



Department
of Health &
Social Care



UK Health
Security
Agency

Water fluoridation

Health monitoring report for England 2026

Contents

Executive summary6

Background 12

Methods 38

Results 55

Discussion 93

Conclusion 103

References 104

Acknowledgements

This report was prepared by the Water Fluoridation Health Monitoring Working Group on behalf of the Secretary of State for Health and Social Care. The Working Group is composed of colleagues from both UK Health Security Agency (UKHSA) and the Department of Health and Social Care (DHSC). This report is published by the UK Health Security Agency (UKHSA).

The Water Fluoridation Health Monitoring Group would like to thank the Drinking Water Inspectorate for their support in preparing this report.

Abbreviations

Abbreviation	Meaning
ADHD	Attention deficit hyperactivity disorder
AIC	Akaike information criterion
APC	Admitted Patient Care
A priori	Identified before analysis, based on prior knowledge and evidence
BAS	British Ability Scales
BAS-NV	British Ability Scales, Naming Vocabulary
BAS-PC	British Ability Scales, Pattern Construction
BAS-PS	British Ability Scales, Picture Similarities
BAS-WR	British Ability Scales, Word Reading
CADTH	Canadian Agency for Drugs and Technologies in Health
CI	Confidence interval(s)
COVID-19	Coronavirus Disease 2019
CWF	Community water fluoridation
d ₃ mft	Decayed (at dentinal level), missing due to decay, or filled due to decay in primary teeth
D ₃ MFT	Decayed (at dentinal level), missing due to decay, or filled due to decay in permanent teeth
DHSC	Department of Health and Social Care
DPIA	Data protection impact assessment
DWI	Drinking Water Inspectorate
EFSA	European Food Safety Authority
EU	European Union
FCE	Finished consultant episode
FY	Financial year
HES	Hospital Episode Statistics
HMR	Health monitoring report
HRB	Health Review Board (Ireland)
IMD	Index of Multiple Deprivation
IQ	Intelligence quotient
IQR	Interquartile range
IRR	Incidence rate ratio

Abbreviation	Meaning
LAD	Local authority district
LRT	Likelihood ratio test
LSOA	Lower-layer super output area
LTLA	Lower-tier local authority
MCS	Millenium Cohort Study
MSOA	Middle-layer super output area
mg/L	Milligrams per litre
MYE	Mid-year population estimate
N or n	Sample size
NDEP	National Dental Epidemiology Programme
NFER	National Foundation for Education Research, Progress in Maths
NFER-PiM	National Foundation for Education Research
NHMRC	National Health and Medical Research Council (Australia)
NTP	National Toxicology Programme (United States of America)
NVQ	National Vocational Qualification
NZ MoH	New Zealand's Ministry of Health
OECD	Organization for Economic Cooperation and Development
OHID	Office for Health Improvement and Disparities (within Department of Health and Social Care)
OHS	Oral health survey
ONS	Office for National Statistics
OR	Odds ratio
PYAR	Person-years at risk
SCHER	Scientific Committee on Health and Environmental Risks (European Union)
SD	Standard deviation
TSH	Thyroid stimulating hormone
UKHSA	United Kingdom Health Security Agency
ULTA	Upper tier local authority
WHO	World Health Organization
WSZ	Water supply zone

Executive summary

In England, about one in 10 people receive public drinking water served by a fluoridation scheme. This Health Monitoring Report aimed to monitor the health effects of water fluoridation schemes, and to assess the associations between concentrations of fluoride in public water supplies and selected dental and non-dental health outcomes. This report found that water fluoridation is a beneficial public health intervention for reducing dental caries in children and reducing inequalities in dental health. It observed no evidence of an association with cognitive ability in children and no convincing evidence of an association with hip fractures.

Background

The Water Fluoridation Health Monitoring Working Group, on behalf of the Secretary of State for Health and Social Care, is required by the Water Industry Act (1991) to monitor the effects of water fluoridation schemes on health, and to produce reports at least once every 4 years. This report, the fourth in the series, fulfils this requirement.

Fluoride occurs naturally in the environment and can be present in water and some foods in varying concentrations. In some areas with low natural fluoride levels, fluoride is added to public drinking water to improve dental health. In England, around one in 10 people receive public drinking water served by a fluoridation scheme, which aims to achieve a level of 1.0 mg of fluoride per litre of water (1.0 mg/L). The World Health Organization (WHO) guidance recommends a maximum concentration of fluoride in public water supplies of 1.5 mg/L, with risks of dental and skeletal fluorosis increasing above this level.

The protective effect of community water fluoridation on dental caries is well established. Dental caries, also known as dental or tooth decay, is a disease that affects people at all life stages and affects both primary (baby) and permanent (adult) teeth. Inequalities in the prevalence of dental caries exist between affluent and deprived communities, and it is a common cause of hospital admissions in children for the removal of decayed teeth. The available evidence indicates that community water fluoridation at concentrations within WHO guidelines does not harm non-dental health, but for some non-dental health outcomes high-quality evidence is limited. The international evidence for effects on the following non-dental health outcomes was synthesised: birth outcomes, bladder cancer, blood pressure effects, bone cancers, hip fractures, kidney effects, neurodevelopment and cognitive effects, osteoarthritis, skeletal fluorosis, and thyroid effects.

The aim of the report was to assess the association between the concentration of fluoride in public water supplies in England and selected dental and non-dental health outcomes in order to monitor the potential health effects of water fluoridation schemes.

Methods

The report used an ecological study design, where fluoride exposure and most health outcomes were measured for small geographical areas (lower-layer super output areas (LSOAs) containing between 1000 and 3000 people), except for cognitive ability which was measured at the individual level. The study population included only people living in England.

Fluoride exposure was measured in 2 ways: the average fluoride concentration in mains drinking water for each LSOA, and whether a water fluoridation scheme was operating in the LSOA. Individuals with health outcomes were then mapped to LSOAs based on their recorded address and so assigned a fluoride exposure value.

Dental health outcomes (prevalence and severity of caries experience in 5 and 10 or 11 year olds, and hospital admissions for caries-related tooth extractions in those aged 0 to 19 years) were included to continue monitoring the impact of fluoride on dental health and were chosen according to the availability of new data since the 2022 health monitoring report.

The non-dental health outcomes investigated were emergency hospital admissions for hip fractures, which had also been investigated in the previous 2014, 2018 and 2022 health monitoring reports and, for the first time in the series, a measure of cognitive ability in children. There is increasing international evidence for an association between higher exposures to fluoride and an effect on child neurodevelopment and cognitive outcomes, but very little evidence has assessed an association at lower fluoride concentrations similar to those found in England (<1.5 mg/L).

Drinking water fluoride data was obtained from the Drinking Water Inspectorate. Data on the prevalence and severity of dental caries experience came from the National Dental Epidemiology Programme's nationally representative oral health surveys in 2022 and 2024 (5 year olds) and 2023 (10 or 11 year olds). Data on tooth extractions and hip fracture came from hospital admissions records (Hospital Episode Statistics data) in England between April 2021 and March 2024. Data on cognitive ability came from scores on 6 tests on language, reasoning and maths skills administered to children in the Millenium Cohort Study at ages 5 and 7 years old.

The frequency of health outcomes for people living in areas with different fluoride concentrations and with or without fluoridation schemes was compared using statistical models (multivariable regression models), adjusting where possible for age group, sex, ethnicity and deprivation. These models were then further stratified by deprivation (dental health outcomes) or age and sex (hip fractures). The models were also used to generate predicted prevalence for dental caries experience and predicted incidence rates for caries-related tooth extractions and hip fractures.

Results

Distribution of fluoride in drinking water supplies in England

In the 2017 to 2024 period, this report found that the concentrations of fluoride in LSOAs ranged between 0.01 mg/L and 1.3 mg/L. All LSOAs were within the 1.5 mg/L regulatory limit for drinking water, and 0.6% of LSOAs had concentrations above 1.0 mg/L which is the target concentration for fluoridation schemes.

Approximately 85% of the population in England lived in areas with an average drinking water fluoride concentration below 0.40 mg/L, and 9% lived in areas with a concentration at or above 0.70 mg/L.

Dental caries experience and severity scores

Oral health survey data were collected from 62,649 5 year olds in 2022 and 81,905 5 year olds in 2024 and were approximately representative of the general population of that age in England. The prevalence of dental caries experience in primary teeth (number of children with any teeth with caries) was 23% in both 2022 and 2024. The mean severity score (mean number of teeth with caries per child) was 0.82 in 2022 and 0.80 in 2024.

Five year olds living in areas with a fluoridation scheme were found to have 25% lower odds of caries experience in 2022 and 34% lower odds in 2024 compared to those in areas without a fluoridation scheme and with low levels (<0.20 mg/L) of natural fluoride. 5 year olds living in areas with the highest category of drinking water fluoride concentrations (≥ 0.70 mg/L) were found to have 27% lower odds of dental caries experience in 2022 and 44% lower odds in 2024 compared to those in areas with the lowest fluoride category (<0.10 mg/L).

There was no clear trend in the odds of caries experience across different levels of deprivation. However, because more children in the most deprived areas were affected by dental caries, they benefitted the most in terms of absolute reductions in model-predicted prevalence of dental caries experience.

Five year olds living in areas with fluoridation schemes or with higher fluoride concentrations were found to have a lower probability of being in the highest dental caries severity score category in both the 2022 and 2024 surveys, compared to those living in areas without schemes or with the lowest fluoride concentrations.

There was no clear trend in the relative reductions in the probability of being in the highest dental caries severity score category across levels of deprivation in 2022. However, in 2024, there was an indication that those in the more deprived areas experienced the strongest protective effect of the highest fluoride concentrations.

Oral health survey data in 2023 were collected for 53,073 Year 6 children (10 or 11 year olds). The prevalence of dental caries experience in permanent teeth was 16% and the mean severity score was 0.30. Issues with assessing caries in permanent teeth in this age group mean these are expected to be underestimates. Due to methodological concerns with the data for dental caries experience and severity scores in 10 or 11 year olds, these data were not assessed statistically for associations with fluoride.

Tooth extractions

Among children aged 0 to 19 years old, there were 87,235 hospital admissions for caries-related tooth extractions between April 2021 and March 2024. The incidence rate for these tooth extractions was 213 per 100,000 person-years at risk.

Children living in areas with a fluoridation scheme were found to have a 20% lower incidence rate of tooth extractions compared to those in areas without a fluoridation scheme and with low levels (<0.20 mg/L) of natural fluoride. Children living in areas with the highest category of drinking water fluoride concentrations (≥ 0.70 mg/L) were found to have a 28% lower incidence rate of tooth extractions compared to those in areas with the lowest fluoride category (<0.10 mg/L).

The most deprived areas benefited most from higher fluoride concentrations and experienced a 34% lower incidence rate of admissions for caries-related tooth extractions for children living in the highest (≥ 0.70 mg/L) compared to the lowest fluoride category (<0.10 mg/L). Because more children in the most deprived areas are admitted to hospital for caries-related tooth extractions, they also benefitted the most in terms of absolute reductions in model-predicted incidence of tooth extractions.

Hip fractures

There were 199,879 emergency hospital admissions for hip fractures among people of all ages between April 2021 and March 2024. The incidence rate for hip fractures was 112 per 100,000 person-years at risk.

The findings in this report, considered alongside the wider international evidence and the limitations of this study, did not provide convincing evidence of a relationship between water fluoridation and hip fracture risk. These findings were consistent with those of the 2018 and 2022 health monitoring reports. The observed associations between fluoride exposure and hip fracture risk varied by age and sex. For people 65 years and over, there was a suggestion of a slightly higher risk of emergency hospital admission for hip fracture if living in areas with fluoridation schemes, or living in areas with fluoride concentrations at or above 0.40 mg/L. For those under 65 years old, there was a suggestion of a lower risk of hip fracture if living in areas with fluoride concentrations between 0.10 and 0.39 mg/L, but there was no evidence of a relationship with fluoride concentrations at or above 0.40 mg/L or with living in areas with a fluoridation scheme. Most confidence intervals for effect estimates included the possibility of no effect. The overall small effect sizes and the lack of statistical

confidence of estimates, the methodological limitations of the study including the uncertainty in exposure assignment for this health outcome, and the conclusions of international reviews which provide no evidence of an association between fluoride levels below 1.5 mg/L and bone fractures, contribute to this report's conclusion that there is no convincing evidence of an association between water fluoridation and hip fracture risk.

Cognitive ability

MCS data on cognitive ability outcomes were collected from 9,722 children at age 5 and 8,883 children at age 7 in England.

This report does not find an association between fluoride exposure and cognitive ability test scores in 5 and 7 year olds. Estimates for the difference in test scores were close to zero and were inconsistent in direction of effect across increasing categories of drinking water fluoride concentration exposure for all 6 cognitive ability sub-tests.

Analysis for the water fluoridation scheme exposure measure was not conducted because no association was detected between cognitive ability and the water fluoride concentration exposure measure.

Strengths and limitations

The 2026 HMR uses the same overall approach as previous reports, providing a consistent way to monitor the health effects of fluoride over time. This report draws on nationally representative health data from different types of data sources, assessing associations between a range of health outcomes and 3 different measures of fluoride exposure. This rich combination of data and analyses allows rigorous and robust epidemiological evidence to be generated to inform national level public health policy. The report assesses a cognitive ability outcome for the first time in the series and continues to assess whether fluoride has an effect on dental inequalities, helping to address gaps in the evidence at low fluoride exposure levels (<1.5 mg/L).

Improvements in this HMR compared with previous reports strengthen the robustness of the 2026 HMR findings. These improvements include the assessment of associations with hospital admissions data at smaller geographical units, improved assignment of fluoride based on the potential biological window of effect on health outcomes, and statistical modelling refinements. As some methods have changed, statistical model results should not be directly compared with earlier reports.

The ecological design means that exposure and other risk factors observed at the LSOA level may not correctly represent individual-level experiences, and fluoride exposure was inferred from the drinking water fluoride concentration of the current residential LSOA rather than individual exposure histories. This represents a limitation of the exposure assignment in this report.

Non-participation and selection bias are also potential concerns, as participation rates in the oral health surveys were approximately 60% and in the Millenium Cohort Study across the different data collection waves was about 68%.

Finally, the potential effect of residual or unmeasured confounding and the challenges of multiple comparisons should be accounted for when interpreting results. Multiple comparisons were made across fluoride exposure measures and population subgroups, meaning that some associations may arise by chance, and results should therefore be interpreted with emphasis on consistency and the overall pattern of findings rather than effect estimates of observed associations and statistical inference tests.

Conclusion

In line with previous HMRs, the findings of the 2026 HMR are consistent with the view that water fluoridation at levels within the regulatory limit for England (<1.5 mg/L) is a beneficial public health intervention for reducing dental caries in children, with no convincing evidence of harm to non-dental health. This report continues to find that the dental health benefits are largest in the more deprived areas, where baseline dental health and uptake of dental care tend to be poorer, and so water fluoridation makes an important contribution to reducing dental health inequalities. This report observed no evidence of an association with cognitive ability in children and no convincing evidence of an association with hip fractures.

Our findings are consistent with those from wider systematic reviews of international evidence for the effects of fluoride at concentrations below the regulatory limit of 1.5 mg/L. In practice, fluoride concentrations in fluoridated areas in England are well below this regulatory limit, averaging below 0.8 mg/L in all years since 2016.

This series monitors the potential population health effects of fluoride over time using data that is representative of the wider English population, such that the evidence provided is informative at the national level. This report contributes to an important gap in the wider public health and epidemiological literature assessing associations with selected non-dental health outcomes and inequalities in dental health at levels well below the WHO guideline value of 1.5 mg/L. Due to some of the limitations of this study, all findings should be interpreted with caution and in the context of the wider scientific evidence. This report provides epidemiological evidence that can inform an understanding of associations between drinking water fluoride exposure and our selected health outcomes. However, it cannot by itself determine whether these associations are causative, and a lack of observed associations does not definitively confirm the absence of a relationship.

The methods used in this report are not exactly the same as in previous reports in the HMR series, and as such findings from the 2022 and 2018 reports cannot be directly compared.

The Water Fluoridation Health Monitoring Working Group continues to keep the wider evidence under review and will publish a further report within the next 4 years.

Background

The Secretary of State for Health and Social Care, is required by legislation to monitor the effects of water fluoridation schemes on health and to produce reports at least once every 4 years.¹ The Water Fluoridation Health Monitoring Work Group has produced this report, the fourth in the series, to fulfil this requirement.

Monitoring the health effects of fluoridation schemes

Section 90A of the Water Industry Act 1991, as amended, requires a “relevant authority”, that has entered into fluoridation arrangements to monitor the effects of the arrangements on the health of persons living in the area specified in the arrangements ([1](#)). It also requires that such an authority publishes reports containing an analysis of those effects, making available any information, or summaries of information, collected by it for these purposes.

As of 1 April 2013, the Secretary of State for Health and Social Care is the “relevant authority” in England for the purposes of the fluoridation provisions. The Secretary of State's functions in relation to fluoridation health monitoring and reporting are exercised by the Water Fluoridation Health Monitoring Working Group (the working group), whose membership includes epidemiologists, consultants in public health and dental public health, and scientists from the Department of Health and Social Care (DHSC) and UK Health Security Agency (UKHSA). The first 3 reports monitoring the health effects of fluoride in drinking water were published in March 2014, March 2018 and March 2022 ([2](#), [3](#), [4](#)). Further reports are required at intervals of no greater than 4 years, beginning with the date on which the last report was published, unless the schemes in question are terminated.

The protective effect of community water fluoridation (CWF) on dental caries (tooth decay) is well established. The 2014, 2018 and 2022 health monitoring reports (HMRs) found evidence for water fluoridation reducing the prevalence and severity of dental caries experience, reducing the incidence rate of hospital admission for removal of caries-related teeth, and for narrowing dental health inequalities ([2](#), [3](#), [4](#)). The 2018 report also provided an updated understanding of the relationship between water fluoridation and dental fluorosis in England and added to the evidence base on possible associations with non-dental health outcomes. Due to capacity constraints during the COVID-19 pandemic, the 2022 report had a reduced scope and assessed dental caries and hip fracture outcomes only. The UK Chief Medical Officer recently commissioned a report on the optimal concentration for water fluoridation in the UK from the Academy of Medical Sciences, which considered evidence from previous HMRs and the wider international scientific literature. Its conclusions confirmed the relevance of current UK target fluoride concentrations for water fluoridation schemes ([5](#)).

Changes over time in diet and oral hygiene, including exposure to fluoride from sources other than drinking water, can affect dental caries risk. Re-assessment of the association between fluoride in drinking water and dental health is therefore important, as well as continuing to monitor possible associations between fluoride and non-dental health outcomes. The present report for the first time includes an updated evidence synthesis for the benefits and potential risks associated with fluoridation, and for the first time includes an assessment of the potential effects of fluoridation on cognitive ability in children in England. The report contributes to the assessment of whether the addition of fluoride to public water supplies in England is a safe, beneficial and equitable public health intervention.

Fluoride

Fluoride occurs naturally in the environment and can be present in water and some foods in varying concentrations ([6](#)). Fluoride is also added to many toothpastes and other preventative dental interventions. Fluoride in drinking water likely makes up about half of people's daily total fluoride intake in Europe, with diet and oral hygiene products also contributing ([7](#)).

In some areas, fluoride is added to public drinking water to improve dental health. The first water fluoridation scheme was introduced in the USA in 1945 ([8](#)). Following pilot schemes, the first substantive water fluoridation scheme in the UK was introduced in Birmingham in 1964, with subsequent schemes established since. In England, about one in 10 people receive public drinking water served by a fluoridation scheme.

Water fluoridation schemes in England aim to achieve a level of 1.0 mg of fluoride per litre of water (mg/L), equivalent to one part fluoride per million parts of water ([9](#)). This was chosen to reduce dental caries without increasing the frequency of dental fluorosis of aesthetic concern ([10](#)). The World Health Organization (WHO) guidance recommends a maximum concentration of fluoride in public water supplies of 1.5 mg/L, with risks of dental and skeletal fluorosis increasing above this level ([11](#)). Recent evidence from the European Union's Food Safety Authority (EFSA) has similarly derived a reference point of 1.5 mg/L as protective against potential adverse outcomes, including impacts on the central nervous system ([7](#)).

The WHO's guideline value of 1.5 mg/L is mirrored in UK drinking water standards covering both public and private supplies ([12](#)). Due to underlying geology in the area people live, about a quarter of a million people in non-fluoridated areas in England receive drinking water with levels of fluoride that are close to those achieved by the majority of fluoridated areas (≥ 0.70 mg/L). Water companies that operate fluoridation schemes must comply with the requirements of the Code of Practice published by the Drinking Water Inspectorate (DWI), the water quality regulator for England and Wales ([9](#)).

Existing evidence for the health impacts of fluoride

Evidence from previous health monitoring reports in England

Previous HMRs published in 2018 ([3](#)) and 2022 ([4](#)) assessed associations between drinking water fluoride concentrations and a range of dental and selected non-dental health outcomes. The findings of these reports are presented in [Table 1](#). The 2014 HMR results were not included here as the report only analysed associations with the presence of a water fluoridation scheme as its measure of fluoride exposure, however the findings from 2014 were consistent with the later HMRs in this series.

These reports found that higher fluoride exposure (up to concentrations between 0.7 mg/L and approximately 1.0 mg/L) was associated with lower prevalence of dental caries experience and lower severity of dental caries in 5 year olds, and lower incidence rates of hospital admissions for caries-related tooth extractions for 0 to 19 year olds compared to fluoride exposure of less than 0.1 mg/L ([3](#), [4](#)). Reports also found that reductions in dental caries experience, severity and extractions were larger in the most deprived areas. Evidence was less clear for an association with dental caries experience in 3 year olds.

Dental fluorosis of at least mild aesthetic concern was more common in areas with water fluoridation schemes compared to those without, but this did not lead to significant differences in ratings of satisfaction with the appearance of children's teeth in these areas. Reports found no convincing evidence of a causal association between water fluoridation and hip fracture, kidney stones, bladder cancer, Down syndrome or osteosarcoma.

Table 1. Findings from previous health monitoring reports in England for the association between drinking water fluoride exposure and dental and non-dental health outcomes

Outcome	Health monitoring report 2018 (3)	Health monitoring report 2022 (4)	Findings
Prevalence and severity of dental caries experience in 5 year olds	X	X	<p>The 2018 and 2022 HMRs found that higher drinking water fluoride exposure was associated with lower odds of experiencing caries and lower odds of experiencing higher severity of caries in 5 year olds.</p> <p>The 2018 HMR found that for 5 year olds living in areas with fluoride concentrations ≥ 0.7 mg/L compared to in areas with the lowest concentrations of < 0.1 mg/L, the odds of experiencing caries were 23% (95% CI: 9%, 39%) lower in the least deprived areas and 52% (47%, 56%) lower in the most deprived areas. Increasing fluoride concentration was associated with lower odds of having the highest severity caries score, and children in the most deprived areas saw larger reductions in the odds of having more severe caries compared to children in the least deprived areas.</p> <p>The 2022 HMR found similar results but the reduction in odds were more moderate for those living in the most deprived areas. For 5 year olds living in areas with water fluoride concentrations ≥ 0.7 mg/L compared to in areas with the lowest concentration of < 0.1 mg/L, the odds of experiencing caries were 26% (95% CI: 12%, 37%) lower in the least deprived areas and 39% (30%, 46%) lower in the most deprived areas. Risk of having the highest caries severity score also reduced with increasing water fluoride concentration.</p>

Outcome	Health monitoring report 2018 (3)	Health monitoring report 2022 (4)	Findings
Prevalence and severity of dental caries experience in 3 year olds		X	<p>The 2022 HMR found that the association between fluoride concentration and dental caries experience varied by deprivation level. There was no evidence of an association between fluoride concentration and dental caries severity.</p> <p>In the 2 most deprived quintiles, there was a general trend that the odds of experiencing dental caries lowered as fluoride concentration increased, but confidence intervals were generally quite wide. Associations in other quintiles varied. Similarly mixed evidence was seen for the severity score of dental caries within deprivation quintiles and the association was not considered statistically significant.</p>
Caries-related tooth extractions in 0 to 19 year olds	X	X	<p>The 2018 HMR found that hospital admissions for caries-related tooth extractions were 59% lower (95% CI: 33%, 76%) in areas with a drinking water fluoride concentration ≥ 0.7 mg/L, compared to areas where it was <0.1 mg/L.</p> <p>A greater protective effect was seen with increasing water fluoride concentration. The greatest absolute reduction in admissions was observed for the most deprived children, thus contributing to narrowing dental health inequalities.</p> <p>The 2022 HMR reported similar findings. Hospital admission for caries-related tooth extractions were 60% lower (95% CI: 31%, 77%) in areas with a drinking water fluoride concentration ≥ 0.7 mg/L, compared to areas where it was <0.1 mg/L.</p>
Dental fluorosis in 11 to 14 year olds	X		<p>The 2018 HMR found that the presence of fluorosis does not appear to cause aesthetic concern or, where it does cause concern there is</p>

Outcome	Health monitoring report 2018 (3)	Health monitoring report 2022 (4)	Findings
			<p>an equal level of dissatisfaction due to other factors for example trauma, orthodontic malalignment or caries.</p> <p>The prevalence of fluorosis of at least mild aesthetic concern was 10% in areas with a water fluoridation scheme and 2% in areas without. However, there was no significant difference in the mean self-reported aesthetic score between respondents in the 2 areas.</p>
Hip fracture	X	X	<p>The 2018 HMR found no convincing evidence for a causal association between drinking water fluoride exposure and hip fractures.</p> <p>There was some evidence that fluoride concentrations ≥ 0.10 mg/L were associated with a lower risk of hip fractures in the 0 to 49 year old age group, and a higher risk in the over 80 year old age group. However, there was no consistent change in hip fracture risk within age groups as the concentration of fluoride increased. The report considered that given these inconsistencies and the existing evidence from epidemiological and toxicological studies at levels of water fluoridation observed in England, the findings did not support a causal association.</p> <p>The 2022 HMR reported similar conclusions of no convincing evidence of an association.</p>
Kidney stones	X		<p>The 2018 HMR found no convincing evidence for a causal association between drinking water fluoride exposure and kidney stones.</p> <p>While rates of hospital admissions for kidney stones were 10% lower (95% CI: 2%, 18%) in areas with a fluoridation scheme than in areas without, there was no trend in kidney stone incidence rates as water</p>

Outcome	Health monitoring report 2018 (3)	Health monitoring report 2022 (4)	Findings
			fluoride concentration increased. There were also concerns with data quality and there was a lack of evidence in the literature supporting a causal association.
Bladder cancer	X		<p>The 2018 HMR found no convincing evidence for an association between drinking water fluoride exposure and bladder cancer.</p> <p>While incidence rates of bladder cancer were 6% lower (95% CI: 2%, 10%) in areas with a fluoridation scheme than in areas without, there was no consistent trend in incidence rates as water fluoride concentration increased and there was very little evidence in the literature to support a protective effect.</p>
Down syndrome	X		<p>The 2018 HMR found no convincing evidence for a causal association between drinking water fluoride exposure and Down syndrome incidence.</p> <p>There was very limited statistical evidence for an association between incidence rates of Down syndrome and presence of a fluoridation scheme. There was no consistent change in risk of Down syndrome as the concentration of fluoride increased and there was very little evidence in the literature to support an association.</p>
Osteosarcoma in under 50 year olds	X		<p>The 2018 HMR found no evidence of an association between fluoride exposure and osteosarcoma in 0 to 49 year olds.</p> <p>No association was observed with either fluoride concentrations or presence of a fluoridation scheme.</p>

Abbreviations

CI = confidence interval; HMR = health monitoring report; mg/L = milligrams per litre.

Evidence synthesis

This synthesis aimed to inform the selection of health outcomes to be analysed in this HMR.

We synthesised evidence on the health impacts of fluoride exposure from existing systematic reviews and evidence evaluations conducted by expert authoritative organisations. Fluoride exposure was specified to include a range of valid measures such as total fluoride intake, residence in areas with fluoridation schemes, and drinking water and urinary fluoride concentrations.

The evidence synthesis included 11 reports published between 2010 and 2025. These reports were identified as some of the most recent and comprehensive evidence reviews conducted for countries and regions with fluoridation contexts that are relevant to England – where water fluoridation schemes are in place and where drinking water fluoride concentrations are managed in line with the WHO's maximum guideline value of 1.5 mg/L. These reports were:

- Canadian Agency for Drugs and Technologies in Health (CADTH) – health technology review 2019 ([13](#)) review of neurological and cognitive effects, 2019 ([14](#)) and 2020 update ([15](#))
- Cochrane Oral Health Group (international) – review of water fluoridation for the prevention of dental caries 2024 ([16](#))
- European Food Standards Authority (EFSA) – consumer risk assessment 2025 ([7](#))
- Ireland's Health Review Board (HRB) – evidence review on systemic health excluding oral health 2022 ([17](#)) evidence review on dental health 2025 ([18](#))
- New Zealand's Ministry of Health (MoH) – evidence review on community water fluoridation 2024 ([19](#))
- Australia's National Health and Medical Research Council (NHMRC) – information paper on water fluoridation 2017 ([20](#))
- USA's National Toxicology Program (NTP) – monograph on the state of the science concerning fluoride exposure and neurodevelopment and cognition 2024 ([21](#))
- European Commission's Scientific Committee on Health and Environmental Risks (SCHER) – critical review of evidence 2010 ([22](#))

Where relevant, this synthesis review also references the seminal Dean studies ([23](#), [25](#)) from the mid-20th century which are still considered some of the most authoritative on the topic and provide evidence for the association between water fluoride and dental caries and dental fluorosis outcomes from before the widespread use of fluoridated oral hygiene products.

Twelve health outcomes were considered for inclusion in this HMR, and this synthesis review summarised the state of the evidence for each: dental caries, dental fluorosis, birth outcomes, bladder cancer, blood pressure effects, bone cancers, hip fractures, kidney effects, neurodevelopment and cognitive effects, osteoarthritis, skeletal fluorosis, and thyroid effects. These health outcomes were identified based on the availability of existing evidence, the biological plausibility of an association, and those assessed in previous HMRs.

The state of the evidence for these health outcomes is presented below and summarised in [Table 2](#). This is presented alongside a brief note on the potential biological mechanism for an effect. As water fluoride concentrations vary globally and can reach levels many times higher than those found in England, the evidence is presented for associations found for concentrations below and above the WHO guideline value (1.5 mg/L) ([11](#)) in [Table 2](#).

Dental caries and related dental outcomes

Dental caries result from the breakdown of dietary sugars on the tooth surface, producing acids that demineralise the tooth enamel. Over time this can lead to lesions in the tooth tissue ([26](#)). Regular fluoride exposure maintains a level of fluoride in the plaque biofilm, promoting remineralisation and slowing or reversing caries progression ([26](#)) Fluoride exposure during tooth development also makes teeth more resistant to caries in the long-term ([27](#)).

The synthesis review found that Canada's CADTH, Cochrane, Ireland's HRB and Australia's NHMRC concluded there was consistent evidence that fluoride exposure below the WHO guideline value (1.5 mg/L) was associated with reductions in a range of outcomes measuring the prevalence and/or severity of caries ([13](#), [16](#), [18 to 20](#)). These outcomes included decayed, missing or filled teeth or surfaces in the primary (dmft/s) or permanent (DMFT/S) dentition for children and the proportion of children without caries. Meta-analysis to assess a dose-response relationship was only performed by HRB, which found no evidence of a dose-response relationship between dental caries outcomes and CWF exposure levels between 0.5 and 1.2 mg/L. However, it should be noted that HRB's methods excluded literature published before 1948. The seminal Dean studies do show a dose-response relationship between water fluoride concentration and dental caries prevalence at concentrations ranging between 0.0 and 2.6 mg/L ([24](#), [25](#)).

The 2 reports which focused specifically on exposure to CWF schemes (HRB and Cochrane) determined that the certainty of evidence for associations with caries in primary and permanent teeth was low or very low ([16](#), [18](#)). This was due to imprecision in effect estimates, lack of applicability of the findings to contemporary settings, the inherent risk of bias of included study designs and, for some outcomes, high statistical heterogeneity between study results.

CADTH and NHMRC identified a small number of studies assessing related dental outcomes, including tooth loss, tooth wear, tooth extractions, and dental clinic visits, and concluded the evidence to either be limited (≤ 3 relevant studies) or insufficient to support an association ([13](#), [20](#)).

Dental fluorosis

Dental fluorosis is one of a number of different conditions that can affect the appearance of teeth. In England, it is usually seen as paper-white flecks or lines on the tooth, but it can vary in appearance from barely visible fine white lines to patches which may be of aesthetic concern. The risk period for the development of dental fluorosis in permanent teeth is when the teeth are growing in the jaws; dental fluorosis cannot develop after teeth are formed. The first 2 to 3 years of life are generally accepted to be the period of highest susceptibility to fluorosis affecting the

front teeth (the incisors). There is also an established association between increasing severity of dental fluorosis and increased fluoride exposure from all sources. The mechanism of effect is well established, with fluoride causing changes in the appearance of the tooth's enamel through hypomineralisation ([28](#)).

The synthesis review found that 7 reports (European Union's EFSA, CADTH, Cochrane, HRB, NHMRC, New Zealand's MoH, European Union's SCHER) identified a positive association between fluoride exposure and dental fluorosis risk and/or severity. However, most evidence considered in the reports came from areas with fluoride concentrations above the WHO guideline level (>1.5 mg/L), and evidence for associations at lower exposures was correspondingly weaker.

Cochrane identified a dose-response relationship between water fluoridation at concentrations between 0.1 and 4.0 mg/L and both any dental fluorosis and dental fluorosis of aesthetic concern ([18](#), [31](#)). By contrast, HRB identified no evidence of a dose-response relationship between dental fluorosis and CWF levels between 0.5 and 1.2 mg/L. Data from the seminal Dean studies from earlier in the mid-20th Century show a dose-response relationship between severe dental fluorosis and water fluoride concentrations above 2.0 mg/L ([23](#), [24](#), [30](#)).

The most recent EFSA report for the European Union ([7](#)) did not include dental fluorosis as the association with fluoride was well established in their previous review ([31](#)). However, it noted that fluorosis prevalence was low or nil where drinking water concentrations were <1.0 mg/L, but that more severe fluorosis was consistently seen at concentrations around 2.0 mg/L. Based on both comprehensive older evidence and recent studies, the EFSA Scientific Committee determined that an appropriate updated reference point for protecting against dental fluorosis which might be of aesthetic concern was a drinking water concentration of 1.4 mg/L. NHMRC noted that the mild fluorosis found at similar, low exposure concentrations (<1.5 mg/L) was of no health concern and rarely reported to be a concern to those experiencing it.

Birth outcomes

Birth outcomes were considered for inclusion in the report as fluoride can cross the placenta and a possible cytogenetic effect on the developing foetus at sufficiently high exposures has been suggested ([32](#)).

The synthesis review found that reviews identified studies assessing birth weight and height and Down syndrome outcomes. EFSA noted that the evidence for endpoints such as adverse birth outcome is sparse, limited and inconsistent to date, and, as such, evidence was not considered to be suitable for further consideration in its assessment of health risks ([7](#)).

CADTH, HRB and NHMRC each identified no more than 2 studies assessing associations with birth weight and height. Reports noted the available evidence was hence insufficient to support an association ([13](#), [17](#), [20](#)).

Reports also identified few studies for Down syndrome. The most recent review, conducted by CADTH and updating the evidence presented in the earlier NHMRC report ([22](#)), identified 9 studies and concluded that this limited evidence suggested there was no association with water fluoridation at lower water fluoride concentrations (<1.5mg/L) ([15](#)). HRB similarly found very low certainty evidence suggesting there was no association ([17](#)).

Bladder cancer

Bladder cancer was considered for inclusion in the report as fluoride is excreted in the urine and therefore the bladder lining is exposed to relatively high concentrations.

The synthesis review found that none of the evidence reviews specifically reported on bladder cancer as an outcome, but NHMRC, CADTH and HRB included a small number of studies on bladder cancers in their findings for all-cancer outcomes. CADTH concluded that there was consistent evidence of no association with all-cancer incidence or mortality but did not provide a conclusion for bladder cancer specifically.

CADTH identified 2 previous water fluoridation HMRs for England (2014 ([2](#)) and 2018 ([3](#))). HRB and NHMRC also identified the analyses presented in the 2014 HMR ([2](#), [33](#)). No other studies on bladder cancer were identified in the reports included in the evidence synthesis. Findings from the previous HMRs for England are presented in [Table 1](#).

Blood pressure effects

Blood pressure effects were considered for inclusion in the report, with various mechanisms for an association with fluoride exposure suggested in the literature, although none have been established. These have included fluoride-induced oxidative stress ([34](#)) indirect impacts of improved periodontal health ([35](#), [36](#)) decreased magnesium absorption ([35](#), [36](#)) and effects on inflammation and immune response regulation ([34](#)).

The synthesis review found that only the CADTH report ([13](#)), and the earlier NHRMC report ([20](#)) which it updated, assessed associations with blood pressure, measured as prevalence of hypertension. Both reports found insufficient evidence for an association between water fluoridation at lower concentrations (<1.5 mg/L) and hypertension. Each report identified 5 or fewer studies. All studies either had insufficient or no controlling for confounders, or they identified significant associations only at fluoride concentrations substantially higher than the WHO guideline value (1.5 mg/L). EFSA determined there were too few studies available for an association with blood pressure to merit inclusion in its systematic review ([7](#)).

Bone cancer

Bone cancer was considered for inclusion in the report because fluoride deposits in the bone have been suggested to have a potentially mitogenic effect on osteoblasts ([32](#)).

The synthesis review found that CADTH, EFSA and NHMRC concluded there was sufficient evidence of no association between fluoridated water and bone cancers ([7](#), [13](#), [20](#)). HRB also found evidence suggesting no association, but was more tentative in its conclusion given the very low quality of the evidence base for exposure to CWF schemes, which was mostly based

on ecological studies ([17](#)). Most studies identified were conducted in areas where all fluoride exposures were below the WHO guideline value (1.5 mg/L). Reporting on the European Union, SCHER found no clear link between drinking water fluoride and osteosarcoma, and noted that animal studies supported this conclusion ([22](#)).

Hip fractures

Approximately half of the fluoride ingested by adults is taken up by bone, and its accumulation over time may affect the bone's mechanical properties ([37](#)). Fluoride can increase bone density, but excessive long-term intake may reduce bone strength ([31](#)) and could affect the risk of fractures. Both protective and adverse effects are theoretically possible. Hip fractures have been specified for use as an outcome related to these potential effects on bone, as they are a common and serious condition for which data suitable for analysis is available.

The synthesis review found that reports differed in their conclusions on the strength of evidence for an association between fluoride exposure and hip fractures. The most recent detailed report from EFSA integrated available human, animal and in vitro evidence. EFSA judged that the overall evidence was too limited to conclude on the presence of an association with fractures at low exposures (<1.5 mg/L), identifying only one study of high reliability. It found that some effects of fluoride intake on bone mineral density may occur at fluoride exposure levels around 3 mg per day. However, it is not clear whether or not these effects on bone mineral density are adverse, and the fluoride exposure threshold at which changes in bone mineral density may result in decreased mechanical strength with an effect on fracture risk is unknown ([7](#)). The NHMRC ([20](#)) review, and the later CADTH ([13](#)) review which updated it, both concluded there was sufficient evidence of no association between hip fractures and fluoride exposure at lower fluoride concentrations (<1.5 mg/L). HRB more tentatively concluded that the evidence suggested no association between hip fractures and water fluoridation, but highlighted that the quality of the body of evidence was very low as most studies were ecological and failed to control for osteoporosis ([17](#)).

Kidney effects

Effects on the kidney were considered for inclusion in the report because the kidney is exposed to relatively high fluoride concentrations as most ingested fluoride is excreted through it ([32](#)).

The synthesis review found that reviews identified some studies assessing kidney stones and chronic kidney disease outcomes. CADTH, HRB and NHMRC each identified no more than 3 studies assessing associations with either outcome.

CADTH concluded there was limited evidence that kidney stone incidence was lower in areas with water fluoridation compared to areas without, based mostly on evidence from 2 previous HMRs in England (2014 ([2](#)) and 2018 ([3](#))). HRB did not present a conclusion based on the single study it identified, and NHMRC found there was insufficient evidence for an association with kidney stones.

CADTH and NHMRC concluded there was a lack of evidence to assess an association with chronic kidney disease ([13](#), [20](#)).

Neurodevelopment and cognition

Neurodevelopment and effects on cognition were considered for inclusion in the report. While no mechanism for an effect on neurodevelopment and cognition has been established, changes in thyroid hormones have been proposed as one potential mediator ([21](#), [22](#)).

The synthesis review found that, at concentrations below the WHO guideline value (1.5 mg/L), CADTH, EFSA and USA's NTP reported there was uncertain or insufficient evidence to conclude that fluoride concentrations were associated with adverse neurodevelopment outcomes ([7](#), [13](#), [15](#), [21](#)). NHMRC found that evidence from a single study suggested there was no association between water fluoridation and cognitive function or Intelligence Quotient (IQ) in children and adults ([20](#)). HRB reported inconsistent findings for associations with IQ and neuropsychological development and noted that most studies had important methodological or data quality limitations. New Zealand's MoH instead concluded that at their current drinking water fluoride concentrations (<1.5 mg/L), neurodevelopment and cognitive impacts were not a concern ([19](#)).

At concentrations exceeding the WHO guideline value (1.5 mg/L), NTP concluded there was moderate confidence of an association between higher fluoride concentrations and lower IQ scores in children ([21](#)), and EFSA concluded there was reasonable confidence that adverse effects on neurodevelopment occurred ([7](#)). The review by New Zealand's MoH did not provide a formal conclusion but echoed an earlier government review's finding ([38](#)) that chronic exposure to very high fluoride levels could negatively affect neurodevelopment and cognition, although precise concentrations were not given ([21](#)). Across reports, evidence of effects at higher concentrations (≥ 1.5 mg/L) commonly came from studies in China or India and ranged from values close to the guideline value (1.5 mg/L) to many times higher.

The majority of studies included in reports assessed IQ in children as the outcome. Other outcomes included attention deficit hyperactivity disorder (ADHD) in children and different measures of cognitive impairment in adults. However, evidence for these outcomes was considered to be insufficient in all reports due to the small number of studies and heterogeneity in study design and outcome measurements.

Osteoarthritis

Osteoarthritis was considered for inclusion in the report as it has been suggested that high levels of fluoride exposure could exacerbate the growth of osteophytes in the bone and joints ([17](#)).

The synthesis review found that only EFSA ([7](#)) assessed evidence on the impacts on osteoarthritis. It identified 2 studies for osteoarthritis in the knee and elbow and concluded that, overall, the available evidence was too limited to draw firm conclusions.

Skeletal fluorosis

Skeletal fluorosis is a bone disease caused by prolonged exposure to high concentrations of fluoride, which accumulates in the bones. This can result in joint stiffness and chronic pain in the bones and joints, and in its most severe forms can lead to calcification of tendons and ligament and bone deformities (39). WHO reports that the condition has been observed at drinking water fluoride concentrations between 3 and 6 mg/L, with these concentrations most commonly found in areas of India, China, Central Africa and South America (11). This is far higher than the concentrations identified in fluoridated drinking water in the UK which is adjusted to a target level of 1.0 mg/L.

The synthesis review found that agencies' conclusions on associations with skeletal fluorosis focused on the meaning for their country contexts where drinking water concentrations were below 1.5 mg/L. The most recent report by EFSA (7) stated that evidence on causality between exposure and skeletal fluorosis was already well established and skeletal fluorosis likely only occurred at concentrations above the agency's previous tolerable upper intake level for adults (7.0 mg per day) (31). Skeletal fluorosis was therefore not prioritised in their systematic review. The NHMRC and CADTH reports both concluded there was insufficient evidence for an association at the lower concentrations found in their respective countries (<1.5 mg/L) (13, 20).

Thyroid effects

Thyroid effects were considered for inclusion in the report as there has been some evidence suggesting an association between high levels of fluoride exposure and thyroid effects, including reduced thyroid hormone levels and altered thyroid function. While various mechanisms including reduced production and impaired transport of thyroid hormones have been suggested, no clear mechanism has been demonstrated (7, 31).

The synthesis review found that CADTH, EFSA, HRB and NHMRC concluded there was limited and inconsistent evidence for an association with effects on the thyroid and determined that current evidence was insufficient to draw reliable conclusions (7, 13, 17, 20). However, EFSA noted that limited human evidence suggested fluoride exposure at concentrations similar to or above the guideline value (1.5 mg/L) was associated with higher mean thyroid stimulating hormones (TSH) levels (7). The New Zealand MoH report (19) discussed a recent meta-analysis (40) which found that the effects on TSH were only present at water fluoride concentrations of at least 2.0 to 2.5 mg/L. NTP identified some evidence of changes in TSH levels in children, but the studies were too heterogeneous and limited in number to determine an association (21).

Most studies assessed TSH levels as the outcome, with a limited number also examining other thyroid hormones and outcomes such as self-reported thyroid disorders. EFSA noted that the few studies which did assess other thyroid hormones (T3 and T4) reported associations inconsistent with reported increased TSH levels, reducing the confidence in the interpretation of the TSH findings (7). Only the EFSA report included animal and in vitro evidence. Most animal studies were judged to be of low validity, and the evidence provided by in vitro studies was judged to be insufficient to support a mode of action for fluoride's effects on the thyroid due to high heterogeneity and concerns with study designs.

Table 2. Evidence for associations between fluoride exposure and selected health outcomes based on major reports by international expert authoritative organisations

Outcome	State of the evidence: fluoride exposure below WHO guideline value (<1.5 mg/L)	State of the evidence: fluoride exposure at or above WHO guideline value (≥1.5 mg/L)	Review sources
Dental caries and related dental outcomes	<p>CADTH, Cochrane, HRB and NHMRC found evidence that water fluoridation was associated with decreased occurrence and severity of dental caries in children and adults. NZ MoH report did not provide a formal conclusion but similarly suggested a beneficial effect.</p> <p>Evidence for other dental outcomes such as tooth wear, tooth loss and dental visits was very limited or insufficient to draw conclusions.</p>	No reviews presented conclusions for associations at higher exposure levels.	CADTH (13), Cochrane (16), HRB (18), NHMRC (20), NZ MoH (19)
Dental fluorosis	<p>Seven reviews (EFSA, CADTH, Cochrane, HRB, NHMRC, NZ MoH, SCHER) noted evidence of a positive association with dental fluorosis risk and/or severity. Some of this evidence was from areas with fluoride concentrations <1.5mg/L.</p> <p>NHMRC also noted that the mild fluorosis commonly found in areas with drinking water concentrations <1.5 mg/L was rarely reported to be of concern by those who had it.</p>	<p>Seven reports (EFSA, CADTH, Cochrane, HRB, NHMRC, NZ MoH, SCHER) noted evidence of a positive association with dental fluorosis risk and/or severity.</p> <p>Most evidence considered in the reviews came from areas with fluoride concentrations >1.5 mg/L.</p> <p>EFSA concluded that severe fluorosis was consistently found at fluoride concentrations around 2 mg/L.</p>	EFSA (70< CADTH, Cochrane, HRB, NHMRC, NZ MoH, SCHER (21))

Outcome	State of the evidence: fluoride exposure below WHO guideline value (<1.5 mg/L)	State of the evidence: fluoride exposure at or above WHO guideline value (≥1.5 mg/L)	Review sources
	<p>Cochrane found evidence of a dose-response relationship at concentrations of water fluoridation between 0.1 and 4.0 mg/L. HRB found no evidence of a dose-response relationship at concentrations of water fluoridation between 0. mg/L and 1.2 mg/L. EFSA found that fluorosis prevalence was very low or absent at exposure to water concentrations <1.0 mg/L and that a reference point of 1.4 mg/L may be protective.</p>		
Birth outcomes	<p>HRB, CADTH and NHMRC found insufficient evidence for an association with birth weight and height.</p> <p>HRB, CADTH and NHMRC identified limited evidence suggesting no association with Down Syndrome, with most studies being of low quality and conducted in areas where all fluoride exposures were below guideline values.</p>	No reviews presented conclusions for associations at higher exposure levels.	CADTH, HRB (17), NHMRC
Bladder cancer	CADTH, HRB and NHMRC identified only the previous HMRs for England 2014 (2) and 2018 (3), of which the more recent report found no convincing evidence for a protective effect on bladder cancer incidence.	No studies identified.	CADTH, HRB

Outcome	State of the evidence: fluoride exposure below WHO guideline value (<1.5 mg/L)	State of the evidence: fluoride exposure at or above WHO guideline value (≥1.5 mg/L)	Review sources
Blood pressure	NHMRC and CADTH identified 2 studies that reported correlations at concentrations which ranged from below to above the guideline value. CADTH and NHMRC found insufficient evidence of an association at concentrations found in their countries (all below the guideline value).	A small number of low quality studies which were likely to be confounded. No reviews presented conclusions for associations at higher exposure levels.	CADTH, NHMRC
Bone cancers	Four reviews (EFSA, CADTH, HRB, NHMRC) concluded there was no evidence of an association. Most studies identified were conducted in areas where all fluoride exposures were below guideline values.	Few studies identified. No reviews presented conclusions for associations at higher exposure levels.	EFSA, CADTH, HRB, NHMRC
Hip fractures	CADTH and NHMRC concluded there was evidence of no association with hip fracture below 1.5 mg/L. HRB noted that included studies tended to show no association, although the evidence was limited. EFSA judged that the overall evidence was too limited to conclude on the presence of an association with fractures at low exposures.	No reviews presented conclusions for associations at higher exposure levels.	EFSA, CADTH, HRB, NHMRC
Kidney effects	HRB, CADTH and NHMRC found limited or insufficient evidence for an association with kidney stones or chronic kidney disease.	No reviews presented conclusions for associations at higher exposure levels.	HRB, CADTH, NHMRC

Outcome	State of the evidence: fluoride exposure below WHO guideline value (<1.5 mg/L)	State of the evidence: fluoride exposure at or above WHO guideline value (≥1.5 mg/L)	Review sources
	Two of the 3 studies identified across all reports for kidney stones came from 2 previous HMRs for England (2018 and 2014 (3 , 2), where all fluoride exposures were below guideline values.		
Neuro-development and cognition	Five reviews (EFSA, CADTH, NHMRC, NTP, SCHER) identified insufficient or unclear evidence for an association. HRB found mixed results from a limited number of studies for associations between CWF and non-CWF areas. NZ MoH did not present a formal conclusion but indicated evidence suggested neurodevelopment and cognitive impacts were not a concern at current low exposure levels.	EFSA and NTP concluded with 'moderate' or 'reasonable' confidence that there was an association with adverse neurodevelopment outcomes. NZ MoH's review made more tentative statements to support the plausibility of negative impacts from chronic exposure to very high concentrations, although did not state a threshold.	EFSA, CADTH (13 , 15), HRB, NHMRC, NTP (21), NZ MoH, SCHER
Osteoarthritis	Evidence is too limited to draw conclusions.	Evidence is too limited to draw conclusions.	EFSA
Skeletal fluorosis	The EFSA and SCHER stated that skeletal fluorosis was unlikely to occur at concentrations found in the EU. CADTH and NHMRC concluded there was a lack of evidence to draw a conclusion.	EFSA stated that evidence on causality between fluoride exposure and skeletal fluorosis is well established and skeletal fluorosis likely only occurs at drinking water concentrations >1.5 mg/L.	EFSA, CADTH, NHMRC, SCHER
Thyroid effects	NZ MoH identified a meta-analysis that found there was no effect on thyroid function at	EFSA and NZ MoH identified that associations with effects on TSH levels	EFSA, CADTH,

Outcome	State of the evidence: fluoride exposure below WHO guideline value (<1.5 mg/L)	State of the evidence: fluoride exposure at or above WHO guideline value (≥1.5 mg/L)	Review sources
	<p>concentrations comparable to those used in CWF.</p> <p>CADTH and NHMRC reported that there was insufficient evidence for an association at concentrations below the guideline value. HRB found mixed results from a limited number of studies for associations between CWF and non-CWF areas.</p>	<p>tended to be seen at concentrations at or above 1.5 or 2 mg/L, respectively.</p> <p>EFSA included 2 studies showing effects in the same direction which it determined insufficient on which to base conclusions.</p> <p>NTP did not disaggregate by exposure level but found some evidence of an association between exposure to fluoride and higher TSH levels in children.</p>	HRB, NHMRC. NZ MoH, NTP

Abbreviations

CADTH = Canadian Agency for Drugs and Technologies in Health; CWF = Community Water Fluoridation; EFSA = European Food Safety Authority; EU = European Union; HMR = Health monitoring report; HRB = Health Research Board; IQ = Intelligence Quotient; mg/L = milligrams per litre; NZ MoH = New Zealand Ministry of Health; NHMRC = National Health and Medical Research Council; NTP = National Toxicology Program; SCHER = Scientific Committee on Health and Environmental Risks; TSH = Thyroid Stimulating Hormone; UL = Upper Intake Levels.

Notes

Note 1: Guideline values are derived from the WHO Quality of Drinking-water Guidelines, 2022, which suggest fluoride concentrations below 1.5 mg/L in drinking water would not result in any significant risk to health over a lifetime of consumption ([11](#)). Most countries with fluoridation schemes aim to keep all concentrations below this level.

Overall, this synthesis finds that evidence reviews from key international authoritative organisations report consistent evidence that fluoride exposure below 1.5 mg/L is associated with reductions in dental caries outcomes. The relationship with dental fluorosis is well established but is of no health concern and is not likely to be of aesthetic concern at concentrations below 1.4 mg/L. The relationship with skeletal fluorosis is also well established but is only found at substantially higher concentrations than 1.5 mg/L, and there are no known clinical cases from consuming drinking water in England. While there was moderate or reasonable confidence of an adverse effect on neurodevelopment for fluoride concentrations above 1.5 mg/L, evidence from areas with concentrations below 1.5 mg/L was uncertain or insufficient. Some reviews found sufficient evidence of no association between hip fractures and concentrations below 1.5 mg/L, but the most recent and comprehensive review concluded there was insufficient evidence at these exposure levels to determine an association. Reviews found limited evidence of no association with Down syndrome and sufficient evidence of no association with bone cancers. There was very limited or insufficient evidence to conclude on the presence of an association with birth weight or height, bladder cancer, blood pressure, kidney effects, osteoarthritis or thyroid effects at fluoride concentrations below 1.5 mg/L.

These findings are in line with those of the Academy of Medical Science's evidence synthesis report on the optimal concentration of water fluoridation in the UK (5). It found that the effects of water fluoridation in England are, overall, beneficial to dental health in children and adults at the current target concentration of 1.0 mg/L, and that there is no evidence of a harmful effect of water fluoridation on non-dental health outcomes.

The international scientific evidence summarised in the present evidence synthesis was considered alongside the availability of appropriate data and the analyses of health outcomes in previous HMRs to inform the selection of health outcomes included in analysis in this report.

Reducing dental inequalities

Part of the public health rationale for water fluoridation schemes in England is based on the consistent evidence of reductions in dental health inequalities in areas with higher drinking water fluoride concentrations. In both the 2018 and 2022 HMRs, children in the most deprived areas experienced greater benefits to their dental health from higher fluoride concentrations than other children. In 2018, for 5 year old children living in areas with the highest water fluoride concentrations (≥ 0.7 mg/L) compared to the lowest (< 0.1 mg/L), the odds of experiencing caries was 23% lower (95% CI: 9% to 39%) in the least deprived areas and 52% lower (95% CI: 47% to 56%) in the most deprived areas. A similar pattern was observed in 2022, although the reduction in odds among those in the most deprived areas was more (Table 1).

The international authoritative agencies included in the evidence synthesis above varied to the extent to which they found evidence that water fluoridation schemes in reduce inequalities in dental health. This may reflect differences in study designs or differences between England and other areas in how deprivation relates to other factors linked to dental caries risk, such as diet, tooth-brushing habits, and access to dental care. The most recent review, by Cochrane

collaborators, concluded there was currently a lack of consistent, robust evidence for fluoridation schemes leading to reductions in disparities globally but emphasised that a lack of evidence of an effect was not evidence of no effect ([16](#)). The NHMRC and CADTH reports assessed the effects of any exposure to fluoride in water and found that there was some limited global evidence suggesting a greater reduction in dental caries experience among those from lower socio-economic groups. However, they found that there either remained large uncertainty around this effect or the effect was sensitive to the measure of socioeconomic disparity used ([15](#), [22](#)). In contrast, the New Zealand Ministry of Health's evaluation repeated its previous 2021 report's conclusion that water fluoridation schemes were important in reducing socioeconomic inequities in health in New Zealand based on a small group of studies from the country ([19](#), [39](#)).

This fourth report in the health monitoring series, like the previous reports, assessed exposure to fluoride from drinking water sources only. This approach likely produces cautious estimates of changes in dental health inequalities. This is due to 2 potential mechanisms: 1) as disparities exist in the use of oral hygiene products (containing fluoride) and diet, there may be larger exposure differences in total fluoride intake between groups than observed for drinking water fluoride intake alone, with more affluent groups potentially having a greater total fluoride intake; 2) more deprived groups are more likely to have poorer baseline dental health and uptake of dental health care ([43](#)). Both these mechanisms potentially contribute to larger reductions in dental inequalities between deprivation groups which are not fully captured in this HMR.

Feasibility

Selection of health indicators

There is strong evidence that fluoride in water at levels permitted by England's water quality regulations has an effect on 2 dental health outcomes: dental caries and dental fluorosis. This report includes analysis of the relationship between fluoride and dental caries, using 3 outcome measures: prevalence of dental caries experience in children at age 5 and children in Year 6 (10 or 11 year olds), severity of dental caries in children at age 5 and in Year 6 (10 or 11 year olds), and hospital admissions for caries-related tooth extractions in those aged 0 to 19 years old. Dental fluorosis was assessed in the 2018 HMR ([3](#)). The 2023 oral health survey among Year 6 children reported on symmetrical diffuse white patches, but did not assess dental fluorosis as in the Pretty and colleagues ([42](#)) study used in the 2018 HMR. Dental fluorosis was not included in this report for this reason.

[Table 3](#) summarises the dental and non-dental health outcomes included in this report. [Table 4](#) summarises those which were considered for inclusion in this report, and the rationale for their exclusion. All had previously been considered for analysis in the 2018 and 2022 reports ([3](#), [4](#)) with the exceptions of blood pressure and osteoarthritis which were newly considered for inclusion based on a review of endpoints analysed in recent literature. Further examination based on the synthesis review subsequently found insufficient evidence of an association to justify moving forwards with investigation for these 2 outcomes. The decisions to not include other outcomes in this report were largely based on no evidence of an association identified

either in the 2018 HMR or in the wider literature, or a lack of new outcome data made available since previous HMR analyses.

Two non-dental health outcomes are analysed in this report: emergency hospital admissions for hip fractures, and cognitive ability in children. There is international evidence of the adverse health effects of long-term exposure to high levels of fluoride on bone, including skeletal fluorosis and fracture, but the most serious impacts may only occur at exposure above 6 to 14 mg per day ([11](#)). Evidence at low exposures (<1.5 mg/L) as found in England is very limited, with an insufficient number and quality of studies to inform an understanding of the relationship between water fluoridation and risk of effects on the bone and hip fractures ([13](#), [17](#), [20](#)). The 2018 and 2022 HMRs found no convincing evidence of a causal association, with no consistent change in hip fracture admission rates within age groups. Due to this gap in international evidence, the findings of past HMRs and the common and serious nature of hip fractures as a health outcome in England, emergency hospital admissions for hip fracture have been included again for analysis in this edition of the HMR series, using subsequent years' hospital admissions data.

While not assessed in previous HMRs, this report includes an analysis of the association between fluoride exposure and cognitive ability in children. Recent reviews find evidence for an association between higher fluoride exposures (>1.5 mg/L) and children's neurodevelopment and cognition ([7](#), [21](#)). However, evidence for an association at lower exposures as found in England remains limited and unclear. No mechanism for neurotoxicity or adverse cognitive effects has been identified, though indirect mechanisms via thyroid effects have been suggested ([21](#)). A battery of measures of cognitive ability in children was identified in the Millenium Cohort Study (MCS) and was considered appropriate for analysis in this report.

Table 3. Selected health outcome indicators for fluoride monitoring

Outcome	Proposed indicator	Rationale for inclusion
Dental caries experience	Prevalence of dental caries experience (d ₃ mft or D ₃ MFT >0) in 5 and 10 or 11 year olds	<p>There is strong evidence of a protective association between fluoride and dental caries. The 2018 and 2022 reports found that the greatest benefit was seen in children in the most deprived quintile of geographical areas surveyed. Additional oral health survey data is available from 2022 and 2024 for 5 year old children and from 2023 for Year 6 children (10 and 11 year olds). Additional data on hospital admissions for caries-related tooth extractions is available for the 3 financial years from April 2021 to March 2024.</p> <p>Analysing the association between fluoride and caries prevalence, caries severity and hospital admissions for tooth extractions using additional years of data enables ongoing monitoring of a known benefit and of the effect on health inequalities.</p>
Dental caries severity scores	Mean dental caries severity scores (mean d ₃ mft or D ₃ MFT) in 5 and 10 or 11 year olds	
Caries-related tooth extractions	Hospital admission for caries-related tooth extraction 0 to 19 year olds	
Hip fractures	Emergency hospital admissions for hip fractures at all ages	<p>The 2018 and 2022 reports found no consistent trend in incidence rates of hip fractures with increasing drinking water fluoride concentrations within age groups. Overall, they concluded there was no convincing evidence for a causal association.</p> <p>However, hip fractures are a very common and serious health outcome in older age groups and an adverse effect on bone is plausible. Wider scientific evidence at low fluoride exposures is limited. It was considered worth repeating analysis with subsequent years' hospital data.</p>
Cognitive ability	<p>BAS scores at age 5</p> <p>NFER PiM and selected BAS test scores at age 7</p>	Recent evidence suggests that higher fluoride concentrations (≥ 1.5 mg/L) are associated with a poorer neurodevelopment and cognition outcomes in children. However, there is currently limited evidence suggesting an association with neurodevelopment and cognition at lower drinking water

Outcome	Proposed indicator	Rationale for inclusion
		fluoride concentrations as found in England. Where data on certain measures of cognitive ability was available in the UK, associations with fluoride exposure were investigated.

Abbreviations

BAS = British Ability Scales, mg/L = Milligrams per litre, NFER = National Foundation for Education Research, PiM = Progress in Maths.

Table 4. Health outcomes considered for analysis but not included

Outcome	Rationale for exclusion
Dental fluorosis	Dental fluorosis was assessed in the 2018 HMR, which found that although 11 to 14 year olds in fluoridated areas had a higher prevalence of the condition, there was no important difference in self-reported aesthetic dissatisfaction compared to peers in non-fluoridated areas. The report used 2015 data from Pretty and colleagues (42) which used photographic methods for determining dental fluorosis in 11 to 14 year olds and also recorded participants' views on the appearance of their teeth. The 2023 oral health survey of Year 6 children (10 or 11 year olds) includes the prevalence of symmetrical diffuse white patches on any of the erupted permanent anterior tooth surfaces as a proxy for the prevalence of dental fluorosis. They did not record different levels of severity or self-reported perceptions of dental appearance. Due to this, further investigation was considered unlikely to change the conclusions drawn previously. Furthermore, the link between fluoride exposure and dental fluorosis is well established, but the condition typically causes limited aesthetic concern at the levels of fluoride exposure found in England.
Skeletal fluorosis	There is no feasible measure to use for analysis. Evidence suggests that skeletal fluorosis only occurs at far higher concentrations of fluoride than permissible under UK drinking water standards (11).
Thyroid effects	Evidence reviews have found limited and inconsistent evidence for an association at higher fluoride concentrations, and little or no evidence for exposures below 1.5 mg/L. Exploration of data sources for studying the incidence of thyroid effects has identified potentially suitable datasets. Work is ongoing to assess their quality and the sufficiency of information available for inclusion in future HMR analyses.

Outcome	Rationale for exclusion
Bladder cancer	Previous HMRs have not found evidence for an association between fluoride exposure and bladder cancer. No other evidence from outside the English context was identified by reviews in the evidence synthesis. Identified datasets for potential use in this edition of the report either had data quality limitations and were not recommended for use in epidemiological studies or were outdated.
Blood pressure	Evidence for an association with blood pressure is considered very limited and does not support an association at water fluoride concentrations found in England.
Bone cancer	While a mechanism for an effect on bone cancer may be plausible, the 2018 HMR found no evidence of an association between fluoride and new diagnoses of osteosarcoma in England. Identified datasets for use in this edition of the report either were outdated or had data quality limitations and were not recommended for use in epidemiological studies.
Birth outcomes	The 2018 HMR found no convincing evidence of an association between fluoride and Down syndrome. Wider international evidence on an association is limited but suggests no association. Evidence for an association with birth weight and height is weak, with an unclear mechanism for effect.
Kidney effects	Existing evidence on an association between fluoride exposure and kidney stones is very limited and largely draws on previous health monitoring reports for England. The 2018 HMR found inconsistent results for kidney stones. Rates of kidney stones admissions were higher in the low to mid-range fluoride concentration categories compared to the lowest concentration, but no dose-response relationship was observed. Overall, this was judged to provide no convincing evidence for a causal association, and the analysis will not be repeated in this edition of the report. Wider international evidence is considered too limited to make a judgement on an association with chronic kidney disease.
Osteoarthritis	Epidemiological evidence for an association with osteoarthritis is considered very limited and does not currently convincingly support an association.

Aims and objectives

Aims

To monitor the health effects of water fluoridation schemes, and to assess the associations of fluoride concentrations in public water supplies with selected dental and non-dental health outcomes.

Objectives

The objectives were:

- to describe the distribution of fluoride concentrations in public water supplies across England
- to describe the frequency of selected dental and non-dental health outcomes across fluoride concentrations and, where possible, across age, sex, and ethnicity groups and levels of deprivation
- to determine and assess the association between water fluoride concentration and selected dental and non-dental health outcomes, where possible adjusting for age group, sex, ethnicity and deprivation
- to determine and assess the association between exposure to a water fluoridation scheme and selected dental and non-dental health outcomes, where possible adjusting for age group, sex, ethnicity and deprivation

Methods

Overview

This report assessed the association between average fluoride exposure and 5 health outcomes in England: dental caries prevalence, dental caries severity, hospital admissions for tooth extractions, hospital admissions for hip fractures, and cognitive ability. Fluoride exposure was measured at the lower-layer super output area (LSOA) level. LSOAs are small geographical units containing between 1,000 and 3,000 people ([45](#)). Exposure was characterised in 3 ways: 1) categories of drinking water fluoride concentration, 2) a continuous measure of drinking water fluoride concentration, and 3) presence of a water fluoridation scheme.

For each health outcome, descriptive statistics and adjusted regression estimates were presented.

The data sources, age groups, timing of outcome ascertainment, fluoride exposure periods, and statistical techniques varied across each health outcome.

Study population

The populations used in the studies presented in this report are from England: children participating in oral health surveys, hospital admissions as proportions of the general population, and children who were followed up as part of a birth cohort. The specific samples, age groups and time periods included in analyses varied for each health outcome assessed and are presented later ([Table 8](#)).

Study design

As fluoride exposure was measured at the LSOA level, all analyses used an ecological study design.

Research approval

This report conducted a data protection impact assessment (DPIA) for all health outcomes to assess potential risks associated with the processing of personal data and the appropriate ethical and privacy safeguards were put in place. Drinking water fluoride data was provided through a data sharing agreement (DSA) between UKHSA and DWI. For the cognitive ability outcome analyses, the UKHSA Research Ethics and Governance Group (Reference: NR0343) granted ethics approval, and the analysis used secondary data where individuals were not identifiable.

Health outcomes and data sources

Dental caries experience and severity score

Data on dental caries was obtained from the most recent oral health surveys of 5 year old children (2022 ([44](#)) and 2024 ([45](#))) and Year 6 children (10 or 11 year olds, 2023 ([46](#))) for the National Dental Epidemiology Programme (NDEP) for England. The surveys are conducted in state schools by trained and calibrated examiners. Data was available at the LSOA level. Details on the survey methods are described in detail in the national survey protocols ([47 to 49](#)).

Dental caries is defined as visually obvious dentinal decay, or teeth that are missing or have been filled due to decay. This is denoted as d_3mft in primary teeth and D_3MFT in permanent teeth. The ' d_3 ' or ' D_3 ' indicates decay into the dentine, which is the layer of tooth beneath the enamel. The surveys of 5 year olds measured caries in primary teeth only (d_3mft). The surveys of Year 6 children (10 or 11 year olds) measured dental caries in permanent teeth only (D_3MFT).

From this data, we define 2 dental caries outcomes that are relevant to public health. First, dental caries experience captured children surveyed in each LSOA with at least one tooth with dental caries ($d_3mft > 0$ or $D_3MFT > 0$). Second, dental caries severity score captured the mean number of teeth with dental caries in each LSOA (mean d_3mft or D_3MFT). Mean severity score was divided into 4 categories, 'Zero', 'Low', 'Medium' and 'High'. The 'Zero' category indicates that none of the children examined in the LSOA had any teeth with caries. The remaining 3 categories are formed by dividing LSOAs' mean severity scores into tertiles.

Data on D_3MFT among Year 6 (10 or 11 year olds) children from the oral health survey 2023 had known methodological challenges that may impact data quality and validity. Dental caries in permanent teeth in children tends to take time to become visible, so the prevalence at age 10 or 11 may be substantially lower than in children a few years older. In addition, dental caries tends to be found more often in molar and premolar teeth rather than in incisors. Premolars erupt between ages 9 and 12 years, and second molars around ages 11 to 13 years. Dental caries experience in Year 6 children is consequently mainly concentrated in the occlusal surfaces of first permanent molars, which erupt at age 6 to 7 years. These surfaces are the most vulnerable to dental caries and they may also have had sealants or sealant restorations placed on those surfaces which can mimic or mask dental caries experience. These teeth can also be affected by molar-incisor hypomineralisation, which can mimic dental caries or make the tooth more susceptible to dental caries. This can lead to challenges in identifying dental caries in this age group, and these limitations informed the approach to analysis, and ultimately only descriptive statistics were produced using the data.

Hospital admissions for caries-related tooth extractions

Data on hospital admissions for caries-related tooth extractions among individuals aged 0 to 19 years old was obtained from the Hospital Episode Statistics (HES) Admitted Patient Care (APC)

dataset for the 3 financial years from April 2021 to March 2024. Cases were defined as Finished Consultant Episodes (FCE) showing surgical removal or simple extraction of teeth (HES codes: F09 and F10) with diagnosed dental caries (ICD10 codes: K021, K025, K028, K029, K040, K045, K046, or K047). The incidence rate of tooth extractions due to dental caries in each LSOA was determined by dividing the number of admissions by total person-years at risk (PYAR). PYAR was calculated by summing the Office for National Statistics (ONS) mid-year estimates (MYE) corresponding to the year of outcome measurement for each LSOA by age group (0 to 4, 5 to 9, 10 to 14, 15 to 19 years old) and sex for each year.

It should be noted that there are tooth extractions conducted by community dental services in hospital settings, and this activity is not always included in the HES data. Older children are also more likely to have tooth extractions performed in primary care facilities, and these events would not be recorded in hospital admissions data. Further data considerations are noted in the annual statistical release for tooth extractions ([50](#)).

Emergency hospital admissions for hip fractures

Data on emergency hospital admissions for hip fracture among individuals of all ages was obtained from HES APC datasets for the 3 financial years from April 2021 to March 2024. Cases were defined as emergency consultant episodes for admissions for hip fracture (ICD10 codes: S72.0, S72.1, or S72.2 as the first or second diagnosis code; admission method filtered for emergency admissions (code: 2)). Records were deduplicated using the unique HES identification number to ensure only one record per new admission episode was selected. The incidence rate of hip fractures in each LSOA was determined by dividing the number of admissions by total PYAR. PYAR was calculated by summing the ONS MYE corresponding to the year of outcome measurement for each LSOA by age group (0 to 49, 50 to 64, 65 to 79, ≥80 years old) and sex for each year.

Cognitive ability test scores

Data on cognitive ability outcomes in children was obtained from selected survey waves ('sweeps') conducted in the UK Millennium Cohort Study. MCS is a nationally representative birth cohort study that follows the health and development of 18,818 children born in the UK between 1 September 2000 and 31 August 2001 ([51](#)). Sweeps collected data from the cohort as children aged. For this report, one child from multiple births was randomly selected for inclusion.

For each child, different measures of cognitive ability were assessed in different MCS sweeps. This report used data from sweep 3 (when children were 5 years old) and sweep 4 (when children were 7 years old). In these sweeps, children were administered selected British Ability Scales (BAS) tests and the National Foundation for Education Research (NFER) Progress in Maths (PiM) exam ([Table 5](#)).

BAS is a battery of core sub-tests measuring cognitive ability and educational achievement ([54](#)). Four BAS tests were available: Picture Similarities (BAS-PS), Naming Vocabulary (BAS-NV),

Pattern Construction (BAS-PC), and Word Reading (BAS-WR). NFER-PiM is a mathematics test requiring the child to complete a series of calculations on paper after being read questions aloud. For all cognitive ability measures, a higher score indicates higher ability (52). For the BAS tests, raw scores tabulated using the Rasch model (53, 54) were converted to standardised T-scores using age-specific population norms (see Table 5).

Table 5. Overview of cognitive ability measures used, including standardised score scales

Cognitive assessment	Acronym	Age surveyed	Mean standardised score (SD)
BAS test: Naming Vocabulary	BAS-NV	5 years old	50 (10)
BAS test: Picture Similarities: Pictorial Non-verbal reasoning	BAS-PN	5 years old	50 (10)
BAS test: Pattern Construction	BAS-PC	5 years old and 7 years old	50 (10)
BAS test: Word Reading	BAS-WR	7 years old	100 (15)
NFER: Progress in Maths	NFER-PiM	7 years old	100 (15)

Abbreviations

BAS = British Ability Scales, MCS = Millenium Cohort Study, NFER = The National Foundation for Educational Research, SD = standard deviation.

Notes

Children aged 5 and aged 7 were captured in MCS sweeps 3 and 4, respectively.

Exposure measurement and definition

In this report, fluoride exposure is measured in mains drinking water.

Mains drinking water is likely the major source of total fluoride intake for people receiving water with a fluoride concentration of about 0.3 mg/L and above (22). For those exposed to lower drinking water concentrations, other sources including diet and fluoride-containing toothpastes may contribute a larger share. However, there is limited data on exposure to these other sources and there is also limited biomonitoring data (such as urinary fluoride levels) which may reflect intake from all sources for English sub-populations. Consumption of non-mains water (for example, private boreholes, bottled water), may also affect fluoride exposure, but data on exposure from these other water sources is not available.

Drinking water fluoride data

Fluoride concentration in drinking water is routinely monitored in all water supply zones (WSZs) in England by the DWI. Water fluoride data (monitored fluoride concentration in drinking water,

operation status of fluoridation schemes and WSZ boundaries) is provided by calendar year (January to December) by the DWI for use in the HMR.

This report included both the most recent exposure data (2016 to 2024) and exposure data used in the previous HMRs.

An annual mean fluoride concentration was assigned to each LSOA in England following a similar process to that used in the 2022 HMR ([4](#)). This involved overlaying the population-weighted centroid of the LSOA onto WSZ boundaries. WSZ geographical boundaries change over time, and the number and size of these vary each year (2016 to 2024 average: $n=1,707$, $\text{area}=80 \text{ km}^2$).

The cognitive ability outcomes analysis involved data from before 2005 (exposure window 2000 to 2008), the year for which WSZ boundary maps were first available. Pre-2005 data points were assigned fluoride exposures by overlaying fluoride measurement point data onto the 2005 WSZ boundaries ([55](#)). As for the other outcomes, LSOAs were then overlain on these boundaries and assigned the appropriate fluoride exposure values.

All spatial data processes were conducted using ArcMap in ArcGIS 10.5.1 ([56](#)).

Exposure definitions

Exposure to fluoride via drinking water for each LSOA was defined in 3 ways: by 1) categories of fluoride concentration in drinking water; 2) a continuous measure of fluoride concentration in drinking water; and 3) presence of a fluoridation scheme. For each outcome, separate models for each exposure measure were fitted. This approach is the same as used in previous reports ([3](#), [4](#)) with analysis of the first 2 measures based on fluoride concentration aiming to understand the relationship between exposure to drinking water fluoride and health outcomes of interest, and analysis of the third measure aiming to fulfil the monitoring requirements in the Water Industry Act 1991 ([1](#)) to monitor and analyse the effects of water fluoridation schemes.

The 3 exposure measures are detailed in [Table 6](#).

The categorical exposure variable may support detecting a potential threshold effect or non-linear dose-response relationship with the health outcome of interest. Using fluoride concentration as a continuous variable allows for tests of linear or non-linear dose-response relationship with the outcomes of interest.

The presence of a fluoridation scheme as an exposure definition has been included to directly address the requirements of the Water Industry Act 1991 ([1](#)). As in previous HMRs, analysis using this exposure measure was performed if an association between the health outcome and the mean fluoride concentration measure (categorical and continuous) was observed, making it epidemiologically reasonable to further investigate the association.

Table 6. Characteristics of the 3 fluoride exposure measures used for analysis

Exposure measure	Variable type	Exposure definition
Drinking water fluoride concentration (categorised)	Ordered categorical (<0.10, 0.10 to 0.19, 0.20 to 0.39, 0.40 to 0.69, ≥0.70; mg/L)	The grand mean (mean of annual means) drinking water fluoride concentration for each LSOA, over the exposure period of interest defined for each health outcome. The exposure is split into 5 ordered categories. Category boundaries were defined in previous HMRs based on international evidence suggesting that dental caries reduction may plateau at 0.70 mg/L (57) and based on the distribution of fluoride concentrations in England's water supply, with low concentrations found in most LSOAs (all <1.5 mg/L; median: 0.12 mg/L; interquartile range (IQR): 0.07 to 0.21 mg/L (4)).
Drinking water fluoride concentration (continuous)	Continuous (mg/L)	The grand mean (mean of annual means) drinking water fluoride concentration for each LSOA, over the exposure period defined for each health outcome. The exposure is scaled by dividing each value by the IQR (the difference between the value at the 25th percentile and the value at the 75th percentile) of all fluoride concentration values for LSOAs between 2011 and 2024. A one-unit increase in the outcome corresponds to an IQR increase in fluoride concentration (mg/L). The cognitive ability outcome is scaled by the IQR of the fluoride concentration values measured at 9 months old.
Presence of fluoridation scheme	Binary (with fluoridation scheme, without fluoridation scheme)	LSOAs were classified as having a fluoridation scheme if one operated during any year of the exposure period, regardless of grand mean fluoride concentration. LSOAs were classified as without a fluoridation scheme if no scheme operated during any year and the grand mean fluoride concentration was <0.20 mg/L. LSOAs without a scheme but with a grand mean ≥0.20 mg/L were classified as areas with 'natural fluoridation' and excluded in multivariable analyses to remove areas with naturally higher fluoride levels.

Abbreviations

IQR = Interquartile range, LSOA = Lower-layer super output area, mg/L = milligrams per litre.

The years of exposure data used varied according to the plausible exposure window for each health outcome being considered. These are presented and discussed in [Table 7](#).

Table 7. Water fluoridation exposure periods of interest

Outcome	Exposure window	Rationale
Prevalence and severity of dental caries experience	5 year olds: 6 years Year 6 (10 or 11 year olds): 10 years	<p>Incorporation of fluoride into developing tooth tissue and into teeth after eruption are both likely to play a role in modifying dental caries risk (58 to 60).</p> <p>The development of dental caries detected in a dental survey or hospital records of tooth extractions is hence likely affected by exposure to fluoride during both the pre-eruptive and post-eruptive periods of tooth development.</p> <p>As the pre-eruptive period begins during fetal development, and it is thought that fluoride can cross the placenta (61, 62) (though the relationship between maternal and fetal exposure is less clear, and the placenta may act as a partial barrier) (63), the induction period for effects in primary teeth should include fluoride exposure in utero. The development of permanent teeth instead begins around birth.</p> <p>Hence, exposures for data from 5 year olds extended back over a 6-year window, and from 10/11 year olds extended over a 10-year window.</p>
Caries-related tooth extractions	5 years	As the data covered a mixed age group from ages 0 to 19 years, the relevant exposure period was less clearly definable than for dental caries prevalence and severity above. A 5-year window before the calendar year of tooth extraction occurrence was chosen.
Hip fractures	10 years	As the data covered all ages, the relevant exposure period was not clearly definable. Fluoride accumulates in the bone over time, and a suitable period was thought to be at least 10 years preceding the event. Hence, a 10-year window from the calendar year of the hip fracture occurrence was chosen. However, it is recognised that in adults, and particularly in the older adults, this window is unlikely to reflect lifetime fluoride exposure.
Cognitive ability	Annual mean concentration at 9 months old, 5 years old and 7 years old.	Central nervous system development starts as early as the prenatal period and continues into childhood (66). Exposure data for individuals at age 9 months old was used, with data on exposure at 5 and 7 years old also tested in sensitivity analyses. Exposure at 9 months is thought to represent well exposure in the first year of life and potentially also before birth.

Other risk factors

Different parts of England have different characteristics, such as their age and sex distribution, levels of deprivation, and the proportion of people from different ethnic groups. These characteristics may be linked to differences in the distribution of health outcomes and can potentially affect the relationship with the main exposure of interest, fluoride exposure in drinking water.

Inclusion of a risk factor was considered when:

- an effect on the size of the association between fluoride and the health outcome was considered likely
- data was available for the same unit of analysis (LSOAs or individuals) as the outcome

Where data was available, the models were adjusted for level of deprivation, ethnicity, sex and age group (see [Table 8](#)). For cognitive ability outcomes, a wide variety of potentially relevant risk factors were available in the MCS, and a different approach to inclusion in the models was adopted. This approach is described in the 'Statistical methods' section.

In addition, some risk factors were treated as effect modifiers. Previous reports have found deprivation to be an important effect modifier of dental outcomes ([3](#), [4](#)). Area-level deprivation, as measured by the 2019 Index of Multiple Deprivation (IMD), is one ecological indicator among several socioeconomic status measures that have demonstrated associations with risk factors such as smoking ([65](#)), diet ([66](#)), tooth brushing ([67](#)) consumption of alcohol ([68](#)) and bone mineral density and bone health ([69](#), [70](#)). Sex and age group were also treated as effect modifiers for hip fractures, given well-documented higher incidence in women and older adults ([71](#)).

Risk factor variable definitions for dental caries, tooth extractions and hip fractures

Risk factor definitions varied across outcomes. The data sources and risk factors considered for inclusion in models for each outcome are presented in [Appendix Table A1](#). These consisted of deprivation, ethnicity, age and sex.

Deprivation was measured using IMD 2019 quintiles for LSOAs and was coded as an ordered categorical variable. Depending on the year of the health outcome and exposure window, either the 2011 or 2021 LSOA boundary dataset was used.

Ethnicity was classified as 'White' or 'All other ethnic groups combined'. For dental caries analyses, the ethnicity of surveyed children was available and was coded as a binary variable. For tooth extractions and hip fractures, the percentage of the LSOA from white backgrounds was taken from ONS census estimates and was coded as a continuous variable. For tooth

extractions, census ethnicity data was provided for the 0 to 15 years old age group and is used to proxy the percentage of the population for the 0 to 19 age group used in the tooth extractions analysis. For hip fractures, the census ethnicity data was provided for the 0 to 49, 50 to 64 and the 65 to 79 years old age groups. The 65 to 79 years old age group data was used to proxy the percentage of the population for the ≥ 80 years old age group.

Age was available at the individual case level and categorised into age groups (tooth extraction: 0 to 4, 5 to 9, 10 to 14, 15 to 19; hip fractures: 0 to 49, 50 to 64, 65 to 79, ≥ 80). The width of age groups was defined *a priori* in line with those used in past HMRs.

Sex was available at the individual case level for tooth extractions and hip fractures. It was coded as a binary variable.

Risk factor variable definitions for cognitive ability

The definitions of risk factors used in the cognitive ability analysis is presented in the [Appendix Table A2](#). Variables included 15 risk factors grouped as individual-level child and maternal characteristics, household- and neighbourhood-level measures of socioeconomic status, and individual-level child education factors. All variables were coded as binary, categorical or ordered categorical, with the exceptions of 2 continuous variables (maternal age at birth and child age).

For more detailed information on risk factors, including those used for the cognitive ability outcome, see [Table A1 and Table A2 in the Appendix](#).

[Table 8](#) summarises the health outcomes analysed in this report, alongside the exposure period as assigned to specific health outcomes, and other risk factors included in the analyses.

Table 8. Summary of the characteristics of the health outcomes, exposure periods and other risk factors included in analysis

Health outcome	Outcome indicator	Outcome data source	Outcome unit of analysis	Outcome measurement year	Fluoride exposure period	Other major risk factors
Dental caries experience	Prevalence of dental caries experience (d ₃ mft >0 or D ₃ MFT >0) at age 5 or age 10 or 11 years old (Year 6)	OHS	LSOA	2022 (age 5) 2023 (age 10 or 11) 2024 (age 5)	2016 to 2022 2013 to 2023 2018 to 2024	Deprivation Ethnicity
Dental caries severity score	Mean severity score (mean d ₃ mft) at age 5 or age 10 or 11 years old (Year 6)).	OHS	LSOA	2022 (age 5) 2023 (age 10 or 11) 2024 (age 5)	2016 to 2022 2013 to 2023 2018 to 2024	Deprivation Ethnicity
Caries-related tooth extractions	Incidence of hospital admissions for extraction of ≥1 primary or permanent teeth due to dental caries at ages 0 to 19 years old).	HES – APC	LSOA	FY 2021/2022 FY 2022/2023 FY 2023/2024	2016 to 2021 2017 to 2022 2018 to 2023 2019 to 2024	Deprivation Ethnicity Age Sex Calendar year
Hip fractures	Incidence of emergency hospital admissions for hip fractures at all ages.	HES – APC	LSOA	FY 2021/2022 FY 2022/2023 FY 2023/2024	2011 to 2021 2012 to 2022 2013 to 2023 2014 to 2024	Deprivation Ethnicity Age Sex Calendar year

Health outcome	Outcome indicator	Outcome data source	Outcome unit of analysis	Outcome measurement year	Fluoride exposure period	Other major risk factors
Cognitive ability	British Ability Scales: Naming Vocabulary, Picture Similarities, Pattern Construction, Word Reading at age 5 and/or 7 years old. National Foundation for Educational Research: Number skills (PiM) at age 7 years old.	MCS	Individual	2006 and 2008	2000 to 2001, 2006, 2008	See Table A2 in the Appendix .

Abbreviations

APC = Admitted Patient Care, FY = financial year, HES = Health Episode Statistics, LSOA = Lower-layer super output area, MCS = Millenium Cohort Study, OHS = Oral health survey, PiM = Progress in Maths.

Statistical analysis

Different descriptive analysis and regression techniques were used to assess each health outcome, as appropriate to the different data types. These specific models are outlined first, followed by the common approaches to model construction which were used across all health outcomes.

Data management, cleaning and analysis was performed in R 4.4.0 ([72](#)) SAS 9.4 ([73](#)) and Stata 18.5 ([74](#)).

Distribution of drinking water fluoride concentration

Boxplots were constructed for mean fluoride concentration (2011 to 2024) at the LSOA level and were presented overall and for LSOAs with an operating fluoridation scheme. The use of data extending back 14 years was done using 2011 LSOA boundaries and allows comparison across years.

Other descriptive results on the exposure used only data from recent years (2017 to 2024) and applied the 2021 LSOA boundaries. Counts and percentages across categories of mean fluoride concentration for LSOAs and for the English general population were presented. Maps were presented showing the distribution of fluoride concentrations and the areas receiving water served by fluoridation schemes across England. The mean and median fluoride concentrations, along with their corresponding standard deviation and interquartile range, were presented for each IMD quintile.

Dental caries experience and severity scores

Data for 5 year olds from the 2022 and 2024 oral health surveys were analysed separately to allow identification of changes over time. For our descriptive analysis, counts for the number of children examined, the number of children with dental caries, the prevalence of dental caries experience, and the mean severity score of dental caries were computed for categories of mean drinking water fluoride concentration and the presence of a fluoridation scheme.

The distribution of children surveyed in the oral health survey across IMD deciles and ethnicity categories was compared to the distribution of children in the general population using ONS MYE population estimates from 2022, 2023 and 2024. These are presented in the [Appendix](#). LSOA-level ONS MYE population statistics for 2023 and 2024 were not yet available when this report was being prepared, so estimates for these years were approximated from 2022 MYE populations statistics that were available at the local authority district (LAD) level using proportional allocation. To do this, the proportion of the LAD population falling into each LSOA in 2022 was multiplied by the total population of the LAD in 2023 and 2024.

The mean severity score outcome measures the total number of teeth with dental caries per child on a continuous scale. The variable exhibited severe skewness and contained a large number of zeros. To capture dental caries severity, the mean severity scores were grouped into 4 ordered categories: zero, low, medium, and high. LSOAs with a mean d₃mft of 0 were assigned to the 'zero' category, and the remaining LSOAs were grouped into tertiles.

For dental caries experience, univariate and multivariable regression analyses were conducted using a logistic model. Odds ratios (ORs) were calculated to estimate the effect at each category of fluoride concentration relative to the lowest category. Other potential confounders such as ethnicity and deprivation (IMD quintile) were adjusted for in the main multivariable regression model. A likelihood ratio test (LRT) was conducted to assess potential interaction by deprivation, and the results of the test were considered alongside findings from previous HMRs to inform the decision to then stratify the main model.

To aid interpretation, the same fully adjusted and stratified models were used to generate predicted prevalence of dental caries experience across quintiles of IMD, expressed as a percentage. Predicted prevalences were calculated for each level of mean fluoride concentration while holding the ethnicity covariate at its reference category (children from white background). These model-predicted estimates refer to the proportion of individuals who are expected to experience dental caries, based on the predicted probabilities generated by the models at different fluoride concentrations.

For dental caries severity scores, univariate and multivariable regression analyses were conducted using a partial proportional odds threshold model, allowing the model parameters to vary across mean severity score categories, with the latent variable assumed to follow a logistic distribution. This was chosen as initial results after fitting a proportional odds model indicated a violation of the proportional odds assumption. The outputs compared the cumulative probability of being in a given severity score category or higher versus all lower severity score categories. Effect estimates are reported as regression coefficients (beta) on the log-odds scale. To clarify interpretation, only the regression coefficients for being in the highest severity score category versus all lower categories are presented in the main report. Full tables are provided in the [Appendix](#). Other potential confounders such as ethnicity and deprivation (IMD quintile) were adjusted for in the main multivariable regression model. An LRT was conducted to assess potential interaction by deprivation, and the results of the test were considered alongside findings from previous HMRs to inform the decision to then stratify the main model.

Admissions for caries-related tooth extractions

Counts and percentages for hospital admissions, and the PYAR and the incidence per 100,000 PYAR, were computed across categories of mean drinking water fluoride concentration. These descriptive statistics were also computed for age groups, sex, IMD quintiles and calendar year and are presented in the [Appendix](#).

Univariate and multivariable regression analyses were conducted using a negative binomial model, as inspection of the distribution of the data detected overdispersion (defined as a ratio of residual deviance to degrees of freedom ≥ 2). Regression coefficients were reported as incidence rate ratios (IRRs). Other potential confounders such as deprivation (IMD quintile), age group, sex, the proportion of the LSOA from white backgrounds (ethnicity) and calendar year were adjusted for in the main multivariable regression model. An LRT was conducted to assess potential interaction by deprivation and the results of the test were considered alongside findings from previous HMRs to inform the decision to then stratify the main model.

To aid interpretation, the same fully adjusted and stratified models were used to generate predicted incidence of hospital admissions for caries-related tooth extractions across quintiles of IMD, expressed as events per 100,000 PYAR. Predicted rates were calculated for each level of mean fluoride concentration while holding all other covariates at their reference categories (age group 5 to 9, male, admitted in 2023, and the mean proportion of proportion of children from white backgrounds). These model-predicted estimates show the expected absolute incidence of caries-related tooth extractions at different fluoride concentrations.

Emergency admissions for hip fractures

Counts and percentages for emergency hospital admissions, and the PYAR and the incidence per 100,000 PYAR, were computed across categories of mean drinking water fluoride concentration. These descriptive statistics were also computed for age groups, sex, IMD quintiles, and calendar year and are presented in the [Appendix](#). These descriptive statistics were also further computed for fluoride concentration categories and stratified by fluoridation scheme status and are presented in the [Appendix](#).

Univariate and multivariable regression analyses were conducted using a negative binomial model, as inspection of the distribution of the data detected overdispersion (defined as a ratio of residual deviance to degrees of freedom ≥ 2). Regression coefficients were reported as IRRs. Other potential confounders such as deprivation (IMD quintile), age group, sex, the proportion of the LSOA from white backgrounds (ethnicity) and calendar year were adjusted for in the main multivariable regression model. An LRT was conducted to assess potential interaction by age and sex, and the results of the test were considered alongside findings from previous HMRs to inform the decision to then stratify the main model.

To aid interpretation, the same fully adjusted and stratified models were used to generate predicted incidence of emergency hospital admissions for hip fractures in males and females across age groups, expressed as events per 100,000 PYAR. Predicted rates were calculated for each level of mean fluoride concentration while holding all other covariates at their reference categories (IMD quintile 5, admitted in 2023, and the mean proportion of

people from white backgrounds). These model-predicted estimates show the expected absolute incidence of hip fracture at different fluoride concentrations.

Cognitive ability test scores

Counts and percentages were computed for the distribution of the study population at ages 5 and 7 (data from MCS sweep 3 and sweep 4, respectively) across categories of mean drinking water fluoride concentration at age 9 months. These descriptive statistics were also computed for sex, birthweight, breastfeeding status, exposure to passive cigarette smoke in the home at age 5 or 7 years, child interview age and mother's age at childbirth, and are presented in the [Appendix](#).

Univariate and multivariable regression analyses were conducted using a linear mixed-effects model that accounted for the complex survey design of the MCS. Regression coefficients were presented for the difference in children's test scores between each fluoride concentration category and the reference category (<0.10 mg/L) or per IQR increase in fluoride concentration. Other potential confounders as shown in [Appendix Table A2](#) were adjusted for in the multivariable regression models. Both the mean structure and the residual variance were modelled for each cognitive ability outcome, allowing for stratum-specific (MCS strata: advantaged, disadvantaged, ethnic) heterogeneity ([75](#)).

Model construction for dental caries, tooth extractions, and hip fracture outcomes

Univariate regression was used to estimate crude regression coefficients and 95% confidence intervals (CI) for each category of fluoride exposure for each health outcome, as well as for each of the potential risk factors (sex, age group, ethnicity, calendar year and IMD quintile, where available).

Multivariable models were constructed to estimate the adjusted regression coefficients and 95% CIs. Confidence intervals were used to interpret the strength of evidence against the null hypothesis that the regression coefficient did not vary by level of fluoride exposure. A backwards selection approach was used to determine inclusion of other risk factors in the model. All analyses used a complete case approach where missing data was quantified but removed before regression analyses.

For all outcomes, a random effect for clustering by LAD was applied to the model as the final step. As LSOAs are grouped within LAD areas, the random effect allows each LAD area to have its own underlying level of the outcome. Therefore, our model estimates aimed to capture additional contextual variation and geographic heterogeneity at the LAD level that was not explained by the included covariates. The improvement of applying a random effect model was assessed by checking whether the Akaike Information Criterion (AIC) was lower than for the non-random effects model. These models were presented as the final fully adjusted models.

Model construction for the cognitive ability outcomes

Separate models were fitted for each cognitive ability outcome, but all models applied the same stratum-specific random effects and the same specification for the residual variance. The models differed only in their fixed effects components.

To examine the shape of the association between continuous covariates and cognitive ability scores, bivariate scatter plots were first used to identify potential non-linear relationships. For variables showing non-linearity, polynomial regression models were then tested sequentially (cubic, quadratic, then linear if needed) using a Wald test to assess significance ($p=0.05$). Multicollinearity was assessed for each variable, and any variable with a Variance Inflation Factor (VIF) greater than 4 was excluded from the model.

The construction of the final model was informed by an initial stepwise model building process (see [Appendix Table A2](#)), followed by specific adjustments, first with stratum-specific (MCS strata: advantaged, disadvantaged, ethnic) random effects, then an extension of modelling the residual variance structure to allow for heteroscedasticity across each stratum. LSOAs were included in the linear predictor as a random effect to capture additional contextual variation and geographic heterogeneity that was not accounted for by fluoride exposure or risk factors (for example, neighbourhood socioeconomic status). All analyses used a complete case approach where missing data was quantified but removed before regression analyses.

Main and sensitivity analyses

Different types of analysis were conducted in order to implement the statistical plan outlined in this Methods section and to fulfil the monitoring requirements of the Water Industry Act 1991 ([1](#)).

The main analyses for each outcome assessed the association between the health outcomes and water fluoride exposure (categorical and continuous concentration, and fluoridation scheme), with and without stratification by risk factors such as age, sex and deprivation level where evidence of an interaction was identified. This aimed to support a better understanding of the relationship between fluoride exposure and the selected health outcomes.

Where an association was identified in the models with drinking water fluoride concentration categories, the association between the health outcome and the presence or absence of a water fluoridation scheme in the area was then also assessed.

Sensitivity analyses were conducted for the hip fractures and cognitive ability outcomes. A sensitivity analysis for the hip fracture outcome assessed the association with the continuous measure of drinking water fluoride concentration stratified by areas with fluoridation schemes versus those without schemes (including those with natural fluoridation

where fluoride concentrations were ≥ 0.20 mg/L). Sensitivity analyses for the cognitive ability outcome assessed the association with fluoride concentrations measured at 5 and 7 years old (that is at the same time as the tests were administered, as opposed to at 9 months old in the main analysis) to examine the potential role of later exposures. Another sensitivity analysis restricted the sample to children without special education needs to examine the possibility of mediating the impacts of water fluoridation exposure on cognitive ability for those with special education needs at age 7 (approximately 7% of the study population at age 7; special needs status was not assessed at age 5). These results are shown in the [Appendix](#).

Results

Exposure to fluoride in water supplies in England

There are 33,755 LSOAs in England. Between 2017 and 2024, all LSOAs had annual mean drinking water fluoride concentrations below the regulatory limit of 1.5 mg/L ([12](#)). This report found that concentrations in LSOAs ranged between 0.01 mg/L and 1.3 mg/L over the period. Only 0.6% of LSOAs had concentrations above 1.0 mg/L (data not shown), which is the target concentration for fluoridation schemes. About 13% of LSOAs were in areas served by fluoridation schemes. 149 LSOAs (<0.01%) were in areas not served by fluoridation schemes but had fluoride concentrations above 0.70 mg/L due to the underlying geology of the area ([Table 9](#) and [Figure 1](#)).

In terms of the English population, this report found that approximately 85% of people lived in areas with an average fluoride concentration below 0.40 mg/L and 9% lived in areas with a concentration at or above 0.70 mg/L between 2017 and 2024 ([Table 9](#)). The distribution of fluoride concentrations across England and the areas served by fluoridation schemes are mapped in [Figure 1](#). This figure also shows the locations of the 38 LSOAs with missing fluoride concentration information in all years between 2017 and 2024 and the areas that are not served by a fluoridation scheme but have higher naturally occurring fluoride (≥ 0.70 mg/L).

When assessing the distribution of fluoride concentrations by deprivation levels, this report found that the median fluoride concentration in LSOAs did not vary by deprivation category but the mean fluoride concentration was slightly higher in the most deprived LSOAs compared to less deprived LSOAs ([Table 10](#)).

Fluoride concentrations across LSOAs in England remained relatively stable between 2011 and 2024, with a median concentration across the period of 0.13 mg/L (IQR: 0.15) ([Figure 2](#)). Fluoride concentrations in LSOAs with water fluoridation schemes varied slightly year to year between 2011 and 2024, with an annual median drinking water concentration ranging between 0.67 mg/L (2016, IQR: 0.36) and 0.92 mg/L (2012, IQR: 0.22) across England ([Figure 3](#)). The LSOAs with concentrations above 1.1 mg/L ([Figure 2](#)) were in areas with naturally occurring fluoride from geological sources rather than in areas with fluoridation schemes.

Table 9. Population exposure to fluoride in drinking water, 2017 to 2024, England

Fluoride concentration category, mg/L	Total LSOAs, N (%)	Total population, N (%)	LSOAs with fluoridation scheme, N (%)	Population with fluoridation scheme, N (%)
<0.10	12,084 (36)	19,871,000 (35)	0 (0)	0 (0)
0.10 to 0.19	12,288 (36)	20,874,900 (37)	39 (1)	63,700 (1)
0.20 to 0.39	4,725 (14)	7,967,300 (14)	299 (7)	473,700 (7)
0.40 to 0.69	1,679 (5)	2,769,900 (5)	1,055 (25)	1,747,800 (25)
≥0.70	2,941 (9)	4,940,600 (9)	2,792 (65)	4,693,500 (67)
Missing concentration data	38 (<0.1)	66,400 (<0.1)	-	-
Total	33,755 (100)	56,490,100 (100)	4,287 (100)	6,978,800 (100)

Abbreviations

LSOA = Lower-layer super output area; mg/L – milligrams per litre.

Notes

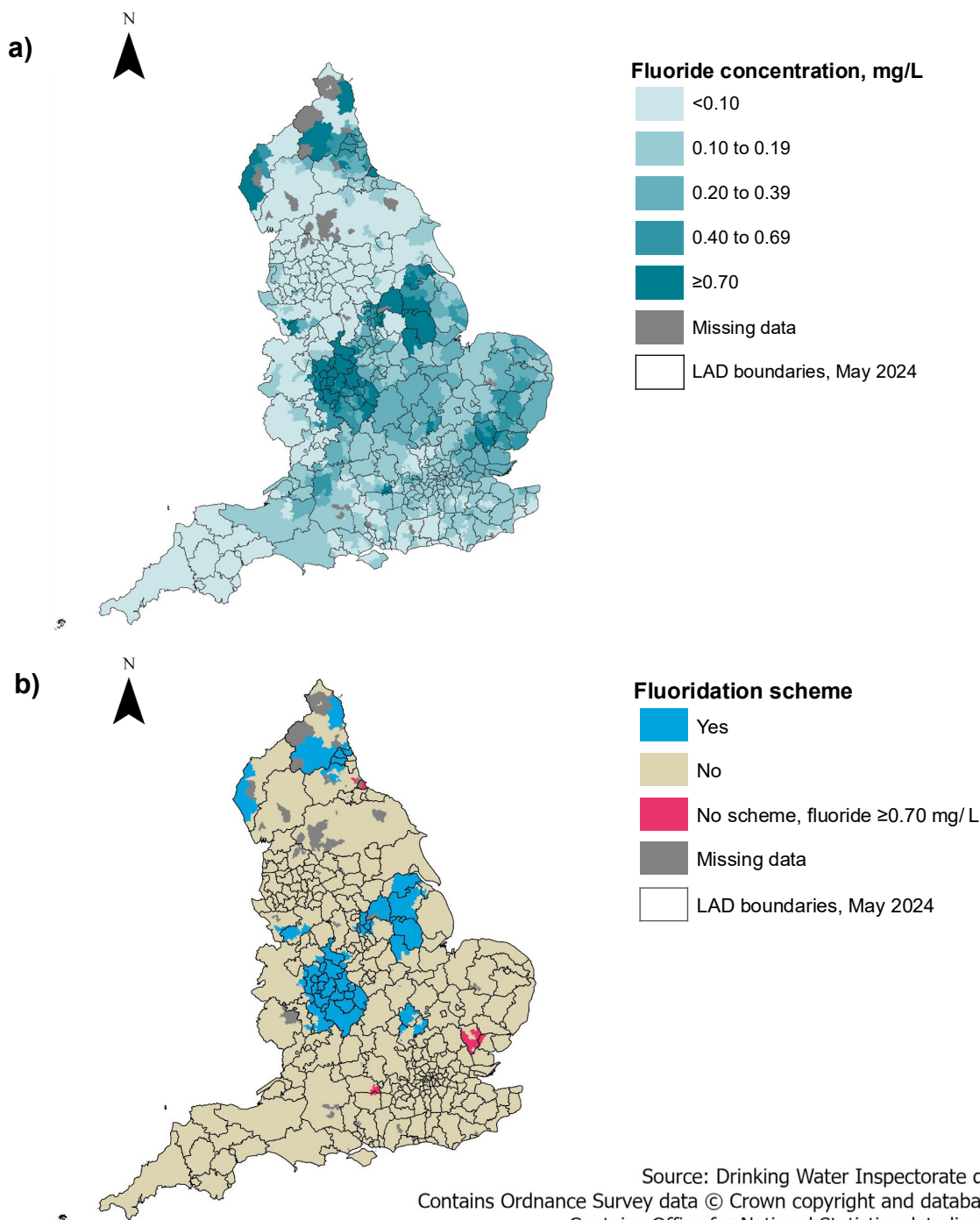
Note 1: Revisions to LSOA boundaries in 2021 restricted the ability to link fluoride exposure data to population census estimates for the 2012 to 2016 period, hence only data for the 2017 to 2024 period is presented.

Note 2: Not shown in the table are the 102 (<0.1%) LSOAs with missing data on the presence of an operating fluoridation scheme. These LSOAs contain 169,452 people (<0.1% of the English general population).

Note 3: Population estimates are based on the 2021 census and rounded to the nearest hundred. The population across categories may not sum to the total due to rounding.

Note 4: Percentages may not sum to the total due to rounding.

Figure 1. a) Average of annual mean drinking water fluoride concentration and b) fluoridation scheme status, 2017 to 2024, England



Source: Drinking Water Inspectorate data 2017-2024
 Contains Ordnance Survey data © Crown copyright and database rights 2025.
 Contains Office for National Statistics data licensed under the
 Open Government License v3.0

Abbreviations

LAD = Local authority district; mg/L = milligrams per litre.

Notes

Note 1: LSOAs are classified as having an operating fluoridation scheme in this figure if a scheme was operating in at least one year over the 2017 to 2024 period.

Table 10. Mean and median drinking water fluoride concentrations in LSOAs by IMD quintile, 2017 to 2024, England

IMD quintile	Total LSOAs, N (%)	Total population, N (%)	Mean fluoride concentration, mg/L (SD)	Median fluoride concentration, mg/L (IQR)
Quintile 5 (least deprived)	6,751 (20.0)	11,043,600 (19.6)	0.20 (0.21)	0.13 (0.09, 0.23)
Quintile 4	6,752 (20.0)	11,153,000 (19.8)	0.21 (0.22)	0.13 (0.09, 0.24)
Quintile 3	6,750 (20.0)	11,358,400 (20.1)	0.21 (0.22)	0.13 (0.09, 0.23)
Quintile 2	6,751 (20.0)	11,505,200 (20.4)	0.21(0.22)	0.13 (0.09, 0.23)
Quintile 1 (most deprived)	6,751 (20.0)	11,430,000 (20.2)	0.24 (0.27)	0.13 (0.07, 0.28)
Total	33,755 (100.0)	56,490,100 (100.0)	0.21 (0.23)	0.13 (0.08, 0.24)

Abbreviations

IMD = Index of Multiple Deprivation; IQR = interquartile range; LSOA = Lower-layer super output area; mg/L = milligrams per litre.

Notes

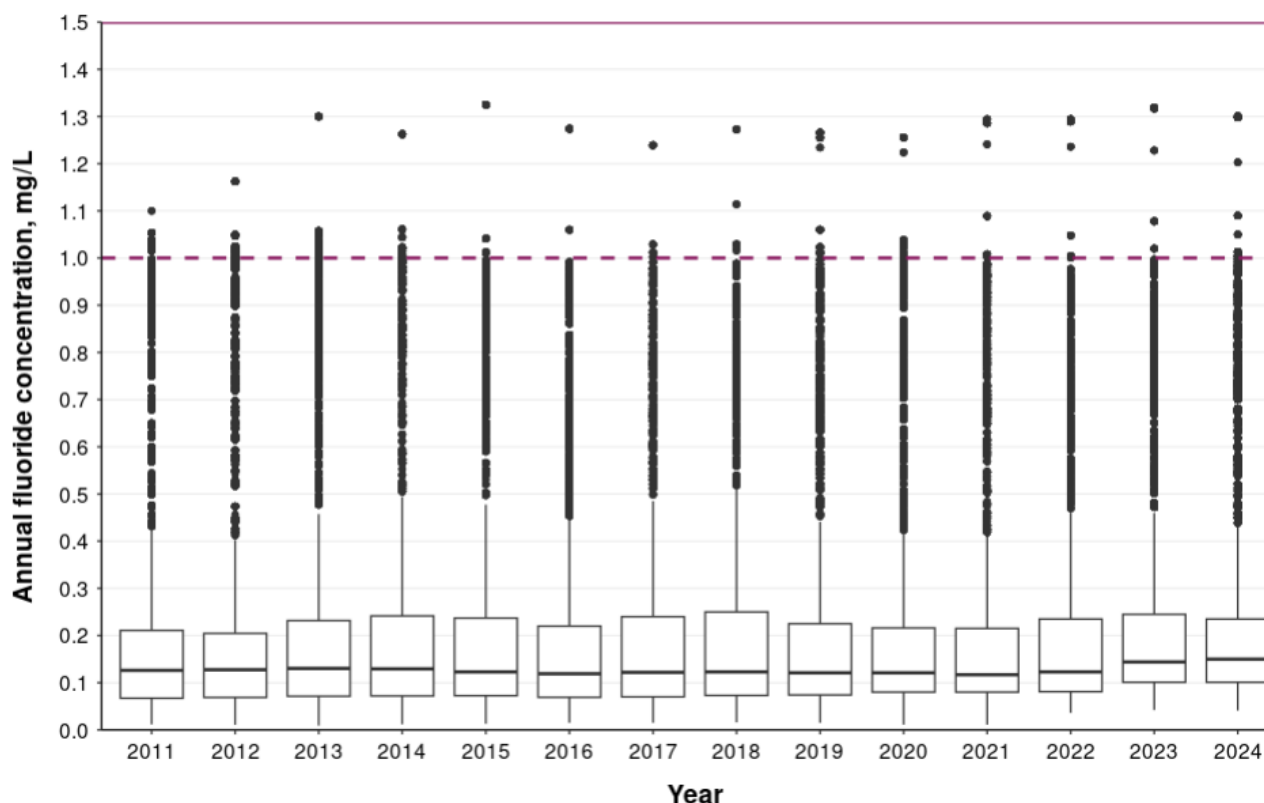
Note 1: The interquartile range is the difference between the fluoride concentration value at the 25th percentile and at the 75th percentile of the data. This range captures the middle 50% of values.

Note 2: Mean and median fluoride concentration was calculated as the mean or median of annual means for 2017 to 2024.

Note 3: Population estimates are based on the 2021 census and rounded to the nearest hundred. Population across categories may not sum to the total due to rounding.

Note 4: Percentages may not sum to the total due to rounding.

Figure 2. Annual drinking water fluoride concentration across LSOAs (n =32,705 to 32,830) by year, 2011 to 2024, England



Abbreviations

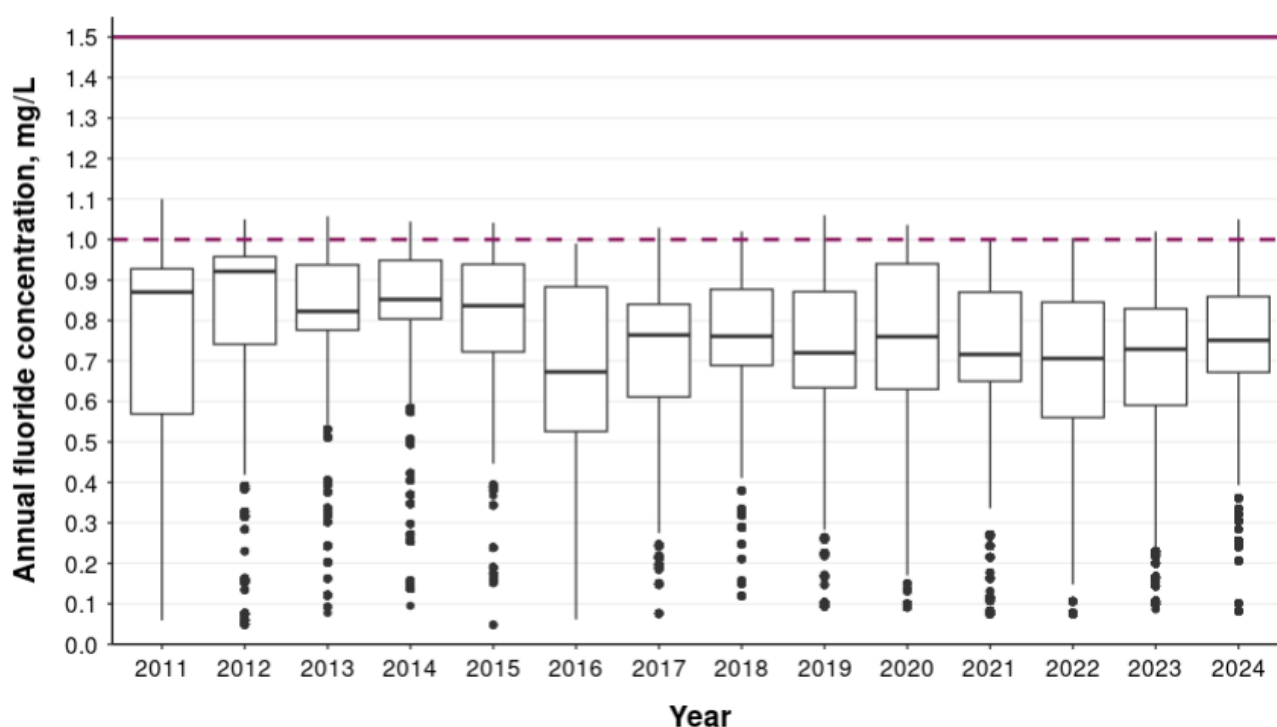
LSOA = Lower-layer super output area; mg/L = milligrams per litre.

Notes

Note 1: The dashed purple line marks a 1.0 mg/L concentration (target concentration for fluoride in drinking water). The solid purple line marks a 1.5 mg/L concentration (regulatory limit for drinking water).

Note 2: Boxes represent values from the 25th to 75th percentiles of fluoride concentrations (that is, half of values lie within the box). The solid horizontal line in each box represents the median value. The dots represent outlying values, determined as values more than 1.5 times the interquartile range above the 75th percentile or below the 25th percentile.

Figure 3. Annual drinking water fluoride concentration across LSOAs with operating fluoridation schemes (n=3,749 to 4,035) by year, 2012 to 2024, England



Abbreviations

LSOA = Lower-layer super output area; mg/L = milligrams per litre.

Notes

Note 1: The dashed purple line marks a 1.0 mg/L concentration (target concentration for fluoride in drinking water). The solid purple line marks a 1.5 mg/L concentration (regulatory limit for drinking water).

Note 2: Boxes represent values from the 25th to 75th percentiles (that is, half of values lie within the box) of fluoride concentrations. The solid horizontal line in each box represents the median value. The dots represent outlying values, determined as values more than 1.5 times the interquartile range above the 75th percentile or below the 25th percentile.

Dental caries in 5 year olds

Descriptive summary of dental caries experience and severity scores in 2022 and 2024

Oral health survey data was collected from 62,649 5 year olds (9% of English population of this age group) in 2022 and 81,905 5 year olds (13% of English population) in 2024 ([Table 11](#) and [Table 12](#)). The survey covered approximately half of LSOAs in England in 2022 (n=16,764) and 2024 (n=18,742) ([44](#), [45](#)). Both the 2022 and 2024 survey samples were approximately representative of the general population of 5 year olds in England in terms of deprivation and ethnicity distributions ([Appendix Table A3 to Table A6](#)).

For 2022, approximately 99% of children were linked to drinking water fluoride concentration data and 93% were linked to fluoridation scheme data and were included in the respective analyses. For 2024, over 99% of children were linked to both drinking water fluoride concentration data and fluoridation scheme data and were included in the respective analyses.

[Table 11](#) and [Table 12](#) show that in both the 2022 and 2024 oral health survey data, 23% (2022 95% CI: 23%, 24%; 2024: 22%, 23%) of children in the study had at least one decayed, missing or filled primary tooth ($d_{3mft} > 0$, dental caries experience). The mean severity score (number of decayed, missing or filled teeth per child) was 0.82 (0.81, 0.83) in 2022 and 0.80 (0.79, 0.81) in 2024.

In both the 2022 and 2024 survey rounds, the crude prevalence and severity of dental caries experience were lower in areas with higher fluoride concentrations, and were slightly higher in areas without fluoridation schemes compared to areas with schemes or with natural fluoridation (no scheme, ≥ 0.20 mg/L) ([Table 11](#), [Table 12](#)).

Crude dental caries prevalence and severity scores varied by deprivation and ethnicity ([Appendix Table A9](#) and [Table A10](#)). The percentage of children with dental caries experience was approximately 2 times higher in those in the most deprived compared to the least deprived areas and was approximately 1.5 times higher in children from all other ethnic groups combined compared to white groups. Dental caries severity scores were approximately 3 times higher in those in the most deprived compared to least deprived areas and were approximately 2 times higher in children from all other ethnic groups combined compared to white groups.

Mean severity scores were categorised for further analyses. [Table 13](#) presents the median, minimum and maximum values for each of the four categories. In the highest severity score category, the median number of teeth with dental caries per child examined was 3.00 in 2022 and 2.50 in 2024.

Table 11. Prevalence of dental caries experience ($d_{3mft} > 0$) and mean severity score in 5 year olds in 2022, by drinking water fluoride exposure

Fluoride exposure	Children examined, N (%)	Children with dental caries experience, N (%)	Children with dental caries experience, % (95% CI)	Mean severity score per child (95% CI)
Fluoride concentration, mg/L				
<0.10	20,871 (33.3)	5,550 (38.0)	26.6 (26.0, 27.2)	0.95 (0.93, 0.97)
0.10 to 0.19	20,300 (32.4)	4,623 (31.6)	22.8 (22.2, 23.4)	0.81 (0.79, 0.83)
0.20 to 0.39	11,458 (18.3)	2,431 (16.6)	21.2 (20.5, 22.0)	0.74 (0.72, 0.76)
0.40 to 0.69	4,331 (6.9)	804 (5.5)	18.6 (17.4, 19.8)	0.61 (0.58, 0.64)
≥ 0.70	5,689 (9.1)	1,207 (8.3)	21.2 (20.2, 22.3)	0.73 (0.70, 0.76)

Fluoride exposure	Children examined, N (%)	Children with dental caries experience, N (%)	Children with dental caries experience, % (95% CI)	Mean severity score per child (95% CI)
Fluoridation scheme				
Yes	9,315 (14.9)	1,917 (13.1)	20.6 (19.8, 21.4)	0.71 (0.69, 0.73)
No	37,725 (60.2)	9,365 (64.1)	24.8 (24.4, 25.3)	0.88 (0.87, 0.89)
Natural fluoridation	11,274 (18.0)	2,341 (16.0)	20.8 (20.0, 21.5)	0.71 (0.69, 0.73)
Missing	4,335 (6.9)	992 (6.8)	22.9 (21.7, 24.2)	0.83 (0.79, 0.87)
Total	62,649 (100)	14,615 (100)	23.3 (23.0, 23.7)	0.82 (0.81, 0.83)

Abbreviations

CI = confidence interval; d₃mft = Decayed (at dentinal level), missing, or filled primary teeth; mg/L = milligrams per litre.

Notes

Note 1: These prevalence and mean severity scores vary slightly to those published in the 2022 NDEP oral health survey report ([44](#)), as their summary statistics are weighted by IMD quintile.

Note 2: Fluoridation scheme status was defined as follows: 'Yes': LSOAs where a water fluoridation scheme operated for at least one year in the 6 years preceding the oral health survey. 'No': LSOAs where a water fluoridation scheme did not operate in any year, and where the average water fluoride concentration was below 0.20 mg/L. 'Natural fluoridation': no fluoridation scheme and fluoride concentrations at or above 0.20 mg/L.

Note 3: Percentages may not sum to the total due to rounding.

Table 12. Prevalence of dental caries experience (d₃mft >0) and mean severity score in 5 year olds in 2024, by drinking water fluoride exposure

Fluoride exposure	Children examined, N (%)	Children with dental caries experience, N (%)	Children with dental caries experience, % (95% CI)	Mean severity score per child (95% CI)
Mean fluoride concentration, mg/L				
<0.10	22,327 (27.3)	5,664 (30.5)	25.4 (24.8, 25.9)	0.95 (0.93, 0.97)
0.10 to 0.19	24,102 (29.4)	5,791 (31.2)	24.0 (23.5, 24.6)	0.87 (0.86, 0.89)
0.20 to 0.39	16,336 (19.9)	3,393 (18.3)	20.8 (20.2, 21.4)	0.70 (0.68, 0.71)
0.40 to 0.69	5,406 (6.6)	992 (5.3)	18.4 (17.3, 19.4)	0.60 (0.57, 0.62)
≥0.70	13,675 (16.7)	2,722 (14.7)	19.9 (19.2, 20.6)	0.63 (0.62, 0.64)
Missing	59 (0.1)	*	*	*
Fluoridation scheme				
Yes	18,418 (22.5)	3,581 (19.3)	19.4 (18.9, 20.0)	0.62 (0.61, 0.63)
No	46,283 (56.5)	11,428 (61.5)	24.7 (24.3, 25.1)	0.91 (0.90, 0.92)
Natural fluoridation	16,995 (20.7)	3,522 (19.0)	20.7 (20.1, 21.3)	0.70 (0.68, 0.71)
Missing	209 (0.3)	40 (0.2)	19.1 (14.4, 25.0)	0.50 (0.43, 0.58)
Total	81,905 (100.0)	18,571 (100.0)	22.7 (22.4, 23.0)	0.80 (0.79, 0.81)

Abbreviations

CI = confidence interval; d₃mft = Decayed (at dentinal level), missing, or filled primary teeth; mg/L = milligrams per litre.

Notes

Note 1: These prevalence and mean severity scores vary slightly to those published in the 2022 NDEP oral health survey report ([44](#)) as their summary statistics are weighted by IMD quintile.

Note 2: 'Natural fluoridation' refers to areas without a fluoridation scheme, but which had natural fluoride concentrations ≥0.20 mg/L. These areas are excluded from multivariable analyses comparing fluoridation scheme status.

Note 3: Asterisks denote the value was suppressed (based on fewer than 5 observations) to prevent deductive disclosure.

Note 4: Percentages may not sum to the total due to rounding.

Table 13. Category boundaries for dental caries severity scores in 2022 and 2024

Dental caries severity score category	2022: Median of mean severity score	2022: Category boundaries (minimum, maximum)	2024: Median of mean severity score	2024: Category boundaries (minimum, maximum)
Zero	0	0, 0	0	0, 0
Low	0.33	0.04, 0.65	0.33	0.04, 0.63
Medium	1.00	0.67, 1.73	1.00	0.64, 1.48
High	3.00	1.75, 15.00	2.50	1.50, 19.00

Abbreviations

CI = confidence interval; LSOA = Lower-layer super output area; mg/L = milligrams per litre.

Notes

Note 1: The 'Zero' category indicates that none of the children examined in the LSOA had any teeth with caries. After these LSOAs were labelled, the remaining LSOAs were divided into tertiles based on their mean severity score and labelled as 'Low', 'Medium' and 'High'.

Association between fluoride in drinking water and dental caries experience

[Table 14](#) shows the odds ratios for the association between drinking water fluoride concentration and dental caries experience in children after adjusting for deprivation, ethnicity and residual clustering by LAD. Overall, the odds ratios for dental caries experience were lower in areas with higher fluoride concentrations (≥ 0.40 mg/L in 2022 and ≥ 0.20 mg/L in 2024). In 2022, areas in the highest fluoride concentration category (≥ 0.70 mg/L) had 27% (95% CI: 15%, 37%) lower odds of dental caries experience compared to areas in the lowest category (< 0.10 mg/L). In 2024, areas in the highest fluoride exposure category had 44% (47%, 50%) lower odds of dental caries experience compared to areas in the lowest fluoride category. See [Appendix Table A15 and Table A16](#) for the fully adjusted model including estimates for all other risk factors.

There was evidence of an interaction between fluoride exposure and deprivation (IMD quintiles) on dental caries experience in both the 2022 and 2024 oral health survey data and previous HMRs. Therefore, the main results are presented with stratification by IMD quintile in [Table 15](#). In both the 2022 and 2024 oral health survey data, the odds of dental caries experience were lower in areas with higher fluoride concentrations in all IMD quintiles after adjusting for ethnicity, deprivation and residual clustering by LAD, with the most consistent effects of water fluoride concentrations observed in the most deprived quintile (≥ 0.70 mg/L, 2022 adjusted OR: 0.59, 95% CI: 0.43, 0.73; 2024: 0.53, 95% CI: 0.44, 0.63).

Findings from the continuous exposure measure were consistent with those observed for the categorical exposure measure in both the IMD-stratified and non-stratified models. An IQR (0.15

mg/L) increase in fluoride concentration was associated with lower odds of dental caries experience in all IMD quintiles, with the strongest effects in the most deprived quintile ([Table 14](#) and [Table 15](#)).

[Figure 4](#) shows the model-predicted prevalence of dental caries experience in 5 year olds across fluoride concentration groups in each IMD quintile after adjusting for deprivation, ethnicity and residual clustering by LAD. Absolute reductions in model-predicted prevalence of dental caries experience (that is, the contrast between the highest and the lowest fluoride concentration categories) were larger in more deprived areas. In the most deprived quintile, areas with fluoride concentrations ≥ 0.70 mg/L had 11 percentage points (2022) or 12 percentage points (2024) lower prevalence of dental caries experience than those in the lowest fluoride category. In the least deprived quintile, model-predicted prevalence was 2 percentage points (2022) or 5 percentage points (2024) lower for the same comparison.

[Table 16](#) shows the association between dental caries experience and exposure to a fluoridation scheme after adjusting for deprivation, ethnicity and residual clustering by LAD. The odds ratios for dental caries experience were lower for areas where a fluoridation scheme was operating compared to areas without schemes and with low levels (<0.20 mg/L) of natural fluoride (2022 adjusted OR: 0.75, 95% CI: 0.66, 0.85; 2024 adjusted OR: 0.66, 95% CI: 0.60, 0.72). While we examined potential interaction by deprivation as in the main analysis, there was no observable difference in the association across levels of deprivation, and confidence intervals for these estimates largely overlapped.

Table 14. Adjusted odds ratios for the association between drinking water fluoride concentration and dental caries experience ($d_3mft > 0$) in 5 year olds in 2022 and 2024

Mean fluoride concentration, mg/L	2022: Adjusted OR (95% CI)	2024: Adjusted OR (95% CI)
<0.10	1.00	1.00
0.10 to 0.19	0.92 (0.84, 1.02)	0.97 (0.89, 1.05)
0.20 to 0.39	0.93 (0.83, 1.04)	0.78 (0.71, 0.86)
0.40 to 0.69	0.74 (0.63, 0.87)	0.71 (0.63, 0.81)
≥ 0.70	0.73 (0.63, 0.85)	0.56 (0.50, 0.63)
Continuous	0.93 (0.91, 0.95)	0.91 (0.89, 0.92)

Abbreviations

CI = Confidence interval, d_3mft = decayed, missing or filled primary teeth, OR = Odds ratio.

Notes

Note 1: The models were adjusted for deprivation, ethnicity and residual clustering by local authority district.

Note 2: Mean fluoride concentration was calculated as the mean of annual means in the 6 years preceding each survey.

Note 3: The continuous fluoride exposure model estimates show the change in effect per interquartile range (0.15 mg/L) increase in fluoride concentration. The interquartile range is the difference between the fluoride concentration value at the 25th percentile and at the 75th percentile of the data. This range captures the middle 50% of values.

Table 15. Adjusted odds ratios for the association between drinking water fluoride concentration and dental caries experience (d3mft >0) in 5 year olds in 2022 and 2024, by deprivation group

IMD quintile	Mean fluoride concentration, mg/L	2022: Adjusted OR (95% CI)	2024: Adjusted OR (95% CI)
Quintile 5 (least deprived)	<0.10	1.00	1.00
	0.10 to 0.19	0.93 (0.77, 1.13)	0.98 (0.82, 1.18)
	0.20 to 0.39	0.87 (0.69, 1.09)	0.90 (0.73, 1.10)
	0.40 to 0.69	0.78 (0.52, 1.15)	0.78 (0.57, 1.07)
	≥0.70	0.80 (0.57, 1.12)	0.61 (0.46, 0.80)
	Continuous	0.95 (0.91, 1.00)	0.91 (0.87, 0.94)
Quintile 4	<0.10	1.00	1.00
	0.10 to 0.19	0.80 (0.67, 0.95)	0.93 (0.79, 1.10)
	0.20 to 0.39	0.85 (0.70, 1.04)	0.81 (0.68, 0.97)
	0.40 to 0.69	0.68 (0.50, 0.93)	0.67 (0.50, 0.90)
	≥0.70	0.54 (0.40, 0.74)	0.70 (0.56, 0.88)
	Continuous	0.90 (0.87, 0.94)	0.92 (0.89, 0.95)
Quintile 3	<0.10	1.00	1.00
	0.10 to 0.19	1.00 (0.85, 1.18)	1.11 (0.96, 1.30)
	0.20 to 0.39	0.90 (0.74, 1.10)	0.94 (0.79, 1.13)
	0.40 to 0.69	0.75 (0.56, 0.99)	0.82 (0.63, 1.07)
	≥0.70	0.83 (0.63, 1.10)	0.75 (0.61, 0.93)
	Continuous	0.95 (0.92, 0.99)	0.92 (0.90, 0.95)
Quintile 2	<0.10	1.00	1.00
	0.10 to 0.19	1.03 (0.88, 1.20)	1.03 (0.89, 1.18)
	0.20 to 0.39	0.89 (0.74, 1.08)	0.86 (0.73, 1.02)
	0.40 to 0.69	0.77 (0.60, 0.99)	0.79 (0.63, 0.99)
	≥0.70	0.93 (0.72, 1.20)	0.61 (0.50, 0.74)
	Continuous	0.96 (0.93, 0.99)	0.90 (0.87, 0.93)
Quintile 1 (most deprived)	<0.10	1.00	1.00
	0.10 to 0.19	0.64 (0.55, 0.75)	0.83 (0.73, 0.95)

	0.20 to 0.39	0.78 (0.64, 0.94)	0.72 (0.62, 0.85)
	0.40 to 0.69	0.59 (0.47, 0.74)	0.68 (0.55, 0.84)
	≥0.70	0.59 (0.48, 0.73)	0.53 (0.44, 0.63)
	Continuous	0.91 (0.88, 0.94)	0.89 (0.87, 0.91)

Abbreviations

CI = confidence interval, d3mft = decayed, missing or filled primary teeth; IMD = Index of Multiple Deprivation; LAD = Local authority district; LSOA = Lower-layer super output area, mg/L = milligrams per litre; OR = Odds Ratio.

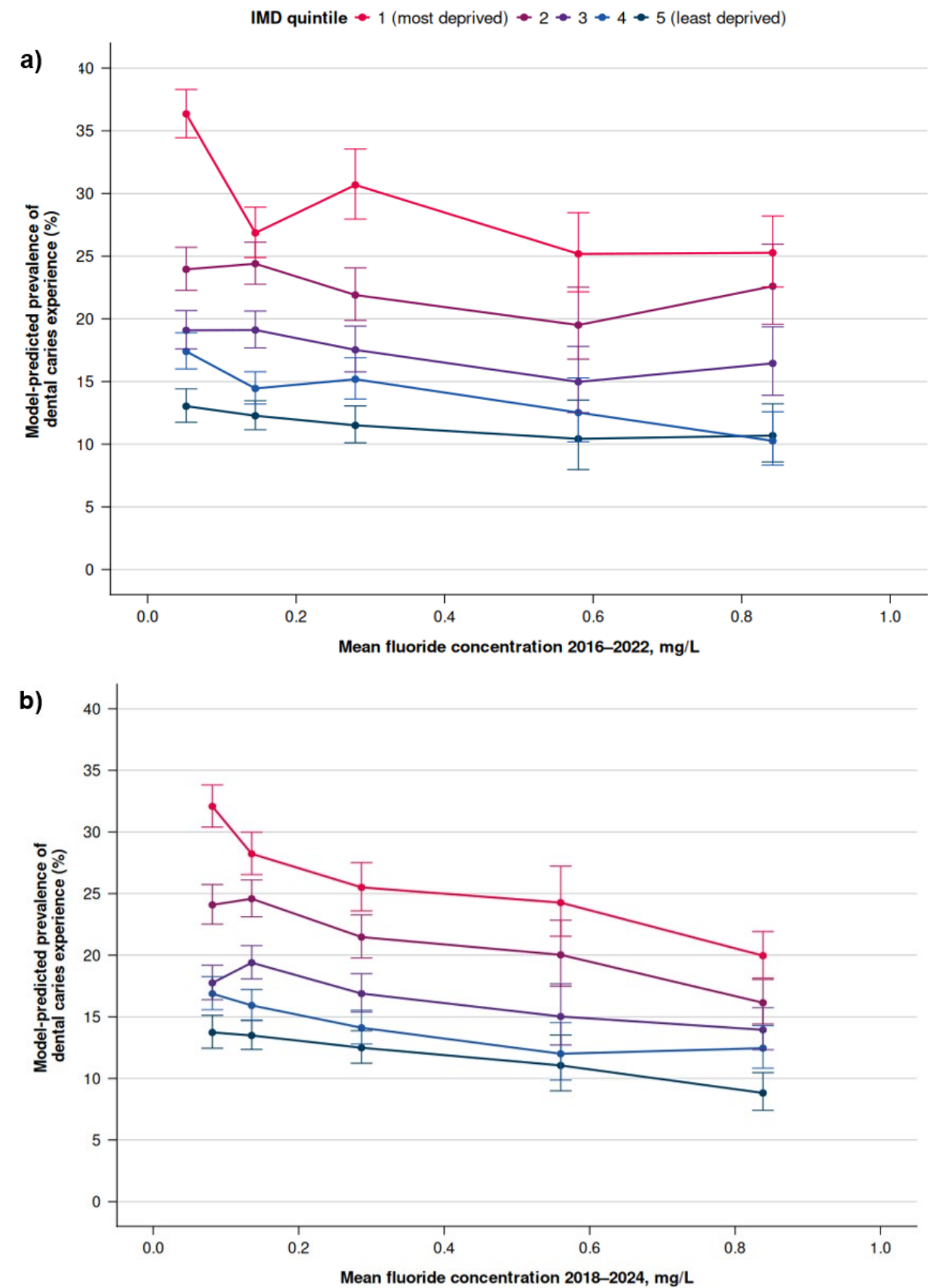
Notes

Note 1: Models were adjusted for deprivation, ethnicity and residual clustering by local authority district.

Note 2: Mean fluoride concentration was calculated as the mean of annual means in the 6 years preceding each survey.

Note 3: The continuous fluoride exposure model estimates show the change in effect per interquartile range (0.15 mg/L) increase in fluoride concentration. The interquartile range is the difference between the fluoride concentration value at the 25th percentile and at the 75th percentile of the data. This range captures the middle 50% of values.

Figure 4. Model-predicted prevalence of dental caries experience (d₃mft >0) in 5-year-olds in a) the 2022 oral health survey, and b) the 2024 oral health survey, by drinking water fluoride concentration and deprivation group



Abbreviations

IMD = Index of Multiple Deprivation; LAD = Local authority district; mg/L = milligrams per litre.

Notes

Note 1: Mean fluoride concentration was calculated as the mean of annual means in the 6 years preceding each survey.

Note 2: The models were adjusted for deprivation, ethnicity and for residual clustering by local authority district. The model-predicted prevalences are displayed at the reference level for ethnicity which is white in this figure.

Note 3: Estimates are plotted at the mean fluoride concentration in each fluoride exposure category (<0.1, 0.1 to 0.19, 0.20 to 0.39, 0.40 to 0.69, ≥0.70; mg/L). The continuous x axis and lines connecting the point estimates for each category are to aid visualisation of trends across fluoride categories only and do not imply a continuous or linear exposure-response relationship.

Note 4: the numerical values for estimates presented in these figures are presented in [Appendix Table A21](#).

Table 16. Adjusted odds ratios for the association between fluoridation scheme status and dental caries experience in 5 year olds in 2022 and 2024, by deprivation group

IMD quintile	Fluoridation scheme	2022: Adjusted OR (95% CI)	2024: Adjusted OR (95% CI)
Overall	No	1.00	1.00
	Yes	0.75 (0.66, 0.85)	0.66 (0.60, 0.72)
Quintile 5 (least deprived)	No	1.00	1.00
	Yes	0.77 (0.62, 0.96)	0.68 (0.58, 0.80)
Quintile 4	No	1.00	1.00
	Yes	0.67 (0.55, 0.82)	0.71 (0.61, 0.82)
Quintile 3	No	1.00	1.00
	Yes	0.80 (0.67, 0.95)	0.72 (0.63, 0.83)
Quintile 2	No	1.00	1.00
	Yes	0.84 (0.71, 0.99)	0.63 (0.56, 0.72)
Quintile 1 (most deprived)	No	1.00	1.00
	Yes	0.69 (0.59, 0.81)	0.59 (0.52, 0.66)

Abbreviations

CI = confidence interval; d3mft = decayed, missing or filled primary teeth; OR = Odds Ratio.

Notes

Note 1: The models were adjusted for ethnicity and residual clustering by local authority district.

Note 2: Fluoridation scheme status was defined as follows: 'Yes': LSOAs where a water fluoridation scheme operated for at least one year in the 6 years preceding the oral health survey. 'No': LSOAs where a water fluoridation scheme did not operate in any year, and where

the average water fluoride concentration was below 0.20 mg/L. Areas with no fluoridation scheme and fluoride concentrations at or above 0.20 mg/L were excluded from the analysis.

Association between fluoride in drinking water and dental caries mean severity score

[Table 17](#) shows the regression coefficients for the association between drinking water fluoride concentration and the probability of being in the highest dental caries severity score category versus the zero, low or medium category, after adjusting for deprivation, ethnicity and residual clustering by LAD. Overall, the probability of being in the highest severity score category was lower in areas with higher fluoride concentrations in both 2022 and 2024. In both years, areas in the highest fluoride concentration category (≥ 0.70 mg/L) had the lowest probability of being in the highest dental caries severity score category (adjusted beta 2022: -0.54, 95% CI: -0.74, -0.34; 2024: -1.01, 95% CI: -1.20, -0.83). See [Appendix Table A16 and Table A17](#) for the fully adjusted models including estimates for all other risk factors.

There was evidence of an interaction between fluoride exposure and deprivation on dental caries severity score categories in both the 2022 and 2024 oral health survey data and previous HMRs. Therefore, the main results are presented with stratification by IMD quintile in [Table 18](#). In both 2022 and 2024, the probability of being in the highest severity score category was lower in areas with higher fluoride concentrations in all IMD quintiles, after adjusting for deprivation, ethnicity and residual clustering by LAD. There was no clear trend in the strength of effects across IMD quintiles in 2022, and confidence intervals for effect estimates for fluoride concentration categories were wide and largely overlapped. There was a suggestion in 2024 that the protective effects of the highest fluoride concentrations were stronger for those in the more deprived quintiles. [Tables A24 to Table A27 in the Appendix](#) show the full model outputs, with the probability of experiencing all dental caries severity score categories versus other categories in the model.

Findings from the continuous exposure measure were consistent with those observed for the categorical exposure measure in both the IMD-stratified and non-stratified models. An IQR (0.15 mg/L) increase in fluoride concentration was associated with a lower probability of being in the highest severity score category overall ([Table 17](#)). In the IMD-stratified model for 2024, there was a suggestion that the protective effects of an IQR increase in fluoride concentration was stronger for those in the more deprived quintiles ([Table 18](#)).

[Table 19](#) shows the association between dental caries experience and exposure to a fluoridation scheme after adjusting for deprivation, ethnicity and residual clustering by LAD. The probability of being in the highest dental caries severity score category compared to lower severity score categories was lower for areas where a fluoridation scheme was operating compared to areas without schemes and with low levels (< 0.20 mg/L) of natural fluoride (adjusted beta 2022: -0.47, 95% CI: -0.64, -0.29; adjusted beta 2024: -0.83, 95% CI: -0.99, -0.68). While we examined potential interaction by deprivation as in the main analysis, there was no observable difference in the association across levels of deprivation, and confidence

intervals for these estimates were wide and overlapped and in the [Appendix](#) show the full model outputs by fluoridation scheme, with the probability of experiencing all dental caries severity score categories versus other categories in the model.

Table 17. Adjusted regression coefficients for the association between drinking water fluoride concentration and experiencing the highest category of dental caries severity score, in 5 year olds in 2022 and 2024

Mean fluoride concentration, mg/L	2022: Highest vs medium, low or zero severity score category, adjusted beta (95% CI)	2024: Highest vs medium, low or zero severity score category, adjusted beta (95% CI)
<0.10	0.00	0.00
0.10 to 0.19	-0.16 (-0.28, -0.03)	-0.13 (-0.24, -0.01)
0.20 to 0.39	-0.17 (-0.32, -0.02)	-0.35 (-0.49, -0.21)
0.40 to 0.69	-0.60 (-0.82, -0.38)	-0.58 (-0.79, -0.37)
≥0.70	-0.54 (-0.74, -0.34)	-1.01 (-1.20, -0.83)
Continuous	-0.12 (-0.15, -0.08)	-0.22 (-0.26, -0.17)

Abbreviations

CI = Confidence interval, IMD = Index of Multiple Deprivation, mg/L = Milligrams per litre.

Notes

Note 1: The model was adjusted for deprivation, ethnicity and for residual clustering by local authority district.

Note 2: Severity categories are based on tertiles of non-zero values for the LSOA-level mean d3mft and thresholds are presented in [Table 13](#).

Note 3: Regression coefficients for severity score categories can be interpreted as follows: a negative beta indicates a lower probability of being in the highest severity score category relative to the medium, low or zero category. A positive beta indicates a higher probability.

Note 4: The continuous fluoride exposure model estimates show the change in effect per interquartile range (0.15 mg/L) increase in fluoride concentration. The interquartile range is the difference between the fluoride concentration value at the 25th percentile and at the 75th percentile of the data. This range captures the middle 50% of values.

Table 18. Adjusted regression coefficients for the association between drinking water fluoride concentration and experiencing the highest category of dental caries severity score, in 5 year olds in 2022 and 2024, by deprivation group

IMD quintile	Mean fluoride concentration, mg/L	2022: Highest versus medium, low or zero severity score category, adjusted beta (95% CI)	2024: Highest versus medium, low or zero severity score category, adjusted beta (95% CI)
Quintile 5 (least deprived)	<0.10	0.00	0.00
	0.10 to 0.19	-0.05 (-0.36, 0.26)	0.04 (-0.25, 0.34)
	0.20 to 0.39	0.07 (-0.30, 0.43)	-0.24 (-0.60, 0.11)
	0.40 to 0.69	-0.39 (-1.15, 0.38)	-0.45 (-1.06, 0.17)
	≥0.70	-0.62 (-1.28, 0.05)	-0.61 (-1.13, -0.10)
	Continuous	-0.13 (-0.17, -0.08)	-0.14 (-0.23, -0.05)
Quintile 4	<0.10	0.00	0.00
	0.10 to 0.19	-0.14 (-0.63, 0.35)	-0.05 (-0.51, 0.42)
	0.20 to 0.39	-0.18 (-0.76, 0.39)	-0.22 (-0.78, 0.34)
	0.40 to 0.69	-0.76 (-1.97, 0.45)	-0.66 (-1.68, 0.36)
	≥0.70	-0.98 (-2.04, 0.08)	-0.75 (-1.57, 0.07)
	Continuous	-0.08 (-0.16, -0.005)	-0.17 (-0.31, -0.02)
Quintile 3	<0.10	0.00	0.00
	0.10 to 0.19	-0.02 (-0.50, 0.46)	0.15 (-0.31, 0.60)
	0.20 to 0.39	-0.20 (-0.77, 0.37)	-0.12 (-0.68, 0.44)
	0.40 to 0.69	-0.21 (-1.36, 0.93)	-0.54 (-1.51, 0.43)
	≥0.70	-0.51 (-1.52, 0.49)	-0.52 (-1.30, 0.26)
	Continuous	-0.10 (-0.19, -0.001)	-0.15 (-0.29, -0.02)
Quintile 2	<0.10	0.00	0.00
	0.10 to 0.19	0.08 (-0.39, 0.55)	-0.04 (-0.48, 0.40)
	0.20 to 0.39	-0.18 (-0.74, 0.38)	-0.30 (-0.84, 0.24)
	0.40 to 0.69	-0.73 (-1.88, 0.41)	-0.58 (-1.51, 0.35)
	≥0.70	-0.11 (-1.09, 0.87)	-1.06 (-1.83, -0.29)
	Continuous	-0.17 (-0.27, -0.07)	-0.21 (-0.35, -0.08)
Quintile 1 (most deprived)	<0.10	0.00	0.00
	0.10 to 0.19	-0.49 (-0.96, -0.02)	-0.38 (-0.82, 0.05)
	0.20 to 0.39	-0.12 (-0.67, 0.42)	-0.55 (-1.08, -0.02)
	0.40 to 0.69	-0.68 (-1.79, 0.44)	-0.60 (-1.51, 0.31)

IMD quintile	Mean fluoride concentration, mg/L	2022: Highest versus medium, low or zero severity score category, adjusted beta (95% CI)	2024: Highest versus medium, low or zero severity score category, adjusted beta (95% CI)
	≥0.70	-0.64 (-1.60, 0.32)	-1.27 (-2.02, -0.52)
	Continuous	-0.11 (-0.22, 0.01)	-0.22 (-0.35, -0.08)

Abbreviations

CI = Confidence interval, IMD = Index of Multiple Deprivation, LAD = Local authority district, mg/L = Milligrams per litre.

Notes

Note 1: The model was adjusted for deprivation, ethnicity and for residual clustering by local authority district.

Note 2: Severity categories are based on tertiles of non-zero values for the LSOA-level mean d3mft and thresholds are presented in [Table 13](#).

Note 3: Regression coefficients for severity score categories can be interpreted as follows: a negative beta indicates a lower probability of being in the highest severity score category relative to the medium, low or zero category compared to areas in the reference category. A positive beta indicates a higher probability compared to the reference category.

Note 4: The continuous fluoride exposure model estimates show the change in effect per interquartile range (0.15 mg/L) increase in fluoride concentration. The interquartile range is the difference between the fluoride concentration value at the 25th percentile and at the 75th percentile of the data. This range captures the middle 50% of values.

Table 19. Adjusted regression coefficients for the association between fluoridation schemes status and experiencing the highest category of dental caries severity score, in 5 year olds in 2022 and 2024, by deprivation group

IMD quintile	Fluoridation scheme	2022: Highest versus medium, low or zero severity score category, adjusted beta (95% CI)	2024: Highest versus medium, low or zero severity score category, adjusted beta (95% CI)
Overall	No	0.00	0.00
	Yes	-0.47 (-0.64, -0.29)	-0.83 (-0.99, -0.68)
Quintile 5 (least deprived)	No	0.00	0.00
	Yes	-0.44 (-0.93, 0.05)	-0.57 (-0.94, -0.19)
Quintile 4	No	0.00	0.00
	Yes	0.10 (-0.67, 0.87)	-0.27 (-0.88, 0.34)
Quintile 3	No	0.00	0.00
	Yes	-0.42 (-1.16, 0.32)	-0.64 (-1.22, -0.06)
Quintile 2	No	0.00	0.00

IMD quintile	Fluoridation scheme	2022: Highest versus medium, low or zero severity score category, adjusted beta (95% CI)	2024: Highest versus medium, low or zero severity score category, adjusted beta (95% CI)
	Yes	-0.34 (-1.07, 0.38)	-0.92 (-1.49, -0.35)
Quintile 1 (most deprived)	No	0.00	0.00
	Yes	-0.46 (-1.17, 0.25)	-0.94 (-1.49, -0.39)

Abbreviations

CI = confidence interval; IMD = Index of Multiple Deprivation; LAD = Local authority district; mg/L = milligrams per litre.

Notes

Note 1: The model was adjusted for deprivation, ethnicity and for residual clustering by local authority district.

Note 2: Fluoridation scheme status was defined as follows: 'Yes': LSOAs where a water fluoridation scheme operated for at least one year in the six years preceding the oral health survey. 'No': LSOAs where a water fluoridation scheme did not operate in any year, and where the average water fluoride concentration was below 0.20 mg/L. Areas with no fluoridation scheme and fluoride concentrations at or above 0.20 mg/L were excluded from the analysis.

Note 3: Severity categories are based on tertiles of non-zero values for the LSOA-level mean d3mft and thresholds are presented in [Table 13](#).

Note 4: Regression coefficients for severity score categories can be interpreted as follows: a negative beta indicates a lower probability of being in the highest severity score category relative to the medium, low or zero category. A positive beta indicates a higher probability of being in the highest severity score category relative to the medium, low or zero category.

Dental caries in 10 or 11 year olds

Descriptive summary of dental caries experience and severity scores in 2023

Oral health survey data was collected for 53,073 Year 6 children (10 or 11 year olds) and covered approximately half of LSOAs (n=15,814) ([Table 20](#)). The survey sample was approximately representative of the general population of 10 and 11 year olds in England in terms of deprivation and ethnicity distributions ([Appendix Table A7 and Table A8](#)).

All children were linked to drinking water fluoride concentration data or fluoridation scheme data and were included in analysis.

The 2023 oral health survey data showed that 16% of children in the study had at least one decayed, missing or filled permanent tooth (D3MFT >0, experience of dental caries). The mean

dental caries severity score (number of decayed, missing or filled teeth) was 0.30 per child ([Table 20](#)).

The crude prevalence and severity of dental caries experience displayed a J-shaped distribution across categories of drinking water fluoride concentration, and were slightly higher in areas with fluoridation schemes compared to areas without schemes and areas with natural fluoridation (no scheme, ≥ 0.20 mg/L) ([Table 20](#)).

Crude dental caries prevalence and severity scores varied by deprivation but not between those from white groups and all other ethnic groups combined ([Appendix Table A11](#)). The percentage of children with dental caries experience and the mean severity scores were more than 2 times higher in the most deprived compared to least deprived areas.

Due to concerns about the validity of the data for permanent teeth in Year 6 children that are noted in the methods, multivariable models are not presented for this data, and these descriptive results should be interpreted cautiously.

Table 20. Prevalence of dental caries experience (d3mft >0) and mean severity score in Year 6 children (10 or 11 year olds) in 2023, by drinking water fluoride exposure

Fluoride exposure	Children examined, N (%)	Children with dental caries experience, N (%)	Children with dental caries experience, % (95% CI)	Mean severity score per child (95% CI)
Mean fluoride concentration, mg/L				
<0.10	16,638 (31.3)	2,883 (33.7)	17.3 (16.8, 17.9)	0.31 (0.30, 0.32)
0.10 to 0.19	16,209 (30.5)	2,264 (26.5)	14.0 (13.4, 14.5)	0.25 (0.24, 0.26)
0.20 to 0.39	9,785 (18.4)	1,326 (15.5)	13.6 (12.9, 14.2)	0.24 (0.23, 0.25)
0.40 to 0.69	3,624 (6.8)	668 (7.8)	18.4 (17.2, 19.7)	0.38 (0.36, 0.40)
≥ 0.70	6,817 (12.8)	1,410 (16.5)	20.7 (19.7, 21.7)	0.40 (0.39, 0.41)
Fluoridation scheme				
Yes	9,538 (18.0)	1,957 (22.9)	20.5 (19.7, 21.3)	0.41 (0.40, 0.42)
No	32,594 (61.4)	5,115 (59.8)	15.7 (15.3, 16.1)	0.28 (0.28, 0.29)
Natural fluoridation	10,735 (20.2)	1,450 (17.0)	13.5 (12.9, 14.2)	0.24 (0.23, 0.24)
Missing	206 (0.4)	29 (0.3)	14.1 (10.0, 19.5)	0.27 (0.22, 0.33)
Total	53,073 (100.0)	8,551 (100.0)	16.1 (15.8, 16.4)	0.30 (0.29, 0.30)

Abbreviations

CI = confidence interval; d3mft = Decayed (at dentinal level), missing, or filled permanent teeth.

Notes

Note 1: Mean fluoride concentration is calculated as the mean of annual mean values for the 10 years prior to the survey.

Note 2: Fluoridation scheme status was defined as follows: ‘Yes’: LSOAs where a water fluoridation scheme operated for at least one year in the 10 years preceding the oral health survey. ‘No’: LSOAs where a water fluoridation scheme did not operate in any year, and where the average water fluoride concentration was below 0.20 mg/L. ‘Natural fluoridation’: no fluoridation scheme and fluoride concentrations at or above 0.20 mg/L.

Note 3: Percentages may not sum to the total due to rounding.

Hospital admissions for caries-related tooth extractions in 0 to 19 year olds

Descriptive summary of caries-related tooth extractions in 2021 to 2024

There were 87,235 hospital admissions for caries-related tooth extractions in people aged 0 to 19 years old between April 2021 and March 2024 in England (Table 21). The crude incidence rate over the study period were 213 (95% CI: 212, 214) admissions per 100,000 PYAR.

Over 99% of admissions were linked to drinking water fluoride concentration data or fluoridation scheme data and were included in analysis.

Crude incidence rates were generally lower in areas with higher fluoride concentrations. Areas without fluoridation schemes had a higher crude incidence rate of caries-related tooth extractions than other areas, including those with fluoridation schemes or natural fluoridation (no scheme, fluoride ≥0.20 mg/L) (Table 21).

Crude incidence rates varied most by deprivation and age group ([Appendix Table A12](#)). Incidence rates were more than 3 times higher in the most deprived compared to least deprived areas, and were more than twice as high among 5 to 9 year olds as among any other age group. Incidence rates were also slightly higher among girls compared to boys and were slightly lower in 2021 compared to in 2022, 2023 or 2024.

Table 21. Incidence rates for hospital admissions for caries-related tooth extractions in 0 to 19 year olds between April 2021 and March 2024, by drinking water fluoride exposure

Fluoride exposure	Admissions, N (%)	PYAR, person-years (%)	Incidence per 100,000 PYAR (95% CI)
Mean fluoride concentration, mg/L			
<0.10	40,317 (46.2)	14,806,472 (36.2)	272 (269, 275)
0.10 to 0.19	31,966 (36.6)	14,707,590 (35.9)	217 (215, 219)
0.20 to 0.39	7,852 (9.0)	5,892,952 (14.4)	133 (130, 136)

Fluoride exposure	Admissions, N (%)	PYAR, person-years (%)	Incidence per 100,000 PYAR (95% CI)
0.40 to 0.69	3,460 (4.0)	1,975,352 (4.8)	175 (169, 181)
≥0.70	3,547 (4.0)	3,473,426 (8.5)	102 (99, 105)
Missing	93 (0.1)	70,970 (0.2)	131 (107, 161)
Fluoridation scheme			
Yes	7,145 (8.2)	5,090,948 (12.4)	140 (137, 143)
No	72,089 (82.6)	29,415,107 (71.9)	245 (243, 247)
Natural fluoridation	7,798 (8.9)	6,291,506 (15.4)	124 (121, 127)
Missing	203 (0.2)	129,200 (0.3)	157 (137, 180)
Total	87,235 (100.0)	40,926,761 (100.0)	213 (212, 214)

Abbreviations

CI = Confidence interval, mg/L = Milligrams per litre, PYAR = Person-years at risk.

Notes

Note 1: Mean fluoride concentration is calculated as the mean of annual mean values for the 5 years prior to the year of the hospital admission.

Note 2: Fluoridation scheme status was defined as follows: 'Yes': LSOAs where a water fluoridation scheme operated for at least one year in the 5 years preceding the hospital admission. 'No': LSOAs where a water fluoridation scheme did not operate in any year, and where the average water fluoride concentration was below 0.20 mg/L. 'Natural fluoridation': no fluoridation scheme and fluoride concentrations at or above 0.20 mg/L.

Note 3: Percentages may not sum to the total due to rounding.

Association between fluoride in drinking water and caries-related tooth extractions

[Table 22](#) shows incidence rate ratios for the association between drinking water fluoride concentration and hospital admissions for caries-related tooth extractions after adjusting for age group, sex, calendar year, deprivation, ethnicity, and residual clustering by LAD. Overall, the incidence rate ratios for tooth extractions were lower for areas with higher fluoride concentrations (above 0.20 mg/L). Areas in the highest fluoride concentration category (≥0.70 mg/L) had a 28% (95% CI: 22%, 34%) lower incidence rate of tooth extractions compared to those in the lowest category (<0.10 mg/L). See [Appendix Table A18](#) for the fully adjusted model including estimates for all other risk factors.

There was evidence of an interaction between fluoride exposure and deprivation on the incidence rates of caries-related tooth extractions in this study and previous HMRs. Therefore, the main results are presented with stratification by IMD quintile in [Table 23](#). This suggested a stronger protective effect of higher fluoride concentration categories (≥0.40 mg/L) in areas with

increasing deprivation, although confidence intervals for each fluoride category in different IMD quintiles largely overlapped. Exposure to the highest category of fluoride concentration compared to the lowest category was associated with a 17% lower rate (95% CI: 0%, 32%) of tooth extractions in the least deprived quintile and a 34% lower rate (25%, 41%) in the most deprived quintile.

Findings from the continuous exposure measure were consistent with those observed for the categorical exposure measure in both the IMD-stratified and non-stratified models. An IQR (0.15 mg/L) increase in fluoride concentration were associated with a lower overall incidence rate of tooth extractions ([Table 22](#)). In the IMD-stratified model, the protective effect was seen across all deprivation groups, although the effect was stronger in more deprived areas ([Table 23](#)).

[Figure 5](#) shows the model-predicted incidence rates for admissions for tooth extractions across fluoride concentration groups and in each IMD quintile after adjusting for age group, sex, calendar year, deprivation, ethnicity, and residual clustering by LAD. Absolute reductions in model-predicted incidence rates of admissions (that is, the contrast between the highest and the lowest fluoride concentration categories) were larger in more deprived areas. In the most deprived quintile, areas with fluoride concentrations of 0.70 mg/L or more had 171 fewer tooth extractions per 100,000 PYAR than those in the lowest fluoride category (<0.10 mg/L). In the least deprived quintile, there were 27 fewer tooth extractions per 100,000 PYAR for the same comparison.

[Table 24](#) shows the association between caries-related tooth extractions and exposure to a fluoridation scheme after adjusting for age group, sex, calendar year, deprivation, ethnicity, and residual clustering by LAD. The incidence rate of tooth extractions was 20% lower (95% CI: 13%, 26%) in areas with a fluoridation scheme compared to in areas without schemes and with low levels (<0.20 mg/L) of natural fluoride. While we examined potential interaction by deprivation, there was no observable difference in the association across levels of deprivation and confidence intervals largely overlapped.

Table 22. Adjusted incidence rate ratios for the association between drinking fluoride concentration and hospital admissions for caries-related tooth extraction, in 0 to 19 year olds between April 2021 and March 2024

Mean fluoride concentration, mg/L	Adjusted IRR (95% CI)
<0.10	1.00
0.10 to 0.19	1.02 (0.98, 1.05)
0.20 to 0.39	0.91 (0.86, 0.96)
0.40 to 0.69	0.80 (0.76, 0.86)
≥0.70	0.72 (0.66, 0.78)
Continuous	0.93 (0.91, 0.94)

Abbreviations

CI = confidence interval; IMD = Index of Multiple Deprivation; IRR = Incidence rate ratio.

Notes

Note 1: The model was adjusted for deprivation, age group, sex, calendar year and ethnicity, allowing for clustering of residuals at the local authority district level.

Note 2: Mean fluoride concentration is calculated as the mean of annual mean values in the 5 years preceding the hospital admission.

Note 3: The continuous fluoride exposure model estimates show the change in effect per interquartile range (0.15 mg/L) increase in fluoride concentration. The interquartile range is the difference between the fluoride concentration value at the 25th percentile and at the 75th percentile of the data. This range captures the middle 50% of values.

Table 23. Adjusted incidence rate ratios for the association between drinking water fluoride concentration and hospital admissions for caries-related tooth extraction, in 0 to 19 year olds between April 2021 and March 2024 stratified, by deprivation group

IMD quintile	Mean fluoride concentration, mg/L	Adjusted IRR (95% CI)
Quintile 5 (least deprived)	<0.10	1.00
	0.10 to 0.19	1.06 (0.98, 1.14)
	0.20 to 0.39	1.03 (0.92, 1.15)
	0.40 to 0.69	0.92 (0.78, 1.09)
	≥0.70	0.83 (0.68, 1.00)
	Continuous	0.96 (0.93, 0.98)
Quintile 4	<0.10	1.00
	0.10 to 0.19	1.07 (1.00, 1.14)
	0.20 to 0.39	0.97 (0.87, 1.07)
	0.40 to 0.69	0.83 (0.71, 0.96)
	≥0.70	0.81 (0.69, 0.95)
	Continuous	0.95 (0.92, 0.97)
Quintile 3	<0.10	1.00
	0.10 to 0.19	1.07 (1.01, 1.14)
	0.20 to 0.39	0.99 (0.90, 1.09)
	0.40 to 0.69	0.79 (0.69, 0.90)
	≥0.70	0.70 (0.60, 0.81)
	Continuous	0.92 (0.90, 0.94)
Quintile 2	<0.10	1.00
	0.10 to 0.19	1.02 (0.96, 1.08)

IMD quintile	Mean fluoride concentration, mg/L	Adjusted IRR (95% CI)
	0.20 to 0.39	0.83 (0.76, 0.91)
	0.40 to 0.69	0.77 (0.68, 0.87)
	≥0.70	0.74 (0.65, 0.85)
	Continuous	0.92 (0.90, 0.94)
Quintile 1 (most deprived)	<0.10	1.00
	0.10 to 0.19	0.95 (0.90, 1.00)
	0.20 to 0.39	0.84 (0.78, 0.92)
	0.40 to 0.69	0.78 (0.71, 0.86)
	≥0.70	0.66 (0.59, 0.75)
	Continuous	0.91 (0.90, 0.93)

Abbreviations

CI = confidence interval; IMD = Index of Multiple Deprivation; IRR = Incidence rate ratio; LAD = Local authority district; LSOA = Lower-layer super output area; mg/L = milligrams per litre.

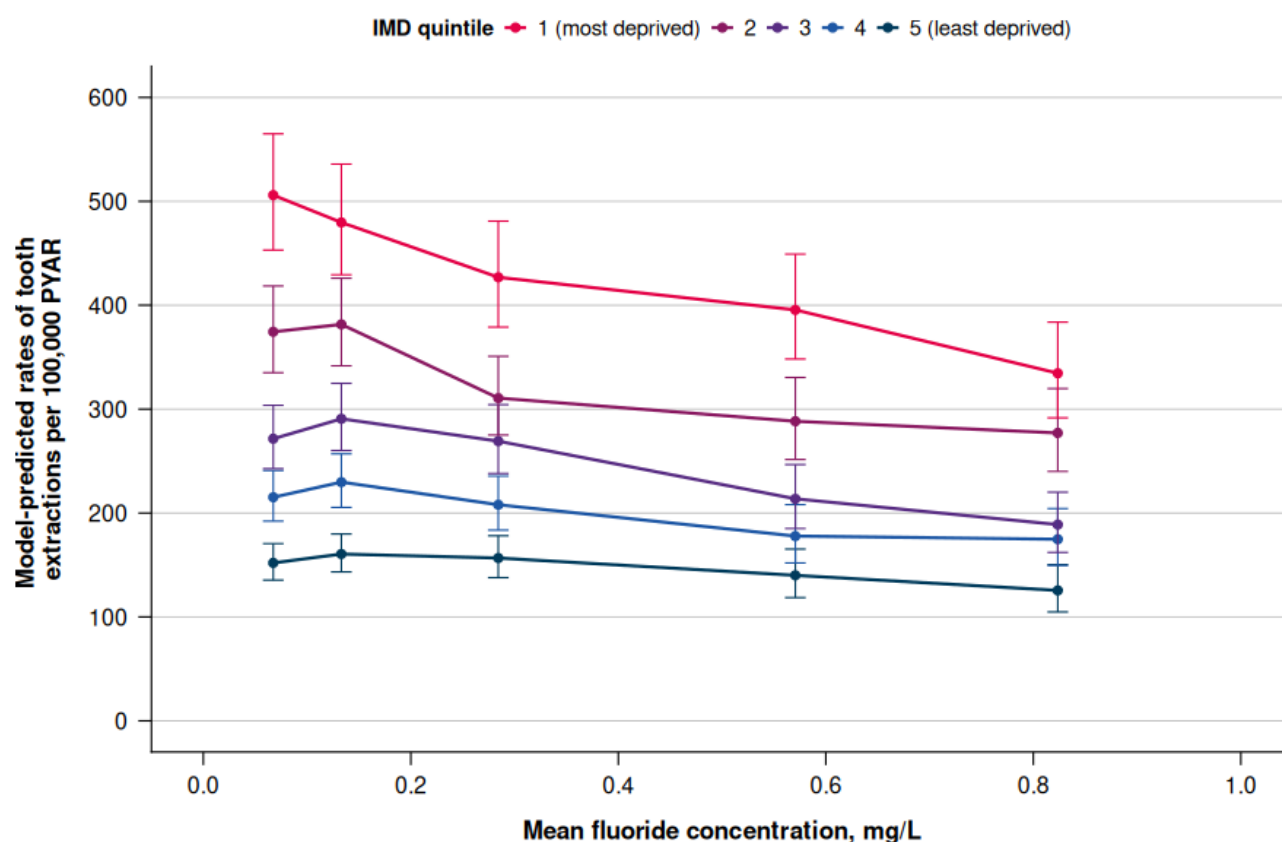
Notes

Note 1: The model was adjusted for deprivation, age group, sex, calendar year, ethnicity and for residual clustering by local authority district.

Note 2: Mean fluoride concentration is calculated as the mean of annual mean values in the 5 years preceding the hospital admission.

Note 3: The continuous fluoride exposure model estimates show the change in effect per interquartile range (0.15 mg/L) increase in fluoride concentration. The interquartile range is the difference between the fluoride concentration value at the 25th percentile and at the 75th percentile of the data. This range captures the middle 50% of values.

Figure 5. Model-predicted incidence rates for hospital admissions for tooth extractions in 0 to 19 year olds, by drinking water fluoride concentration and deprivation group



Abbreviations

IMD = Index of Multiple Deprivation; LAD = Local authority district; LSOA = Lower-layer super output area; mg/L = milligrams per litre; PYAR = Person-years at risk; % = percentage.

Notes

Note 1: Mean fluoride concentration is calculated as the mean of annual mean values in the 5 years preceding the hospital admission.

Note 2: The model was adjusted for deprivation, age group, sex, calendar year, ethnicity and for residual clustering by local authority district. The model-predicted incidence rates are displayed at reference levels set for these factors, which is age group 5 to 9 years old, male, admitted in 2023, at the mean proportion of children from white backgrounds.

Note 3: Estimates are plotted at the mean fluoride concentration in each fluoride exposure category (<0.1, 0.1 to 0.19, 0.20 to 0.39, 0.40 to 0.69, ≥0.70; mg/L). The continuous x axis and lines connecting the point estimates for each category are to aid visualisation of trends across fluoride categories only and do not imply a continuous or linear exposure-response relationship.

Note 4: The numerical values for estimates presented in these figures are presented in [Appendix Table A22](#).

Table 24. Adjusted incidence rate ratios for the association between fluoridation scheme status and hospital admissions for caries-related tooth extractions in 0- to 19-year-olds between April 2021 and March 2024, by deprivation group

IMD quintile	Fluoridation scheme	Adjusted IRR (95% CI)
Overall	No	1.00
	Yes	0.80 (0.74, 0.87)
Quintile 5 (least deprived)	No	1.00
	Yes	0.85 (0.77, 0.96)
Quintile 2	No	1.00
	Yes	0.81 (0.73, 0.90)
Quintile 3	No	1.00
	Yes	0.75 (0.68, 0.83)
Quintile 4	No	1.00
	Yes	0.79 (0.72, 0.87)
Quintile 1 (most deprived)	No	1.00
	Yes	0.81 (0.75, 0.89)

Abbreviations

CI = confidence interval; IMD = Index of Multiple Deprivation; IRR = Incidence rate ratio; LAD = Local authority district; LSOA = Lower-layer super output area; mg/L = milligrams per litre.

Notes

Note 1: The model was adjusted for deprivation, age group, sex, calendar year, ethnicity and for residual clustering by local authority district.

Note 2: Fluoridation scheme status was defined as follows: 'Yes': LSOAs where a water fluoridation scheme operated for at least one year in the 5 years preceding the hospital admission. 'No': LSOAs where a water fluoridation scheme did not operate in any year, and where the average water fluoride concentration was below 0.20 mg/L. Areas with no fluoridation scheme and fluoride concentrations at or above 0.20 mg/L were excluded from the analysis.

Emergency hospital admissions for hip fractures at all ages

Descriptive summary of emergency hospital admissions for hip fractures in 2021 to 2024

There were 199,879 emergency hospital admissions for hip fractures among people of all ages between April 2021 and March 2024 in England ([Table 25](#)). The crude incidence rate over the

study period was 112 (95% CI: 112, 112) emergency hospital admissions for hip fractures per 100,000 PYAR.

Over 99% of admissions were linked to drinking water fluoride concentration data or fluoridation scheme data and were included in analysis.

Crude incidence rates showed differences across increasing fluoride concentration categories, but these were inconsistent. Crude incidence rates were slightly higher in areas with natural fluoridation (no scheme, ≥ 0.20 mg/L) or with a fluoridation scheme as compared to areas without fluoridation schemes (Table 25).

Crude incidence rates varied by age group and sex ([Appendix Table A13](#)). Incidence rates were over 100 times higher in those aged 80 and older compared to those aged under 65 and were over 17 times higher for those aged 65 to 79 compared to those aged under 65. Incidence rates were approximately twice as high among females compared to males and were slightly lower in the more compared to the less deprived areas. Incidence rates were similar across 2021, 2022 and 2023 and were slightly lower in January to March 2024.

Table 25. Incidence rates for emergency hospital admissions for hip fracture in people of all ages between April 2021 and March 2024, by drinking water fluoride exposure

Fluoride exposure	Admissions, N (%)	PYAR, person-years (%)	Incidence per 100,000 PYAR (95% CI)
Mean fluoride concentration, mg/L			
<0.10	81,415 (40.7)	68,313,146 (38.3)	119 (118, 120)
0.1 to 0.2	59,796 (29.9)	62,309,075 (34.9)	96 (95, 97)
0.2 to 0.4	28,427 (14.2)	24,170,906 (13.5)	118 (117, 119)
0.4 to 0.7	11,595 (5.8)	8,539,887 (4.8)	136 (134, 138)
≥ 0.70	18,635 (9.3)	15,240,006 (8.5)	122 (120, 124)
Missing	11 (<0.1)	37,956 (<0.1)	29 (16, 52)
Fluoridation scheme			
Yes	26,759 (13.4)	21,571,908 (12.1)	124 (123, 125)
No	140,480 (70.3)	129,801,000 (72.7)	108 (107, 109)
Natural fluoridation	32,045 (16.0)	26,566,371 (14.9)	121 (120, 122)
Missing	595 (0.3)	671,697 (0.4)	89 (82, 96)
Total	199,879 (100.0)	178,610,976 (100.0)	112 (112, 112)

Abbreviations

CI = confidence interval; IMD = Index of Multiple Deprivation; PYAR = Person-years at risk; mg/L = milligrams per litre.

Notes

Note 1: Mean fluoride concentration is calculated as the mean of annual mean values in the 10 years preceding the year of the hospital admission.

Note 2: Fluoridation scheme status was defined as follows: 'Yes': LSOAs where a water fluoridation scheme operated for at least one year in the 10 years preceding the hospital admission. 'No': LSOAs where a water fluoridation scheme did not operate in any year, and where the average water fluoride concentration was below 0.20 mg/L. 'Natural fluoridation': no fluoridation scheme and fluoride concentrations at or above 0.20 mg/L.

Note 3: Percentages may not sum to the total due to rounding.

Note 4: A breakdown of incidence rates by drinking water fluoride exposure stratified by fluoridation scheme is available in the Appendix [Table A27](#).

Association between fluoride in drinking water and hip fractures

[Table 26](#) shows incidence rate ratios for the association between drinking water fluoride concentration and emergency hospital admissions for hip fractures after adjusting for age group, sex, calendar year, deprivation, ethnicity, and residual clustering by LAD. Those living in areas in the highest fluoride concentration category (≥ 0.70 mg/L) showed a 5% higher incidence rate of admissions (adjusted OR: 1.05, 95% CI: 1.02, 1.09) compared to those in areas in the lowest exposure category (< 0.10 mg/L). See [Appendix Table A19](#) for the fully adjusted model including estimates for all other risk factors.

There was evidence of an interaction between fluoride exposure and both age and sex impacts on the incidence rates of hip fractures for this study and previous HMRs. Therefore, the main results are presented with stratification by age and sex in [Table 27](#). For those under 65 years old, lower incidence rates of hip fractures were observed for those living in areas with lower fluoride concentrations (0.10 to 0.19 mg/L and 0.20 to 0.39 mg/L), as compared to those living in areas with the lowest concentrations (< 0.10 mg/L). This effect was not seen in the higher fluoride concentration category (0.40 to 0.69, and ≥ 0.70 mg/L). Most confidence intervals for the effect estimates included the possibility of no effect, except for selected associations (0.10 to 0.19 mg/L: females aged 0 to 49 adjusted IRR: 0.83, 95% CI: 0.71, 0.97; females aged 50 to 64 adjusted IRR: 0.90, 95% CI: 0.84, 0.96; and 0.20 to 0.39 mg/L: males 50 to 64 adjusted IRR: 0.84, 95% CI: 0.75, 0.94). Conversely, slightly higher incidence rates of hip fractures were observed amongst those aged 65 and older living in areas with higher fluoride concentrations (0.40 to 0.69 and ≥ 0.70 mg/L). Most confidence intervals for the effect estimates included the possibility of no effect, except for one association (≥ 0.70 mg/L: males aged 65 to 79 adjusted IRR: 1.13, 95% CI: 1.04, 1.23).

Continuous models were consistent with the overall categorical models. An IQR (0.15 mg/L) increase in fluoride concentration was associated with a 1% (95% CI: 0%, 2%) higher overall incidence rate of hip fracture ([Table 26](#)). In the age- and sex-stratified models, a 1% (0%, 2%) to 2% (1%, 3%) increase in the incidence rate of hip fractures was observed per IQR increase in

fluoride concentration in those aged 65 and older. For those under 65 years old, no clear association was observed ([Table 27](#)).

[Figure 6](#) shows the model-predicted incidence rates for admissions for hip fractures across fluoride concentration groups and in each age group for males and females after adjusting for age group, calendar year, deprivation, ethnicity, and residual clustering by LAD. Model-predicted incidence rates were highest for the ≥ 80 years old age group. The incidence rates changed little across fluoride concentration categories within each age group for those under 65 years old. A slightly higher incidence rate was observed in the highest compared to the lowest fluoride concentration categories for the 65 to 79 and the ≥ 80 years old age groups (see [Appendix Table A23](#)).

[Table 28](#) shows the association between hip fracture and exposure to a fluoridation scheme after adjusting for age group, sex, calendar year, deprivation, ethnicity, and residual clustering by LAD. Overall, those living in areas with a fluoridation scheme had a 4% (95% CI: 0%, 7%) higher incidence rate of hip fracture compared to those living in areas without schemes and with low levels (<0.20 mg/L) of natural fluoride. When the model was stratified by age and sex, for those living in areas with a fluoridation scheme there was a suggestion of a higher incidence rate for people aged 65 years old and over.

[Table A29 in the Appendix](#) showed a 1% higher incidence rate of hip fractures for an IQR increase in the continuous measure of drinking water fluoride concentrations in both areas with fluoridation schemes and areas without schemes (including natural fluoridation, where fluoride was ≥ 0.20 mg/L).

Table 26. Adjusted incidence rate ratios for the association between drinking water fluoride concentration and emergency hospital admissions for hip fracture in people of all ages between April 2021 and March 2024

Mean fluoride concentration, mg/L	Adjusted IRR (95% CI)
<0.10	1.00
0.10 to 0.19	0.98 (0.96, 1.00)
0.20 to 0.39	1.01 (0.98, 1.03)
0.40 to 0.69	1.03 (0.99, 1.06)
≥ 0.70	1.05 (1.02, 1.09)
Continuous	1.01 (1.00, 1.02)

Abbreviations

CI = confidence interval; IMD = Index of Multiple Deprivation; IRR = Incidence rate ratio; LAD = Local authority district; mg/L = milligrams per litre.

Notes

Note 1: The model was adjusted for age group, sex, IMD quintile, calendar year, an area-level measure of ethnicity, and for residual clustering by local authority district.

Note 2: Mean fluoride concentration is calculated as the mean of annual mean values in the 10 years preceding the year of the hospital admission.

Note 3: The continuous fluoride concentration variable estimates show the change in effect per interquartile range (0.15 mg/L) increase in fluoride concentration. The interquartile range is the difference between the fluoride concentration value at the 25th percentile and at the 75th percentile of the data. This range captures the middle 50% of values.

Table 27. Adjusted incidence rate ratios for the association between drinking water fluoride concentration and emergency hospital admissions for hip fracture by in people of all ages between April 2021 and March 2024, by age group and sex

Age, years	Mean fluoride concentration, mg/L	Adjusted IRR (95% CI): Female	Adjusted IRR (95% CI): Male
0 to 49	<0.10	1.00	1.00
	0.10 to 0.19	0.83 (0.71, 0.97)	0.90 (0.81, 1.00)
	0.20 to 0.39	0.83 (0.67, 1.03)	0.89 (0.77, 1.03)
	0.40 to 0.69	0.90 (0.65, 1.24)	0.93 (0.75, 1.15)
	≥0.70	1.11 (0.88, 1.39)	0.98 (0.83, 1.16)
	Continuous	1.02 (0.99, 1.06)	1.00 (0.98, 1.02)
50 to 64	<0.10	1.00	1.00
	0.10 to 0.19	0.90 (0.84, 0.96)	0.94 (0.86, 1.02)
	0.20 to 0.39	0.93 (0.85, 1.02)	0.84 (0.75, 0.94)
	0.40 to 0.69	1.01 (0.89, 1.16)	0.90 (0.77, 1.06)
	≥0.70	1.01 (0.91, 1.13)	1.03 (0.91, 1.17)
	Continuous	1.01 (0.99, 1.02)	1.00 (0.98, 1.02)
65 to 79	<0.10	1.00	1.00
	0.10 to 0.19	0.98 (0.94, 1.02)	0.99 (0.94, 1.04)
	0.20 to 0.39	1.00 (0.95, 1.06)	0.99 (0.93, 1.07)
	0.40 to 0.69	1.01 (0.94, 1.09)	1.00 (0.91, 1.10)
	≥0.70	1.06 (0.99, 1.13)	1.13 (1.04, 1.23)
	Continuous	1.01 (1.00, 1.02)	1.02 (1.01, 1.03)
≥80	<0.10	1.00	1.00
	0.10 to 0.19	1.00 (0.97, 1.03)	1.00 (0.96, 1.04)
	0.20 to 0.39	1.02 (0.98, 1.07)	1.06 (1.00, 1.12)
	0.40 to 0.69	1.06 (1.00, 1.12)	1.03 (0.96, 1.12)
	≥0.70	1.05 (0.99, 1.11)	1.05 (0.98, 1.13)
	Continuous	1.01 (1.00, 1.02)	1.01 (1.00, 1.02)

Abbreviations

CI = confidence interval; IMD = Index of Multiple Deprivation; IRR = Incidence rate ratio; LAD = Local authority district; mg/L = milligrams per litre.

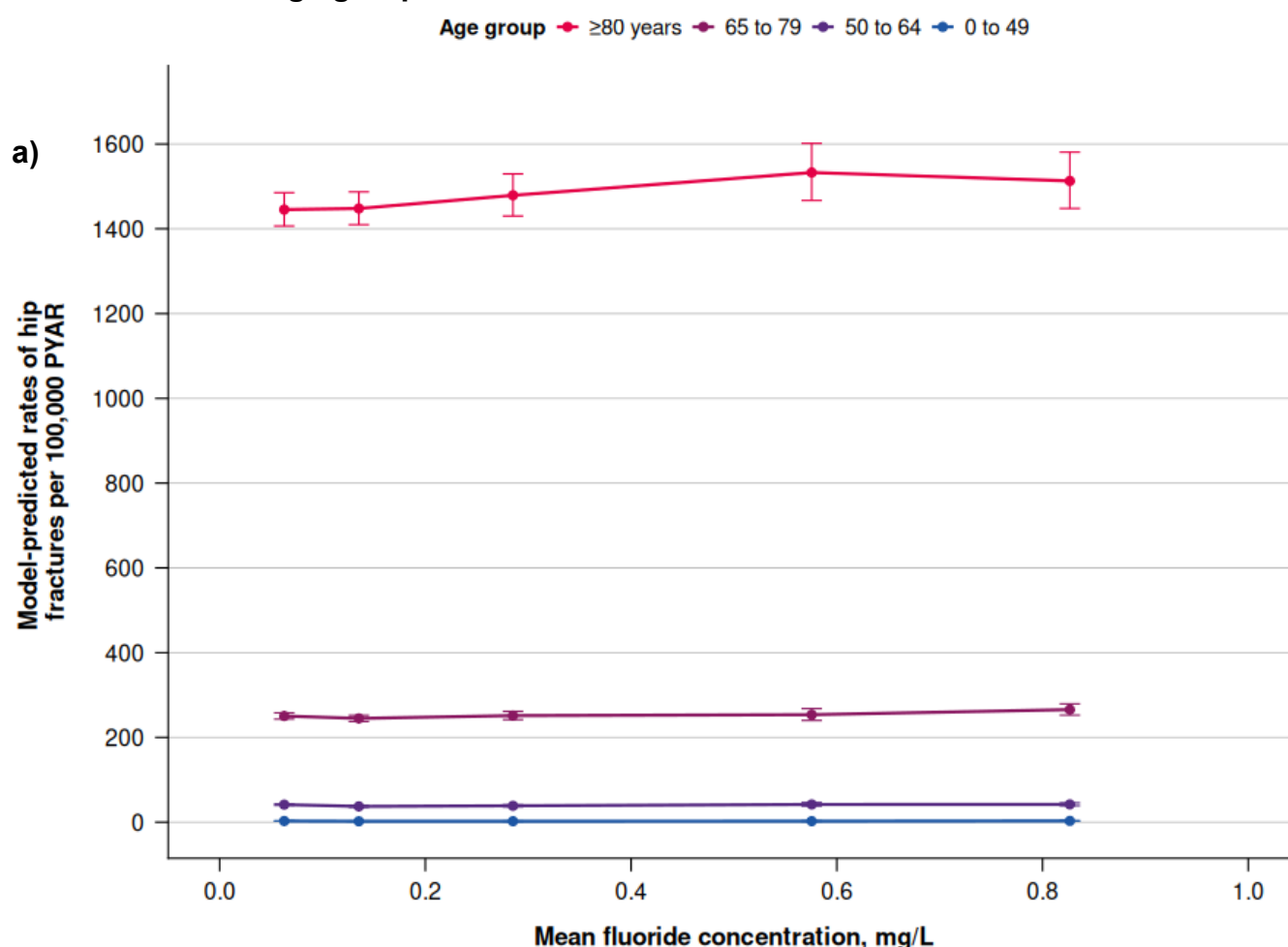
Notes

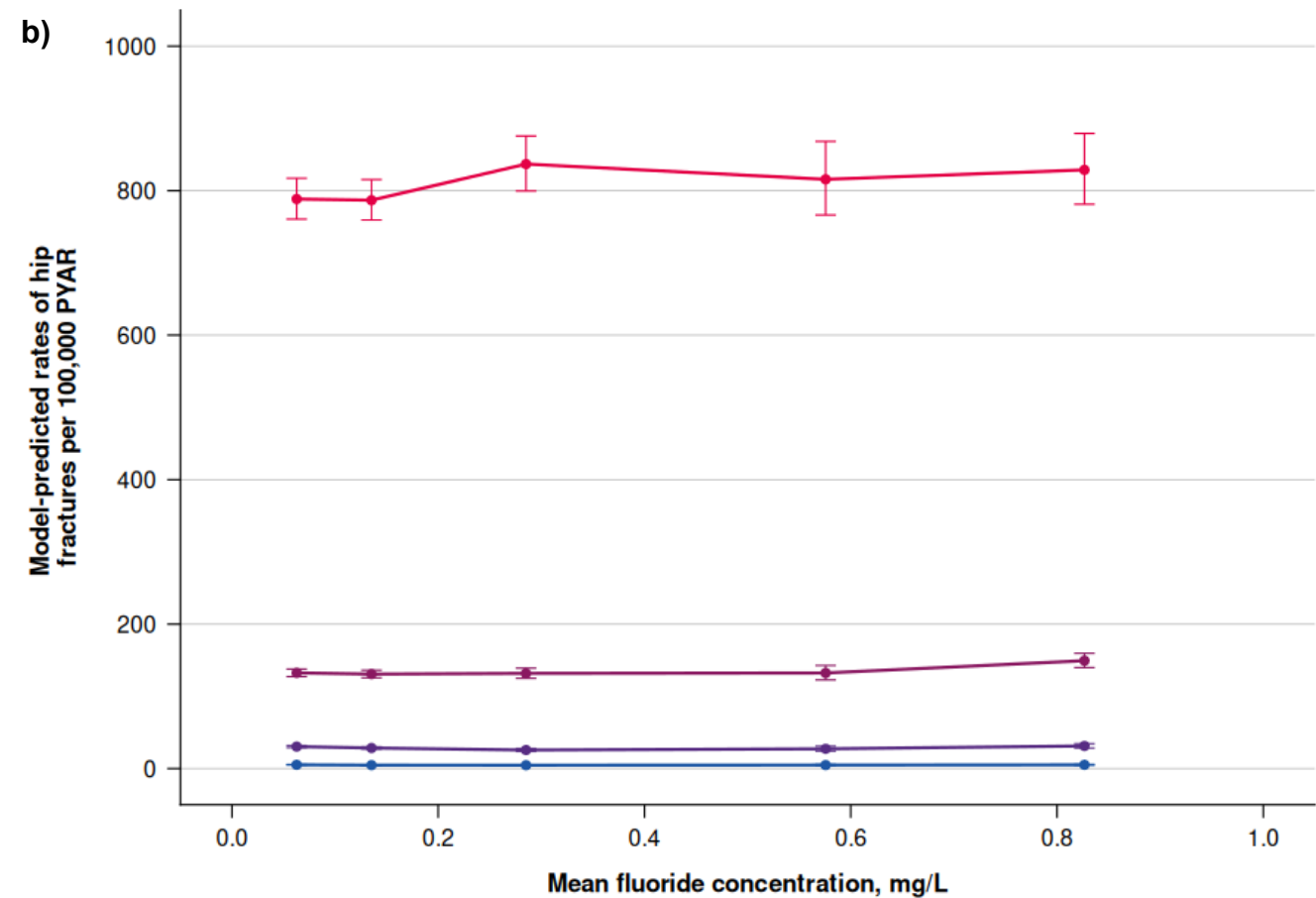
Note 1: The models were adjusted for deprivation, calendar year, ethnicity and for residual clustering by local authority district.

Note 2: Mean fluoride concentration is calculated as the mean of annual mean values in the 10 years preceding the year of the hospital admission.

Note 3: The continuous fluoride exposure model estimates show the change in effect per interquartile range (0.15 mg/L) increase in fluoride concentration. The interquartile range is the difference between the fluoride concentration value at the 25th percentile and at the 75th percentile of the data. This range captures the middle 50% of values.

Figure 6. Model-predicted incidence rates for emergency hospital admissions for hip fractures in people of any age for a) females, and b) males, by drinking water fluoride concentration and age group





Abbreviations

IMD = Index of Multiple Deprivation; LAD = Local authority district; mg/L = milligrams per litre; PYAR = Person-years at risk.

Notes

Note 1: The models were adjusted for deprivation, calendar year, ethnicity and for residual clustering by local authority district. The model-predicted incidence rates are displayed at reference levels set for these factors, which the least deprived areas (IMD quintile 5), admitted in 2023, at the mean proportion of people from white backgrounds.

Note 2: Mean fluoride concentration is calculated as the mean of annual mean values in the 10 years preceding the year of hospital admission.

Note 3: Estimates are plotted at the mean fluoride concentration in each fluoride exposure category (<0.1, 0.1 to 0.19, 0.20 to 0.39, 0.40 to 0.69, ≥0.70; mg/L). The continuous x axis and lines connecting the point estimates for each category are to aid visualisation of trends across fluoride categories only and do not imply a continuous or linear exposure-response relationship.

Note 4: the numerical values for estimates presented in these figures are presented in [Appendix Table A22](#).

Table 28. Adjusted incidence rate ratios for the association between fluoridation scheme status and emergency hospital admissions for hip fracture in people of all ages between April 2021 and March 2024, by age group and sex

Age, years	Fluoridation scheme	Adjusted IRR (95% CI): Overall	Adjusted IRR (95% CI): Female	Adjusted IRR (95% CI): Male
Overall	No	1.00		
	Yes	1.04 (1.00, 1.07)		
0 to 49	No		1.00	1.00
	Yes		1.11 (0.95, 1.30)	1.02 (0.91, 1.13)
50 to 64	No		1.00	1.00
	Yes		1.04 (0.97, 1.13)	0.99 (0.91, 1.08)
65 to 79	No		1.00	1.00
	Yes		1.04 (1.00, 1.09)	1.08 (1.02, 1.15)
≥80	No		1.00	1.00
	Yes		1.04 (1.00, 1.08)	1.04 (0.99, 1.10)

Abbreviations

CI = confidence interval; IMD = Index of Multiple Deprivation; IRR = Incidence rate ratio; LAD = Local authority district.

Notes

Note 1: The model was adjusted for age group, sex, IMD quintile, calendar year, ethnicity and for residual clustering by local authority district.

Note 2: Fluoridation scheme status was defined as follows: 'Yes': LSOAs where a water fluoridation scheme operated for at least one year in the 10 years preceding the hospital admission. 'No': LSOAs where a water fluoridation scheme did not operate in any year, and where the average water fluoride concentration was below 0.20 mg/L. Areas with no fluoridation scheme and fluoride concentrations at or above 0.20 mg/L were excluded from the analysis.

Cognitive ability in 5 and 7 year olds

Descriptive summary of cognitive ability in the Millenium Cohort Study

MCS data on cognitive ability outcomes was collected from 9,722 children at age 5 and 8,883 children at age 7 in England. After removing those who had changed residency, had not completed all cognitive abilities subtests, and who could not be linked to a fluoride exposure category, 8,142 of children in sweep 3 and 7,043 of children in sweep 4 were included in our sample (Table 29). Due to missing data for one or more of the other risk factors used in analysis, approximately 97% of children in the sample were then included in the analysis.

At age 9 months old, approximately 70% of children in the study at ages 5 and 7 were exposed to drinking water fluoride concentrations below 0.20 mg/L and approximately 7% of children were exposed to concentrations above 0.70 mg/L (Table 29).

The distribution of children according to sociodemographic characteristics and fluoride exposure at ages 5 and 7 are presented in [Appendix Table A14 and Table A30](#).

Table 29. Distribution of children in the Millenium Cohort Study used in analysis by drinking water fluoridation exposure

Mean fluoride concentration, mg/L	Children at age 5 N (%)	Children at age 7 N (%)
<0.1	2,306 (30.1)	1,991 (30.0)
0.1 to 0.19	3,429 (40.5)	2,939 (40.4)
0.2 to 0.39	1,163 (16.1)	1,012 (15.9)
0.4 to 0.69	353 (6.1)	314 (6.0)
≥0.7	621 (7.3)	542 (7.6)
Total	7,872 (100.0)	6,798 (100.0)

Abbreviations

mg/L = milligrams per litre; n = number.

Notes

Note 1: Percentages are weighted using the MCS sweep survey weights to account for sampling design.

Note 2: Children aged 5 and 7 years old were assessed in MCS sweep 3 and sweep 4, respectively.

Note 3: Mean fluoride exposure was measured for the area that the child lived in when they were approximately 9 months old.

Note 4: Percentages may not sum to the total due to rounding.

Association between fluoride in drinking water and cognitive ability

[Table 30](#) shows the estimated difference in cognitive ability test scores at 5 and 7 years old for each drinking water fluoride concentration category at 9 months old, after adjusting for the selected risk factors (see [Appendix Table A2 and Table A20](#)). Overall, the results did not suggest an association between fluoride exposure at 9 months old and cognitive ability at 5 and 7 years old. Most differences in test scores between areas in the lowest fluoride concentration category (<0.10 mg/L) and areas with higher concentrations were close to zero. Confidence intervals for the estimated difference in test score included zero in all but one instance, and there was no consistency in the direction of effect or suggestion of a trend across fluoride concentration categories for any cognitive ability sub-test. This was also the case for findings from the continuous exposure measure. See the [Appendix Table A20](#) for the fully adjusted models including estimates for all other risk factors.

Sensitivity analyses using mean fluoride concentration at age 5 or 7 years old, or assessing outcomes at age 7 years old after excluding those with learning disabilities, similarly found no evidence of an association (see [Appendix Table A31](#) and [Table A32](#)).

In accordance with the analysis plan, analysis for the water fluoridation scheme exposure measure was not conducted because no association was detected between cognitive ability and the water fluoride concentration exposure measure.

Table 30. Adjusted regression coefficients for the association between drinking water fluoride concentration and cognitive ability test scores in 5 and 7 year olds in the Millenium Cohort Study

Child age at assessment	Cognitive ability test	Mean fluoride concentration, mg/L	Difference in test score, Adjusted beta (95% CI)
Age 5	Naming vocabulary (BAS-NV)	<0.10	0.00
		0.10 to 0.19	-0.47 (-1.03, 0.09)
		0.20 to 0.39	-0.67 (-1.40, 0.06)
		0.40 to 0.69	0.63 (-0.52, 1.78)
		≥0.70	0.33 (-0.61, 1.27)
		Continuous	0.10 (-0.03, 0.23)
	Pattern construction (BAS-PC)	<0.10	0.00
		0.10 to 0.19	-0.02 (-0.58, 0.54)
		0.20 to 0.39	-0.14 (-0.89, 0.61)
		0.40 to 0.69	-1.24 (-2.43, -0.04)
		≥0.70	0.57 (-0.38, 1.51)
		Continuous	0.04 (-0.09, 0.17)
	Picture similarities (BAS-PS)	<0.10	0.00
		0.10 to 0.19	0.43 (-0.19, 1.04)
		0.20 to 0.39	-0.39 (-1.20, 0.42)
		0.40 to 0.69	-0.40 (-1.65, 0.85)
		≥0.70	-0.69 (-1.73, 0.36)
		Continuous	-0.11 (-0.25, 0.03)
Age 7	Word reading (BAS-WR)	<0.10	0.00
		0.10 to 0.19	0.62 (-0.36, 1.60)
		0.20 to 0.39	0.89 (-0.39, 2.17)
		0.40 to 0.69	0.49 (-1.51, 2.48)
		≥0.70	-0.55 (-2.19, 1.10)
		Continuous	-0.06 (-0.28, 0.16)

Child age at assessment	Cognitive ability test	Mean fluoride concentration, mg/L	Difference in test score, Adjusted beta (95% CI)
	Pattern construction (BAS-PC)	<0.10	0.00
		0.10 to 0.19	-0.09 (-0.76, 0.58)
		0.20 to 0.39	0.07 (-0.80, 0.93)
		0.40 to 0.69	0.81 (-0.55, 2.18)
		≥0.70	-0.33 (-1.45, 0.78)
		Continuous	-0.01 (-0.15, 0.14)
	Progress in maths (NFER-PiM)	<0.10	0.00
		0.10 to 0.19	-0.07 (-0.84, 1.19)
		0.20 to 0.39	0.57 (-1.42, 1.28)
		0.40 to 0.69	0.76 (-1.51, 2.65)
		≥0.70	0.18 (-1.02, 2.53)
		Continuous	0.09 (-0.14, 0.33)

Abbreviations

CI = confidence interval; BAS = British Ability Scale; IMD = Index of Multiple Deprivation; IQR = Interquartile range; mg/L = milligrams per litre; NFER = National Foundation for Educational Research; OECD = Organization for Economic Cooperation and Development.

Notes

Note 1: Difference in test score compared to the lowest group (<0.10 mg/L, categorical exposure) or difference per the interquartile range increase in fluoride (0.13 mg/L, continuous exposure) in drinking water fluoride exposure, adjusted for other common risk factors: age at interview, sex, maternal ethnicity, breastfeeding status, OECD income-weighted quintiles, highest parental academic qualification, sample weights, and clustering. In addition to the common risk factors, each cognitive ability test was adjusted for further factors: BAS-NV (maternal age at childbirth, exposure to smoke, IMD deciles, child started school, speech or language concerns), BAS-PC at age 5 (birthweight, IMD deciles, child started school, speech or language concerns), BAS-PS (birthweight, maternal age at childbirth, speech or language concerns), BAS-WR (birthweight, exposure to smoke, child has special needs), BAS-PC at age 7 (IMD deciles, child has special needs), NFER-PiM (birthweight, maternal age at childbirth, child has special needs). Models also accounted for residual clustering by LSOA.

Note 2: Mean fluoride exposure was measured for the area that child lived when they were approximately 9 months old.

Note 3: The interquartile range is the difference between the fluoride concentration value at the 25th percentile and at the 75th percentile of the data. This range captures the middle 50% of values.

Discussion

This is the fourth HMR published by the working group. The series assesses the associations between drinking water fluoride exposure and dental and non-dental health outcomes every 4 years in order to provide evidence on the public health benefits and any potential harms of water fluoridation in England.

The scope of the reports has changed over time to appropriately address the public health questions relevant to monitoring the health effects of water fluoridation. The 2014 report assessed the potential health impacts associated with areas with water fluoridation schemes compared to areas without. The 2018 report additionally measured exposure based on drinking water fluoride concentrations in the area, and this exposure approach has been continued in 2022 and 2026.

All reports have assessed associations with dental caries prevalence and severity and hospital admissions for tooth extractions. Dental fluorosis was additionally investigated in 2014 and 2018. The range of non-dental health outcomes included has varied over time. The 2014 report identified a range of potential non-dental health outcomes that had been discussed in the literature and had suitable data available for England: hip fractures, kidney stones, all-cause mortality, Down syndrome, bladder cancer, osteosarcoma, and all-cancers. The 2018 report assessed the same health outcomes except for all-cause mortality and all-cancer outcomes. Due to pressures on research capacity caused by the COVID-19 pandemic, the 2022 report had a more limited scope and hip fracture was the only non-dental health outcome assessed. This 2026 HMR evaluated the range of potential non-dental health outcomes for inclusion as suggested in the literature and previous reports. Based on this evaluation and feasibility, this HMR conducted analysis for hip fractures and cognitive ability.

The overall findings of this HMR are similar to those of the 2014, 2018 and 2022 reports. It has been consistently observed that higher drinking water fluoride exposure is associated with better dental health outcomes, and that dental health benefits are greatest for the more deprived areas which have the largest burden of poor dental health in children. Reports, including the 2026 HMR, have consistently observed no convincing evidence of an association between fluoride exposure and adverse non-dental health outcomes. As the methods used in this report were not exactly the same as those followed in the previous reports, point estimates should not be directly compared across reports.

Dental outcomes

Overall, this report observed evidence of lower odds of dental caries experience prevalence, lower probability of having a higher dental caries severity score, and lower incidence rates of tooth extractions for those living in areas with water fluoridation schemes compared to in areas without schemes and with low levels of natural fluoride (<0.20 mg/L). These dental outcomes

were also lower in areas with higher compared to lower drinking water fluoride concentrations. There was a greater absolute reduction in the prevalence and incidence rates of poor dental health outcomes at higher fluoride concentrations in the most deprived compared to the least deprived areas, thus contributing to narrowing dental health inequalities. Children in the most deprived areas experience the highest levels of poor dental health outcomes, making water fluoridation an important and equitable public health intervention for improving children's dental health outcomes in England.

These findings are in line with previous HMRs and other published international evidence for water fluoridation concentrations below the WHO guideline value (1.5 mg/L). The 2022 and 2018 HMRs found that areas with fluoridation schemes or higher fluoride concentrations had lower prevalence of dental caries experience, dental caries severity score and hospital admissions for caries-related tooth extractions. Both reports found that these benefits to dental health from higher fluoride concentrations were greatest in the most deprived areas, thus contributing to narrowing dental health inequalities. International evidence has also consistently found that higher levels of fluoride in drinking water, even at levels well below the WHO guideline value (1.5 mg/L), can reduce the occurrence of adverse dental outcomes in children (13, 16, 18, 20). A recent Cochrane meta-analysis reported that the initiation of water fluoridation schemes is associated with a reduction in the total proportion of children with dental caries experience and also with a reduction in the number of decayed, missing or filled primary teeth per child, although effect estimates were imprecise (16). The biological mechanism for the role of fluoride in increasing tooth resistance to dental caries and in slowing dental caries progression is well established.

Water fluoridation allows all people accessing mains drinking water to receive these benefits without changing their normal behaviour, making it an important public health intervention to support equitable population-level improvements in dental health.

This analysis uses an ecological design and uses recent water fluoride concentrations in the person's local area to estimate exposure. As fluoride concentrations in England varied little across recent years and between nearby LSOAs, the 10-year exposure window for 0 to 19 year olds and particularly the 6-year window for 5 year olds used in the dental outcomes analyses were considered reasonable measures of their lifetime exposure. This analysis adjusted for area-level deprivation and a binary measure of ethnicity. As dental outcomes can also be influenced by diet, oral hygiene behaviour, caregiver care-seeking behaviours, availability and access to primary dental care and oral health improvement programmes, we cannot rule out residual or unmeasured confounding from one or more of these factors. However, area-level deprivation likely captures some important aspects of variation in these factors (67).

Dental caries experience

This report finds that approximately 23% of 5 year olds in England experienced dental caries (had at least one tooth with visible decay at the dentinal level, or a missing or filled tooth) in both

the 2022 and 2024 surveys. This is similar to the prevalence reported in previous HMRs (2022: 23% ([4](#)); 2018: 25% ([3](#)); 2014: 26% ([2](#))).

This HMR, for both the 2022 and 2024 oral health surveys, observed lower odds of dental caries experience for children living in areas with fluoridation schemes compared to without, in areas in higher drinking water fluoride concentration categories compared to the lowest category, and for increasing concentrations of fluoride in water. The trend in the relative reduction of the odds of dental caries experience by increasing water fluoride concentrations was similar across all levels of deprivation, but only statistically important for the most deprived areas. The most deprived areas benefitted the most as observed in the absolute reductions in model-predicted prevalence of child dental caries experience. This is important from a public health perspective, as the populations 'at risk' of dental caries are disproportionately greater in the most deprived areas, with a greater burden of adverse dental health, and worse uptake of dental care ([41](#)).

Findings in this HMR are in line with the 2018 and 2022 HMR results. These reports had found that lower dental caries experience was associated with living in areas with higher fluoride levels in all quantiles of deprivation, however there was no clear trend in these associations across the quantiles of deprivation. As the most deprived areas had the worst baseline levels of dental caries experience, the reductions in the outcome observed at higher levels of fluoride meant that the most deprived areas benefitted the most in absolute terms.

While data from the 2023 oral health survey conducted in Year 6 children (10 or 11 year olds) was included for the first time in the report series, limitations of the data meant only descriptive statistics were presented for this outcome. Approximately 16% of Year 6 students had dental caries experience in their permanent teeth, affecting an average of 0.3 permanent teeth per child. However, this is likely an underestimate as, at age 10 or 11 years old, typically only a few permanent teeth have erupted and can be assessed for decay, and these often have not yet expressed their full dental caries susceptibility to the extent that can be identified under survey conditions ([76](#)). The 2023 survey round included in this report was the first time the oral health survey was undertaken in this age group, so changes over time cannot be determined.

Dental caries severity score

This HMR finds a mean dental caries severity score (average number of teeth with dental caries per child) among 5 year olds of 0.82 in 2022 and 0.80 in 2024. These values are similar to those reported in previous years, with scores of 0.87, 0.82 and 0.77 reported in the 2014, 2018 and 2022 HMRs, respectively.

This HMR, for both the 2022 and 2024 oral health surveys, observed a lower probability of being in the highest dental caries severity score category for children living in areas with fluoridation schemes compared to areas without, in areas with higher drinking water fluoride concentration categories compared to areas with the lowest category, and for increasing concentrations of fluoride in water. There was some evidence in the 2024 oral health survey

data that those in the more deprived areas saw a larger protective effect from the highest fluoride concentrations compared to those in less deprived areas. This effect was not observed for the 2022 oral health survey data.

Findings in this HMR are in line with the 2018 and 2022 HMR results. These reports found a reduction in the probability of being in the highest dental caries severity score category compared to the others across increasing fluoride concentration categories, although the 2018 HMR did not find evidence of a clear trend across increasing fluoride concentration categories. In the 2026, 2022 and 2018 HMRs, children in the most deprived areas saw the greatest reductions in probability of being in the highest severity score category when exposed to higher fluoride concentrations.

Caries-related tooth extractions

This HMR finds an incidence rate of 213 hospital admissions for caries-related tooth extractions per 100,000 PYAR in 0 to 19 year olds between April 2021 and March 2024 in England. This is lower than the incidence rates of 249 and 310 admissions per 100,000 PYAR reported in the 2022 (4) and 2018 (3) HMRs, respectively (the 2014 HMR did not report this value). This decrease in incidence is likely due to the impact of the COVID-19 pandemic on hospital services and the continuing recovery from that impact through to 2024 (50).

This report observed lower incidence rates of hospital admissions for caries-related tooth extractions for children living in areas with fluoridation schemes compared to areas without, in areas with higher drinking water fluoride concentration categories compared to areas in the lowest category, and for increasing concentrations of fluoride in water. These lower incidence rates were observed across all deprivation groups but were statistically important and lowest in the most deprived areas. Absolute reductions in model-predicted incidence rates of admissions in the highest versus lowest fluoride concentration categories were larger in more deprived areas.

These findings are consistent with those reported in the 2018 and 2022 HMRs which observed lower incidence rates for tooth extraction with increasing fluoride concentration categories, with a clear trend across categories. As incidence rates for tooth extractions are highest in the most deprived areas of England, like all previous reports, this HMR found that this led to absolute reductions in model-predicted incidence rates for areas with higher compared to lower fluoride exposure that were largest in the most deprived areas.

Hip fractures

This HMR finds an incidence rate of 112 emergency hospital admissions for hip fractures per 100,000 PYAR between April 2021 and March 2024 in England. This is similar to the incidence rates of 115, 112 and 119 admissions per 100,000 PYAR reported in the 2022 (4) 2018 (3) and 2014 (2) HMRs, respectively.

Overall, this report concluded that the findings on the association between hip fracture risk and fluoride exposure did not provide convincing evidence of a relationship when considered alongside the wider international evidence and the limitations of this study. The observed associations for hip fractures varied by age and sex. For people 65 years and over, there was a suggestion of a slightly higher risk of emergency hospital admission for hip fracture if living in areas with fluoridation schemes, or living in areas with fluoride concentrations at or above 0.40 mg/L. For those under 65 years old, there was a suggestion of a lower risk of hip fracture if living in areas with fluoride concentrations between 0.10 and 0.39 mg/L, but there was no evidence of a relationship with fluoride concentrations at or above 0.40 mg/L or with living in areas with a fluoridation scheme. Most confidence intervals for effect estimates included the possibility of no effect.

These results are in line with findings in the 2018 and 2022 HMRs. Past reports concluded that, overall, there was no convincing evidence of a causal association when considering the wider literature, limitations of the study design, inconsistencies across age groups and the small effect sizes.

This 2026 HMR analysis uses recent water fluoride exposure as opposed to a measure of lifetime fluoride intake. The exposure measure used was the average annual fluoride concentration, or the presence of a fluoridation scheme, over the previous 10 years in the LSOA in which the individual was recorded as resident at the time of the event (admission for hip fracture). In the older age groups, the likelihood that this accurately reflects lifetime exposure diminishes as individuals age and potentially move between locations with different fluoride concentrations during. The exposure assigned may therefore not be representative of their total lifetime fluoride exposure. Furthermore, lifetime intake of fluoride reflects other features which may have changed over the lifetime, including initiation of water fluoridation schemes, water consumption rates, historical changes in dental care practices and the use of fluoride treatments, use of fluoridated toothpastes and other dental products, dietary intake and other factors ([7](#)).

This analysis adjusted for sex, age group, calendar year of admission and area-level measures of ethnicity and deprivation to account for other risk factors and potential confounding. Hip fracture risk is also affected by individual-level factors not available for inclusion in this analysis including bone mineral density, prior fragility fracture, parental history of hip fracture, smoking, systemic corticosteroid use, excess alcohol intake and rheumatoid arthritis ([77](#)). Area-level factors that may not be captured by the IMD such as access to preventive health services, prescription services for osteoporosis or hormone replacement therapy in females, and wider regional differences in lifestyle factors, may also influence findings ([78](#), [79](#)). Although we do not have an explanation for how these factors at the individual- or area-level may be related to the distribution of water fluoride exposures, we cannot rule out potential residual or unmeasured confounding.

This HMR's findings can be placed in the context of wider international evidence, and particularly those from studies assessing lower fluoride concentrations (<1.5 mg/L). Bone and

hip fractures are known to be more common at older ages due to increasing frailty and propensity to falls and are more frequent in older women due to changes in hormonal status after menopause. Two authoritative organisations, Australia's NHMRC and Canada's CADTH, have found evidence of no association between fluoride exposure below 1.5 mg/L and hip fractures ([13](#), [20](#)). The most recent detailed assessment of the evidence conducted by EFSA (2025) for bone fractures overall suggested that there was insufficient evidence at lower exposures (<1.5 mg/L) to conclude on the presence of an association. They note that, even at relatively low water concentrations leading to an intake above approximately 3 mg per day, fluoride may affect bone mineral density, however whether these findings reflect an adverse effect on health, and the threshold at which this results in decreased mechanical strength of the bone and has an effect on overall fracture risk is unknown ([7](#)). The EFSA report did not quantify any dose-response relationship between fluoride and hip fractures, but a well-conducted recent meta-analysis by Mazzoli and colleagues ([78](#)) found no association between hip fractures and drinking water fluoride concentrations in the range of exposures assessed (0.0 to 1.8 mg/L).

Placed within the wider international evidence, the findings of this report were not considered to provide convincing evidence of a relationship between water fluoridation and hip fracture risk. This conclusion reflects the small effect sizes and lack of statistical confidence of estimates observed across age- and sex-specific groups, the study limitations including the substantial uncertainty in exposure assignment for this health outcome, and the absence of evidence provided by authoritative international reviews for an association between drinking water fluoride concentrations below 1.5 mg/L and bone fractures. Continued monitoring remains justified, both to assess any changes in the wider evidence and to address some of the key methodological limitations of the study design for the hip fractures analysis used in the present HMR.

Cognitive ability

This HMR assessed cognitive ability using 6 standardised measures from the British Ability Scales and the National Foundation for Education Research tests in children aged 5 and 7 years old. This report did not find that exposure to drinking water fluoride early in life (ranging from 0.01 to 1.0 mg/L) was associated with cognitive ability outcomes at ages 5 and 7 years old, after controlling for individual- and area-based covariates. Our sensitivity analyses did not show any evidence of an association when fluoride was measured at age 5 or age 7 or when excluding children aged 7 with special educational needs.

International evidence reviews identified insufficient or unclear evidence for an association between neurodevelopment and cognition outcomes and drinking water fluoride concentrations below the WHO guideline value (1.5 mg/L) ([7](#), [15](#), [20 to 22](#)). This is one of the largest studies to date examining cognitive ability in young children at fluoridation levels well below the WHO guideline value, and our findings contribute to this evidence gap. As other environmental exposures have been shown to affect cognitive ability and may play an important role in the association between drinking water fluoride and cognitive ability, such as lead and inorganic

arsenic concentrations in water ([80 to 83](#)), air pollution ([84 to 86](#)) noise and access to green space ([84](#)) we cannot rule out residual or unmeasured confounding from one or more of these other risk factors. A separate scientific manuscript focused on the cognitive ability analysis has been submitted to an academic journal, and more detail will be available in that paper.

Strengths and limitations

Strengths

The 2026 HMR is similar in overall approach to the 2014, 2018 and 2022 HMRs, and has several strengths which are:

- this series, publishing analyses at 4-year intervals, allows monitoring of the potential population health effects of fluoride over time, integrating new international evidence, updated data sources and improved analysis methods
- the health data used is selected to be representative of the wider English population, by either using surveys with representative designs or using routine data that captures all recorded hospital admissions within the study period, so that the evidence provided is generalisable and informative at the national level
- in this 2026 HMR, 3 measures of fluoride exposure are assessed (categories of drinking water fluoride concentration, a continuous measure of water fluoride concentration and whether an area has an operating fluoridation scheme), which supports an understanding of how associations with health outcomes change at different fluoride concentrations found in England, in addition to fulfilling the requirement to monitor the potential effects of water fluoridation schemes
- 3 dental health outcomes (dental caries experience, dental caries severity score categories and hospital admissions for caries-related tooth extractions) are analysed, which allows comparison of findings across data sources, age groups, and severity of health impact, and includes those with both treated and untreated dental caries. This allows consistency in effect to be assessed and strengthens the confidence in our findings on dental health outcomes
- a comprehensive range of non-dental health outcomes have been assessed across the HMRs, and some such as hip fractures have been consistently examined across the years, allowing continued monitoring
- this HMR also continues to assess if the relationship between health outcomes and fluoride exposure differs across deprivation levels, thus providing important evidence about the potential of water fluoridation as a public health intervention for reducing dental health inequalities, for which there is a gap in the wider public health literature ([16](#))
- over 85% of the English population is exposed to drinking water fluoride concentrations <0.40 mg/L and the evidence provided by this and previous HMRs contributes to an important gap in the wider public health and scientific literature on the effectiveness of drinking water fluoridation as a public health measure at concentrations well below the WHO guideline value (<1.5 mg/L)

There are several notable improvements in the latest 2026 report. A synthesis of conclusions from recent systematic and evidence reviews written by international authoritative organisations was conducted, to inform the justification for selection of the health outcomes included in the analyses. A cognitive ability outcome for children was included and assessed for the first time, responding to the need to assess the impact of drinking water fluoride concentration levels well below the WHO guideline value (<1.5 mg/L) on child neurodevelopment. The exposure measurement was improved in 2 key ways. Drinking water fluoride concentration exposures were assigned to smaller geographic area units, LSOAs (areas of 1,000 to 3,000 people) rather than MSOAs (5,000 to 15,000 people) which were used in previous HMRs, and therefore likely reduced the ecological misclassification of exposure. For selected health outcomes (hospital admissions for tooth extractions and hip fractures, and cognitive ability outcomes), fluoride exposure was assigned using methods that better reflected the exposure latency period and potential biological window of effect; previous reports had used average water fluoride concentrations across all available exposure years for all outcomes. Additional model testing and validation was also included in the statistical protocol for this HMR, to ensure estimation approaches to improve robustness.

Limitations

Despite the above strengths of this HMR, there are some notable limitations that should inform interpretation of our findings.

Exposure measurement

Although drinking water fluoride exposure data was available annually from 2011 to 2024, the residential addresses of the study populations were only available at the time of the health event or survey measurement. Exposure assignment was based on the residential address (at the LSOA level) at the time of the health event or survey, assuming that the assigned exposure was representative of individual exposure over a time period relevant to the health outcome. As our analysis does not account for residential mobility during the exposure period, this can potentially lead to misclassification of exposure in our study populations. In younger populations (of children) in our study, these exposure assignments were more likely to reflect their individual- or area-level exposure experience as the plausible biological windows of exposure were closer in time to the health event or measurement. For hip fractures, due to the wide age range, this was more difficult to assume, as the most recent 10-year exposure window may not reflect lifetime exposures and this may impact the interpretation of our findings. Individuals may also live in an area with a given drinking water fluoride concentration but work or attend school elsewhere with a different fluoride concentration and therefore have a different overall exposure. However, most of the population in England lives in areas with similar low exposure levels, with over 85% of the population exposed between 2017 and 2024 to concentrations below 0.40 mg/L ([Table 9](#)). There is also no reason that such exposure misclassification would be differential by outcome status and as such our estimates could be interpreted as conservative.

As this analysis assumes that the main source of fluoride is from mains drinking water, for those exposed to fluoride concentrations <0.30 mg/L, which represents a majority of the population, other sources such as dental care products and diet may be a larger contributor to total fluoride intake. While data on intake from other sources was not available, our analyses show that regardless of these factors, higher levels of fluoride in water continue to be associated with better dental health outcomes.

Selection bias

The oral health surveys required parental agreement for children to participate, and this has been shown to adversely affect participation rates. Among children from whom parental agreement for participation was sought, approximately 60% of children completed the survey in 2022 and 2024. There were also issues with wider areas of England not commissioning the survey at the local level; in both survey years 12% to 15% of upper tier local authorities (UTLAs) did not commission the survey and 34% to 46% of lower tier local authority areas (LTAs) did not achieve the minimum sample size and so were removed from the final survey sample. UTLAs not commissioning the survey were mostly in the South East and Yorkshire and the Humber. Despite this, the final sample remained largely representative of the English population of the same age in terms of deprivation levels and ethnicity. However, it remains possible that parental agreement to participate was lower for children with worse dental caries outcomes, leading to an underestimation of dental caries experience and severity. Further details on the extent of these issues and implications for potential bias are detailed in the NDEP oral health survey reports ([44 to 46](#)).

Routine data used for the tooth extractions outcome in this report can have some limitations related to completeness, accuracy and timeliness. There are also known procedural intricacies that mean that children admitted to hospital for tooth extractions may not be recorded in the HES APC dataset under certain referral pathways. However, there is no reason to expect the completeness of the data to be differential across fluoride exposure levels, so it is unlikely to impact results. Data on hip fracture admissions is expected to be relatively complete and timely as they are reliably diagnosed.

The first MCS survey sweep had an overall response rate of 68% ([87](#)). Of the eligible sample in sweep 3 and sweep 4, 98% and 99% provided partially or fully complete data for the child cognitive assessments ([88](#), [89](#)). Analyses in the MCS technical report suggest that families lost before fieldwork do not appear to contribute to a biased final study population as higher exclusion rates in disadvantaged areas were offset by higher opt-out rates in advantaged areas ([51](#)). The MCS provides survey weights ([51](#)) for each sweep that were applied to correct for differential attrition and maintain representativeness. With this correction, the MCS data likely provides a fair approximation of the English 5 and 7 year old population, although there will have been some secular changes in the characteristics of this age group in England since the outcome data was collected in 2006 to 2008.

Analyses using the fluoridation scheme exposure measure had a reduced analytical sample due to missing information related to existence of a fluoridation scheme at LSOA-level. Our definition of fluoridation scheme exposure was intentionally stringent and required LSOAs to have data in each year in the exposure window, which further limited the number of LSOAs with complete data. Because LSOAs with missing information may differ systematically from those with complete data, this may introduce selection bias, reduce generalisability and decrease statistical power for this part of the analysis.

Residual and unmeasured confounding

This report adjusted analyses for selected potential risk factors with available data that could also act as confounders in our study. Not all potential risk factors were included due to a lack of data and the level of information available for some risk factors may insufficiently capture their variability across population groups. This may result in unmeasured or residual confounding in this report. Population health risk factors do vary by socioeconomic and deprivation status, and those with poorer health typically also experience worse overall life conditions. By including a composite measure of deprivation (IMD) ([90](#)) in our analyses, we consider to have partially accounted for those other risk factors and residual or unmeasured confounding.

Multiple testing

In this report, we have investigated the associations between 3 fluoride exposure measures (continuous and categorical drinking water fluoride concentrations and presence of a fluoridation scheme) and 5 different health outcomes (dental caries experience, dental caries severity, caries-related tooth extraction, hip fractures and cognitive ability). In some analyses, we had also stratified the results due to expected modification of the effect of fluoride exposure on health outcomes. Therefore, multiple estimates with confidence intervals were reported in this HMR. We cannot exclude the possibility that some statistically important findings will have occurred by chance, and all estimates should be interpreted cautiously.

Conclusion

In line with previous HMRs, the findings of the 2026 HMR are consistent with the view that water fluoridation at levels within the regulatory limit for England (<1.5 mg/L) is a beneficial public health intervention for reducing dental caries in children, with no convincing evidence of harm to non-dental health. This report continues to find that the dental health benefits are largest in the more deprived areas, where baseline dental health and uptake of dental care tend to be poorer, and so water fluoridation makes an important contribution to reducing dental health inequalities. This report observed no evidence of an association with cognitive ability in children and no convincing evidence of an association with hip fractures.

Our findings are consistent with those from wider systematic reviews of international evidence for the effects of fluoride at concentrations below 1.5 mg/L. In practice, fluoride concentrations in fluoridated areas in England are well below the regulatory limit, averaging below 0.8 mg/L in all years since 2016.

This series monitors the potential population health effects of fluoride over time using data that is representative of the wider English population, such that the evidence provided is informative at the national level. This report contributes to an important gap in the wider public health and epidemiological literature assessing associations with selected non-dental health outcomes and inequalities in dental health at levels well below the WHO guideline value of 1.5 mg/L. Due to some of the limitations of this study, all findings should be interpreted with caution and in the context of the wider scientific evidence. This report provides epidemiological evidence that can inform an understanding of associations between drinking water fluoride exposure and our selected health outcomes. However, it cannot by itself determine whether these associations are causative, and a lack of observed associations does not definitively confirm the absence of a relationship.

The methods used in this report are not exactly the same as in previous reports in the HMR series, and as such findings from the 2022 and 2018 reports cannot be directly compared.

The Water Fluoridation Health Monitoring Working Group continues to keep the wider evidence under review and will publish a further report within the next 4 years.

References

1. Water Industry Act (c.56) 1991
2. '[Water Fluoridation: Health monitoring report for England 2014](#)' Public Health England 2014
3. '[Water fluoridation: Health monitoring report for England 2018](#)' Public Health England 2018
4. '[Water fluoridation: Health monitoring report for England 2022](#)' Office for Health Improvement and Disparities 2022
5. '[Evidence synthesis report on the optimal concentration of water fluoridation in the UK](#)' Academy of Medical Sciences 2025
6. Zohoori F, Maguire A. 'Database of the Fluoride (F) content of Selected Drinks and Food in the UK and Ireland' Teesside University and Newcastle University 2019
7. European Food Safety Authority (EFSA) Committee, Bennekou SH, Allende A and others. 'Updated consumer risk assessment of fluoride in food and drinking water including the contribution from other sources of oral exposure' EFSA Journal 2025: volume 23, issue 7, e9478
8. '[2022 National Water Fluoridation Statistics](#)' Centers for Disease Control and Prevention (viewed 14 October 2025)
9. '[Code of Practice on Technical Aspects of Fluoridation of Water Supplies 2021](#)' Drinking Water Inspectorate 2021
10. '[Fluoridation of Drinking Water](#)' Drinking Water Inspectorate 2023 (viewed 20 February 2026)
11. '[Guidelines for drinking-water quality: fourth edition incorporating the first and second addenda](#)' World Health Organization 2022
12. '[The Water Supply \(Water Quality\) Regulations \(2016 No. 614\)](#)' legislation.gov.uk 2016
13. 'Community Water Fluoridation Programs: A Health Technology Assessment – Review of Dental Caries and Other Health Outcomes' Canadian Agency for Drugs and Technologies in Health (CADTH) 2019
14. 'Community Water Fluoridation Exposure: A Review of Neurological and Cognitive Effects' Canadian Agency for Drugs and Technologies in Health (CADTH) 2019
15. 'Community Water Fluoridation Exposure: A Review of Neurological and Cognitive Effects – a 2020 update' Canadian Agency for Drugs and Technologies in Health (CADTH) 2020
16. Ihezor-Ejiofor Z, Walsh T, Lewis SR, and others. 'Water fluoridation for the prevention of dental caries' Cochrane Database of Systematic Reviews 2024: volume 10, issue 10, CD010856
17. Lambe K, Farragher A, Moloney T, Sunday S, Long J. 'Impact of community water fluoridation on systemic health excluding oral health: An evidence review' Dublin: Health Research Board 2022
18. Long J, Waldron C, Farragher A, and others. 'Effect of artificial community water fluoridation on dental health: An evidence review' Health Research Board 2025
19. 'Community Water Fluoridation: An evidence review' New Zealand Ministry of Health 2024

20. 'Information Paper – Water fluoridation: dental and other human health outcomes' Clinical Trials Centre at University of Sydney, National Health and Medical Research Council (NHMRC) 2017
21. 'NTP monograph on the state of the science concerning fluoride exposure and neurodevelopment and cognition: a systematic review' USA National Toxicology Program (NTP) 2024
22. 'Critical review of any new evidence on the hazard profile, health effects, and human exposure to fluoride and the fluoridating agents of drinking water' European Union Scientific Committee on Health and Environmental Risks (SCHER) 2010
23. Dean HT. 'Epidemiological Studies in the United States in Dental Caries and Fluorine' Science Press, American Association for the Advancement of Science 1946
24. 'Fluoride: Dose-Response Analysis For Non-cancer Effects' Health and Ecological Criteria Division, Office of Water, US Environmental Protection Agency (EPA) 2010
25. Dean HT. 'Fluorine and Dental Caries' American Journal of Orthodontics and Oral Surgery 1947: volume 33, issue 2, B49 to B67
26. '[Delivering better oral health: an evidence-based toolkit for prevention](#)' Department of Health and Social Care and NHS England 2014 (2025 update)
27. Bardsley A, Eason C, Elwood J, and others. 'Health effects of water fluoridation: A review of the scientific evidence' Office of the Prime Minister's Chief Science Advisor 2014
28. DenBesten PK. 'Biological mechanisms of dental fluorosis relevant to the use of fluoride supplements' Community Dentistry and Oral Epidemiology 1999: volume 27 issue 1, pages 41 to 47
29. Iheozor-Ejiofor Z, Worthington HV, Walsh T, and others. 'Water fluoridation for the prevention of dental caries' Cochrane Database of Systematic Reviews 2015: volume 2015, issue 6, CD01085
30. Dean HT. 'The investigation of physiological effects by the epidemiological method' Fluoride and Dental Health 1942: volume 19, pages 23 to 31
31. EFSA Nutrition, Novel Foods and Food Allergens (NDA) Panel. 'Opinion of the Scientific Panel on Dietetic Products, Nutrition and Allergies (NDA) on a request from the Commission related to the Tolerable Upper Intake Level of Fluoride' EFSA Journal 2005
32. National Academies of Sciences, Engineering, and Medicine. 'Fluoride in Drinking Water: A Scientific Review of EPA's Standards' National Academies Press 2006
33. Young N, Newton J, Morris J, and others. 'Community water fluoridation and health outcomes in England: a cross-sectional study' Community Dentistry and Oral Epidemiology 2015: volume 43, issue 6, pages 550 to 559
34. Oyagbemi AA, Omobowale TO, Asenuga ER, and others. 'Sodium fluoride induces hypertension and cardiac complications through generation of reactive oxygen species and activation of nuclear factor kappa beta' Environmental Toxicology 2017: volume 32, issue 4, pages 1,089 to 1,101
35. Sontia B, Touyz RM. 'Role of magnesium in hypertension' Archives of Biochemistry and Biophysics 2007: volume 458, issue 1, pages 33 to 39
36. Machoy-Mokrzynska A. 'Fluoride-magnesium interaction' Journal of the International Society for Fluoride Research 1995: volume 28, pages 175 to 177

37. Liteplo R, Gomes R, Howe P, and others. 'Fluorides' World Health Organization 2002
38. 'Evidence summary: Fluoride in our drinking water: An update on the evidence' Office of the Prime Minister's Chief Science Advisor in New Zealand (OPMCSA) 2021
39. Zohoori FV, Duckworth RM. 'Fluoride: Intake and Metabolism, Therapeutic and Toxicological Consequences' chapter 44 in Collins JF, ed. 'Molecular, Genetic, and Nutritional Aspects of Major and Trace Minerals' Academic Press 2017: pages 539 to 550
40. Iamandii I, De Pasquale L, Giannone ME, and others. 'Does fluoride exposure affect thyroid function? A systematic review and dose-response meta-analysis' Environmental Research 2024: volume 242 page 117,759
41. '[Inequalities in oral health in England](#)' Public Health England 2021
42. Pretty IA, Boothman N, Morris J, and others. 'Prevalence and severity of dental fluorosis in four English cities' Community Dental Health 2016: volume 33, issue 4, pages 292 to 296
43. '[Census 2021 geographies](#)' Office for National Statistics (ONS)
44. '[National Dental Epidemiology Programme \(NDEP\) for England: oral health survey of 5 year old children 2022](#)' Office for Health Improvement and Disparities 2023
45. '[National Dental Epidemiology Programme \(NDEP\) for England: oral health survey of 5 year old schoolchildren 2024](#)' Office for Health Improvement and Disparities 2025
46. '[National Dental Epidemiology Programme \(NDEP\) for England: oral health survey of children in year 6, 2023](#)' Office for Health Improvement and Disparities 2024
47. '[Oral health survey of 5 year old schoolchildren, 2023 to 2024: national protocol](#)' Office for Health Improvement and Disparities 2023
48. '[National Dental Epidemiology Programme: Oral health survey of 5-year-old children 2021 to 2022: national protocol](#)' Public Health England 2021
49. '[National Dental Epidemiology Programme: Oral health survey of children in year 6, 2022 to 2023: national protocol](#)' Office for Health Improvement and Disparities 2022.
50. '[Short statistical commentary for hospital tooth extractions in 0 to 19 year olds 2024](#)' Office for Health Improvement and Disparities 2025 (viewed on 11 February 2026)
51. Plewis I, Calderwood L, Hawkes D, Gareth H, Joshi H. 'The Millennium Cohort Study: Technical Report on Sampling' Centre for Longitudinal Studies, University of London 2007
52. Connelly R. 'Millennium Cohort Study Data Note 2013 or 1: Interpreting Test Scores' Centre for Longitudinal Studies, University of London 2013
53. Rasch G. 'Studies in mathematical psychology: I. Probabilistic models for some intelligence and attainment tests' 1960
54. Rasch G. 'On general laws and the meaning of measurement in psychology' in 'Fourth Berkeley symposium on mathematical statistics and probability 1961' Neyman J, editor 1961: pages 321 to 333
55. Roberts DJ, Morris J, Wood A, Verlander NQ, Leonardi GS, Fletcher T. 'Use of public water supply fluoride concentration as an indicator of population exposure to fluoride in England 1995 to 2015' Environmental Monitoring and Assessment 2020: volume 192, issue 8, page 514
56. ArcGIS Desktop, release 10.5.1. Redlands, CA: Environmental Systems Research Institute (ESRI) 2017

57. ['Public Health Service Recommendation for Fluoride Concentration in Drinking Water for Prevention of Dental Caries'](#) 80 FR 24936. Department Health and Human Services. Federal Register, 1 May 2015: pages 24,936 to 24,947
58. Cho HJ, Jin BH, Park DY, and others. 'Systemic effect of water fluoridation on dental caries prevalence' Community Dentistry and Oral Epidemiology 2014: volume 42, issue 4, pages 341 to 348
59. Groeneveld A, Van Eck AA, Backer Dirks O. 'Fluoride in caries prevention: is the effect pre- or post-eruptive?' Journal of Dental Research 1990: volume 69, special number 751 to 755, discussion pages 820 to 823
60. Singh KA, Spencer AJ. 'Relative effects of pre- and post-eruption water fluoride on caries experience by surface type of permanent first molars' Community Dentistry and Oral Epidemiology 2004: volume 32, issue 6, pages 435 to 446
61. Peckham S, Lowery D, Spencer S. 'Are fluoride levels in drinking water associated with hypothyroidism prevalence in England? A large observational study of GP practice data and fluoride levels in drinking water' Journal of Epidemiology and Community Health 2015: volume 69, issue 7, pages 619 to 624
62. ['Toxicological Profile for Fluorides, Hydrogen Fluoride, and Fluorine'](#) US Agency for Toxic Substances and Disease Registry 2003
63. Shimonovitz S, Patz D, Ever-Hadani P, and others. 'Umbilical cord fluoride serum levels may not reflect fetal fluoride status' Journal of Perinatal Medicine 1995: volume 23, issue 4, pages 279 to 282
64. National Research Council and the Institute of Medicine Committee on Integrating the Science of Early Childhood Development. 'From Neurons to Neighborhoods: The Science of Early Childhood Development' in 'The Developing Brain' National Academic Press 2000
65. ['Deprivation and the impact on smoking prevalence, England and Wales: 2017 to 2021'](#) Office for National Statistics 2023
66. ['National Diet and Nutrition Survey 2019 to 2023'](#) Office for Health Improvement and Disparities 2025
67. ['Child Dental Health Survey 2013, England, Wales and Northern Ireland'](#) Health and Social Care Information Centre, National Health Service 2015
68. ['Health Survey for England 2019: Adults' health-related behaviours'](#) NHS Digital, Office for National Statistics 2020.
69. Brennan SL, Pasco JA, Urquhart DM, Oldenburg B, Wang Y, Wluka AE. 'Association between socioeconomic status and bone mineral density in adults: a systematic review' Osteoporosis International 2011: volume 22, issue 2, pages 517 to 527
70. Mahmud M, Muscatello DJ, Rahman MB, Osborne NJ. 'Association between socioeconomic deprivation and bone health status in the UK biobank cohort participants' Osteoporosis International 2024: volume 35, issue 9, pages 1,573 to 1,584
71. Marks R. 'Hip fracture epidemiological trends, outcomes, and risk factors, 1970-2009' International Journal of General Medicine 2009
72. Team RC. 'R: A Language and Environment for Statistical Computing' R Foundation for Statistical Computing 2024
73. SAS Institute Inc. SAS software 2017

74. StataCorp. Stata Statistical Software. StataCorp LLC 2023
75. Centre for Longitudinal Studies. 'Millenium Cohort Study: A Guide to the Datasets (Eighth Edition), First, Second, Third, Fourth and Fifth Surveys' University of London, Institute of Education 2014
76. 'Tooth eruption – The permanent teeth' Journal of the American Dental Association 2006: volume 137, issue 1, page 127
77. Kanis JA, Johansson H, Harvey NC, and others. 'An assessment of intervention thresholds for very high fracture risk applied to the NOGG guidelines: A report for the National Osteoporosis Guideline Group (NOGG)' Osteoporosis International 2021: volume 32, issue 10, pages 1,951 to 1,960
78. Mazzoli R, Filippini T, Iamandii I, and others. 'The association of fluoride exposure with bone density and fracture risk: a dose-response meta-analysis' Global Environmental Health 2025: volume 24, issue 1
79. Bhimjiyani A, Neuburger J, Jones T, Ben-Shlomo Y, Gregson CL. 'Inequalities in hip fracture incidence are greatest in the North of England: regional analysis of the effects of social deprivation on hip fracture incidence across England' Public Health 2018: volume 162, pages 25 to 31
80. Kampouri M, Zander E, Gustin K, and others. 'Associations of gestational and childhood exposure to lead, cadmium, and fluoride with cognitive abilities, behavior, and social communication at 4 years of age: NICE birth cohort study' Environmental Research 2024: volume 263
81. Saeed M, Rehman MYA, Farooqi A, Malik RN. 'Arsenic and fluoride co-exposure through drinking water and their impacts on intelligence and oxidative stress among rural school-aged children of Lahore and Kasur districts, Pakistan' Environmental Geochemistry and Health 2022: volume 44, issue 11, pages 3,929 to 3,951
82. Crabbe H, Fletcher T, Close R, and others. 'Hazard Ranking Method for Populations Exposed to Arsenic in Private Water Supplies: Relation to Bedrock Geology' International Journal of Environmental Research and Public Health 2017: issue 14, issue 12
83. Hayes CR, Hydes OD. 'UK experience in the monitoring and control of lead in drinking water' Journal of Water and Health 2012: volume 10, issue 3, pages 337 to 348
84. Garkov S, Dearden L, Armstrong B, Milojevic A. 'The Relationship between PM, Greenness, and Road Noise Exposures and Children's Cognitive Performance in England: The Millennium Cohort Study' Environments 2024: volume 11, issue 10
85. Milojevic A, Dutey-Magni P, Dearden L, Wilkinson P. 'Lifelong exposure to air pollution and cognitive development in young children: the UK Millennium Cohort Study' Environmental Research Letters 2021: volume 16, issue 5
86. Midouhas E, Kokosi T, Flouri E. 'The quality of air outside and inside the home: associations with emotional and behavioural problem scores in early childhood' BMC Public Health 2019: volume 19
87. 'Millenium Cohort Study: User Guide (Surveys 1 to 5)' University College London, Institute for Education 2020
88. Gray JC, Gatenby R, Simmonds N. 'Millennium Cohort Study Sweep 3: Technical Report' National Centre for Social Research 2009

89. Gray JC, Gatenby R, Simmonds N, Huang Y. 'Millennium Cohort Study Sweep 4: Technical Report' National Centre for Social Research 2010
90. '[English indices of deprivation 2019](#)' Ministry of Housing Communities and Local Government 2019

About the UK Health Security Agency

UKHSA is responsible for protecting every member of every community from the impact of infectious diseases, chemical, biological, radiological and nuclear incidents and other health threats. We provide intellectual, scientific and operational leadership at national and local level, as well as on the global stage, to make the nation health secure.

[UKHSA](#) is an executive agency, sponsored by the [Department of Health and Social Care](#).

© Crown copyright 2026

Published: March 2026

Publishing reference: GOV-20385



You may re-use this information (excluding logos) free of charge in any format or medium, under the terms of the Open Government Licence v3.0. To view this licence, visit [OGL](#). Where we have identified any third party copyright information you will need to obtain permission from the copyright holders concerned.



UKHSA supports the
Sustainable Development Goals

