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Who are the 10%? Characteristics of the populations and communities receiving fluoridated water in England

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Objectives: In England, around 10% of the population receive optimally fluoridated water. This coverage has evolved through a combination of historical local decision-making and natural geography, rather than being strategically targeted at the national level. It is important to understand if the current distribution is equitable according to indicators of oral health need and to identify any population-level differences in socio-demographic characteristics that could introduce bias to studies evaluating the effectiveness of water fluoridation. ***Basic research design***: Descriptive analysis comparing the census characteristics of populations that received optimally fluoridated (=/> 0.7 mg F/L) and non-fluoridated water (<0.7 mg F/L) between 2009 and 2020. ***Results***: Populations receiving fluoridated water between 2009-2020 were on average slightly younger, more urban, more deprived, with lower education levels, higher unemployment and lower car and home ownership than the populations who received non-fluoridated water. They are more ethnically diverse, with a higher proportion of Asian ethnicity and a lower proportion of White ethnicity, compared to the non-fluoridated population. ***Discussion***: This descriptive analysis provides evidence that water fluoridation coverage within England is targeted reasonably equitably in relation to population-level indicators of need. It also confirms the need to consider the impact of underlying differences in age, deprivation, rurality, and ethnicity when evaluating the impact of water fluoridation on health outcomes in England.

Keywords: *Oral health, Public health, Fluoridation*

Introduction

Following the discovery of the caries protective effect of fluoride in drinking water in the 1930s, water fluoridation schemes have been implemented in 25 countries around the world. Countries with some of the highest population coverage are Singapore (100%), Australia (89%), USA (74%), the Republic of Ireland (73%) and Chile (65%) (British Fluoridation Society, 2012). In the U.K., water fluoridation is implemented only within England and in a typical year around 10% of the English population receive water with a fluoride concentration equal to or greater than 0.7 mg of fluoride per litre (F/L) (Nyakutsikwa *et al.*, 2022). The first water fluoridation programme in England was implemented in 1964, in Birmingham and Solihull. Worcester followed in 1965 and further schemes were agreed in 1968 for Newcastle, Gateshead, Durham, Northumberland and Cumbria (Public Health England, 2020). The most recent fluoridation scheme to be introduced was in Worcestershire in 1991 (British Fluoridation Society, 2012).

In the period when most English water fluoridation schemes were introduced, throughout the 1960s, the power to decide to implement a new scheme was held by local government. This was the case until 1974 when the National Health Service Reorganization Act (1973) transferred public health functions to the NHS. In 2013, in England, the Health and Social Care Act (2012) came into force and the decision-making powers for fluoridation were once again returned to local government. The factors to be considered when making decisions on water fluoridation include population oral health, feasibility in terms of water flows, population served, estimated complexity and costs of implementation, and the expected benefits based on levels of disease and evidence of effectiveness and cost-effectiveness. In addition to the collated evidence, as with all policy making, external, context-specific factors strongly influence such decisions (Dobrow *et al.*, 2004). These may include the political ideology and personal experiences, values and beliefs of decision-makers, local public opinion and political 'saleability' of any proposals, the timing of the decision, and competing pressures on local government resources.

With decision-making occurring locally and many factors aside from evidence of population need to be considered, the question arises of whether the current distribution of water fluoridation in England is equitable? Does the 10% of the English population who currently receive water fluoridation have higher predicted oral health needs than those not receiving it? Understanding who is exposed to an intervention is a key part of evaluating whether it is delivered equitably, how effective it is at reducing oral health inequalities, and where additional investment in water fluoridation might generate the largest impact on oral health. Additionally, many of the older studies on the effectiveness of water fluoridation did not account for potential differences between fluoridated and non-fluoridated populations (e.g. through adjustment of confounders)

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(Iheozor-Ejiofor *et al.*, 2015). Without an understanding of what the differences are, it is difficult to evaluate the likely impact of confounding and selection bias on their findings, and indeed on those of contemporary studies.

Age, ethnicity, socio-economic status, general health and / or disability, and access to dental services influence oral health status and may be unequally distributed between fluoridated and non-fluoridated groups as a result of geography and spatial clustering of demographic groups (Dearden, Lloyd and Catney, 2019; Public Health England, 2021). Utilisation of services is related to distance from them, particularly for more deprived patients or those without access to a car. Regular dental attenders have been shown to have lower caries severity and fewer missing teeth than irregular attenders (Thomson *et al.*, 2010; Crocombe *et al.*, 2012). A recent analysis of the geographic distribution of dental practices in England found that whilst 99% of the urban population lived within 2.5km of a dental practice, the same was true for around 54% of the rural population (dependent on age group) (Jo, Kruger and Tennant, 2021).

The aim of this research is to explore population coverage of water fluoridation in England in relation to routinely available statistics associated with oral health need.

Objectives

To compare the following characteristics of the populations who received optimally fluoridated (>/= 0.7 mg F/l) and sub-optimally fluoridated water (<0.7 mg F/L) water in England between 2009 and 2020:

- Deprivation
- Ethnicity
- Rurality, population density and median age
- Area classification supergroup

Methods

Water fluoride sample data (mg F/L) were obtained from water companies in England under the Environmental Information Regulations 2004. The sample data were originally supplied linked to Water Supply Zones (WSZs). WSZs were mapped onto Lower Super Output Areas (LSOAs) using GIS shapefile mapping in R. LSOAs are statistical units of the UK Census which include on average, 1,500 people. The population-weighted-centroid for each LSOA, produced by the Office for National Statistics (ONS), was used to locate LSOAs within WSZ boundaries. Water fluoride sample data were then assigned to the corresponding LSOAs. The methods behind the production of the water fluoride concentration by LSOA data are described more fully in Nyakutsikwa *et al.* (2022) and the data are publicly available, with appropriate attribution, under a Creative Commons license (Nyakutsikwa *et al.*, 2021).

The average of annual mean water fluoride concentrations 2009-2020 (grand mean) were used to assign an LSOA as being "fluoridated" or "non-fluoridated", with the cut point being equal to or greater than 0.7 mg F/L. No differentiation was made between fluoride present naturally and fluoride added as part of a public health programme. LSOA codes were used to link LSOA fluoridation status to national statistics, using the most recent routinely published statistical data available. All linkages to national statistics were performed in Microsoft Excel.

Index of Multiple Deprivation deciles (IMD 2019) for each LSOA were obtained from the Department for Communities and Local Government. The IMD is a standardised method ranking the 32,844 LSOAs in England in terms of relative deprivation. The ranks are then grouped into deciles, with 1 being the most and 10 being the least deprived 10% of LSOAs. Deprivation is assessed across seven domains: income, employment, education, health, crime, housing, and living environment. IMD 2019 deciles were linked to Office for National Statistics (ONS) mid-2020 population estimates and fluoridation status to create the analysis for deprivation. For the Census-derived statistic of ethnic group, the denominator for the percentages is the 2011 usual resident population (Census table KS201EW).

The ONS urban-rural classification for small area geographies is a national statistic which classifies LSOAs into eight categories ranging from the most urban, 'Major Conurbation' to the most rural, 'Village and Dispersed in a Sparse Setting'. Four of the categories are classified as 'urban', which means the LSOA belongs to a settlement with 10,000 people or more, and four are classified as 'rural'(Office for National Statistics, 2013). LSOA urban-rural classification was linked to water fluoridation status and mid-2020 population numbers. Population density for each LSOA was created by dividing mid-2020 population estimates into hectares per LSOA, sourced from the ONS 2011 Census usual resident population table (KS101EW). Median age by LSOA was sourced from the ONS 2011 Census age structure table (KS102EW).

The ONS area classifications use 60 Census variables to identify similar clusters of LSOAs, based on their demographic structure, household composition, housing, socio-economic characteristics, and employment patterns. They are intended to provide an informal portrait of the average characteristics of an area and its population. The highest level of area classification (supergroup) is used in this analysis, which groups LSOAs into eight types. LSOA area classification supergroup was linked to mid-2020 population numbers and water fluoridation status.

Results

The data for WSZs covered 32,789 of the 32,844 LSOAs in England (99.8%). A total of 3019 LSOAs were classified as fluoridated (grand mean water fluoride concentration of >/= 0.7 mg F/L) between 2009 and 2020 (Nyakutsikwa *et al.*, 2022). The estimated population (mid-2020) living in LSOAs classified as 'non-fluoridated' between 2009 and 2020 was 51.3 million, compared to 5.2 million living in areas classified as 'fluoridated'. The mid-2020 population living in LSOAs which we could not assign a fluoridation status to is 99,197. This includes the Isles of Scilly and mostly remote areas with a private water supply. These populations are not included in any of the following analyses.

Deprivation deciles group LSOAs into 10 categories of deprivation and each LSOA has a roughly similar population size (Figure 1). If there was no association between fluoridation and deprivation, there should be approximately 10% of the fluoridated population and 10% of the non-fluoridated population living in each deprivation decile. In fact, there is a clear gradient, with

a greater proportion of the fluoridated population living in the most deprived deciles than would be expected by chance distribution of the intervention. Within the fluoridated population, 18.7% are living in most deprived 10% of areas in England, and 6.7% are living in the least deprived 10% of areas. This can be compared to the relatively flat distribution of deprivation in the non-fluoridated population; 9.1% living in the most deprived decile and 9.9% living in the least deprived decile.

With regards to ethnicity, fluoridated areas have a lower proportion of White ethnic groups (82.5%) compared to the non-fluoridated LSOAs (85.7%) (Figure 2). In fluoridated areas there is a higher proportion of Asian ethnic groups (10.9%) compared to non-fluoridated (7.5%). The proportions of Black, Mixed and Other ethnic groups are relatively equal between fluoridated and non-fluoridated LSOAs.

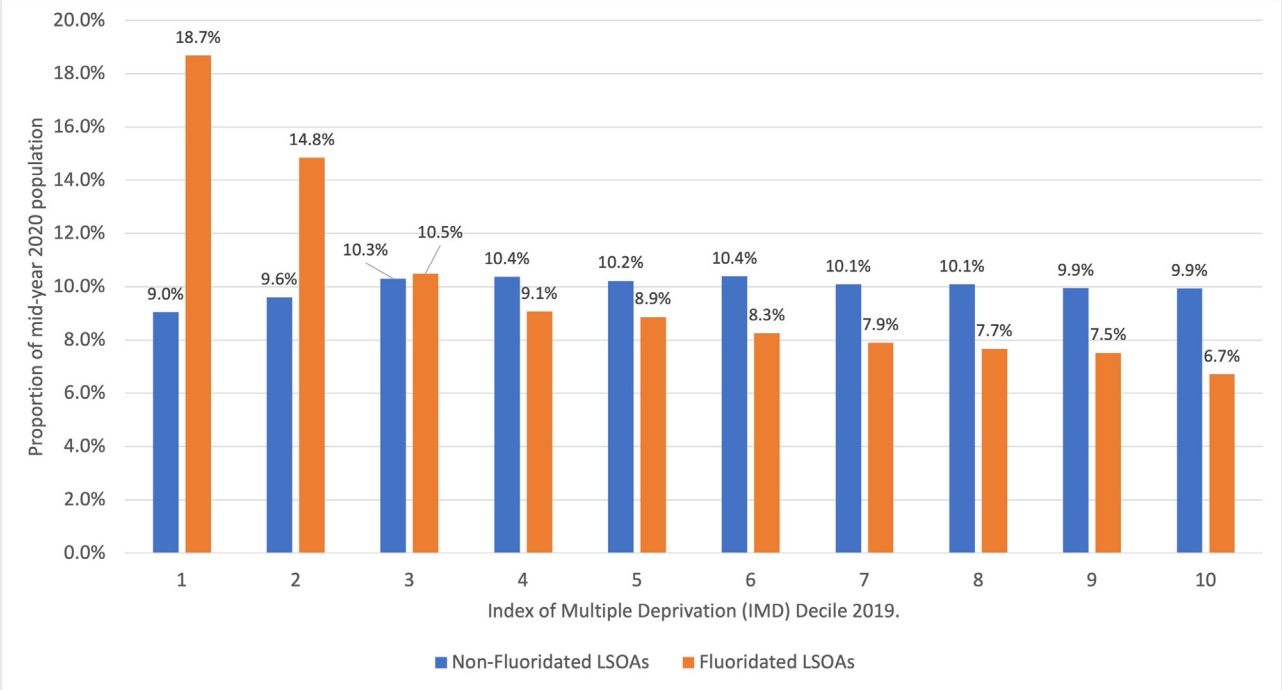

Figure 1. *Proportion of fluoridated and non-fluoridated population (mid-2020) in each deprivation decile (IMD 2019).*

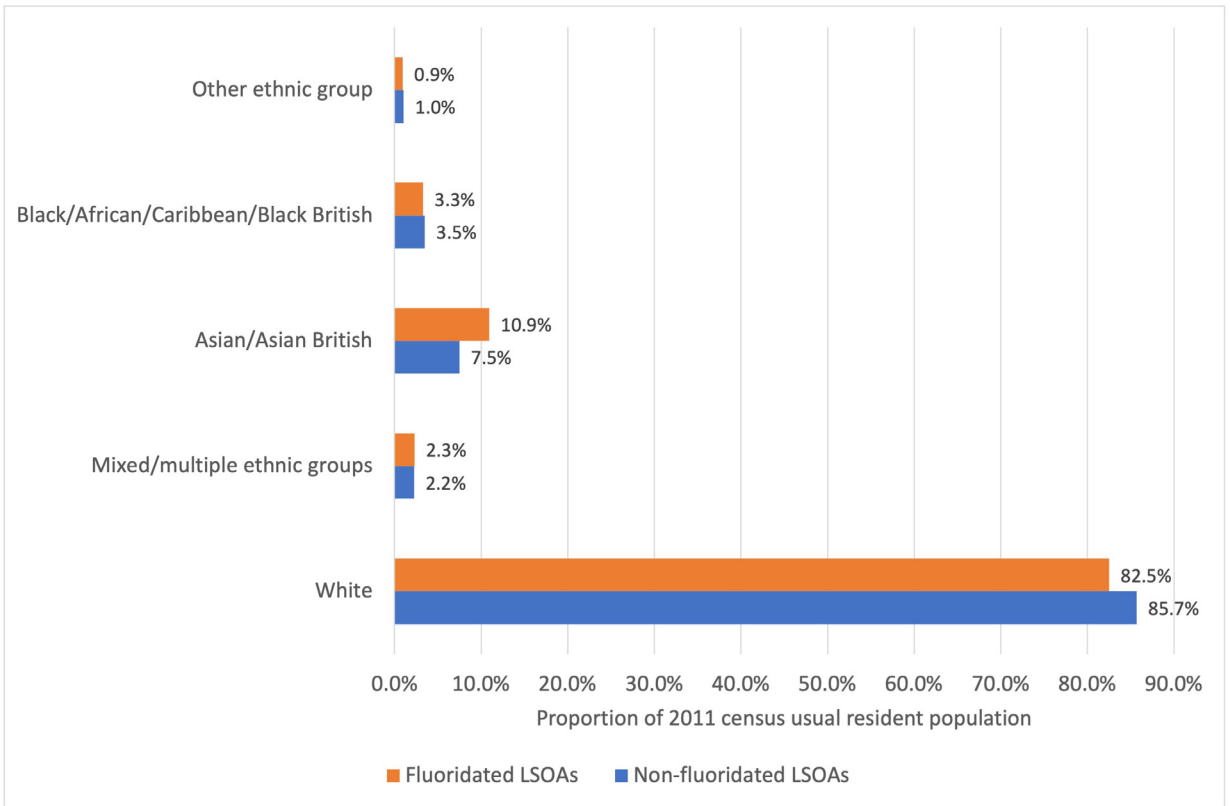

Figure 2*. Ethnicity of usual resident population (2011) by LSOA fluoridation status 2009-2020.*

Most of the English population, in both fluoridated and non-fluoridated LSOAs live in urban areas (Figure 3). However, those living in fluoridated LSOAs are more likely to be found in the major urban conurbations (60.4%), compared to the non-fluoridated population (33.4%). A lower proportion of the fluoridated population lives in rural areas (13.1%) compared to the fluoridated population (17.4%). Reflective of the clustering of water fluoridation in more urban areas, population density (mid-2020) is higher in the fluoridated areas (5.9 persons per hectare) compared to the non-fluoridated areas (4.4 persons per hectare), and the population is slightly younger (the 2011 average of median ages across fluoridated LSOAs was 40.8, years compared to an average of 42.3 years in non-fluoridated LSOAs).

Across England the 'industrial communities' area classification supergroup is the largest in terms of resident population (20.6%). This is reflected in Figure 4, which illustrates that this is the most common supergroup for both the fluoridated (20.1%) and non-fluoridated (18.5%) populations. Industrial communities are characterised by employment in industries such as manufacturing and construction, and compared to the national average they have an older age profile, a higher proportion of UK born residents and a lower proportion of the population with post-16 educational qualifications. Housing is mixed (detached, semi-detached or terraced) and is more likely to be socially rented than the national average.

For the fluoridated population, after 'industrious communities', the next most common supergroups are 'multicultural living' (18.7%), and 'hard pressed communities' (18.5%). These supergroups are located in larger urban areas and the housing is most likely to be socially or privately rented terraced houses or flats (apartments), with relatively low levels of home and car ownership. These two supergroups have the highest levels of unemployment of all supergroups. The differences between them are that the 'multicultural living' supergroup is characterised by average education levels, a higher than average mix of ethnicities and lower proportions of UK-born residents. The 'hard pressed communities' supergroup typically live in former industrial areas, have below average qualification levels and an above average proportion of UK-born residents.

For the non-fluoridated population, after 'industrial-communities' the next most common supergroups are 'suburban living' and 'ethnically diverse professionals' (15.9%). The 'suburban living' supergroup contains a higher than average number of UK born residents. Levels of higher qualifications are above the national average and unemployment is the lowest of all of the supergroups. This supergroup are much more likely than average to live in a detached house, own their own property and own multiple cars. The 'ethnically diverse professionals' supergroup typically live within or close to cities and have a higher than average mix of ethnicities and slightly below average number of UK born residents. The population tends to have higher qualification levels than average and lower rates of unemployment.

Discussion

This is the first time that a profile has been created of the characteristics of the populations and communities that receive fluoridated water in England and compared to the non-fluoridated population. The implementation of water fluoridation in England evolved over a long time

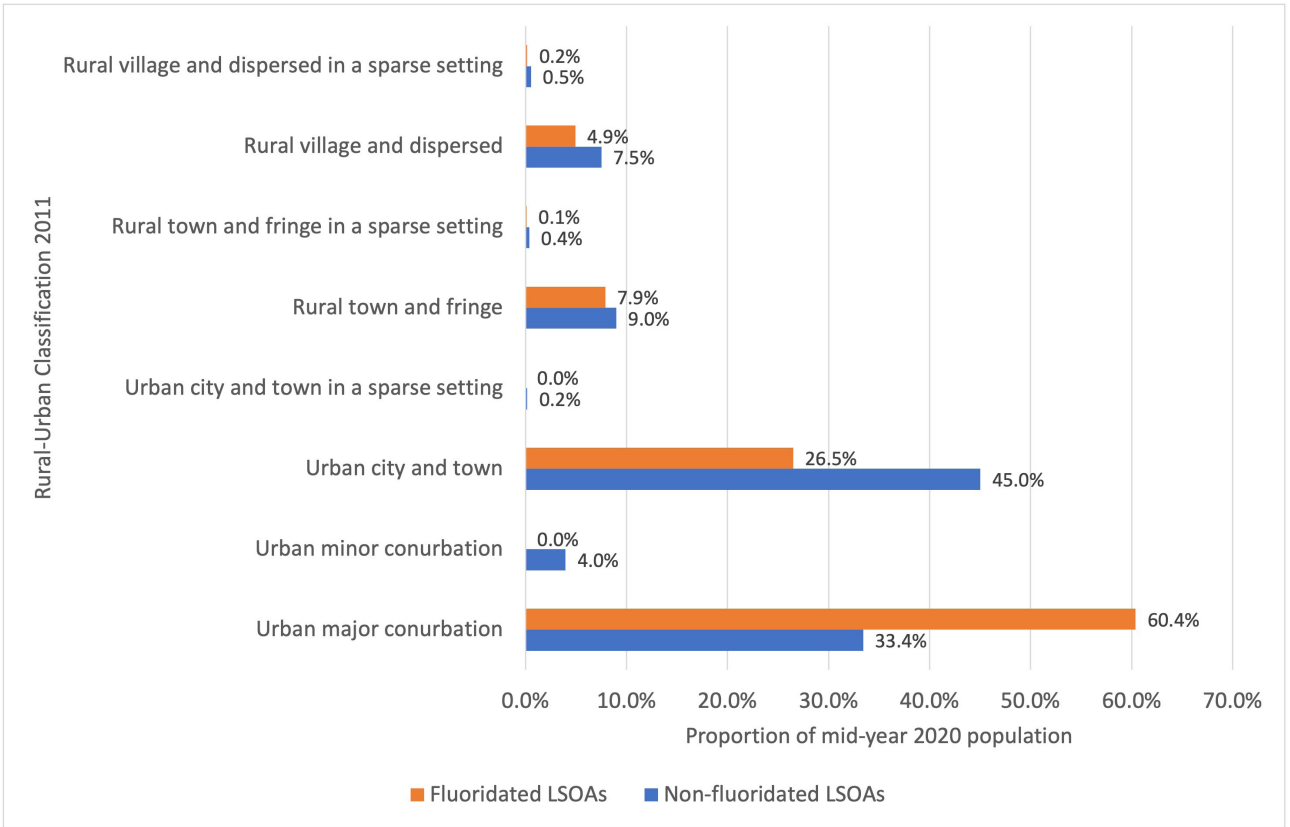

***Figure 3**. Urban-rural classification of fluoridated and non-fluoridated LSOAs applied to mid-2020 population numbers.*

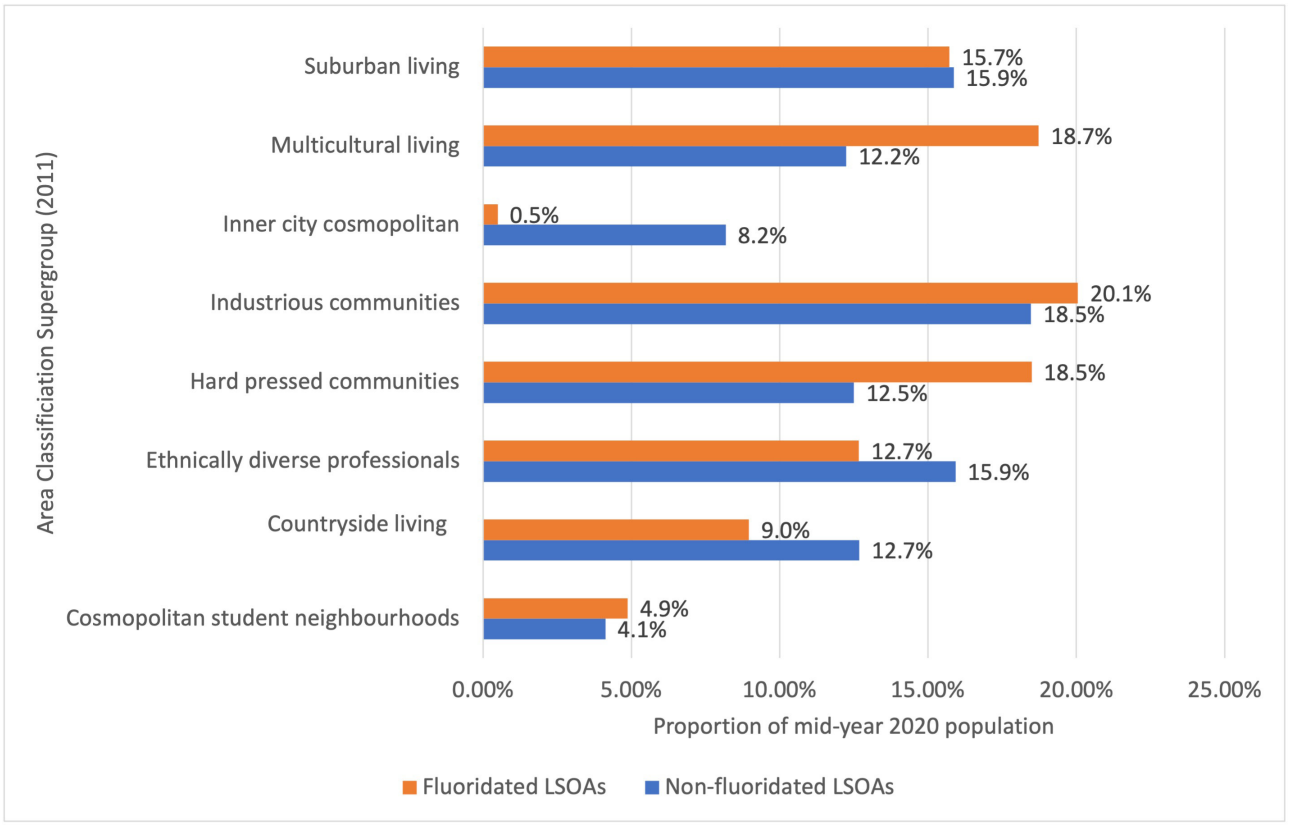

***Figure 4**. ONS Supergroup Area Classifications (2011) for fluoridated and non-fluoridated LSOAs.*

and was shaped by geography, local politics and context, as well as population oral health. Despite this, it does appear to be targeted relatively equitably with regards to socio-economic indicators associated with need, including area-based deprivation, education levels, employment status and car ownership. The fluoridated population has a higher proportion of people of Asian ethnicity and lower proportion of White ethnicity, although the extent and direction of the effect of ethnicity on dental caries and oral health in England is not fully understood at present.

A recent review of oral health inequalities in England identified seven studies that had examined ethnic inequalities in caries in children (Public Health England, 2021). Six of the seven studies found that children of Asian ethnicity had higher levels of caries than those of White / White British ethnicity, but only one of these had adjusted for the separate effect of deprivation. Studies of ethnic inequalities in adults have found that after controlling for socio-economic factors, Asian ethnic groups were less likely to have experienced fillings and extractions than Whites, less likely to be edentulous and more likely to have a functional dentition (Arora *et al.*, 2016; Delgado-Angulo *et al.*, 2019). Non-White groups report visiting the dentist less frequently, and are less likely to report having been successful when trying to make an NHS dental appointment within the last two years, compared to White ethnic groups, which may partly contribute to some of these differences and could reflect unmet needs rather than better oral health (Arora *et al.*, 2016). However, the differences in fillings, extractions and functional dentition between Asian and White ethnic groups remained significant after adjustment for differences in dental service use (Arora *et al.*, 2016).

The higher coverage of water fluoridation in more urban populations is understandable because its cost-effectiveness is influenced by the number of water treatment plants and size of the population served. In Australia, lower coverage of water fluoridation outside of urban areas accounts for inequalities in oral health between urban and rural populations (Crocombe *et al.*, 2016). We did not identify any studies that had investigated differences in the oral health of urban and rural populations in England, though one study of Scottish five-year-olds found higher caries levels in urban areas, after controlling for deprivation (Levin *et al.*, 2010). Urban-rural disparities have been identified in the US and Canada, in relation to dental attendance, oral health related quality of life and edentulousness, though the geographic distances involved are much smaller in England so the results of these studies may not be applicable (Saman *et al.*, 2014; Gaber *et al.*, 2018; Cha and Cohen, 2021).

Comparable literature from other countries examining the socio-demographic distribution and equity of water fluoridation coverage is relatively sparse. A study in Brazil identified that water fluoridation was more likely to be implemented in socio-economically advantaged regions, as a result of greater access to mains-supplied water and higher population numbers (Gabardo *et al.*, 2008). Another study of water fluoridation coverage in the US also found that population density was one of the strongest predictors of county-level coverage, in addition to a higher proportion of the population having post high-school education (Curiel *et al.*, 2020). The authors attributed the relationship between higher education and greater coverage to higher health literacy and more support for fluoridation in local democratic processes. In contrast

to this finding, the fluoridated population in England appears to have lower education levels on average, when compared to the non-fluoridated population using the area classification supergroup profiles.

Identifying which communities already receive water fluoridation leads on to a consideration of which communities have the greatest potential to benefit from further expansion. The Health and Care Act 2022 transferred decision-making powers on the implementation of water fluoridation programmes from local, to national government. If water fluoridation was to be planned strategically at the national level, a useful set of metrics to target further expansion might include population density, the proportion of the population living in the most deprived deciles, and existing water fluoride concentrations. Our analysis of water fluoride samples illustrates that water fluoride concentrations are lowest in the North-West and South-West of England and are highest in the South-East (Nyakutsikwa *et al.*, 2022). The North-West has the highest population density of any region outside of London and contains two of the five local authorities with the highest proportions of most deprived neighbourhoods in England (Liverpool and Manchester). Furthermore, children in the North-West are consistently found to have the highest prevalence and severity of caries in England, making the case for greater coverage of water fluoridation strongest in this region (Public Health England, 2021).

A limitation of this study is that some of the statistical data were collected 10 years ago, as part of the 2011 Census. However, demographic changes such as ethnicity and urban-rural designation are expected to occur relatively slowly and whilst the absolute figures may be slightly different when the 2021 Census results are published, it is unlikely that the general conclusions would change with regards to differences between fluoridated and non-fluoridated populations. Other limitations relate to the potential for errors of misclassification in the water fluoridation variable as a result of transforming sample data from WSZs to LSOAs and the lack of availability of water fluoride sample data for data for 0.2% of LSOAs (covering 99,197) people (Nyakutsikwa *et al.*, 2022). Similarly, it was not possible to dis-aggregate the areas and populations who received fluoridated water as part of a population health programme or because of geological sources as no 'water fluoridation programme' indicator could be supplied by the water companies. However, just 5% of the fluoridation coverage in England is naturally occurring (British Fluoridation Society, 2012). Finally, it must be borne in mind that the ONS area classification supergroups aim to provide a high-level overview of the population living in LSOAs in England. Classifications necessarily generalise, and not all individuals living within these areas will align with the averages that are used to create the profiles.

This analysis provides evidence that water fluoridation coverage within England is targeted reasonably equitably in relation to population-level socio-demographic indicators of need. It also confirms the need to consider differences in rurality, age structure, deprivation and ethnicity when comparing the health outcomes of fluoridated and non-fluoridated populations. Further research is needed to investigate the extent and direction of oral health inequalities resulting from ethnicity and rurality in England.

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