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The health equity implications of the Health (Fluoridation of Drinking Water) Amendment Act 2021 for access to (and performance of) community water fluoridation in New Zealand

Tim Chambers, Jonathan Broadbent, Mario Puente-Sierra, Samuel Carrington, Matthew Hobbs

Abstract

Background: New Zealand (NZ) is currently expanding community water fluoridation (CWF) through the implementation of the Health (Fluoridation of Drinking Water) Amendment Act 2021. The aim of this study was to assess access to and performance of CWF in NZ and the health equity potential of the Health (Fluoridation of Drinking Water) Amendment Act 2021.

Methods: We conducted a longitudinal audit of CWF schemes using 66,700 weekly fluoride testing results from 111 water distribution zones (WDZ).

Results: We estimated that 50.7% of the NZ population had access to CWF, including 44.2% of the Māori population and 52.0% of the non-Māori population. People living in areas of highest deprivation had greater access (53.6%) than those living in areas with the least deprivation (49.4%). Water suppliers met the optimal fluoride level only 60.7% of the time during the observation period. We estimated that the first tranche of directives to councils to fluoridate would reduce inequity in access to CWF for Māori by 75%, while there would be an even greater proportion of people living in areas of high deprivation with access.

Conclusion: The Health (Fluoridation of Drinking Water) Amendment Act is pro-equity and will facilitate greater access and potential performance of CWF in NZ.

Introduction

Community water fluoridation (CWF) is a population-level public health intervention that improves oral health and reduces health inequities (Office of the Prime Minister's Chief Science Advisor, 2021). At concentrations of 0.7 to 1.0 parts per million (ppm), fluoride in drinking water helps prevent dental caries (tooth decay) by reducing demineralization of the tooth surface and reducing the acid tolerance of oral bacteria (World Health Organization, 2019).

Aotearoa New Zealand (NZ) is in the process of expanding CWF through the implementation of the Health (Fluoridation of Drinking Water) Amendment Act 2021, referred to from here on as "the Act" . The Act gives New Zealand's Director General of Health the power to direct a territorial authority (TA) to fluoridate particular water supplies (Health (Fluoridation of Drinking Water) Amendment Act, 2021). In NZ, 67 TAs are responsible for providing drinking water to about 85% of the total population (Puente-Sierra *et al*., 2023). Currently, 27 out of 67 TAs fluoridate drinking water in at least one water distribution zone (WDZ) in their jurisdiction. This serves approximately 2.5 million people, approximately 50% of the population (Cabinet Social Policy Committee, 2016). On 27 July 2022, 14 TAs were instructed to prepare to fluoridate water in one or more WDZ (Kelly, 2022). This decision would leave 26 TAs without a fluoridated supply in NZ. Despite this, a 2023 High Court decision has recently found that the Director General of Health made a procedural error when issuing the instructions by not making a specific consideration of rights under the New Zealand Bill of Rights Act 1990 in each order (High Court of New Zealand, 2023). Thus, the 2023 High Court decision has brought into question the validity of the instructions given to the 14 TAs to fluoridate water in WDZs. As a result, the fluoridation process may be halted or revisited, potentially affecting the fluoridated water supply in those areas.

Until recently, there has been limited available NZ evidence on differential access to and performance of CWF schemes (Tirtawijaya *et al*., 2017; Chambers *et al*., 2022). Estimates of access to CWF have been based on rough population estimates provided by TAs and do not allow for disaggregation by sociodemographic characteristics such as ethnicity or deprivation. In, 2023, we compiled the first national geospatial dataset of WDZ that were spatially linked with Census information, providing population estimates for each WDZ by ethnicity and area-level deprivation (Puente-Sierra *et al*., 2023). In 2022, an analysis of NZ CWF schemes using recently obtained data from 1992 to 2022 across fluoridating TAs found that they have consistently fallen short of the target amount of fluoride, meeting oral health targets only 54% of the time (Chambers *et al*., 2022). This is much lower than in other jurisdictions (i.e. United States > 80%, England > 90% (Nyakutsikwa *et al*., 2022b; Boehmer *et al*., 2023). However, that analyses did not link WDZ to population statistics, and so it could not assess the differential performance of WDZ by sociodemographic characteristics. It was also missing data from some TAs.

Prior to the implementation of the Act, there were no regulatory requirements for TAs to meet fluoride levels required for oral health benefit. The only regulatory requirement for TAs was that they did not breach the

maximum acceptable value (MAV) of 1.5 ppm as part of the drinking water standards to prevent dental fluorosis (New Zealand Parliament, 2022b). The 2022 paper mentioned above observed 10,201 weeks out of 22,220 weeks (45.9%) of non-compliance with the optimal range.

Under the Act, violations under section 116L include *"failing to take all practicable steps to ensure that the specified level of fluoride is present",* which is punishable by fines up to $200,000 and $10,000 per day if the offence continues (Health (Fluoridation of Drinking Water) Amendment Act, 2021). However, the Government inquiry into the Havelock North waterborne outbreak that sparked a suite of water reforms in NZ recommended that future legislation not use the term *"all practical steps"* because it makes *"compliance discretionary in many cases"* and justifies a cautious approach to enforcement (Department of Internal Affairs, 2017). This sentiment was reinforced by technical advisory committee of the new water services regulator Taumata Arowai (Taumata Arowai Quality Assurance Panel, 2021). Thus, it is unclear how *"all practical steps"* will be interpreted under the legislation and how the this will be interpreted in the context of the CWF directives.

Oral conditions are a global public health challenge, with dental caries being the most widespread non-communicable disease worldwide (Peres *et al*., 2019). In 2019, 41% of 5-year-old children in NZ had evidence of dental caries, making it the most prevalent chronic health condition in children (Cure Kids, 2022). Dental caries experience has a strong social gradient, making poor oral health a major contributor to health inequities (Peres *et al*., 2019). Currently, Māori have higher rates of caries-affected teeth during childhood and almost 50% higher hospitalisation rates due to dental issues during childhood than non-Māori (Cure Kids, 2022). Children living in areas of high deprivation also experience greater untreated caries and missing teeth, and these conditions have sustained impacts on their quality of life (Ministry of Health, 2010).

Inequity in dental caries, avoidable dental-related hospitalisations (Hobbs *et al*., 2020), potentially inequitable access to and performance of CWF as well as inequity in health and access to health services are not consistent with NZ's foundational document, Te Tiriti o Waitangi (the Māori and authoritative version under the international legal doctrine of *contra proferentem*). CWF has proven an effective public health tool for reducing oral health inequities between Māori and non-Māori (Office of the Prime Minister's Chief Science Advisor, 2021). However, based on previous evidence of ethnic inequities in access to quality drinking water (Department of Internal Affairs, 2022), it is possible that these inequities extend to the access to and performance of CWF.

The economic impact of poor oral health in NZ is uncertain, but it is estimated that between NZD$1 and 1.5 billion is spent on dental care annually, with around NZD$200 million being spent on public dental care (Coughlan, 2020). One NZ study estimated that the national net savings from universal CWF of WDZ serving more than 500 people over 20 years would be NZD$1.4 billion (Moore *et al*., 2017). A 2015 costing for extending CWF to non-fluoridated WDZ in NZ was estimated at NZD$144 million over a 20-year period, with a net saving of NZD$600 million (Moore and Poynton, 2015). Considering this previous evidence, this study aimed to:

1) assess access to CWF in NZ before and after the implementation of the Health (Fluoridation of Drinking Water) Amendment Act 2021 by ethnicity and deprivation;
2) identify WDZ without CWF with the highest equity potential for future consideration by the Director General of Health; and
3) assess inequities in performance of CWF over time by ethnicity and deprivation.

Methods

Study design

Longitudinal audit of drinking water quality data from TAs with CWF.

Water distribution zones (WDZ) data

A water system in NZ is comprised of sources (i.e. the abstracted source water either from surface, rain or ground waters), treatment plants (i.e. the facilities where water is treated before entering the distribution zone) and the WDZ (i.e. the reticulated network providing water to customers).

In 2023, the authors compiled the first national geospatial dataset of WDZ in NZ, which was spatially linked with Census information to calculate population totals for each WDZ for the overall, Māori, non-Māori, low, moderate and high area-level deprivation (now publicly accessible; Puente-Sierra *et al*., 2023). In total, our dataset contained 636 WDZ, serving a total of 4,132,700 people (~87.6% of the estimated 2018 population). A score on the 2018 New Zealand Deprivation Index (NZDep) of 1-3 was defined as low deprivation, 4-7 moderate and 8-10 high (Atkinson *et al*., 2019).

Fluoride data

Fluoride is added to the water at the treatment plant. If fluoride is added, a TA must test the water from each treatment plant weekly at an accredited laboratory to ensure that it complies with the drinking water standards (less than 1.5 ppm), however, there is no monitoring regime to ensure fluoride levels are within the optimal range for oral health (0.7 to 1.0 ppm; Taumata Arowai, 2022). Fluoride testing data from TAs were not collated centrally by the Ministry of Health or Taumata Arowai, so testing data were compiled and maintained to varying extents across the TAs. Between 2021 and 2022, we sent multiple official information requests (OIA) to all TAs for all water quality data for as far back as records permitted. We obtained 31,000 weekly observations at the treatment plant-level.

To convert treatment plant-level measurements to WDZ-level measurements, we took two approaches. For simple WDZ, characterised by having only one treatment plant (n = 80), we took the treatment plant measurement as the WDZ fluoride level. For the 31 complex WDZ, characterised by having two or more treatment plants, we took the average of all the treatment plant values for each week. We also calculated the difference between the minimum and maximum treatment plant fluoride levels to assess the potential impact of aggregating values. In total, 90% of the weekly observations had a within-week

difference between treatment plants of < 0.1 ppm, while 5% of observations had > 0.2 ppm (see Supplementary Figure 1 for the distribution of this variation).

Our final CWF dataset includes 66,700 weekly laboratory accredited observations from 111 WDZ. The number of weekly observations is greater at the WDZ-level because the same treatment plants serve multiple WDZ in complex systems. The data we obtained spanned from 1992 to 2022 but over 80% of the observations are from 2010 onwards (see Supplementary Figure 2 for data availability for each WDZ). In NZ, non-fluoridated water supplies almost universally have naturally low levels of fluoride (< 0.1 ppm; Choi *et al*., 2012).

For the purposes of this study, we classified WDZ that had permanently stopped CWF during the observation period as non-fluoridated. For example, fluoride data was available for Hastings, New Plymouth and Ruapehu TAs but each TA had ceased CWF so their data was excluded.

Defining access to community water fluoridation

To assess access to CWF, we assigned a CWF status to each WDZ based on their CWF status as of 2022 and their expected future CWF status as of 2025 as a result of the Act. The 2025 fluoridated supplies included all 2022 WDZ as well as the 39 WDZ from the 14 TA receiving a fluoridation directive (see Supplementary Table 1 for full details). We summed the population from WDZ to estimate access in 2022 and 2025 for the total population. To highlight non-fluoridated supplies with the greatest health equity potential, we identified those WDZ that had a Māori population that was proportionately higher than the overall Māori population (16.7%) among WDZ with a population > 5000 people.

Performance of community water fluoridation

We defined compliant observations as those in the optimal range (0.7 to 1.0 ppm) for oral health benefit. All other values were defined as non-compliant. To assess overall performance of WDZ, we converted all weekly observations into person-weeks by multiplying the fluoride value for each observation week by the population served. For example, if the population served for a WDZ was 35,000 and the fluoride level for observation week 1 Jan 2017 was 0.7 ppm, this would contribute 35,000 person-weeks at 0.7 ppm. We divided all person-weeks by 52 to generate person-years for reporting purposes.

To assess ten-year trends in performance (2012-2021), we calculated a yearly compliance percentage for each WDZ, which was the number of compliant observation weeks divided by the total number of observation weeks for each year. We excluded years for WDZ that had fewer than 12 observations (e.g. fewer than one per month).

Ethics approval and funding

Ethical approval was granted by the University of Otago Human Ethics Committee (Health) (reference HD22/115). Māori consultation was undertaken with the Ngāi Tahu Research Consultation Committee (reference 23679_20221114). This work was supported by a 2023 Ministry of Health Oral Health Research Fund Project Grant.

Statistical analyses

Descriptive statistics for access and performance analyses were calculated in R. We conducted a sensitivity analysis for performance by removing all observations that had a difference of > 0.1 ppm between treatment plants within the same WDZ. To estimate the equality gap in access and performance by ethnicity and deprivation, we multiplied the total 2018 Māori population and people living in high neighbourhood deprivation by the proportion of non-Māori and people living in low deprivation, respectively. This measure provides an estimate of the additional people required to get equal service provision. The equality gap is reported as a negative number when those groups with poorer oral health receive worse service provision (e.g. Māori and people living in high deprivation) and as a positive number when these groups receive greater service provision. To assess ten-year temporal trends in compliance percentage, we conducted a simple linear regression on each WDZ to examine the impact of year (independent variable) on WDZ compliance percentage (dependent variable) in R.

Results

Access to community water fluoridation

Table 1 provides our estimates of access to CWF in 2022 and in 2025 after the expected implementation of CWF directives. In 2022, an estimated 50.7% (n = 2,381,000/4,699,000) of the 2018 population was estimated to have access to CWF. Proportionally fewer Māori (44.2%, n = 348,000/786,000) than non-Māori (52.0%, n = 2,033,000/3,913,000) had access to CWF. This equality gap was -7.7% in 2022, and the number of additional Māori needing access to CWF to achieve equal access as non-Māori was 61,000. We estimated that this equality gap would decrease to -1.6% in 2025, following implementation of the expected CWF directives. In contrast, those people living in high area-level deprivation had greater access to CWF (53.6%, n = 790,000/1,475,000) than people living in the least deprivation (49.4%, n = 671,00/1,359,000). Further, this gap is expected to increase from 119,000 in 2022 to 158,000 people in 2025.

Supplementary Table 2 provides the same access analysis but used the population served by WDZs owned by each TA as the denominator, rather than the total TA population (including those using a private supply). Using this denominator, ~71% of the total eligible population will have access to CWF after 2025. The equality gap between Māori and non-Māori is reduced by ~50%.

Gap analysis

After the implementation of the CWF directives, there will still be 43 WDZ that serve over 5,000 people that will not be fluoridated in 2025. Together, these WDZ serve 817,000 people including 117,000 Māori (14%) and 243,000 people in high deprivation areas (29%). Māori are under-represented proportional to their population contribution in the remaining WDZ because they are over-represented in private supplies and smaller public supplies (which are not eligible for CWF). Consequently, if all 43 non-fluoridated supplies for communities of over 5,000 people became

Table 1. Access to CWF in 2022 and in 2025 (after implementation of CWF directives) by ethnicity and neighbourhood deprivation.

	Fluoridated in 2022		Fluoridated in 2025	
Sociodemographic characteristics	Population*	% of total population	Population*	% of total population
Total	2,381,000	50.7%	2,934,000	62.4%
Ethnicity				
Māori	348,000	44.2%	478,000	60.8%
Non-Māori	2,033,000	52.0%	2,456,000	62.8%
Equality gap	-61,000	-7.7%	-16,000	-1.9%
Area-level deprivation				
Low	671,000	49.4%	789,000	58.1%
Moderate	920,000	49.3%	1,129,000	60.6%
High	790,000	53.6%	1,016,000	68.8%
Equality gap	119,000	4.2%	158,000	10.8%

Rounded to the nearest 1000; Totals using the 2018 census population for total = 4,699,000; Māori = 786,000; non-Māori = 3,913,000; low deprivation = 1,359,000; moderate deprivation = 1,864,000; high deprivation = 1,475,000

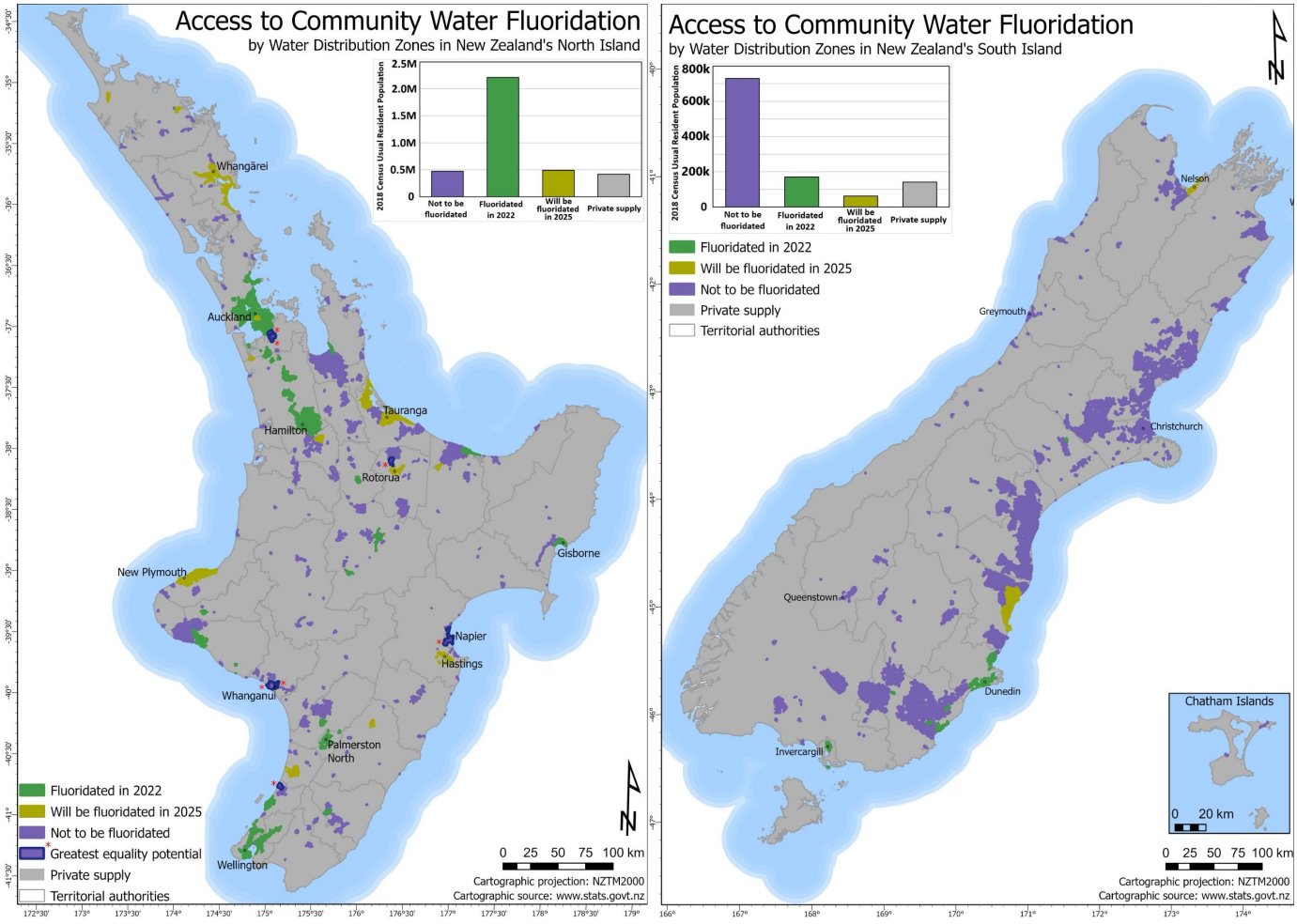

Figure 1. Location of 2022 fluoridated WDZ, 2025 fluoridated WDZ and non-fluoridated WDZ with the greatest equity potential (left = North Island, right = South Island).

fluoridated, the equality gap between Māori and non-Māori would double from 15,700 to 34,700 people.

Of the remaining 43 non-fluoridated WDZ serving over 5,000 people, 16 have a Māori population that is disproportionately higher than their overall population. CWF of these supplies would result in more Māori than non-Māori gaining access to CWF. Each one of the 16 non-CWF WDZ that would increase Māori representation would also increase access for people living in high deprivation. Figure 1 shows the WDZ that were fluoridated in 2022, will be fluoridated in 2025 and those WDZ with the greatest equity potential. Supplementary Table 3 shows the location and equity potential of these 16 pro-equity non-CWF supplies. The extension of CWF within Auckland, Kāpiti Coast, and Rotorua as well as the introduction of CWF in Napier and Whanganui would eliminate the remaining equality gap between Māori and non-Māori.

Performance

Overall performance

Figure 2 provides an overview of the density of person-years spent at each fluoride level on fluoridated supplies. A large number were outside the optimal levels for oral health, with the vast majority being below the optimal range and very few being above it.

Table 2 demonstrates that 60.7% of all person-years of observation were spent at the optimal fluoride levels, 37.5% were below the optimal range, 1.2% were above the optimal range, and 0.6% were above the MAV. Overall performance was better for non-Māori (61.4%) than Māori (56.5%). An additional 201,000 person-years at the optimal range would have been required to provide Māori with the same level of performance as non-Māori. People living in areas with the least deprivation also received proportionally more person-years at the optimal levels (61.5%) than people

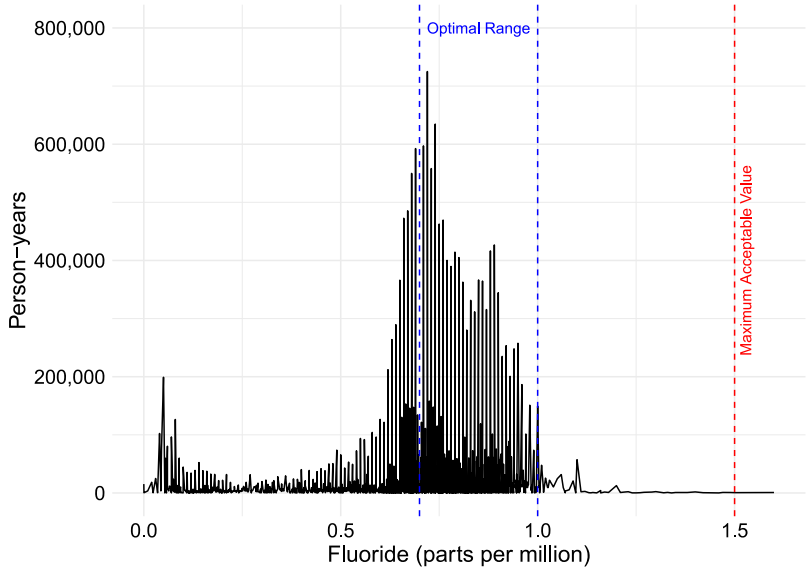

Figure 2. Person-years at each level of fluoride (parts per million).

Table 2. Person-years at optimal (0.7-1.0 ppm), below optimal (< 0.7 ppm), above optimal (1.0-1.49 ppm) and above MAV (≥1.5 ppm), by ethnicity and deprivation.

	Total**	Optimal (0.7-1.0 ppm)		Below optimal (< 0.7 ppm)		Above optimal (1.0-1.49 ppm)		Above MAV* (≥1.5 ppm)	
	Person-years	person-years	%	person-years	%	person-years	%	person-years	%
Total	28,703,000	17,418,000	60.7	10,771,000	37.5	339,000	1.2	175,000	0.6
Ethnicity									
Māori	4,101,000	2,316,000	56.5	1,720,000	41.9	44,000	1.1	21,000	0.5
Non-Māori	24,602,000	15,102,000	61.4	9,051,000	36.8	295,000	1.2	154,000	0.6
Equality gap		-201,000	-4.9						
Deprivation									
Low	8,257,000	5,078,000	61.5	3,014,000	36.5	105,000	1.3	61,000	0.7
Moderate	11,182,000	6,805,000	60.9	4,165,000	37.2	141,000	1.3	71,000	0.6
High	9,264,000	5,535,000	59.8	3,592,000	38.8	93,000	1.0	43,000	0.5
Equality gap		-160,000	-1.7						

*In total 23 weekly observations breached the MAV. Only once were there consecutive weeks of MAV exceedances (n = 3 weeks in a row)

** All person-years rounded to nearest 1,000

in the highest deprivation areas (59.8%). An additional 160,000 person-years at optimal levels would be required for people living in high deprivation to get equal service to those living in the least deprivation. Supplementary Table 4 shows the results of a sensitivity analysis that removes all weekly observations with a within-week difference between treatment plants within a WDZ of > 0.1. It shows a slightly higher overall compliance percentage (62%), because weeks with higher variation are more likely to be non-compliant.

Ten-year trends in fluoride compliance levels

Figure 3 shows the ten-year trends in compliance percentage with WDZ with no statistically significant trend (Blue, n = 15), statistically significant improvements (Green, n = 25) and statistically significant worse performance (n = 71). The figure shows a range of starting points that within each trend status. For example, of those WDZ statistically improving over time (green lines), the starting point for compliance for many of those supplies was very low (e.g. below 25% of weekly observations meeting the optimal fluoride range), while for many of the WDZ getting worse over time (red lines) the starting compliance percentage was much higher (e.g. above 75% of weekly observations meeting optimal fluoride range. The results from each linear regression model are reported in Supplementary Table 5.

Table 3 reports the populations served by different WDZ according to their temporal trends in compliance percentage. Māori were over-represented in WDZ that had no temporal trend or were improving, while non-Māori were over-represented in WDZ that were worsening. Likewise, people living in areas of high deprivation were over-represented on WDZ that have no trend or are getting better, while people living in areas of low deprivation were over-represented on supplies that are getting worse.

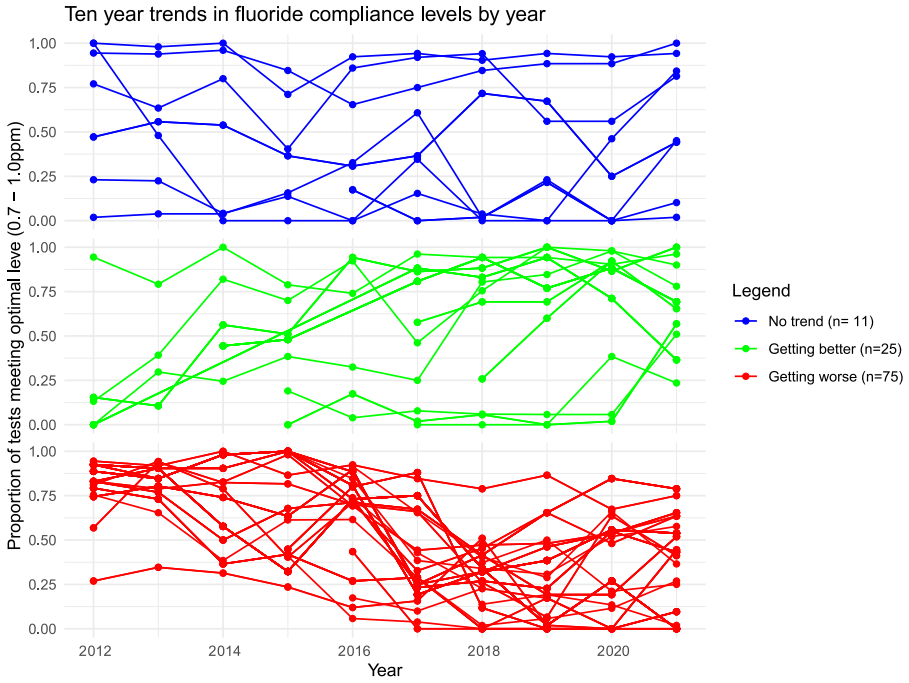

Figure 3. Ten-year trends in fluoride compliance across all 111 community water fluoridation schemes.

Table 3. Populations served by water distribution zones with different temporal trends in compliance percentage, by ethnicity and deprivation.

Population	Total	No trend		Getting better		Getting worse	
	n	n	%	n	%	n	%
Water distribution zones	111	11	9.9%	25	22.5%	75	67.6%
Overall population	2,381,000	140,000	5.9%	397,000	16.7%	1,844,000	77.4%
Ethnicity							
Māori	348,000	33,000	9.5%	81,000	23.3%	234,000	67.2%
Non-Māori	2,033,000	107,000	5.3%	316,000	15.5%	1,610,000	79.2%
Deprivation							
Low	671,000	19,000	2.8%	95,000	14.2%	557,000	83.0%
Moderate	920,000	51,000	5.5%	134,000	14.6%	735,000	79.9%
High	790,000	70,000	8.9%	168,000	21.3%	552,000	69.9%

Discussion

Our study revealed three key findings. First, our findings indicated inequitable access for Māori populations to CWF, with the estimated number of additional Māori needing access to CWF to get equal access as non-Māori currently at 61,000. Second, CWF performance (also known as compliance) in NZ has been poor (60% of person-years) by international standards (Nyakutsikwa *et al*., 2022b; Boehmer *et al*., 2023). Third, performance has been worse in areas with a higher proportion of Māori and/or highly deprived populations in NZ. These findings of poor compliance could, in part, contribute to health system costs and are a hindrance to efforts to close the oral health equity gap for Māori and deprived populations in NZ.

We found important inequities in access to CWF in NZ. For instance, in 2022, an estimated 61,000 additional Māori would need access to CWF to get the same access as non-Māori (around a seven-percentage point difference between groups). This is consistent with indigenous communities in Australia, who experience substantial inequities in access to CWF (> 20 percentage point difference; Senevirathna *et al*., 2023). Substantial inequities in dental caries experience exist between Māori and non-Māori (Cure Kids, 2022), and efforts to address those are likely to have been impeded by inequities in access to CWF. In contrast to the inequity access experienced by Māori, those people living in high area-level deprivation had greater access to CWF (53.6%) than people living in areas with the least deprivation (49.4%). The pro-equity findings by deprivation were consistent with findings from England (Nyakutsikwa *et al*., 2022a) but contrasted with those from Australia, where people living in areas with the greatest deprivation had the least access to CWF (Sexton *et al*., 2023).

Water suppliers' ability to meet optimal fluoride levels (e.g. performance) across the study period was substantially worse than international comparators (e.g. United States > 80%, England > 90%; Nyakutsikwa *et al*., 2022b; Boehmer *et al*., 2023). Only 60.7% of all person-years of observation were at the optimal level. This is slightly higher than the 54% compliance metric previously reported in NZ which was based on weekly tests rather than person-years (population weighted; Chambers *et al*., 2022). Māori received poorer service provision than non-Māori, with a 4.9 percentage point difference in the percentage of weeks meeting the optimal fluoride level. An extra 201,000 more person-years would have been required to achieve equal service provision. That people living in areas with the highest deprivation received poorer performance from their CWF (59.8%) than people in the least deprivation (61.5%) has implications for oral health inequities.

The Health (Fluoridation of Drinking Water) Amendment Act 2021 has the potential to address some of the issues with inequitable access to and performance of CWF in NZ. Overall, access to CWF would increase from 50.7% to 62.4% after the implementation of the first tranche of CWF orders. For Māori, the Act would reduce the equality gap by 75% (from 61,000 to 16,000 person-years). Further, we identified 16 WDZ that could be prioritised to eliminate and reverse the remaining equality gap. The Act would also disproportionately benefit those living in areas of the highest deprivation, and this would build on the existing health equity potential of the existing CWF access in NZ. There is also potential for the Act to improve performance of water CWF schemes via penalties (up to $200,000) for failing to meet the optimal fluoride levels. While multiple reports have identified weaknesses of the phrasing *"all practical steps"* in previous legislation for enforcement (Department of Internal Affairs, 2017; Taumata Arowai Quality Assurance Panel, 2021), it is possible that the threat of penalties alone may improve CWF performance. Previously, there were no regulatory requirements for water suppliers to achieve the optimal fluoride level but there were regulatory requirements to stay below the MAV (1.5 ppm fluoride), and this may have led to an organisational culture prone to under-dosing.

Our study findings should be considered in light of several strengths and limitations. The current study is the first comprehensive national assessment of CWF access and performance in NZ. It was also strengthened by the use of quantifiable water testing data measured by ppm, spatial information on the extent of WDZ and linked to administrative data. As a result, we were able to assess inequities in access to and performance of CWF by ethnicity and deprivation. The study also had a number of weaknesses. First, the spatial extent of our WDZ was based on an 2022 estimate, which is likely to be larger than WDZ from earlier in the observation period (i.e. because most towns/cities get larger over time). Consequently, we may be overestimating the number of person-years under observation in earlier years of the study. Second, we used population estimates from the 2018 population, and those are very likely to be underestimated for 2019-2022 and to overestimate the years prior to 2017; however, we believe that these are robust enough for the purpose of this study. Third, for complex WDZ (i.e. more than one treatment plant per zone), we could not generate a weighted fluoride measurement that accounted for the different volumes of water provided by each treatment plant. It would be preferable to know how much water comes from each treatment plant, but this information was not available. Fourth, our analysis relied on the WDZ dataset which has a number of its own limitations including: (1) the lack of a robust ground truth; (2) arbitrarily splitting spatial files into multiple WDZs; and (3) WDZs containing large numbers of private supplies in rural areas (the full list of considerations is documented in Puente-Sierra *et al*. (2023)).

We have identified several priority areas for future research. First, there needs to be a robust framework for ongoing monitoring of the implementation of the Health (Fluoridation of Drinking Water) Amendment Act 2021 and monitoring of broader compliance. Such a monitoring system would enable water suppliers to be held to account but also facilitate the opportunity to assess the effectiveness of the fluoride directives. Second, evidence on the dose-response relationship between fluoride and prevention of dental caries used to inform the current guideline values for CWF (e.g., 0.7 to 1 ppm) is primarily based on data from the 1930s (Dean *et al*. 1941; Dean *et al*. 1942). As recently as 2017, the Australian Department of Health and the NZ Ministry of Health reviewed the available evidence to set reference values for fluoride and

concluded "no alternative data were identified that could be substituted for Dean's data from the 1930s for critical fluoride concentrations in relation to the prevention of dental caries"(Janis *et al*., 2017, p.3). Importantly, there is no contemporary evidence on the shape of the dose-response relationship in populations with widespread adoption of fluoride toothpaste or substantially higher sugar consumption than in the 1930s. Our fluoride dataset could address this literature gap if paired with robust oral health data in a robust epidemiological study design.

Poor compliance has resulted in inequity in access to CWF, yet this issue has only recently come to light. From a public health policy standpoint, other obstacles to health equity, particularly oral healthcare, garner more attention. These issues include the cost of dental services, lack of health insurance, transportation issues, culture, and workforce shortages. CWF primarily addresses the results of poor dietary habits—dental caries—and so it is important to emphasise the ongoing need for initiatives to enhance the food environment. CWF alone cannot eradicate dental caries, although it shifts the distribution of caries experience among children and adults and increases the proportion of children who are caries-free. Despite the success of CWF and other interventions, there remains a substantial portion of children with dental caries, and some of those require extensive treatment. Vigilance, comprehensive data collection, and diverse health promotion strategies are essential.

The inequitable access to CWF presents a significant challenge for Māori, directly conflicting with the principles set forth in Te Tiriti o Waitangi. Access to fluoridated water is not solely a matter of public health but a crucial element of social justice and equity. Denying certain communities, particularly Māori, access to fluoridated water perpetuates existing disparities in oral health outcomes, amplifying the disproportionate burden of dental ill-health borne by indigenous populations worldwide. Te Tiriti o Waitangi emphasises the importance of tino rangatiratanga, active protection, and equity in achieving positive health outcomes. Accordingly, addressing the lack of access to fluoridated water in communities with significant Māori populations is not only a public health policy imperative but also a moral obligation grounded in the principles of equity and outcomes outlined in Whakamaua–Māori Health Action Plan 2020-2025 (Ministry of Health 2020) and Pae Ora (Healthy Futures) Act 2022 (New Zealand Parliament, 2022a).

Finally, it is important to acknowledge the need for community engagement as a basis for CWF programmes. Implementation of the directive issued by New Zealand's Director General of Health under the CWF Act is currently on hold, due to a procedural issue in that implications of the Bill of Rights Act should have been explicitly mentioned in each directive issued to each locality. This highlights further the need to understand and engage with each community.

Conclusions

Our findings suggest that the Health (Fluoridation of Drinking Water) Amendment Act 2021 will reduce inequities in access to CWF. However, if issues around performance are not addressed, increased access will not translate to improved outcomes. A centralised monitoring system with penalties for non-compliance with the optimal fluoride levels could assist in ensuring compliance.

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Conflict of interest

The authors declare no conflicts of interest.

Author contributions

Conception or design of the work: TC, MH, JMB, SC
Data collection: TC
Data analysis: TC, MH, MPS
Data interpretation: all authors
Drafting the article: TC
Dritical revision of the article: All authors
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Author details

Tim Chambers PhD
Ngāi Tahu Research Centre, University of Canterbury | Te Whare Wānanga o Waitaha, Christchurch | Otautahi, New Zealand | Aotearoa.
*Corresponding author: tim.chambers@canterbury.ac.nz

Jonathan Broadbent BDS PGDipComDent PhD
Sir John Walsh Research Institute and Department of Oral Sciences Faculty of Dentistry | Te Kaupeka Pūniho, University of Otago | Ōtākou Whakaihu Waka, Dunedin | Ōtepoti, New Zealand | Aotearoa.

Mario Puente-Sierra BSc MSc
GeoHealth Laboratory | Te Taiwhenua o te Hauora University of Canterbury | Te Whare Wānanga o Waitaha, Christchurch | Ōtautahi, New Zealand | Aotearoa.

Samuel Carrington BOH DPH MPH CertHSc
Sir John Walsh Research Institute and Department of Oral Sciences Faculty of Dentistry | Te Kaupeka Pūniho, University of Otago | Ōtākou Whakaihu Waka, Dunedin | Ōtepoti, New Zealand | Aotearoa.

Matthew Hobbs BA(Hons) MSc PhD
GeoHealth Laboratory | Te Taiwhenua o te Hauora and Faculty of Health | Te Kaupeka Oranga, University of Canterbury | Te Whare Wānanga o Waitaha, Christchurch | Ōtautahi, New Zealand | Aotearoa.