation in populations who are also using topical fluorides was first articulated in a report by the UK Medical Research Council in 2002 (Medical Research Council, 2002). A 2015 Cochrane systematic review of water fluoridation again highlighted that the majority of the studies included in the review had been conducted prior to 1975 (Iheozor-Ejiofor *et al.*, 2015).

One of the challenges in undertaking research on water fluoridation is determining which populations and / or individuals have been exposed to the intervention (Moore *et al.*, 2021). It has been estimated that around 10% of the UK population receive optimally fluoridated water (British Fluoridation Society, 2012). Most of this (95%) results from public health programmes, with a small (5%) contribution from naturally fluoridated water (British Fluoridation Society, 2012). However, recent research has identified variation in the fluoride concentration of artificially fluoridated water, which suggests that this coverage estimate may be optimistic (Public Health England, 2018; Moore *et al.*, 2019).

The long term dose monitoring records (18-35 years) of eight water treatment works adding fluoride as part of a public health programme revealed that the proportion of samples falling within the optimal range of 0.7-1.0 mg F/L ranged from 27% to 77.8% (Moore *et al.*, 2019). Furthermore, a recent statutory health monitoring report found that 936 (23%) of Lower Super Output Areas (LSOAs) identified as being part of a water fluoridation programme received water with a mean water fluoride concentration of less than 0.7 mg F/L between 2005 and

Correspondence to: Deborah Moore. Email: deborah.moore-2@manchester.ac.uk

2016 (Public Health England, 2018). LSOAs are small area administrative and census geographies in England and Wales that cover populations of around 1,500 individuals (NHS Digital, 2021).

Such studies indicate that a more detailed understanding of the water fluoride concentrations achieved as part of public health programmes in England is required. This is necessary for research purposes, but also in terms of monitoring the implementation and effectiveness of a publicly funded intervention. At present, there is no publicly available record of water fluoride concentrations in England. The dual aims of this research are to compile such a record and to describe and visualise geographic variation in water fluoride concentrations and optimal fluoridation (>/= 0.7 mg F/L) between 2009 and 2020.

The objectives were to:

1. Compile and create a publicly available record of water fluoride concentrations in Lower Super Output Areas (LSOAs) in England from 2009-2020**;**
2. Describe and visualise the variation in fluoride concentrations of water supplies in England between 2009 and 2020**;**
3. Identify which areas within England were optimally fluoridated between 2009 and 2020.

Methods

The geographical units used to describe water of a "similar nature and treatment" are Water Supply Zones (WSZs) (Drinking Water Inspectorate, 2018). WSZs do not align with any other administrative geographies and their names and boundaries change over time (Drinking Water Inspectorate, 2018). Regulations specify that water companies must review their WSZs annually to ensure they contain relatively uniform water from one source and that the population covered does not exceed 100,000. Any zones that no longer meet these requirements must be split into new zones or merged. Water quality regulations specify a minimum number of samples per year, per WSZ, based on population size (Drinking Water Inspectorate, 2018). The samples are taken from the taps of consumers living within the WSZ or can be taken from a supply point higher up in the network, as long as the water at the supply point is the same as within the WSZs. The water companies must report their WSZ designations and the sampling data annually to the Drinking Water Inspectorate (DWI).

We requested data on water fluoride concentrations from the DWI, Public Health England (PHE), and the 24 water suppliers listed by water regulators in England and Wales, OFWAT (OFWAT, 2021). We made our requests under the Environmental Information Regulations (EIR) 2004, via the "What Do They Know" website (mySociety, 2020) and direct emails. We asked for consumer tap sample data on water fluoride concentration (mg F/L) for every WSZ, for every year from 2009-2020, supplied as Microsoft Excel files containing supply zone names and zone codes. When consumer tap samples were unavailable, we requested supply point samples of water fluoride data and a corresponding list of WSZs supplied by these supply points. We requested raw sample data on water fluoride concentrations where possible, rather than the annual summaries of the sample data. To enable the WSZ data to be mapped onto LSOAs, we requested GIS maps (shapefiles) of the WSZ boundaries, for every year from 2009 to 2020. GIS shapefiles show the WSZ boundaries as polygons. A polygon is a series of X (easting) and Y (northing) coordinate pairs that enclose a geographical area.

Upon receipt of the files from each supplier, data were cleaned so that the water fluoride sample data could be matched with the GIS shapefiles. When discrepancies such as differences in zone names and/or codes between the files were detected, we made requests to the water supplier seeking clarity and subsequently modified the files to facilitate linkage. We then created annual descriptive summaries of the fluoride concentration (mg F/L) for each WSZ (mean, median, SD, min, max, Q1, Q3) in R Studio. In some cases, the water companies supplied the data already summarised as annual means, which were also uploaded into R Studio. The summarised water fluoride concentration data were then merged with the shapefiles using the WSZ codes or names as the joining variable. The geographical projection of these shapefiles was adjusted to the OSGB 1936 / British National Grid when necessary (Lansley and Cheshire, 2016; Brunsdon and Comber, 2019a).

We then identified the WSZ of each LSOA; because WSZ boundaries and LSOA boundaries are not co-terminus, we used the 2011 Office for National Statistics (ONS) LSOA population-weighted-centroids (LSOA-PWC) shapefile (Office for National Statistics, 2020c) to link the two geographies. This shapefile contains a single geographic point on the ground where the median distance between all LSOA population members was lowest in the 2011 census (i.e. the weighted centre of where the population resides) (Office for National Statistics, 2017). We used the spatial intersection method (Brunsdon and Comber, 2019b) in R to combine the LSOA-PWC shapefile with the WSZ shapefiles and then assigned the annual mean water fluoride concentration (mg F/L) to each LSOA. The individual files for each water company were then combined, resulting in the final dataset containing fluoride concentrations for English LSOAs from 2009-2020. Where possible (i.e., when raw sample data had been provided), this included mean, median, SD, min, max, Q1, Q3. Maps were then created to allow visualisation of the data using the tmap package in R Studio and the ONS LSOA 2011(Office for National Statistics, 2020b) and Local Authority District (LAD) 2020 boundaries shapefiles (Office for National Statistics, 2020a). Estimates of the proportion of the population receiving optimally fluoridated water were created by linking LSOA water fluoride concentrations to ONS LSOA population estimates (ONS, 2021).

Results

PHE and the DWI were not able to supply the information that we requested and advised that we contact the water suppliers directly. Of the 24 water suppliers listed for England and Wales on the OFWAT website, initial enquiries revealed that several had been subsumed into larger companies, one did not supply any areas within England and some supplied small areas of private land, for example, business parks. Seventeen companies were able to supply WSZ shapefiles and water fluoride concentration data. The WSZ shapefiles that we obtained covered 32,789 of the 32,844 LSOAs in England (99.8%). Areas that were not covered included the Isles of Scilly, national parks, mountainous areas and private water supplies.

In addition to the WSZ maps (shapefiles), fluoride sample data were supplied in corresponding Excel files. Twelve companies provided individual fluoride samples, three supplied summarised annual means, and two supplied a combination of individual samples and annual means. These data comprised 164,111 individual fluoride concentration samples and 3027 annual mean records. Fourteen companies supplied samples taken from consumer taps, one company supplied samples taken at supply points further upstream in the network and indicated which WSZs they related to, and two companies supplied a combination of supply point and consumer taps samples. Where raw sample data was provided, the mean number of samples provided for each WSZ, per year, was 11.07, but this ranged from 1 to 184.

Water fluoride concentration sample data could be mapped to over 99% of LSOAs in England (32,844) between 2011 and 2019. The data were less complete in 2009 (81%), 2010 (97.7%) and 2020 (80.5%) (Table 1) because several water companies could not locate the 2009 and 2010 fluoride sample information and in 2020, some companies had not yet collated their data at the time of the request.

The database of water fluoride concentrations of LSOAs in England 2009-2020 created as a result of this work is publicly available via the University of Manchester Open Data Repository, Figshare (Nyakutsikwa, 2021).

Table 1. Data completeness by year

Year	*Number of LSOAs with water fluoride concentration data available (% of England LSOAs)*
2009	26546 (80.8)
2010	32019 (97.5)
2011	32553 (99.1)
2012	32565 (99.2)
2013	32566 (99.2)
2014	32720 (99.6)
2015	32709 (99.6)
2016	32667 (99.5)
2017	32668 (99.5)
2018	32722 (99.6)
2019	32789 (99.8)
2020	26384 (80.3)

Figure 1 illustrates the mean water fluoride concentration (mg F/L) of LSOAs in England between 2009-2020. The mean uses the most complete data available; for 65.3% of LSOAs, fluoride samples were available in every year 2009-2020. For areas where data was not available for every year, the mean is based on samples from between 1 and 11 years. Areas where we were not provided with a WSZ map that could be linked to an LSOA are shown in Figure 1 as white.

In addition to the higher levels of fluoride (>/= 0.7 mg F/L) which are most commonly found in areas with a water fluoridation programme, there is variation within the lower levels of naturally occurring fluoride (Figure 1). The South and East of England had higher levels of naturally occurring fluoride than the North and South West. Although 1 mg F/L is the target concentration for water fluoride programmes in England, a lower threshold of 0.7 mg F/L has been used as the exposure classification in recent analyses in England (Public Health England, 2018; Weston-Price *et al.*, 2018). Therefore, this threshold will be used to define 'optimal' fluoridation in later analyses.

The maximum permitted level of fluoride in drinking water in England is 1.5 mg F/L (The National Archives, 2016). The highest annual mean fluoride concentration was 1.2 mg F/L, in naturally fluoridated Hartlepool, in 2016. The highest individual fluoride measurements, of 2 mg F/L, were recorded in two areas in 2020. However, these high individual measurements appear to be outliers as the annual means were 0.38 mg F/L (Maldon) and 0.34 mg F/L (Canterbury).

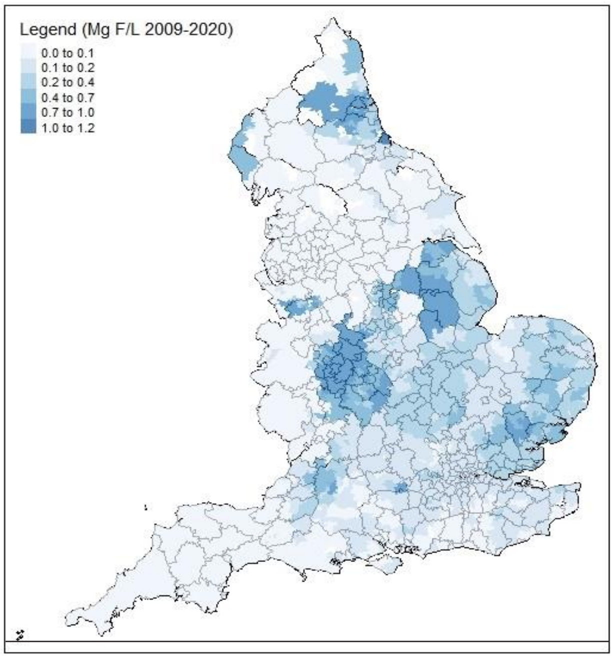

Figure 1. Grand mean water fluoride concentration (mg F/L) of English LSOAs with Local Authority District boundaries (2020) overlaid.

Figure 2 illustrates the proportion of LSOAs in England that had fluoride sample data available and had an annual mean water fluoride concentration of 0.7 mg F/L and above, in each year from 2009-2020. Excluding 2009 and 2020 because fluoride samples were only available for 80% of LSOAs, the year with the highest coverage of optimally fluoridated water (>/= 0.7 mg F/L) was 2014 (10.9% of LSOAs). The lowest coverage of optimally fluoridated water was in 2016 (6.3% of LSOAs).

The extent of geographic variation in the coverage of optimal water fluoridation between 2014 and 2016 can be visualised in Figure 3. LSOAs with a mean water fluoride concentration of >/=0.7 mg F/L are highlighted in blue. The proportion of the England population receiving fluoridated water was estimated to be 10.9% in 2014 and 6.3% in 2016 (ONS, 2021).

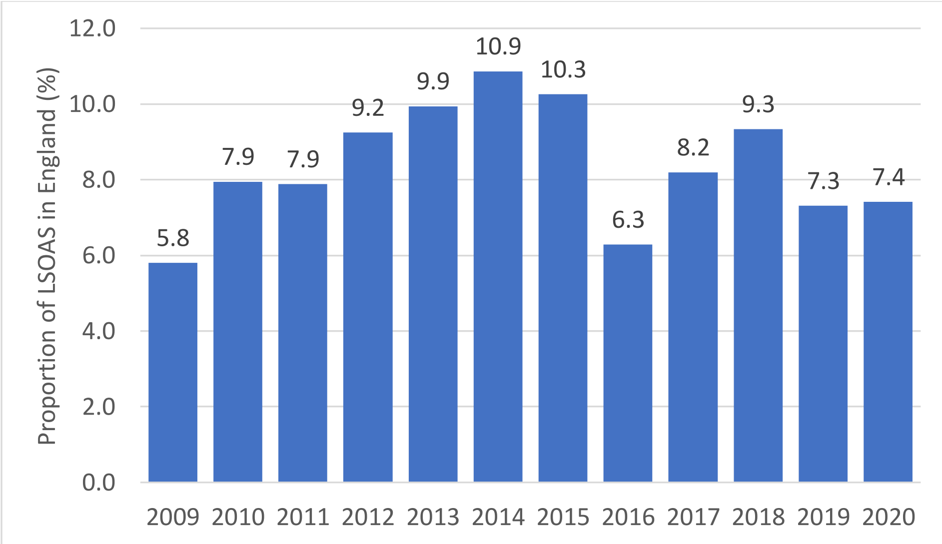

Figure 2. The extent of optimal water fluoridation in England (>/= 0.7 mg F/L), by year 2009-2020. Note that in 2009 and 2020 fluoride sample data were supplied for only 80% of LSOAs in England.

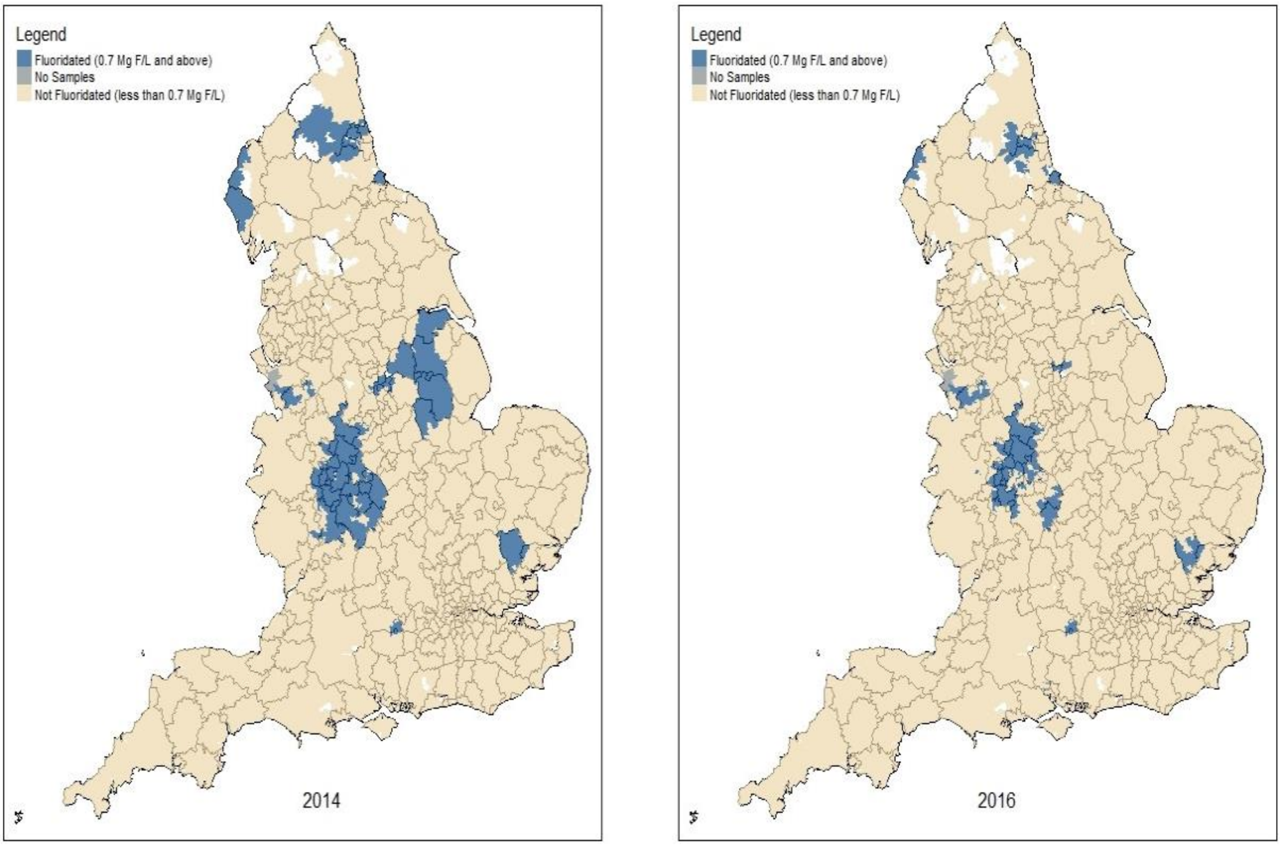

Figure 3. Geographic coverage of optimally fluoridated water (>/= 0.7 mg F /L) in 2014 and 2016.

Across the full period of 2009-2020 4247 LSOAs had an annual mean water fluoride concentration of 0.7 mg F/L or above in at least one year (12.9% of LSOAs in England). These ‘ever fluoridated’ LSOAs can be considered to represent the maximum extent of water fluoridation in England between 2009 and 2020. Over the same period, 3019 LSOAs had a grand mean water fluoride concentration of 0.7 mg F/L or above (9.2%). These ‘optimally fluoridated’ LSOAs represent 71.1% of the ‘ever fluoridated’ category. The geographic coverage of the ‘ever fluoridated’ and ‘optimally fluoridated’ LSOAs, overlaid with Local Authority District (LAD) Boundaries (2020) is shown in Figure 4.

The LADs that can be demonstated to have been wholly optimally fluoridated between 2009-2020 are: East Staffordshire, Lichfield, Cannock Chase, Tamworth, Birmingham, Sandwell, Dudley, Bromsgrove, North Kesteven, Newcastle upon Tyne and Hartlepool.

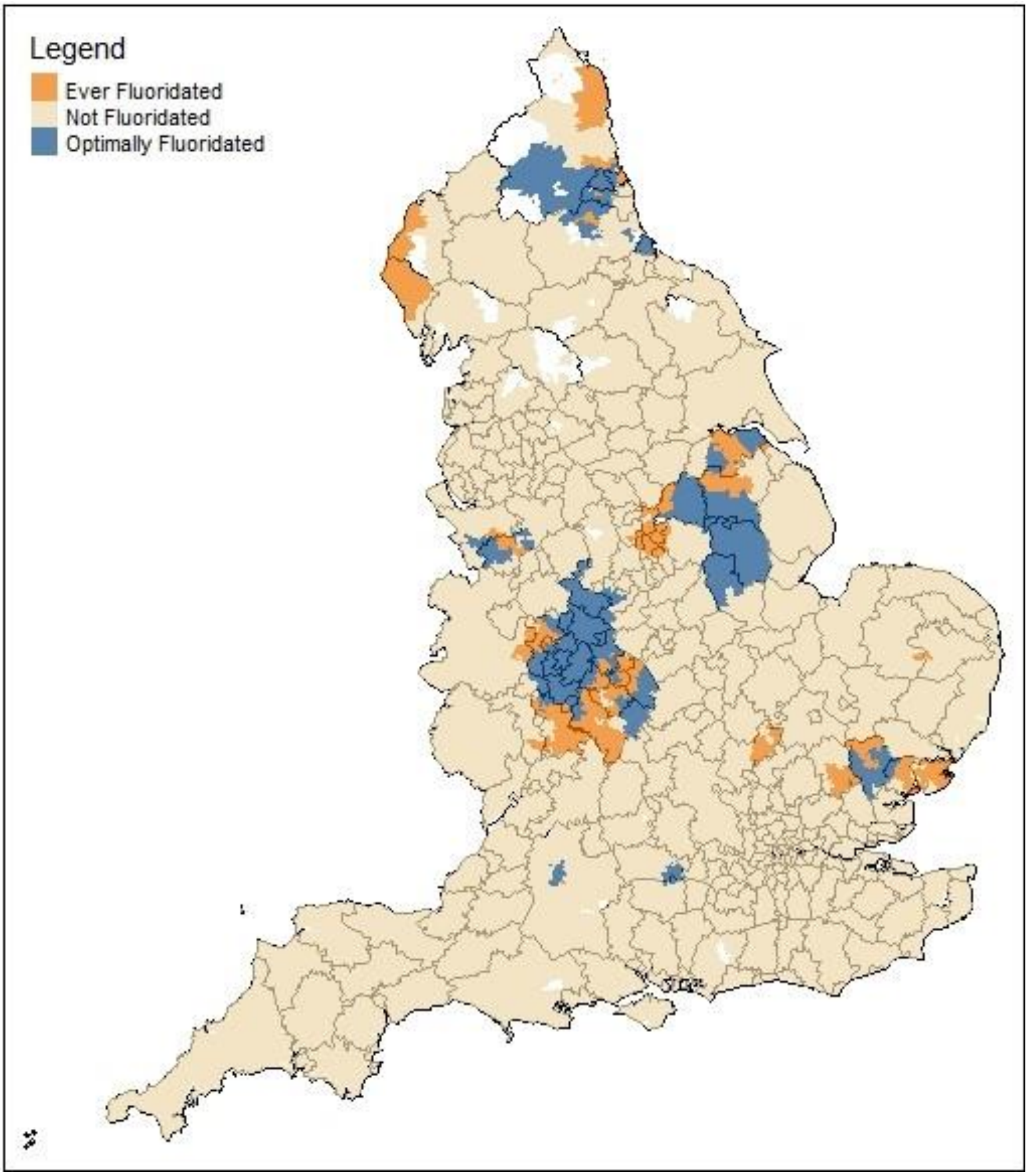

Figure 4. Ever fluoridated and optimally fluoridated LSOAs in England between 2009 and 2020 (mapped at LSOA level with 2020 LAD boundaries overlaid). Ever fluoridated = any year with annual mean water fluoride concentration of >/= 0.7 mg F/L. Optimally fluoridated = Grand mean water fluoride concentration of >/= 0.7 mg F/L.

Discussion

This is the first time that a record of the water fluoride concentrations of small area administrative geographies in England (LSOAs) has been collated and made publicly available. The data that we compiled cover 99.8% of LSOAs in England. Over the twelve-year period for which we requested data 12.9% of LSOAs received water with a grand mean fluoride concentration of 0.7 mg F/L or above. The grand mean masks wide variation in the coverage of optimal water fluoridation over time, from 10.9% of LSOAs in 2014 to 6.3% of LSOAs in 2016. The proportion of ever fluoridated LSOAs (annual mean of 0.7 mg F/L and above in at least one year) that were optimally fluoridated (grand mean 0.7 mg F/L and above between 2009 and 2020) was 71.1%. The fluoride concentration of naturally fluoridated water has been found to exhibit less variability over time than water fluoridated as part of a public health programme (Moore *et al*., 2019; Roberts *et al*., 2020). Therefore, the observed variability in optimal fluoride levels between 2009 and 2020 in England is most likely caused by unwanted disruptions in the implementation of water fluoridation programmes rather than natural variation.

The method we used to map water fluoride concentrations follows that of Roberts et al. (2020), who identified 3261 LSOAs that had a period mean fluoride concentration of 0.7 mg F/L or above between 2005 and 2015. In the present study we identified slightly fewer, at 3019 (2009-2020). This difference could be due to greater disruption in the period covered by our analysis or may be due to limitations in the available data. Roberts et al. reported that 4005 LSOAs were identified as being included in a water fluoridation programme using a binary 'fluoridation' identifier supplied by the DWI, which we also requested, but the DWI could not supply. Roberts et al. reported that 77% of LSOAs included in a fluoridation scheme had received optimally fluoridated water between 2005 and 2009. However, this proportion was calculated after seven WSZs known to have had significant disruptions to their fluoridation operations had been excluded (Public Health England, 2018; Roberts *et al.*, 2020).

Despite slight differences in our estimates of the extent of optimal fluoridation, the present study and Roberts et al. both found significant variability in the implementation of water fluoridation over time (Roberts *et al.*, 2020). This confirms previous work using dosing records from water treatment works (Moore *et al*., 2019). Disruptions to the supply of optimally fluoridated water may be caused by equipment failures, flooding at water treatment works, shortages in the supply of approved fluoride chemicals, lack of trained operators or droughts, which may require the temporary utilisation of unfluoridated supplies from neighbouring areas. Several studies now support the assertion that reliance on knowledge of planned or historical water fluoridation coverage is insufficient when attempting to classify exposure to water fluoridation (Public Health England, 2018; Moore *et al*., 2019; Roberts *et al.*, 2020). Despite this recognition, sourcing the data needed to more accurately assign exposure to water fluoridation is not straightforward.

Public Health England were unable to share the data that they collated up to 2015 (used in the 2018 health monitoring report) due to the restrictions of their data sharing agreement with the DWI (G.Leonardi, personal communication, 3rd July 2020). When we submitted a request to the DWI, they advised that the WSZ shapefiles were owned by the water companies and that we should contact them directly under the provisions of the EIR. Contacting the individual water companies was complex due to company mergers, incorrect information on websites and email addresses that were no longer operational. The timeframe for a response to an EIR request is 20 working days, but this can be extended to 40 days if the request is deemed to be 'complex or voluminous' (Information Commissioner's Office, 2021b). In some cases, the initial requests were refused. The reasons included concerns about the potential for terrorist attacks on the water supply, samples being considered as the personal data of consumers, unreasonable burden or information not held. In such cases, we then needed to request an internal review, which can take an additional 40 days. Furthermore, due to the impact of the COVID-19 pandemic, the Information Commissioners Office issued guidance that organisations would be granted additional flexibility on the timeframes required to respond to EIR and FOI requests (Information Commissioner's Office, 2021a). In one case we were asked to sign a non-disclosure agreement requiring us to treat the WSZ information as confidential, even though other companies supplied it without such requirements. In contrast to Roberts et al. (2020) we were not able to source any indicator of which water supply areas were intended to receive fluoridated water as part of a public health programme.

Whilst it did eventually prove possible to obtain most of the fluoride sample data and WSZ shapefiles using the provisions of the EIR, the process was cumbersome, time consuming and unnecessarily difficult. Due to the time and complexity involved, it will not be possible for the authors to maintain the database beyond 2020. Water fluoridation and the prevention of tooth decay at the population level have been highlighted as key priorities for research by both health professionals and the public (Medical Research Council, 2002; The James Lind Alliance, 2018). The difficulties involved in sourcing useable data on water fluoride concentrations and the extent of water fluoridation programmes in England are a significant barrier to research on this important topic.

The UK Government's National Data Strategy articulates the ambition that *"data and data use are seen as opportunities to be embraced, rather than threats against which to be guarded."* (Department for Digital Culture Media and Sport, 2020). A core principal of the strategy is the policy of 'open by default' for public sector data, first articulated in the 2012 Open Data white paper: Unleashing the Potential (U.K. Government, 2012). An annually maintained database of water fluoride concentrations by LSOAs in England is an essential requirement for monitoring, evaluation and research on water fluoridation. Ideally, fluoride monitoring data mapped to LSOAs could be added to a central repository annually by the water companies or the DWI. Alternatively, a national public health body or academic institution could be commissioned to keep an updated and accessible record in a useable format. An example of an academic institution maintaining such a record is that of the Australian Research Centre for Population Oral Health (Do *et al.*, 2017). External monitoring of fluoride levels in Brazil by the University São Paulo was associated with improved dose control and reduced variability in achieved water fluoride concentrations over time (Buzalaf *et al.*, 2013).

There are several strengths of this paper and the dataset produced in this work. Firstly, we followed a previously documented and peer reviewed method for allocating WSZs to LSOAs, using population weighted centroids (Public Health England, 2018; Roberts *et al.*, 2020). Secondly, minimum standards apply to the conduct and accuracy of water quality sampling, according to ISO 17025 and the Drinking Water Testing Specification and adherence to these standards is regulated by the DWI (United Kingdom Accreditation Service, 2013). Thirdly, we clarified any discrepancies with the water companies to ensure the matching of data was as accurate as possible. Finally, in making the database publicly available, we have adhered as far as possible to criteria for best practice, such as the Berners-Lee 5-star scale for Linked Open Data (Berners-Lee, 2009) and principles of data citation (Ball and Duke, 2015). This included making the data available under an open use licence (Creative Commons Attribution 4.0 International), using a machine readable, non-proprietary format (csv rather than Microsoft Excel), providing metadata about the dataset and linking it to other useful information (such as research papers) and using a persistent identifier (DOI number). The limitations of this work are that we were limited by the data that the water companies could provide, in particular, the data are less complete in 2009, 2010 and 2020 and not all WSZs had samples recorded in every year (though in line with water quality regulations, samples are required at greater frequency in more densely populated areas). Other limitations are that inevitably when linking non-aligned geographies, there will be some element of misclassification, i.e. in LSOAs that cross WSZ boundaries.

In conclusion, we have created a database of water fluoride concentrations in England between 2009 and 2020, which confirms ongoing variability over time and geography in the coverage of water fluoridation programmes and resulting water fluoride concentrations. The existing provisions for obtaining and using these data hinder routine surveillance, quality assurance, public scrutiny and research. An annually updated, open data repository of water fluoride concentrations by standard administrative geographies (LSOA or postcode) is urgently required.

Acknowledgements

This study was funded by the National Institute for Health Research (NIHR) Public Health Research programme (NIHR 128533/PHR). We would like to thank the water companies for the information that they provided. The views expressed are those of the author(s) and not necessarily those of the NIHR or the Department of Health and Social Care, or the water companies that supplied information.

References

Ball, A. and Duke, M. (2015): *How to Cite Datasets and Link to Publications*, *DCC How-to Guides*. Edinburgh. https://www.dcc.ac.uk/sites/default/files/documents/publications/reports/guides/How_to_Cite_Link.pdf

Berners-Lee, T. (2009): *Linked Data*. https://www.w3.org/DesignIssues/LinkedData.html

Bratthall, D., Hänsel-Petersson, G. and Sundberg, H. (1996): Reasons for the caries decline: what do the experts believe? *European Journal of Oral Sciences* **104**, 416–422.

British Fluoridation Society (2012): *The extent of water fluoridation*. https://www.bfsweb.org/extent-of-water-fluoridation

Brunsdon, C. and Comber, L. (2019a): Basics of Handling Spatial Data in R, in *An introduction to R for spatial analysis & mapping*. 2nd edn. pp. 55–117. Los Angeles: Sage.

Brunsdon, C. and Comber, L. (2019b): Using R as a GIS, in *An introduction to R for spatial analysis & mapping*. 2nd edn. pp. 148–190. Los Angeles: Sage.

Buzalaf, M.A.R., Moraes, C.M., Olympio, K.P.K., Pessan, J.P., Grizzo, L.T., Silva, T.L., Magalhães, A.C. and de Oliveira, R.C. (2013): Seven years of external control of fluoride levels in the public water supply in Bauru, São Paulo, Brazil. *Journal of Applied Oral Science* **21**, 92–98.

Centers for Disease Control and Prevention (2018): *Community water fluoridation. Fluoridation statistics.* https://www.cdc.gov/fluoridation/statistics/2014stats.htm

Dean, H., Arnold, F.A., Jay, P. and Knuston, J. (1950): Studies on mass control of dental caries through fluoridation of the public water supply. *Public Health Reports* **65**, 1403–1408.

UK Department for Digital Culture Media and Sport (2020): *National Data Strategy*. https://www.gov.uk/government/publications/uk-national-data-strategy/national-data-strategy

Do, L., Ha, D., Peres, M.A., Skinner, J., Byun, R. and Spencer, J.A. (2017): Effectiveness of water fluoridation in the prevention of dental caries across adult age groups. *Community Dentistry and Oral Epidemiology* **45**, 225-323.

Drinking Water Inspectorate (2018): *Guidance on the implementation of the Water Supply (Water Quality) Regulations 2016 (as amended) in England and the Water Supply (Water Quality) Regulations (Wales) 2018*. http://www.dwi.gov.uk/stakeholders/guidance-and-codes-of-practice/wswq/02-zones.pdf

Iheozor-Ejiofor, Z., Worthington, H.V., Walsht, T., O'Malley, L., Clarkson, J.E., Macey, R., Alam, R., Tugwell, P., Welch, V. and Glenny, A.M. (2015): Water fluoridation for the prevention of dental caries. *Cochrane Database of Systematic Reviews* **6**. https://www.cochranelibrary.com/cdsr/doi/10.1002/14651858.CD010856.pub2/full

Information Commissioner's Office (2021a): *ICO regulatory approach during coronavirus*. https://ico.org.uk/media/2617613/ico-regulatory-approach-during-coronavirus.pdf

Information Commissioner's Office (2021b): *Timelimits for compliance. Environmental Information Regulations*. https://ico.org.uk/media/for-organisations/documents/1622/time-for-compliance-eir-guidance.pdf

Lansley, G. and Cheshire, J. (2016): *Practical 7: Using R as a GIS*, *An Introduction to Spatial Data Analysis and Visualisation in R*. London. https://spatialanalysisonline.com/An Introduction to Spatial Data Analysis in R.pdf

Medical Research Council (2002): *Water fluoridation and health*. London. https://mrc.ukri.org/publications/browse/water-fluoridation-and-health/

Moore, D., Allen, T., Birch, S., Tickle, M., Walsh, T. and Pretty, I. A. (2021): How effective and cost-effective is water fluoridation for adults? Protocol for a 10-year retrospective cohort study. *BDJ Open* **7**. https://www.nature.com/articles/s41405-021-00062-9

Moore, D., Goodwin, M. and Pretty, I. (2019): Long-term variability in artificially and naturally fluoridated water supplies in England. *Community Dentistry and Oral Epidemiology* **48**, 49-55.

MySociety (2020): *What do they know?* https://www.whatdotheyknow.com

NHS Digital (2021): *NHS Data Model and Dictionary*. https://datadictionary.nhs.uk/nhs_business_definitions/lower_layer_super_output_area.html

Nyakutsikwa, B. (2021): *Water fluoride concentrations (mgF/L) per LSOA in England (2009-2020)*. *Dataset*. https://doi.org/10.48420/15104730

Office for National Statistics (2017): *Population Weighted Centroids Guidance*. https://data.gov.uk/dataset/2c5695f2-39d0-457f-a03c-1f4d3617bb48/population-weighted-centroids-guidance

Office for National Statistics (2020a): *Local Authority Districts (December 2020) UK BFC*, *Open Geography Portal*. https://geoportal.statistics.gov.uk/search?collection=Dataset&sort=name&tags=all(BDY_LAD%2CDEC_2020)

Office for National Statistics (2020b): *Lower Layer Super Output Areas (December 2011) Boundaries Super Generalised Clipped (BSC) EW V2*, *Open Geography Portal*. https://geoportal.statistics.gov.uk/search?collection=Dataset&sort=name&tags=all(BDY_LSOA%2CDEC_2011)

Office for National Statistics (2020c): *Lower Layer Super Output Areas (December 2011) Population Weighted Centroids*, *Open Geogrpahy Portal*. https://geoportal.statistics.gov.uk/datasets/ons::lower-layer-super-output-areas-december-2011-population-weighted-centroids/about

OFWAT (2021): *Contact details for your water company*. https://www.ofwat.gov.uk/households/your-water-company/contact-companies/

ONS (2021): *Lower Layer Super Output Area population estimates*, *Mid-2019:SAPE22DT2*. https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/lowersuperoutputareamidyearpopulationestimates

Public Health England (2018): *Water fluoridation: Health monitoring report for England 2018*. London. https://www.gov.uk/government/publications/water-fluoridation-health-monitoring-report-for-england-2018

Roberts, D.J., Morris, J., Wood, A., Verlander, N. Q., Leonardi, G.S. and Fletcher, T. (2020): Use of public water supply fluoride concentration as an indicator of population exposure to fluoride in England 1995–2015. *Environmental Monitoring and Assessment* **192**, 1–16.

The James Lind Alliance (2018): *Oral and Dental Health Priority Setting Partnership*. http://www.jla.nihr.ac.uk/priority-setting-partnerships/oral-and-dental-health/

The National Archives (2016): *The Water Supply (Water Quality) Regulations SI 2016/614*. London. https://www.legislation.gov.uk/uksi/2016/614/contents/made

U.K.Government (2012): *Open Data White Paper : unleashing the potential*. http://www.worldcat.org/title/open-data-white-paper-unleashing-the-potential/oclc/828074427&referer=brief_results

United Kingdom Accreditation Service (2013): *LAB 37: Accreditation Requirements for Sampling and Testing in Accordance with the Drinking Water Testing Specification (DWTS)*. Middlesex. https://www.ukas.com/wp-content/uploads/filebase/publications/publications-relating-to-laboratory-accreditation/LAB37 Edition 3 Jun 13 final.pdf

Weston-Price, S., Copley, V., Smith, H. and Davies, G.M. (2018): A multi-variable analysis of four factors affecting caries levels among five-year-old children; deprivation, ethnicity, exposure to fluoridated water and geographic region. *Community Dental Health*, **35** 217–222.