Evaluation of the impact of national oral health improvement programmes of Chile on the oral health of the child population

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Abstract

Background: Dental caries is reportedly the most prevalent disease worldwide and represents a significant challenge for public health, especially in childhood, with 7.8% of children suffering from untreated caries in their primary teeth worldwide. The Chilean Government is making efforts to gradually improve oral health across the population, with the incorporation of new public health programmes that aim to improve oral health and reduce oral health inequalities, including a community water fluoridation programme; oral health preventive interventions in primary care public clinics, and "Sembrando Sonrisas", a daily supervised toothbrushing and fluoride varnish application programme in state-funded nurseries based on the "Childsmile" national child oral health improvement programme for Scotland. In Chile, there are few published studies that determine the burden of caries in children, and thus far, there has been no formal evaluation of the impact of the national oral health improvement programmes for Chile on child caries outcomes.

Aim: The overarching aim of this thesis was to undertake a quantitative outcome evaluation of the national oral health improvement programmes for Chile on oral health outcomes and related inequalities in children. This overarching aim was met by fulfilling the following objectives: (1) To collect, collate and manage data from the national oral health programmes, along with data on child dental caries and sociodemographic characteristics at the national, regional, and municipality level in Chile; and to assess quality and completeness across datasets; (2) To design and develop an area-based ecological longitudinal cohort to assess the trends in dental caries of six-years-old children in Chile at the national, regional, and municipality levels, and to analyse related area-based socioeconomic inequalities and the impact of the sociodemographic characteristics of the municipalities on child caries levels; (3) To assess the impact of the national oral health programmes, including: community fluoridated water, the preventive interventions delivered in primary care public clinics on the caries levels of six-year-old children in the Chilean public health system at the municipality level, and related inequalities; and (4) To evaluate the impact of the Sembrando Sonrisas programme interventions on dental caries outcomes of five-year-old children covered by the programme since its establishment and rollout, and to assess the programme effect over and above community water fluoridation on child dental caries and related inequalities.

Methods: National information governance approvals were obtained to access, collect and collate aggregated municipality level data (n=346 municipalities) for each year (2008 to 2019) from datasets on child dental caries outcomes; the national oral health improvement programmes (community water fluoridation; preventive interventions delivered in primary care public clinics; Sembrando Sonrisas); area-based socioeconomic deprivation (Socioeconomic Development Index; Multidimensional Poverty Index) and rurality (Rurality Proportion Index; Rurality Level Index) data indexes. Data quality and completeness checks were performed to assemble the ecological cohort.

A novel ecological longitudinal cohort was assembled using the "municipality/years" unit of analysis, along with the design of a continuous variable for the evaluation of child caries outcomes: "Caries Experience", measured as the presence of decay (into dentine), missing (extracted) due to decay, or filled primary teeth, in six-year-old children living in Chile who attend primary care public clinics. Univariate and multivariate weighted linear regression models assessed the trends and the effect of socioeconomic deprivation and rurality on caries experience. The most parsimonious model to evaluate the impact of the national oral health improvement programmes was selected with a forward selection model including significant potential confounders of caries experience. Socioeconomic inequalities in the distribution of caries experience by deprivation category were assessed by summary inequality measures. A detailed description of caries experience and related sociodemographic characteristics was performed at the national, regional, and municipality levels.

Univariate and multivariate weighted linear regression models assessed the independent potential effect of the national oral health improvement programmes interventions on caries experience, including community water fluoridation coverage and annual fluoride concentration, along with the oral health preventive interventions performed in the primary care public clinics: individual toothbrushing advice to parents; application of sealants on primary teeth; and fluoride varnish applications. Potential inequalities in the delivery of the programmes interventions where evaluated via weighted linear regression models.

To assess the impact of Sembrando Sonrisas interventions on caries outcomes of children covered by the programme another, further, separate area-based longitudinal cohort was assembled by merging the data of the two birth cohorts that had being exposed to the Sembrando Sonrisas interventions since its establishment and rollout in 2015. An outcome variable was used, “Sembrando caries experience” in five-year-old children covered by the programme in 2018 and 2019 and examined in the nurseries covered by the programme. Univariate and multivariate weighted linear regression models assessed the independent potential effect of the Sembrando Sonrisas interventions on “Sembrando caries experience”, including the delivery of oral health kits for supervised daily toothbrushing in nurseries (including four toothbrushes and one toothpaste with 1000 ppm of fluoride annually per child) and the application of fluoride varnish in nurseries. Also, multivariate weighted linear regression models assessed the potential impact of those interventions over and above community water fluoridation. Finally, weighted linear regression models evaluated potential inequalities in the delivery of Sembrando Sonrisas interventions.

Results: A novel ecological longitudinal cohort was built including dental examination municipality-level data recorded in the primary care public clinics on 1,397,377 six-year-old children available from 3608 municipality/years. Caries experience significantly reduced from 83% in 2008 to 66% in 2019. Those areas with 90% or greater water fluoridation coverage and fluoride concentrations of 0.6 mg/L or higher demonstrated between 7% to 15% lower caries experience than those not exposed to community water fluoridation. A socioeconomic gradient was observed with those municipality from the most socioeconomic deprived category of the Socioeconomic Development Index bearing a 15% higher dental caries burden, while also having a 50% lower water fluoridation coverage when compared to those from the least socioeconomic deprived category of the Socioeconomic Development Index.

For the preventive interventions performed at primary care public clinics, a higher rate of these interventions prior to age six was associated with a significantly higher caries experience. Also, a higher rate of these interventions was observed in the most socioeconomic deprived municipalities, in comparison with the least deprived communities.

Dental examination municipality-level data recorded in the nurseries covered by the Sembrando Sonrisas programme on 309,360 five-year-old children were available from 637 municipality/years. The delivery of oral health kits for the daily supervised toothbrushing in nurseries to all children participating in the programme was associated with a 5% decrease in caries experience in comparison to those municipality where this was not achieved, even after adjusting for deprivation and the exposure to fluoridated water. The application of fluoride varnish in nurseries covered by the programme was not a significant explanatory variable on the differences in caries experience at the municipality level. Five-year-olds from municipalities with community water fluoridation and where all children received the oral health kits for daily supervised toothbrushing in nurseries showed a caries experience of 52%. In contrast, those from municipalities unexposed to CWF and where not all children received the kits showed a significantly higher caries experience of 65%.

Conclusions: A continuing and significant decrease in the caries experience of six-year-old children at the national and municipality level was observed between 2008 and 2019 in Chile. These improvements were shown to be associated with community water fluoridation coverage and annual fluoride concentration. However, by the end of the study period, the high childhood caries levels and inequalities observed remain a public health challenge in Chile.

Significant inequalities were identified in the national delivery of community water fluoridation, with the least socioeconomic deprived municipalities having lower annual fluoride concentrations. However, for community water fluoridation coverage —the variable with the higher significant explanatory power in the model, a social gradient was observed, with the most socioeconomic deprived municipalities having significantly lower coverage than the least deprived municipalities.

A positive association between caries experience and the preventive interventions delivered in primary care clinics was identified. Some explanations for this observation can be that the variables used in this thesis only accounted for the number of interventions delivered at the population level, without considering the variability of individual contexts and even the possible unintended consequences that can occur as a result of intervening. Most importantly, the circumstances in which children were likely to receive these interventions were probably related to going to the dentist for pain or the need for restorative treatment, causing these interventions to be performed more frequently in children with caries experience.

The caries experience of five-year-olds covered by the Sembrando Sonrisas programme since its establishment and rollout was significantly lower in municipalities where all children received oral health kits for daily supervised toothbrushing in nurseries before the age of five years, even after adjusting for deprivation and over and above the presence of the community water fluoridation programme. The lowest caries experience in five-year-olds was observed in those municipalities that were exposed to both programmes.

These findings call for continued action at national and municipality level to improve child oral health and to address associated inequalities, including the optimisation of community water fluoridation delivery and the Sembrando Sonrisas programme. In addition, further upstream (policy) and midstream (community-level) interventions delivered via a proportionate universal approach need to be considered.

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Author's declaration

Parts of this thesis have been presented in international and national conferences and submitted to peer-review journals.

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I declare that the thesis is my own composition and has not been submitted in part or whole for any other degree.

Andrés Osvaldo Celis Sersen

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Abbreviations

Adj. R^2: Adjusted R-Squared

AIC: Akaike Information Criterion

AAPD: American Academy of Paediatric Dentistry

BASCD: British Association for the Study of Community Dentistry

CASEN: National Socioeconomic Characterization Survey of Chile

CCT: Controlled Clinical Trial

CERO: Dental Assessment with Risk Approach Programme

CESFAM: Family and Community Health Centres of the Chilean Public Health System

COH: Community Oral Health Section of the University of Glasgow

Cp: Mallow's Cp

CWF: Community water fluoridation

DEIS: Department of Health Statistics and Information of Chile

ECC: Early Childhood Caries

FV: Fluoride Varnish

FONASA: National Health Fund of the Chilean Public Health System

GDP: Gross Domestic Product

GES: Explicit Guarantee in Health of Chile

IDSE: Socioeconomic Development Index

INE: National Institute of Statistics of Chile

JUNJI: National Nurseries Board of Chile

MINSAL: Ministry of Health of Chile

MRC: Medical Research Council

NHS: National Health Service, United Kingdom

OECD: Organization for Economic Co-operation and Development

OHPA: Activities and Interventions of the Oral Health Programmes of the Public Health System of Chile

RCT: Randomized Controlled Trial

REM: Monthly Statistical Registry in Health of the Primary Health Services

SEGPRES: General Secretariat of the Presidency of the Government of Chile

SEREMI: Regional Health Services of the Public Health System of Chile

SES: Socio Economic Status

SISS: Superintendence of Sanitary Services of the Ministry of Public Infrastructure of Chile

SQL: Structured Query Language

SSB: Sugar sweetened beverages

UK: United Kingdom

WHO: World Health Organization

CHAPTER 1: INTRODUCTION

Chapter 1 outlines the public health challenge of dental caries and describes oral health trends worldwide and within the context of Chile. The aetiology of dental caries in infants and young children is described, and the impact of the disease considered. Measures to prevent caries are explored, particularly concerning community approaches. In doing so, this chapter provides a background to the development of the oral health programmes in Chile.

This chapter introduces a description of the national oral health programmes of Chile, including community water fluoridation, oral health interventions performed in the primary care public clinics and the 'Sembrando Sonrisas' programme, which were funded and developed in response to the growing public health concern of childhood dental caries. An overview of the components of each programme is provided. The chapter also covers the programme that served as a reference for the creation of the Sembrando Sonrisas programme, the national oral health child programme for Scotland 'Childsmile'. Finally, the gaps in knowledge in relation to the evaluation of the national oral health improvement programmes in Chile and in relation to the international evidence base for such population-based interventions are set out as the rationale for this thesis research.

1.1 Literature review and search strategy

The following chapter provides a narrative review of the literature dedicated to dental caries and the interventions to prevent this disease in the child population.

Electronic literature database searches were performed to identify relevant articles. Firstly, the Medline PubMed database was used to gather articles with no specific filters or year limits on the main topics of interest using terms including: "dental caries", "early childhood caries", "diet", "oral health promotion", "oral health intervention", "oral health programme", "water fluoridation", "fluoride varnish", "education setting", "oral health promotion", “high-caries-risk children”, “Chile”, “health system”, “evaluation framework”, “oral health programme evaluation”, “logic model”, “ecological study”, “natural experiment”. Abstracts of articles determined to be of interest by their title were screened, and if deemed to be of interest, the full article was obtained via the University of Glasgow library. Reference lists in included articles were examined to identify any other resources. In addition, Scielo and Google Scholar were also used to search for relevant literature. Other grey literature and Chilean government reports were located and obtained electronically via organisation websites searched via Google.

1.2 Definition of dental caries

Dental caries is defined as a biofilm-mediated, diet modulated, multifactorial, non-communicable, dynamic disease resulting in net mineral loss of dental hard tissues (Fejerskov, 2004; Pitts *et al.*, 2017). It is determined by biological, behavioural, psychosocial, and environmental factors. Dental caries is the leading cause of tooth loss at all ages (Kidd and Fejerskov, 2013; Manji *et al.*, 2018).

The net mineral loss of dental hard tissues results from an ecological imbalance in the physiological equilibrium between the hard tissues of the tooth and the endogenous biofilm metabolism, due to a drop in pH caused by acid products of the bacterial fermentation of sugar in the diet. When dietary sugars are supplied, cariogenic bacteria initiate efficient acid production, resulting in the demineralization of tooth surfaces. The tooth surfaces are subsequently remineralized, mainly by salivary washing, acid neutralization, and the supply of fluoride, calcium and phosphate ions (Takahashi, 2015). When this imbalance leads to a progressive and localized demineralization of the tooth structure, it causes a detectable net loss of mineral known as a caries lesion (MacHiulskiene *et al.*, 2020).

More recently, there has been a recognition of the social determinants of oral health as proposed models of dental caries (Watt, 2012), which brings social factors more into focus. These factor include poverty, socioeconomic deprivation and social status, the number of years in education and dental insurance coverage, being from an ethnic minority groups; individuals with developmental disabilities and recent immigrants groups (Watt, 2012; Steele *et al.*, 2015; Singh *et al.*, 2019). Therefore, dental caries disproportionally affect impoverished and socially disadvantaged members of society (Peres *et al.*, 2019).

Moreover, the explicit role of sugars in dental caries is being more clearly articulated. Since the 1980s, global production of sucrose (derived from sugar beet and sugar cane), the most readily available sweetener, has been steadily increasing (Kearney, 2010). As a result, dental caries is rising in many low and medium income countries at the same time as reported significant increases in sugar consumption, including sugary drinks (Peres *et al.*, 2019).

1.2.1 Caries lesions

Caries lesions are the clinical sign of the dental caries process, and its evolution is determined by the dynamic balance between protective factors, which lead to remineralization, and pathological factors, which lead to demineralization (Featherstone, 2004). In this way, lesions can progress or not, and this progression can be controlled or stopped (Kidd and Fejerskov, 2013). Caries lesion development is therefore a highly dynamic series of processes with alternating periods of progress and arrest/regression (Takahashi and Nyvad, 2008). Caries lesions can be categorized according to their anatomical location on the tooth (coronal or root/cementum surface), their severity (e.g., non-cavitated, cavitated), depth of penetration into the tissue (e.g., enamel, dentin, pulp), and their activity status (active, inactive).

Caries lesions can manifest initially as white spot lesions, which are small losses of mineral in the sub-surface of the enamel that produces optical changes, these being reversible. If the oral conditions do not improve, the lesion progresses to irreversible caries, to finally reach the destruction and loss of the affected tooth (Chou *et al.*, 2014; Manji *et al.*, 2018).

Hence, the clinical stages of caries can represent signs of past caries experience. What may be perceived clinically as an ‘incipient' or ‘early' lesion may turn out to be an ‘aged' established lesion that has been present in the oral cavity for months or years. Likewise, caries lesions may have experienced significant differences in their history in the oral cavity (Takahashi and Nyvad, 2008). Because of the continuously metabolically active biofilm, it has been suggested that these processes cannot be totally prevented, but can be controlled to the extent that caries lesions do not appear clinically (Takahashi and Nyvad, 2008; Kidd, 2012).

1.2.2 Dental caries in children

Dental caries within pre-school children is considered a distinct condition defined as 'early childhood caries'. Early childhood caries is the early onset of caries in young children with often fast progression, which can finally result in complete destruction of the primary dentition (MacHiulskiene *et al.*, 2020). An epidemiological definition of early childhood caries is the presence of one or more decayed (non-cavitated or cavitated lesions), missing (due to caries), or filled surfaces in any primary tooth of a child under the age of six. With frequent consumption of carbohydrates, especially sugars, and inadequate to absent oral hygiene in small children, early childhood caries demonstrates an atypical pattern of caries attack, particularly on smooth surfaces of upper anterior teeth (Pitts *et al.*, 2017; MacHiulskiene *et al.*, 2020).

Severe early childhood caries is defined (MacHiulskiene *et al.*, 2020) by any sign of smooth-surface caries in a child younger than three years of age, and for children from three to five years old, one or more cavitated, missing (due to caries), or filled smooth surfaces in primary maxillary anterior teeth or a decayed, missing, or filled score of greater than or equal to four (age three), greater than or equal to five (age four), or higher than or equal to six (age five).

1.2.3 Dental caries implications in infants and young children

Oral health habits should be established as early in childhood as possible, to prevent dental caries (Mejàre *et al.*, 2015; Tinanoff *et al.*, 2019). There is an association between child and adult oral health, whereby those who have good oral health in childhood tend to have good oral health in the future (Nunn, 2006). Therefore, ECC represents a substantial risk indicator for the development of caries lesions in the permanent dentition (Leong *et al.*, 2013).

In addition to the potential long-term dental benefits, good oral health in childhood is essential for the health and development of the child generally. As with other aspects of health, oral health can impact upon social and psychological wellbeing (Exley, 2009; Sheiham and James, 2015).

More precisely, ECC has been proposed to have implications for the growth and development of children, and negatively impacts their quality of life (Sheiham, 2006). Its consequences include pain and infection, hospitalisations and visits to emergency rooms, increase in the cost and time of treatment, delay or insufficient physical development, sleep disturbances, and decrease in weight gain (malnutrition) (Leong *et al.*, 2013; AAPD, 2014; Chou *et al.*, 2014).

A systematic and meta-analysis by Rebelo *et al.* (2019), including 18 studies of moderate quality, reported that children with caries experience had a significantly higher risk of poor school performance and attendance than caries-free children associations with school attendance and attainment.

Additionally, procedures such as performing restorations or extractions of affected teeth can be traumatic experiences for infants and can sometimes lead to severe complications (Chou *et al.*, 2014).

Furthermore, Exley (2009), in a narrative review of the sociology of oral health, highlights the consequences of dental disease, suggesting that obvious missing or affected teeth may negatively mark a child as poor. This may result in socially limiting judgements being made against them, impacting upon their life chances (Gregory *et al.*, 2005).

1.3 Epidemiology of dental caries

1.3.1 Epidemiological assessment of dental caries

Dental caries epidemiological surveys may be carried out for various reasons, such as monitoring trends in oral health and disease, policy development, evaluation of dental health programmes and assessment of dental needs (Assaf *et al.*, 2006). Therefore, it is critical to have suitable methods to deliver trustworthy dental epidemiological surveys and conduct well-designed studies (Agbaje *et al.*, 2012).

Different organisations have created standardised criteria for measuring dental caries in populations, mostly based on visual inspection. Dental epidemiology surveys conducted by the National Health Service (NHS) have ensured that the UK has one of the most highly regarded caries surveillance programmes for children. These surveys in the United Kingdom employ a well-documented visual examination method developed by the British Association for the Study of Community Dentistry (BASCD) for evaluating oral health and treatment requirements in population groups (Pitts *et al.*, 1997). The BASCD defines the primary measurement of dental caries as decay into the dentine. These dentinal caries lesions are identified using visual clinical inspection, and are performed with the naked eye under standard lighting, without the use of a dental probe, compressed air, transillumination, or radiography (Ismail, 2004).

The visually 'obvious' caries experience in the permanent dentition is measured by the DMFT index, including decayed teeth ('D'), plus missing ('M') teeth (as a result of an extraction due to caries) and filled ('F') teeth (World Health Organization, 2018c). The same index is used, but with lower case characters (dmft), to refer to obvious caries experience in the primary dentition (World Health Organisation, 2018c).

The World Health Organisation (WHO) has published recommendations for pathfinder oral health surveys, which produce basic but useful data using simple methodologies for countries to conduct standardized surveys that may be used for international comparison (World Health Organization, 2018d). WHO's current methods to assess the burden of disease are based on the dmft and DMFT indexes, which seek to measure the occurrence of decayed, filled or lost by decay teeth (World Health Organization, 2018d).

The International Caries Detection and Assessment System (ICDAS) is the most recently established method, allowing for disease recording at various levels, with a focus on providing appropriate information for diagnosis, prognosis and clinical management at both the individual and public health levels (Pitts and Ekstrand, 2013).

1.3.1 Burden and trends of dental caries worldwide

Dental caries is one of the most prevalent diseases worldwide and represents a significant challenge for public health, especially in childhood (Çolak *et al.*, 2013). Dental caries is a disease that is present in all populations, and its distribution and severity vary significantly within and among populations in the world (Fejerskov, 2004; Petersen and Kwan, 2011). Worldwide, oral diseases accounted in 2015 for US$ 357 billion in direct costs and US$ 188 billion in indirect costs. In the same year, €90 billion was spent on the treatment of oral diseases across the European Union, the third-highest total among noncommunicable diseases, just behind diabetes and cardiovascular diseases (World Health Organisation, 2020).

The World Health Organisation has estimated that between 60% and 90% of children present carious lesions with obvious cavitation (World Health Organisation, 2012). The latest *Global Burden of Disease Study* estimated that oral diseases affected between 3.2 to 3.7 billion people worldwide, with caries of the permanent teeth being the most prevalent of all conditions assessed. Globally, approximately 2.3 billion people suffer from caries of permanent teeth, and 532 million children suffer from caries of primary teeth. The prevalence of untreated caries in primary teeth was 7.8% (Bernabe *et al.*, 2020).

A recent systematic review by Uribe *et al.* (2021), including 64 studies published between 1992 and 2019, reporting the early childhood caries prevalence in 67 countries, showed that early childhood caries affects 48% of preschool children, and its distribution is global, with geographical variations. Africa had a lower prevalence than the global pooled prevalence, whereas Asia, Oceania, and North and Central America had a prevalence above the global estimate. Europe and America were within the global estimate.

1.4 Oral health inequalities

Health inequalities are differences in people's health experience, status or outcomes. Such differences in health are not considered to be random or unavoidable but instead are associated with inequalities. Health inequalities are considered to be avoidable because they arise from the social and political environment (Marmot et al., 2012; Watt, 2012). These inequalities are mainly related to socioeconomic factors, but also other sociodemographic factors such as race or ethnicity, sex, and geographical area (Conway *et al.*, 2019).

A report published in the UK by Marmot (2010), sought to outline the social determinants of health and explain health inequalities. The main themes of the report were the dramatic association between socioeconomic status (SES) and health outcomes. Marmot and colleagues demonstrated this by plotting life expectancy and disability-free life expectancy against deprivation (based on neighbourhood level income). The average difference in disability-free life expectancy between the highest and lowest deprivation deciles was found to be 17 years. Life expectancy has increased on average over time, but the gap between that of the richest and the poorest has also increased.

While there are a variety of measures for collecting data on socioeconomic status (arguably all are proxy measures for a complex multifaceted concept), the Marmot Report outlines that inequalities in health exist and are consistent along every one of these measures (Marmot, 2010). In relation to oral and dental health, a review carried out by Watt (2007) points to a substantial body of dental scientific literature that demonstrates that those of lower socioeconomic status have worse levels of oral and dental health compared to those from higher socioeconomic groups across an increasing gradient. Importantly, Watt argues, as Marmot does, that it is inequality itself over and above absolute levels of income and wealth that influence health. Watt also refers to Sweden as a country where there is less inequality in terms of socioeconomic status and also, consequently, in terms of health outcomes, including oral health (Watt, 2007).

A broader picture emerges in understanding oral health as a consequence of more comprehensive social and economic processes. The determinants of oral health are multi-level, from the upstream level of economic, health and social care policies, infrastructure, and environment, to the more local level of community and social factors and services, down to family dynamics and individual level attitudes, beliefs, and behaviours. These levels are conceptualized as upstream to downstream in terms of both determinants but also as levels of action/intervention (Watt and Sheiham, 2012).

Clinical interventions are considered downstream, focusing on individuals, with community-level interventions in the middle and large-scale national policy interventions such as water fluoridation and taxation on sugar upstream. Upstream interventions have a greater potential to have a broad reach and a population-level impact (Watt, 2012).

The relationship between dental caries and socioeconomic status is found in a stepwise graded fashion and is disproportionately higher among those experiencing socioeconomic deprivation (Watt, 2012). A systematic review on the association between socioeconomic position and dental caries conducted by Schwendicke *et al*. (2015) included 329,798 individuals from 155 studies, concluding that those with low own or parental educational or occupational background or income had a higher risk of having caries lesions or caries experience. Also, a lower socioeconomic position was significantly associated with any untreated caries lesions or any caries experience and the findings suggested that this association might be stronger in developed countries.

Children from parents with low socioeconomic status are less likely to be able to engage in oral health behaviours that help to prevent dental caries and maintain oral health (Leroy, 2013), and are four times more likely to have decay than children with parents in the highest income groups (Petersen, 2014).

1.5 Aetiology of dental caries in children

Dental caries aetiology has been described in-depth by Selwitz *et al*. (2007) and Fontana *et al*. (2010). These narrative reviews show the key factors involved in this complex disease process including sugar consumption, fluoride concentrations present in the oral cavity, aspects on saliva and highly complex environmental influences that can be summarized in behavioural and socioeconomic factors.

As described earlier, the traditional biomedical aetiological models describe dental caries as a dynamic process that results from an ecological imbalance in the physiological equilibrium between the hard tissues of the tooth and the endogenous biofilm metabolism due to a drop in pH caused by acid products of the bacterial fermentation of sugar in the diet. However, as stated previously, recent evidence increases the focus on more current and relevant social determinants of oral and dental health.

Although the aetiology of dental caries in the primary dentition, in general, is similar to the permanent teeth, it can be modified by risk factors related exclusively to infants. For this reason and due to its multifactorial aetiology, there are multiple risk factors, both of the parents and the child, which are associated with early childhood caries. Early childhood caries has been described by numerous terms and attributed to many aetiologies over the years, like “Baby Bottle Syndrome”, “Nursing Caries”, or “Baby Bottle Tooth Decay”, highlighting the traditional biomedical focus on the aetiology of the disease to inappropriate feeding with a baby bottle (Tinanoff *et al*., 2019).

A narrative review by Tinanoff *et al*. (2019) summarised the consensus of the International Association of Paediatric Dentistry regarding the aetiology of early childhood caries, defining three groups of risk and protective factors for dental caries in preschool children: (1) Social/behavioural risk factors, including parents socioeconomic status and low health literacy; frequent exposure to sugar-containing snack or beverages between meals; bottle feeding containing natural or added sugar and breastfeeding beyond 12 months, especially if frequent/nocturnal; mother or caregiver with active dental caries; and children with special healthcare needs; (2) Clinical risk factors, including children caries history; enamel defects; and visible plaque on teeth; and (3) Protective factors, including fluoridated drinking water exposure; toothbrushing with fluoridated toothpaste twice-a-day; professional topical fluoride applications; and access to dental services (Tinanoff *et al.*, 2019).

Kirthiga *et al.* (2019) conducted a systematic review and meta-analysis on early childhood caries risk factors, including 89 studies that evaluated 1,352,097 individuals, identifying 123 risk factors and organising them into six main groups: sociodemographic; dietary; breastfeeding/bottle feeding; oral hygiene; oral microbiota; and 'other' factors.

1.5.1 Biological risk factors

1.5.1.1 Factors related to the oral microbiota

Early acquisition of pathogens and bacterial colonization could be a key risk indicator for the development of dental caries (Selwitz *et al.*, 2007; Parisotto *et al.*, 2010; AAPD, 2014). Although there is substantial evidence that *Streptococcus mutans* are associated with a high caries risk, recent studies based on DNA from caries lesions reveal that other species emerge as significant players in the microbial community, mainly *Lactobacillus* and *Bifidobacteria* (Simón-Soro and Mira, 2015; Takahashi, 2015). Also, high levels of cariogenic bacterial colonization and high levels of oral bacteria in the mother can be related to a higher risk of dental caries in preschool children (Çolak *et al.*, 2013; Chou *et al.*, 2014).

1.5.1.2 Diet and sugar consumption

Sugars play a pivotal role in the development of dental caries (Filho *et al.*, 2021). The development of dental caries is strongly influenced by the consumption of free sugars, which include sugars that are naturally present in honey, syrups, fruit juices, and fruit juice concentrates as well as sugars that are added to foods and drinks (Moores *et al.*, 2022). The age at which sugar is introduced to a child and the frequency of sugar consumption are crucial factors in early childhood caries dietary patterns (Tinanoff *et al.*, 2019).

A systematic review conducted by Burt and Pai (2001) looked at 36 studies published between 1980 and 2000 and found a consistent association between dental caries and higher sugar intakes. Of the 36 identified studies, two indicated a strong association, 16 a moderate association and eight, a weak or no association.

A systematic map of systematic reviews conducted by Harris *et al.* (2004) investigated risk factors associated with the development of dental caries in children aged up to six years and found a significant association between dietary sugar intake and the development of dental caries in young children. However, it was found that in studies conducted in developed countries, sugar consumption appeared to be less critical compared to other factors such as measures of socioeconomic status and oral hygiene habits. Harris report that several studies hypothesized that this could be explained by the widespread use of sugar across populations in developed countries, making it more difficult to isolate it as a factor (Harris *et al.*, 2004).

A critical in-depth review by Sheiham and James (2013) analysed the dose-response relationships between dietary sugars and caries incidence in children aged six years or more and adults with different levels of caries susceptibility. They found that dental caries occurred in children exposed to sugar intakes of only 2–3 % of energy intake for >3 years, and a progressive linear increase in caries throughout life was observed. Exposure to fluoride sources was found to modify sugar impact in caries development and progression, and no evident intake threshold for sugars consumption to provoke adverse effects in children was found.

Most recently, Moores *et al.* (2022) performed a systematic review on the association between the amount of sugar intake and dental caries, reviewing data published from 2011 to 2020. They concluded that the most recent data provide strong evidence underpinning the WHO recommendation to limit intake of free sugars to <5% of energy to prevent dental caries in both adults and children.

1.5.1.3 Oral hygiene

In order to prevent plaque accumulations that may eventually promote the onset of carious lesions, it has been recommended that oral hygiene in children must be incorporated from the earliest months of life (Butera *et al.*, 2022). Kirthiga *et al.* (2019) reported that the two most significant oral hygiene factors associated with early childhood caries were the presence of visible plaque and toothbrushing less frequently than once per day. The age at which toothbrushing began, not brushing teeth before bed, using non-fluoridated toothpaste, and non-parental supervision of brushing were also found as risk factors for the development of dental caries in preschool children.

Additionally, it has been suggested that toothbrushing is more effective at preventing caries than any particular flaw in its ability to disrupt cariogenic plaque biofilms because it consistently introduces fluoride into the oral cavity (Philip *et al.*, 2018).

A systematic review by Mejàre *et al.* (2015) showed that the quality of evidence is high for the caries-preventive effect in children of daily use of fluoride toothpaste and that supervised tooth-brushing is more effective than unsupervised. This result was consistent with a recent systematic review by Yousaf *et al.* (2022), where a 65% reduction was reported when caregivers helped children with toothbrushing in low and middle-income countries.

1.5.1.4 Breastfeeding and bottle feeding

The use of baby bottle and breastfeeding habits, such as night and prolonged use of a bottle, are factors that have been related to the dental caries process (Colak *et al.*, 2013; AAPD, 2014; Chou *et al.*, 2014).

A literature review by Branger *et al.* (2019) suggested that extended breastfeeding is a preventative measure for caries in children under the age of one. Because of the numerous confounding factors, such as food habits that differ across nations and families and dental hygiene practices, it was challenging to conclude protection from or aggravation of caries after one year.

Moynihan *et al.* (2019) conducted a systematic review of 139 studies on factors that modify caries risk in children. They reported that high-level evidence indicated that breastfeeding until two years of age does not increase early childhood caries risk. However, low-level evidence suggests that longer-duration breastfeeding may increase the risk.

A recent umbrella review by Panchanadikar *et al.* (2022), including four systematic reviews, reported that breastfeeding beyond the age of 12 months, accompanied by nocturnal feeding, had a positive association with early childhood caries. They also suggest that this association may be more related to the habit of feeding before sleep without adequately cleaning the mouth than the habit itself. Therefore, further research with a precise categorisation of this habit is needed.

A Cochrane review by Riggs *et al.* (2019) assessed the impact of interventions with pregnant women, new mothers and other primary caregivers for preventing early childhood caries. They concluded that there is moderate-certainty evidence to suggest that providing advice on diet and feeding to pregnant women, mothers or other caregivers with children up to the age of one year probably leads to a slightly reduced risk of early childhood caries.

Regarding bottle feeding, it is still unclear whether bottle feeding is more cariogenic than breastfeeding. A systematic review and meta-analysis on the topic was conducted by Avila *et al.* (2015), including seven low-quality studies, indicated that breastfeeding can protect against dental caries in early childhood and that breastfeeding is more effective at preventing dental caries in early childhood than bottle feeding.

1.5.1.5 Fluoride exposure

Fluoride is the mainstay of oral health improvement programmes (Whelton *et al.*, 2019). Fluoride's physiochemical capacity to prevent enamel demineralization and promote remineralization is largely responsible for its cariostatic effects (Philip *et al.*, 2019). Recent laboratory investigations have supported the idea that fluoride ions can also affect important virulence variables of the cariogenic microbiota, notably lowering acidogenicity, aciduricity, and glucan production (Pandit *et al.*, 2013).

Numerous systematic reviews have been undertaken throughout the years to examine the impact of different methods of fluoride delivery for caries prevention. A detailed literature review on this topic is provided further in section 1.5.2.2.

1.5.2 Socioeconomic factors

As stated previously in this Chapter, a clear socioeconomic gradient has been reported among different populations in favour of the least socioeconomic deprived groups of society, representing a classic example of a social gradient in health. Peres *et al.* (2019) even suggest, based on recent evidence, that there is a causal relationship between dental caries and the socioeconomic status of individuals.

Watt and Sheiham (2012) provided a model for oral health inequalities, adapted from the WHO conceptual framework for action on the social determinants of health. This model includes three categories of context and factors: the socioeconomic and political context; the community context; and the behaviour and biological factors.

Structural factors like governmental economic, social, and welfare policies can impact people's living and working situations. Access to healthcare and pensions can influence community circumstances that determine the social status of people, like the sense of belonging and support in their communities and psychosocial aspects such as stress management and coping skills. Additionally, access to foods, resources, and services that promote health (such as fluoride toothpaste and toothbrushes) can be impacted by monetary, economic, social, and societal factors. These circumstances, in turn, work as intermediate factors that may influence individual biological and behavioural factors such as smoking, alcohol consumption, diet and even the immune system. All these factors interact with each other in a complex network of determinants of health (Watt and Sheiham, 2012; Macpherson *et al.*, 2019a).

Costa *et al.* (2018), in an update of the systematic review and meta-analysis by Schwendicke *et al.* (2015) on the association between socioeconomic factors and dental caries, reported associations between low socioeconomic status and severe dental caries in adults living in highly developed nations; an increase in one unit of the socioeconomic status level was correlated with an increase in 10.35 DMFT score units.

A recent publication by Karam *et al.* (2022) assessed the socioeconomic disparities in untreated dental caries in early childhood according to socioeconomic characteristics in three birth cohorts between 1993 and 2015. They reported that a higher concentration of untreated caries was observed in children belonging to the poorest income quintile and from mothers with a lower level of education in the three birth cohorts.

1.5.3 Commercial factors

Kickbusch *et al.* (2016) defined the commercial determinants of health as 'strategies and approaches that are used by the private sector to promote products and choices that are detrimental to health'. McKee and Stuckler (2018) revisited this concept and identified how the industry influences the structural level, lobbying against policies that can be detrimental to the sugar industry. They identified four main ways corporations influence health: defining the dominant narrative; setting the rules by which society, especially trade, operates; commodifying knowledge; and undermining political, social, and economic rights'.

Commercial determinants of health may also impact dental health, influencing researchers to downplay the role of sugar in the aetiology of dental caries (Peres *et al.*, 2019). According to Kearns and Bero (2019), sugar's contribution to dental caries has been consistently minimised because corporations that promote sugary drinks and confections finance dental research organisations. The authors contend that the sugar industry has supported research to shift attention away from studies on the risks associated with sugar and diet and toward studies on non-dietary interventions like vaccines to prevent dental caries.

1.5.4 Common risk factors

Non-communicable diseases are a major global health challenge —recognised by the United Nations (United Nations, 2019). Oral diseases are considered non-communicable diseases and share many risk factors. Sheiham and Watt (2000) first defined the concept of common risk factors between dental diseases and other non-communicable diseases. Some risk factors like diet, smoking, and socioeconomic status are shared with other diseases such as obesity, diabetes and cancer (Sheiham and Watt, 2000). These factors are increasingly recognised in childhood (World Health Organisation, 2017).

The advantage of a common risk approach is that it can significantly reduce the risk of a wide range of diseases at a lower cost and with higher efficiency and effectiveness than disease-specific treatments (Sheiham and Watt, 2000). Therefore, collaboration between different professions is needed to reduce the risk factors for non-communicable diseases, enhance oral health, and promote overall health and wellbeing, and oral health strategies should be included in all health policies (Murtomaa *et al.*, 2022). Also, reductions in oral health inequalities are more achievable if a multidisciplinary population-based public health approach is undertaken (Watt, 2012). In particular, strategies with common risk factor approach to prevent the consumption of high sugar intake of foods and drinks is especially relevant to early childhood caries (Butera *et al.*, 2022).

1.5 Dental caries prevention in children

Strikingly, while oral health diseases can be debilitating, having profound biological and psychosocial effects, they are for the most part, preventable (Edelstein, 2000). During most of the 20th century, the dominant oral health preventive model had a biomedical and restorative nature and an 'individual risk factors' focus. It is increasingly recognized that this approach alone is ineffective in achieving sustainable oral health improvements across the population or reducing the oral health equity gap. After the call for action of dental public health researchers for a paradigm shift from the biomedical and behavioural approach to one which addresses the underlying social determinants of oral health through a combination of complementary public health strategies (Watt *et al.*, 2019), a new era of promotion of oral health is perhaps emerging (Peres *et al.*, 2019; Watt *et al.*, 2020).

1.5.1 Individual vs population-level approaches for oral health promotion

There is a difference between inquiring about the causes of a disease in a single patient and the determinants of disease incidence at a population level. Individual determinants are linked to each individual’s biological functioning, such as genetics, metabolism, and nutrition. Other specific behaviours, such as exercise frequency, smoking habits, alcohol intake, or oral hygiene knowledge and practices are related to individuals environmental circumstances (Watt and Sheiham, 2012). Most interventions aimed at modifying people's oral health-related behaviours are based on theoretical behavioural models and psychological theories that attempt to explain people's behaviour as a consequence of their beliefs, attitudes, and self-efficacy (Baelum, 2011). This strategy may be insufficient and explain why such interventions may exacerbate socioeconomic health inequalities, as those with more resources are more enabled to access, take up and act on their health behaviours (McLaren, *et al.*, 2010).

Rose has proposed two strategies to improve the population's health. The risk approach includes those aimed at the general public and those in which specific segments of the general public are identified and targeted, either as a group or as individuals, with two types of risk management strategies. In oral health, the ‘high-risk’ method identifies and targets individuals/groups with high caries levels, and the population strategy aims wide population/universal approach (Rose *et al.* 2008).

Deciding whether to use a population or risk approach is relevant in developing oral health programmes, and Rose asks the question: Does a modest increase in risk in a large number of people generate more cases than a significant rise in risk in a few people? Baelum and Lopez (2004), referring to oral diseases in the population, had suggested that sick teeth are ‘nested’ in ‘sick individuals’ who are ‘nested’ within ‘sick populations’.

In a narrative review, Watt has highlighted the limitations of merely using a high-risk approach to prevent oral disease due to the multi-level nature of the determinants of oral health, and the need for a combination of population-based and high-risk approaches, proposing different levels of intervention: ‘upstream’, focused on policies; ‘midstream’, with focus on the community; and ‘downstream’, with interventions at a clinical level (Watt, 2007). In this approach, clinical interventions are at the downstream level, focusing primarily on individuals, with community-level interventions such those in education settings in schools in the middle, and large-scale national policy interventions, such as sugar taxes and water fluoridation, at the top, having the greatest reach and impact across the population (Watt, 2007).

There is also a debate about whether targeted or universal approaches reduce inequalities. Population approaches potentially may perpetuate or increase the unequal distribution of the disease, while the converse – a targeted approach – may bring those in most need who are most socioeconomically deprived to a level more comparable with the population and thus reduce the inequality (Shaw *et al.*, 2009). This debate was resolved by Marmot’s “universal proportionate” approach, which proposes that to reduce the steepness of the social gradient in health, interventions must be universal, but with a scale and intensity that is proportionate to the level of disadvantage faced (Marmot, 2010). This approach was adopted by the “Childsmile” child oral health improvement programme in Scotland, where some components of the programme are available to all children (universal), while others are targeted to more socio-economically deprived areas (Macpherson *et al.*, 2019b), in the hope of resolving the potential conflicts between universal and targeted approaches, where an universal approach can generate a greater uptake among more affluent groups (Shaw *et al.*, 2009).

1.5.2 Strategies for caries prevention and control in children

As mentioned previously, the current paradigm shift in oral health prevention has caused a new focus on social determinants of health, highlighting the need for interventions that act at a upstream level, that are the most effective and cost-effective across the population, in combination with other interventions to modify the individual risk, and this new paradigm is relevant for preventing and controlling the disease in children. The following sections describe the main strategies to prevent dental caries in the child population, at different levels of intervention.

1.5.2.1 Sugar consumption control

There is consistent evidence that the availability, cost, promotion, and nutrition information of unhealthy foods and beverages in stores affect dietary consumption (Mackenbach *et al.*, 2022). In today's culture where carcinogenic foods are freely accessible, dietary adjustment, which requires people to limit their exposure to sugar and other fermentable substrates, is particularly challenging to achieve (Philip *et al.,* 2018). The community and population-based strategies for sugar restriction aim to reduce its consumption, mainly via increasing sugar taxation and advising on the detrimental effects on both oral and general health (Filho *et al.*, 2021).

In 2015, the World Health Organization, based on moderate evidence, made a strong recommendation to limit the intake of free sugars to <10% of dietary energy to minimizing caries risk throughout the life course, and based on low-quality evidence a limit of <5% of dietary energy (World Health Organization, 2018a).

The consumption of sugar sweetened beverages (SSB) is high among children and adolescents (Rousham *et al.*, 2022). Many SSB are high in sugar content and acidity and, therefore, their consumption can contribute in a detrimental way to oral and general health (Tahmassebi and BaniHani, 2020).

Bleich and Vercammen (2018) stated in a systematic review that SSB consumption is strongly associated with dental caries in children. In the 2019

Cochrane review on interventions to reduce the consumption of SSB and their effects on health, the negative effects of SSB on dental caries was also considered. However, no specific intervention to reduce SSB was found to be associated with a reduction in caries levels of children, which may be due to limitations in intervention designs or limitations in the quality of evidence (von Philipsborn *et al.*, 2019).

A narrative review by Alhareky (2021) on the impact of taxation of SBB on dental caries suggested that the impact of SSB taxation has been shown to lower its consumption. In addition, modelling studies from developed and high-income countries have demonstrated that SSB taxation could potentially result in significant reductions in dental caries severity, prevalence and associated treatment costs. However, these findings were from only five observational low-quality studies, and no evidence of this effect was found on studies performed in low and middle-income countries.

Mackenbach *et al.* (2022) conducted a systematic review and meta-analysis on the relationship between the food environment and oral health, including 23 low to moderate-quality studies. They concluded that policies targeting restricting access or increasing prices of unhealthy foods and beverages lead to better oral health, but due to the quality of evidence, further research is need to clarify the impact of food environment on oral health.

1.5.2.2 Fluoride for caries prevention in children

Optimal exposure to fluoride is important for limiting disease progression as fluoride promotes remineralisation (Peres *et al.*, 2019). When present in dental plaque and saliva, it delays the demineralization and promotes the remineralization of incipient enamel lesions, a healing process before caries becomes established. Fluoride is most effective in caries prevention when a low level of fluoride is constantly maintained in the oral cavity (O'Mullane *et al.*, 2016; Filho *et al.*, 2021). Important reservoirs of this fluoride are in plaque, saliva, on the surfaces of the oral soft tissue, and in a loosely bound form on the enamel surfaces (O'Mullane *et al.*, 2016).

Individual-level (toothbrushing with fluoride dentifrices, and the use of mouth rinses), community-level (supervised daily toothbrushing in educational settings, water, salt, and milk fluoridation schemes), and clinical level (varnish) interventions are the most common delivery methods for delivering fluoride in the oral cavity and teeth (Filho *et al.*, 2021).

1.5.2.3 Toothbrushing with fluoride toothpaste

The efficacy of fluoride toothpaste has been demonstrated in the literature and evaluated in a Cochrane review that included 74 studies of more than 42,300 children (Marinho *et al.*, 2003). This systematic review provided evidence for the efficacy of fluoride toothpaste for preventing dental caries in children showing on average a 24% reduction in disease development. One of the included studies reported data on dental caries in primary teeth of 2,008 children, and demonstrated a significant disease reduction of 37%. The evidence indicates that fluoride toothpaste applied via toothbrushing is effective for the prevention of dental caries in both the primary and permanent dentition (Marinho *et al.*, 2003).

In an update of the Cochrane systematic review and meta-analysis on the subject, conducted by Walsh *et al.* (2019), the preventive effects of fluoride toothpaste of different concentrations was assessed based on 96 randomised controlled trials published between 1955 and 2014, where eight studies including 13,856 participants assessed the effects of fluoride toothpaste on the primary dentition. In the primary dentition of young children, 1500 ppm fluoride toothpaste reduced caries mean dmft increment by -0.28 when compared with non-fluoride toothpaste. The effect of 1055 ppm and 550 ppm fluoride toothpaste was found to be similar, but lower that a concentration of 1500 ppm. Also, toothbrushing with 1450 ppm fluoride toothpaste was found to reduce dmft increment and the risk of developing new caries when compared with 440 ppm fluoride toothpaste (Walsh *et al.*, 2019).

Toothbrushing using fluoride toothpaste of at least 1000 ppm of fluoride is an evidence-based intervention for the prevention of dental caries in children (Public Health England, 2016a; NHS Health Scotland, 2018). Toothbrushing, however, is a complicated set of behaviours that can be difficult to set in place and to maintain especially in young children. Barriers to toothbrushing may be around the availability of toothpaste and brushes (Hamilton *et al.*, 2018), parents' beliefs about toothbrushing (Pine *et al.*, 2004), brushing skills and confidence (Huebner and Riedy, 2010; Adair, Burnside and Pine, 2013) or dealing with challenging child behaviours (Amin and Harrison, 2009).

While some interventions have targeted the home, others have introduced a midstream community approach with school toothbrushing programmes in order to increase compliance and reach (Davies *et al.*, 2005; Jackson *et al.*, 2005). Community interventions tend to implement supervised toothbrushing programmes with an educational component (Macpherson *et al.*, 2013), or can be stand-alone supervised toothbrushing interventions (Davies *et al.*, 2005).

Aliakbari *et al.* (2021) performed a systematic review on home-based toothbrushing interventions for parents of young children to reduce dental caries, including 42 intervention studies, and concluded that most of the interventions were one-to-one sessions performed in a health setting addressing barriers to toothbrushing on children. Despite finding an impact on caries levels in some studies, the evidence was not clear on the effect of these interventions on dental caries of young children, suggesting the need for more high-quality research in this area (Aliakbari, Gray-Burrows, Vinall-Collier, Edwebi, Marshman, *et al.*, 2021).

A pioneer randomized controlled trial conducted in schools in Scotland involved an intervention with two components. An in-school toothbrushing programme which used fluoride paste (1000ppm) and a school and home incentives scheme that encouraged twice daily brushing (Pine *et al.*, 2000). The findings of this study confirmed the benefits of twice-daily brushing, showing up to a 50% decay reduction in newly erupted teeth. The incentive scheme aided by brushing charts was thought to be helpful by parents. This intervention was found to be effective in improving child oral health among those at high risk of disease. Other studies of similar school-based toothbrushing programmes have tended to find an improvement in child dental health following programme implementation, and the ways to target younger children may be through nurseries or contact with the health service (Jackson *et al.*, 2005; Al-Jundi *et al.*, 2006; Macpherson *et al.*, 2013; Culler *et al.*, 2017).

A Cochrane systematic review by Cooper *et al.* (2013) reported that there was insufficient evidence for the efficacy of primary school-based behavioural interventions for reducing caries and plaque reduction. There is evidence, though, that supervised toothbrushing programmes in schools and early childhood settings are more likely to be cost-effectively successful when childhood caries rates are high, drinking water is not fluoridated, and children aren't already brushing their teeth twice a day with fluoride toothpaste (Dickson-Swift *et al.*, 2017).

1.5.2.4 Fluoride mouth rinse

Fluoride mouth rinses have previously been utilised to prevent caries in children over the past 40 years, and were particularly popular in school-based programmes in the 1970s and 1980s, before the widespread use of fluoride toothpaste (Marinho *et al.*, 2016). The most common fluoride mouth rinse concentration for school-based programmes is 900 ppm, with a margin of safety for acute toxicity being more than ten times lower than the probable toxic dose for a six-year-old child of average weight (Pollick, 2018).

The most recent Cochrane systematic review on the subject, from 2016, aimed to determine the effectiveness and safety of fluoride mouth rinses in preventing dental caries in the child and adolescent population, and included 37 trials and 15,813 children. Regular supervised use of fluoride mouth rinse by children in a school context was associated with a reduction in caries increase in permanent teeth of 23%, although they only had a moderate certainty of the effect size. This review's conclusions stated the need for further comparisons between mouth rinses and alternative fluoride delivery vehicles and an evaluation of side effects and acceptance (Marinho *et al.*, 2016). No data were provided specifically for dental caries in the primary dentition in the review. This lack of studies in younger children is due to concerns about the natural swallowing reflex, where most children younger than six may be unable to resist swallowing a mouth rinse (Pollick, 2018).

Mouth rinses for daily usage at home contain 225 ppm of fluoride, compared to 900 ppm of fluoride in school-based programmes. Toumba *et al.* (2019) evaluated the data from 24 studies and found a 29% reduction of caries increment in permanent teeth with the use of a daily rinse containing 225 ppm fluoride, but, as stated above, for supervised school-based mouth rinse, its home use was not recommended for children younger than six.

1.5.2.5 Water fluoridation

One way to deliver fluoride at the population level is through water fluoridation, which involves regulating the concentration of fluoride in drinking water at a safe and beneficial level for oral health (National Health and Medical Research Council, 2017). Fluoridation of water is used in numerous areas around the world: as of 2012, about 420 million people worldwide had access to either naturally fluoridated water (approximately 50 million) or water with fluoride concentrations that were at or near optimum levels (about 370 million). The water fluoride concentration in community water fluoridation programmes is considered optimal for caries prevention between 0.5 to 1.1 mg/L. (Toumba *et al.*, 2019). Concentrations less than 0.3 mg/L in drinking water are considered non-fluoridated, and concentrations greater than 1.5 mg/L can put general health at risk (National Health and Medical Research Council, 2017). The great advantage of this fluoride source is its low cost, its broad coverage and not requiring the active participation of each of the individuals (O'Mullane *et al.*, 2016).

Studies have shown the effectiveness of the fluoridation of drinking water. A systematic review by McDonagh *et al.* (2000) on the efficacy and safety of fluoridation of drinking water in children and adolescents from 5 to 14 years old, reported that water fluoridation was associated with a higher proportion of children without caries (14.6%) and a reduction in the number of teeth affected by caries. More recently, a Cochrane review was published by Iheozor *et al.* (2015) which updated the review made by McDonagh and colleagues, showing an average reduction of 1.8 teeth affected by dental caries in the primary dentition and 1.16 in the permanent dentition, associated with water fluoridation, which correspond to a reduction of 35% and 26% in caries levels, respectively.

Additionally, the proportion of “caries-free” children associated with water fluoridation was shown to increase by 15% in the primary dentition and 14% in the permanent dentition (Iheozor-Ejiofor *et al.*, 2015).

It has been suggested that community water fluoridation may reduce inequalities in the distribution of dental caries in the child population (Shen *et al.*, 2021). However, the role of community water fluoridation, including the coverage and optimal fluoride concentrations in closing the gap in oral health among populations with different socioeconomical backgrounds needs to be investigated further (Iheozor-Ejiofor *et al.*, 2015).

Regarding adverse effects, the only one that has been associated with the fluoride concentrations used in community water fluoridation programmes is dental fluorosis, which is hypoplasia of the enamel and a product of excess fluoride during the formation of the tooth, before its eruption. Dental fluorosis, depending on its severity, can occur in the enamel as small, almost imperceptible striae or white spots to rough, and brownish surfaces with loss of enamel integrity in the most severe cases. Its presence is associated with excessive intake of fluoride before age eight, the age when most of the teeth have already formed their enamel (Carey, 2014). The McDonagh *et al.* (2000) review found an dose-dependent increase in fluorosis, estimating 12.5% of fluorosis of aesthetical concern with a fluoride concentration of 1 mg/L. Concerning other adverse effects, no evidence was found to associate water fluoridation with other adverse effects at concentrations between 0.5 mg/L to 1 mg/L (McDonagh *et al.*, 2000; Carey, 2014; Iheozor-Ejiofor *et al.*, 2015). Iheozor-Ejiofor *et al.* (2015) estimated that for a concentration of fluoride in the water of 0.7 mg/l, 12% fluorosis of aesthetic consideration can potentially be expected, which may increase to 40% when considering all types of fluorosis, from the questionable to the severe.

Some mineral waters contain fluoride in concentrations comparable to the community water fluoridation recommended fluoride consumption; hence, due to the increase in bottled drinking water compsumption, this fluoride should be considered a substantial source of fluoride intake in future systematic reviews (Koberová Ivančaková *et al.*, 2021).

1.5.2.6 Milk fluoridation

The use of milk as a delivery vehicle for fluoride has been used in dental public health programmes (Bánóczy *et al.*, 2013). Milk forms an important part of children's diets and has long been used as a nutritional supplement, especially in school-based programmes, being supported by the WHO in their guidelines on caries prevention (Bánóczy *et al.*, 2013). Fluoridated milk is usually supplied in 200 ml packs with 5 ppm or 1 mg of fluoride per pack (Koberová Ivančaková *et al.*, 2021).

Two systematic evaluations looked at the use of milk as a vehicle for supplying extra fluoride in dental public health programmes and its caries-prevention effect on the primary dentition. Cagetti *et al.* (2013) included two low to medium-quality studies. They reported that consumption of fluoridated milk was effective in preventing caries in the primary dentition. One study reported a mean net caries increment of 0.4 dmft for the group exposed to milk fluoridation, and 1.3 dmft for the control group. The second study concluded that the daily consumption of fluoridated milk had a preventive fraction of 75% in school children (Cagetti *et al.*, 2013).

Yeung *et al.* (2015) conducted a Cochrane review to assess the impact of milk with fluoride in the prevention of dental caries. In this review, they found just one relevant randomised controlled trial that included 180 three-year-olds who were given either fluoridated or non-fluoridated milk in nurseries in an area with a high prevalence of dental caries and a low level of fluoride in drinking water. They suggested that fluoridated milk may be beneficial to schoolchildren, substantially reducing the formation of caries in the primary dentition, with a prevented fraction of 31%. There was no information available about any possible adverse events. Overall, the evidence was considered to be low quality due to the lack of relevant studies, the high risk of bias in the identified study, and concerns over the applicability of the results to different settings and populations (Yeung *et al.*, 2015).

1.5.2.7 Salt fluoridation

When water fluoridation is impossible, salt has been recommended as a fluoride delivery medium (O'Mullane *et al.*, 2016). In most countries where this approach was permitted for individual home use, the fluoride level in salt has ranged from 250–350 mg F/kg. A major concern is that promoting salt consumption for oral health advantages would be considered incompatible with general public health and medical advice of reducing salt consumption to reduce the risk of hypertension. Moreover, there are limitations associated with variance in ingestion, making maintaining an optimal fluoride concentration challenging (Toumba *et al.*, 2019).

One systematic review and one meta-analysis have attempted to assess the clinical effectiveness of salt fluoridation. In their systematic review, Cagetti *et al.* (2013) did not find any study related to the use of salt fluoridation in caries prevention, according to their inclusion criteria. A meta-analysis by Yengopal *et al.* (2010) concluded that the contribution of fluoridated salt to the decrease in the prevalence of caries in the permanent dentition could not be quantified. Its effect on the primary dentition in pre-school children was not significant, suggesting further high-quality studies were needed. However, given the wider public health concern associated with salt, it is not widely advocated by the dental public health community.

1.5.2.8 Fluoride varnish for caries prevention in children

Fluoride varnishes (FV) were initially developed to prolong the contact time between fluoride and dental enamel, as they adhere to the tooth surface for extended periods, and prevent the immediate loss of fluoride after application, thus acting as slow-releasing reservoirs of fluoride making acute toxicity unlikely (Øgaard *et al.*, 1994).

Although various formulations of FV are available, almost all contain 5% sodium fluoride, or 22,600 ppm fluoride ions, in a natural resin carrier with some alcohol included as a solvent (Marinho *et al.*, 2013). Other commercial presentations available contain 0.9% difluorosilane (1000 ppm) in polyurethane-based varnish and set to a thin transparent film (Marinho *et al.*, 2013). They are considered safe, despite the high fluoride concentration, because the amount of varnish usually applied to treat one child is only 0.5 ml on average, which delivers 3 to 11 mg of fluoride per dose (Petersson *et al.*, 2004). This is far below the probable toxic dose of 5 mg/kg body weight, even with the potential exposure (ingestion) varying from 3.5 to 11.3 mg of fluoride (Whitford, 1992).

The latest FV Cochrane review identified 22 trials on the effect of FV on caries prevention (Marinho *et al.*, 2013). A meta-analysis of the effects of FV on permanent teeth (13 trials) reported a pooled DMFS prevented fraction of 43% compared with placebo or no treatment. The effect of FV on primary teeth (10 trials) was also statistically significant with a pooled dmfs prevented fraction of 37%. Most studies reviewed by Marinho *et al.* involved twice yearly application, although a small number involved up to four applications per year. Meta-regression showed no significant effect of modifying the frequency of application of FV on estimates of protective fraction for either permanent or primary teeth, suggesting that four applications per year did not decrease caries incidence compared with twice-yearly application and the relative benefit of FV application applied in children irrespective of their baseline caries risk (Marinho *et al.*, 2013).

However, more recently, the effectiveness of FV has come into question. de Sousa *et al.* (2019) performed a meta-analysis of 20 trials on the effectiveness of FV in reducing dentine caries at the patient, tooth, and surface levels, as well as caries-related hospitalizations in pre-schoolers. Findings revealed no significant difference between children who got FV and those who did not at the tooth level and that the probability of developing new dentine caries lesions was reduced by 12% in those exposed to FV. This was stated as a modest benefit since, regardless of FV use, many children developed new dentine caries lesions. Also, there was a lack of cost-effectiveness evidence regarding FV applications in the primary dentition (de Sousa *et al.*, 2019). In this regard, a recent RCT by McMahon *et al.* (2020) aimed to assess the effectiveness and cost-effectiveness of the nursery-based FV applications in the context of a daily supervised toothbrushing programme, concluding that there was a modest non-significant reduction in the worsening of dmft in nursery FV group compared to supervised toothbrushing alone, suggesting that this intervention is unlikely to represent an effective or cost-effective addition to the population oral health improvement programme. An economic evaluation on this intervention conducted by Anopa *et al.* (2022), reported that applying FV in nurseries in addition to all other components of the programme, would not be deemed cost-effective given current UK thresholds, suggesting the need for review of FV as part of oral health improvements programmes in nurseries given its low probability of cost-effectiveness.

1.5.2.9 Sealants for caries prevention in children

Sealants are polymeric polymers used to cover large pits and fissures on the occlusal surfaces of teeth, which are the areas where dental caries occur most frequently in children (Filho *et al.*, 2021).

Although sealants' effectiveness in preventing caries in permanent teeth has been established, the effectiveness of applying pit and fissure sealants to primary teeth is not that clear (Ramamurthy *et al.*, 2022). The most recent Cochrane review of the effectiveness of sealants in permanent teeth of children and adolescents found moderate-certainty evidence that resin-based sealants were more effective than no sealant in preventing dental caries in the permanent dentition, reducing it by 11% to 51% more than children without sealants when measured two years after sealant application (Ahovuo-Saloranta *et al.*, 2017).

However, in the most recent Cochrane review of the effectiveness of sealants in primary teeth conducted by Ramamurthy *et al.* (2022) the available evidence did not allow for a recommendation to be made due to the low quality and methodological flaws of the studies, leading to the conclusion that there is an important evidence gap regarding the caries-preventive effect and retention of sealants in primary teeth, which should be addressed through robust randomized controlled trials.

1.5.3 Child oral health improvement programmes

According to World Health Organisation, “oral health promotion is any planned effort to build healthy public policies, create supportive environments, strengthen community action, develop personal skills or reorient health services in the pursuit of oral health goals”, so health promotion in a society must be achieved by multiple levels of action including “upstream” and “downstream” actions such as health interventions targeting specific health determinants (World Health Organisation, 2016). Oral health promotion for deprived children and their families can be complicated and requires multiple partnerships across different settings —not just simply left to dental services.

A health improvement intervention can be defined as an effort to promote positive health practices or reduce harmful health practices, leading to improved health (Leviton, 2017). Therefore, successful oral health improvement strategies need careful planning, multiple stakeholders and political commitment on multiple levels. Nowak has suggested that in order to reduce oral health inequality and to improve the oral health of the population, universal oral health promotion must be provided, along with a targeted approach that focuses on children with higher risk (Nowak, 2011).

As stated previously in this Chapter, it has been proposed that when universal and targeted approaches are combined, a programme is more likely to be effective at reducing inequality (Marmot, 2010). The theory behind this is that a universal programme can be readily implemented and can achieve population coverage; however, it may lose momentum before ‘hard-to-reach’ groups become engaged with it, so the addition of efforts that are targeted at the hard-to-reach (and most at risk) groups makes it more likely that the social gradient will be attenuated (Marmot, 2010).

Health promotion interventions have for several years, attempted to improve dental health-related behaviours and consequently, childhood dental health outcomes. However, health education promotion interventions have been severely criticised in relation to their potential to widen population inequalities (Macintyre, 2007). Oral and dental health education has been singled out as case-study, with evidence of oral health education messages being taken up by those from higher socioeconomic (education/income) groups, while those from more socioeconomic deprived backgrounds find it more challenging (Schou and Wight, 1994; Macintyre S., 2007).

An international study performed by Adair *et al.* (2004) collected data from 17 countries measuring parents' attitudes towards oral health-related behaviours for their three to four-year-old children, assessing some variables like oral hygiene, sugar, snacks, attendance to dental care and oral health outcomes. Results showed that parents' attitudes towards the behaviours themselves rather than attitudes towards prevention as well as knowledge related to dental hygiene and sugar snacking were significant predictors of the development of dental caries in children. This international study and its findings were consistent across ethnic groups.

Despite the presence of evidence for improvements in oral health knowledge and practices with the educational approach in children, evidence for reductions in caries incidence remains limited and of lower quality. In a systematic review performed by Stein *et al.* (2018) to evaluate the effectiveness of oral health educational actions in the school context in improving oral hygiene and dental caries, that included 12 studies from different countries, the results showed that traditional oral health educational actions were effective in reducing plaque in the short term, but there is no long-term evidence in respect of the effectiveness of these interventions in preventing plaque accumulation, gingivitis and dental caries in the school environment.

1.5.3.1 Childsmile – the national child oral health improvement programme for Scotland

As previously mentioned in this chapter, fluoride exposure is a key pillar of oral health promotion in adults and children. Among the vehicles for their community delivery, community water fluoridation can have a large-scale impact as a population strategy since it supplies controlled fluoride levels with minimal individual effort or behavioural changes, compared to strategies that demand more individual effort (Whelton *et al.*, 2019). Currently, many countries face the dilemma of whether or not to include community water fluoridation, and in many cases, this programme has been rejected, as is the case in Scotland (Attwood and Blinkhorn, 1991; Jones *et al.*, 2022). This has led to the development of other programmes that allow the child population to be exposed to safe and beneficial fluoride levels to prevent caries.

The “Childsmile” programme was developed as pilots in 2006, following the publication of the “Scottish Executive’s Plan for Improving Oral Health and Modernising Dental Services” in 2005. This plan aimed to address the high prevalence of dental caries at young ages, the inequality in the distribution of the disease, and the low percentage of dental registration (Macpherson *et al.*, 2010). Since 2011, Childsmile has been delivered as an integrated complex public health intervention in all Health Board areas throughout Scotland and delivers oral health improvement interventions both within and outside traditional dental clinical settings – in education establishments, community settings, and other healthcare settings (Macpherson *et al.*, 2019b).

The programme's main features are based on the upstream/downstream continuum proposed by Watt and Sheiham (2012). The upstream approaches include the advocacy for developing and the integration of oral health in national strategies, policies and regulations in relation to common risk factors of non-communicable diseases such as sugar control and nutrition (Scottish Govermment, 2018). Other regulatory changes advocated by the programme included the training of dental nurses to apply fluoride varnish as part of community-based programmes and in dental practice settings to promote a preventive-orientated focus in the Scottish General Dental Service (Macpherson *et al.*, 2019b).

The midstream approaches at the community level include components available to all children, while others are targeted according to area-based socioeconomic deprivation, following the principles of “proportionate universalism”. These components include (Macpherson *et al.*, 2019b):

1. Supervised toothbrushing programme: a universal access programme, including all tree- and four-year-old child who attends nurseries, that

offers free supervised toothbrushing and provides free toothbrushes and fluoride toothpaste of 1450 ppm packs and feeding cups to all children. According to area-based socioeconomic deprivation, targeted schools continue with supervised toothbrushing in children aged five and six.

2. Fluoride varnish in nursery and school programme: a targeted intervention that focuses on children aged three to eight years from the most socioeconomic deprived communities. It consists of the application of fluoride varnish (5%) twice per year directly at schools and nurseries provided by dental nurses. Education in oral health is also delivered, along with linking children with their local dentist.

3. Community interventions involving Health Visitors and Dental Health Support Workers: the universal child health surveillance system within the universal health visitor early years pathway links every newborn child in Scotland to Childsmile (Scottish Goverment, 2015). Health visitors regularly meet every child and their parents or caregivers between birth and age five. Health visitors offer oral health recommendations, hand out Dental Packs, and promote early dental visits. Referrals are made to a local Dental Health Support Worker when they believe more assistance is needed to enhance oral health. Dental health support workers support the family, helping them with dental attendance, giving oral health advice and education, and linking to other health improvement programmes.

4. Dental primary care: In all dental practices in Scotland, universal prevention interventions are provided to all children. Upon attendance at their local dental practice, appropriate needs-based “health education” messages regarding toothbrushing and diet advice are provided, and fluoride varnish is applied according to individual needs and clinical guidance. In 2011, payments were introduced into the NHS primary dental care for these interventions.

Several studies have evaluated the impact that Childsmile has had on the oral health of children in Scotland. McMahon *et al.* (2011) showed that the obvious decay experience of three-year-old children in Greater Glasgow and the Clyde dropped from 26% in 2006 to 17% in 2009, following the programme's pilot phase. Another ecological study analysed the relationship between the oral health of five-year-old children and the introduction of the daily supervised toothbrushing programme in nurseries. They reported an improvement in dental health outcomes across different areas and deprivation levels (Macpherson *et al.*, 2013).

The impact that Childsmile has had on the child population of Scotland can be assessed by examining the reported oral health outcomes in 2020; obvious caries experience in five-year-olds across the country had reduced from 55% in 2003 to 26.5% in 2020, and the average dmft dropped to 3.94, and the inequality in the distribution of the disease according to socioeconomic deprivation was reduced (Public Health Scotland, 2020). It is likely that these improvements are linked to the programme, as there was a lack of improvements in children's oral health before Childsmile (Macpherson *et al.*, 2013). Kidd *et al.* (2020) evaluated the Childsmile programme utilising individual-level data linkage of interventions and outcome datasets from routine administrative data. They concluded that the universal interventions (nursery toothbrushing and regular dental practice visits) were independently and most strongly associated with a lower risk of caries in Scotland, with nursery toothbrushing having the largest benefit among children in high-deprivation locations.

In a review of the progress of Childsmile over the last decade of the programme (Macpherson *et al.*, 2019b), crucial gains in dental health of the child population had been achieved. However, caries levels remain an issue and inequalities in the burden of the disease are still a public health challenge in Scotland.

The robust evidence supporting the impact of Childsmile in preventing dental caries and improving children's oral health in Scotland has served as the basis for other countries to include this type of programme in their oral health policies, including Chile.

1.6 Health and health suppliers of the population of Chile

1.6.1 Demography of Chile

Chile possesses the features of a unitary state. The administration is both geographically and functionally decentralized. Chile's territory is divided into regions, provinces, and municipalities. Every region is assigned with a Roman numeral followed by a name. When the regional organization was introduced, Roman numerals were given in ascending format from north to south (Instituto Nacional Estadisticas, 2018). The Metropolitan Region has the largest population; Chile's only landlocked administrative region is recognized as the nation's administrative and commercial hub. The regions of Chile are further divided into provinces. The provinces have many municipalities, each of which is administered by a municipality board. Chile has 16 regions and 346 municipalities (Ministerio de Salud. Gobierno de Chile, 2018d).

According to the projections of the last census of the population in 2017, Chile has a population of little more than 17 million inhabitants, 50.5% are women, and 49.5% are men (Instituto Nacional Estadisticas, 2018). The population density is 20.4 inhabitants per square kilometre, but 86.5% of the population is concentrated in urban areas and 40% in the metropolitan area — the capital, Santiago de Chile (Becerril-Montekio *et al.*, 2011). The proportion of inhabitants that in 2017 declared to belong to one of the eight towns recognized by the indigenous law was 4.6%. Those under 15 years of age represent 25% of the population, while those over 60 represent 11%. The annual growth rate of the population between 1992 and 2002 was 1.2%. In recent years it has fallen to 1%, one of the lowest in Latin America. The fertility rate in 2007 was 1.9 per woman of fertile age (Ministerio de Salud. Gobierno de Chile, 2018d).

1.6.2 Health of the population of Chile

The health of the population of Chile is among the best in America and is similar to that of highly industrialized countries (Bitrán *et al.*, 2010). The infant mortality rate has dramatically decreased between 1970 and 2005: from 82 deaths in children under one-year old per 1,000 live births to 7.9, with few differences within the regions of Chile. These data contrast favourably with those of Mexico (18.1 in 2006) and Brazil (22.6 in 2004) and are comparable to the United States (6.8 in 2004). In 2005, the maternal mortality ratio was 19.8 per 100,000 live births, considerably lower than the Latin American mortality ratio average (82.8). Finally, life expectancy increased from 63.5 years in 1970 to 78.5 years in 2010 (81 years for women and 74 for men) (World Health Organization, 2014). This means that Chileans today have a probability of living at birth four times greater than they had at the beginning of the last century (Becerril-Montekio *et al.*, 2011).

However, these demographic changes have been accompanied by an epidemiological transition characterized by a growing prevalence of non-communicable diseases. According to the National Health Survey 2012 of Chile, the diseases with the highest prevalence are cardiovascular diseases, which affect more than half of the adult population, followed by chronic respiratory diseases, depression, and diabetes. Women's leading causes of death are cerebrovascular diseases, heart disease, hypertension, and diabetes. The leading causes of death in men are heart diseases, cerebrovascular diseases, liver cirrhosis disease, and malignant stomach tumour (Ministerio de Salud. Gobierno de Chile, 2018d).

1.6.3 Health system of Chile

Chile has been recognized as a health system innovator and is one of the first Latin American countries to adopt a social security system that provides workers with health insurance funded by a salary tax. Chile also created a state-run National Health System in the 1950s, based on the British National Health Service model and funded by general tax revenue (Bossert and Leisewitz, 2016). Even after the military coup of the 1970s, Chile's health system was predominantly publicly funded and highly effective by Latin American standards; it has been shown to have a significantly improved communicable disease rate, nutrition, maternal and child health, and Chile's health status was among the best in Latin America (Organization for Economic Cooperation and Development, 2021). The infant mortality rate, which had been 136 per 1000 live births in 1950, dropped to 33 per 1000 live births by 1980, and the prevalence of malnutrition among children under six years of age declined from 37% to 11.5% (Jiménez and Romero, 2007).

In the 1980s, as part of market-oriented policies, the military government began allowing salaried workers to opt out of the social security system and use the legally mandated 7% of wages to purchase private health insurance, creating a two-tiered system. Private insurance companies contracted with private providers, driving rapid growth in private clinics and hospitals (Bossert and Leisewitz, 2016).

As described by Rotarou and Sakellariou (2017), post-1990 democratic governments were faced with a series of problems regarding public health services, including a significant deterioration in the public infrastructure, inefficient management and poor coordination between regional health services and municipal authorities, especially with regards to the quantity and quality of health care in rural areas and poor urban districts, a fact that led to an increase in regional inequality.

Over the same post-1990 period, in relation to the situation of health care services, several reforms in the health system were undertaken (Bitrán *et al.*, 2010). However, the basic structure of health organisation, financing, and service provision were broadly maintained (Trumper and Phillips, 1997). In 2005, a comprehensive health reform was introduced in Chile, intending to increase equity in health access, financing, and service provision. The problems that the reform aimed to address included deficits in benefits coverage in the public health system and deficits in the protection, transparency, and high cost of the private system (Rotarou and Sakellariou, 2017).

Some of the measures undertaken to address these issues included: (a) strengthening and extension of health social protection (especially for the most vulnerable groups), (b) the establishment of explicit guarantees for people in a group of pathologies independent of their ability to pay for health services and treatment, (c) new models for the attention and management in health, (d) introduction of several universal benefits and programmes for health prevention and promotion, and (e) introduction of non-contributory benefits for medical assistance of the vulnerable population including immigrants, disabled people or people suffering from extreme poverty (Armada *et al.*, 2001; Bastías *et al.*, 2008).

While Chile shows significant improvements concerning health indicators, the country suffers from inequalities in access to health care, as pointed out by Paraje and Vásquez (2012), insufficient financial protection and access to timely attention, problems of responsiveness (treatment, autonomy, economic justice), and cost scaling because of ageing, technology, and inefficiencies.

In 2015, Chile spent 7.7% of its GDP on health care (Capurro *et al.*, 2017). Sixty-one per cent of the total spending was allocated to public health services, which cover around 80% of the population. From an administrative standpoint, public health care provision is organized into 29 independent health departments in charge of regional hospitals and secondary outpatient clinics; primary care administration is in charge of 346 independent municipalities (Capurro *et al.*, 2017). From the financing perspective, working citizens are mandated to contribute at least 7% of their monthly income to health care coverage, which can be obtained through the public insurer, the National Health Fund (FONASA) or through multiple for-profit healthcare insurance companies (ISAPRE) (Becerril-Montekio *et al.*, 2011). FONASA covers more than two-thirds of the population, including those officially certified as "indigent" or without an income, who are fully subsidised; about 18% of higher-income Chileans are covered by ISAPREs (Rotarou and Sakellariou, 2017).

Unlike in other countries with dual health care systems, where private health care is optional and complementary to the public one, in Chile's private health insurance companies, ISAPRE is an alternative to FONASA (that is, people must choose one or the other). This has led to a stratification of access to health.

The main functions of FONASA are collecting, managing, and distributing the financial resources of the health sector, financing the health benefits granted to its users, characterizing the people benefited by FONASA, managing health contributions and resources, as well as information about rights and the benefits of Public Health Insurance.

There are two categories of FONASA beneficiaries: i) The contributing beneficiary, who is the person who contributes financially to the financing of the insurance. Monthly, each beneficiary contributes with the legal 7% discount from their remuneration. Contributing beneficiaries are dependent, independent, and pensioned workers. ii) The non-contributing beneficiary is the person who does not contribute financially due to a lack of resources or because their income is not enough to contribute; that is, less than the minimum taxable income. Non-contributing beneficiaries are workers who are at the end of the unemployment insurance period or do not have a new source of employment. When a person is a FONASA beneficiary, the coverage also applies to all family members (Fondo Nacional de Salud Chile, 2019).

1.7 Oral health in Chile

The last National Health Survey of Chile (ENS), conducted between 2016 and 2017, through a household survey and examination by health professionals at the national, regional and municipality levels, reported that 46.2% of the population refered to a “good” or “very good” perception of their oral health. The age group of 15 to 24 years reported a higher positive perception of oral health with 60.9% (Ministerio de Salud. Gobierno de Chile, 2018d).

A significant decrease in the prevalence of obvious caries experience was reported regarding dental caries. While in 2003, 66.3% of the population had cavitated dental caries lesions, in 2017, the presence of cavitated lesions was 54.6%. The results of the ENS also indicate that 27% of individuals have “non-functional dentition”, that is, they have less than 20 remaining teeth (Ministerio de Salud. Gobierno de Chile, 2018d).

1.7.2 Oral health among Chilean children

In Chile, oral diseases continue to be a challenge in public health. The “National Study on Dental Caries and Fluorosis” undertaken by Urbina *et al.* between 1996 and 1999 reported a caries prevalence of 85% in children aged five to six years (Urbina *et al.*, 1999). According to data from the last cross-sectional national oral health survey of six-year-old children commissioned by the Chilean Ministry of Health in 2007, 70% of children had a history of dental caries, which was associated with socioeconomic and geographical inequalities. The severity of dental caries measured by the dmft index was 0.5 at two years of age, 2.3 at four years of age and 3.7 at six years of age (Ministerio de Salud. Gobierno de Chile, 2007a). The authors of this report indicated that the prevalence of dental caries might be higher than reported because the standard used for detecting lesions was the WHO criteria, which only looks for signs of cavitation rather than incipient lesions. To date, it has not been feasible to perform a new national oral health survey to update these epidemiological data. Moreover, there has been limited detailed analysis of child oral health trends and related oral health inequalities.

1.7 Oral Health Policies of Chile

Since the legal establishment of the dental profession in Chile on September 27th, 1917, oral health policies have been evolving in Chile according to the needs of the population and scientific development. The first oral health policy document of the Ministry of Health was published in 1978, and its emphasis was on therapeutic strategies aimed at the population in two large age groups, the population from 2 to 14 years and 15 years and older (Superintendencia de Salud, 2012). In 1983 the first oral health plan was outlined, emphasizing health education programmes, fluoridation of water supplies, the allocation of preferential human resources to the care of children under 15 years of age and the development of a policy of training human resources according to needs (Ministerio de Salud. Gobierno de Chile, 2017b). Since 2000, oral health has been incorporated into the Chilean health goals, prioritizing preventive strategies for people under 20 (Ministerio de Salud. Gobierno de Chile, 2021).

1.7.1 National oral health plan of Chile

In 2015, according to the register of health providers of the Ministry of Health, there were 17,075 registered dentists in Chile, which translates into a ratio of 1 dentist per 1,064 inhabitants in the country. However, according to the information available in the Chilean Secretary of Healthcare Networks, there are 2,855 dentists hired in the primary health centres of the country, which translates into a ratio of 1 dentist every 5,752 people registered and validated in the national primary health service record, and reflects the unequal distribution of professionals between the public and private care network (Ministerio de Salud. Gobierno de Chile, 2017b).

Oral health is a priority in the Chilean public health model, being recognized as an integral part of the well-being of individuals, families, and communities (Organización Panamericana de Salud, 2005). This is why the Ministry of Health of Chile developed the National Oral Health Plan 2020-2030, with the principles of prevention and promotion of the population's oral health, emphasising the most vulnerable groups. It also considers preventive and restorative interventions in prioritised groups through cost-effective actions based on the best available evidence (Ministerio de Salud. Gobierno de Chile, 2021).

The Chilean National Oral Health Plan is based on four strategic pillars:

1. Health promotion and disease prevention which is carried out through the design of interventions that seek to increase oral health knowledge and the participation of the population.

2. The provision of quality dental services focused on the provision of quality preventive and restorative interventions based on the best available evidence in a network of public health centres with a universal coverage approach.

3. The development of human resources, which seeks to improve the availability of dental human resources of all specialities throughout the network, together with the training of the health workforce according to the needs of each community.

4. Research, monitoring and evaluation in order to carry out epidemiological surveillance and evaluation of oral health policies and programmes for their adaptation according to the needs of Chile.

The National Oral Health Plan defined as one of its main objectives ‘to prevent and reduce the oral morbidity of greater prevalence in the child population, with emphasis on the most vulnerable' (Ministerio de Salud. Gobierno de Chile, 2016b). In the next section, the programmes and interventions of the Chilean public health care system introduced to fulfil this goal are described.

1.7.2 Community water fluoridation programme of Chile

The history of this programme dates back to 1953, when water fluoridation began in Chile, based on the successes of initiatives in other countries (Romero *et al.*, 2017). This intervention was founded by a pro-fluoridation committee formed by representatives of health, environmental hygiene, dentistry, and engineering of the University of Chile, the National Health Service, sanitary works of the Ministry of Public Works of Chile and the Rockefeller Foundation. Curicó was chosen as a pilot city for water fluoridation and San Fernando as a control city for comparison by its proximity and apparent similarity (both are urban and rural mixed cities in the central region of Chile). A fluoride concentration of 1 mg/l was artificially added to the water (Ministerio de Salud. Gobierno de Chile, 2018a). The supply of fluoride was difficult due to the difficulties imposed on imports and the lack of a national budget to support this intervention, which led to the water fluoridation programme being suspended and not taken forward.

Subsequently, the Chile Supreme Decree No. 735 of 1969 and its update, Supreme Decree No. 13 of 2006, approved the "Regulation of Water Services Destined for Human Consumption", which established that 'The Regional Ministerial Secretary of Health will determine by resolution the services that in their opinion should incorporate fluorides in the water'. The said regulation would be issued when the population is due to benefit, presents high indicators of dental caries (prevalence and severity), and the level of natural fluorides present in the water is insufficient to prevent caries (<0.5 mg/L) (Ministerio de Salud. Gobierno de Chile, 2018a).

In Chile, the optimum fluoride concentration recommended in drinking water by the programme guidelines, whether natural or artificial, ranges between 0.6 and 1.0 mg/L, with a maximum limit of 1.5 mg/L. These guidelines state that those regions most affected by dental caries, according to the epidemiological information available at the time of the implementation of the programme, should receive a higher concentration of fluoride, within the range of 0.8 to 1.0 mg/L, in contrast to those areas with lower caries levels, where the optimal range should be between 0.6 to 0.8 mg/L (Figure 1.1) (Romero *et al.*, 2017). The regions with a fluoride concentration between 0.6 to 0.8 mg/L are the regions I, II, III, IV, V, VI, XIII and XV, and those with a range between 0.8 to 1.0 mg/L are the regions VII, IX, X, XI, XII, XIV and XVI, and it is estimated that the national coverage of fluoridated drinking water reaches 83% of the urban population, corresponding to 72% of the total population (Ministerio de Salud. Gobierno de Chile, 2017b).

It should be noted that drinking water companies must measure the fluoride concentration daily, deliver monthly analyses to the regional health boards and the Superintendence of Sanitary Services of the Ministry for Public Works of Chile with their daily self-control samples and the concentrations of each plant, which are sent to the Ministry of Health. For its part, the regional health authority must measure at least once a month the concentration of fluorides delivered in drinking water (Ministerio de Salud. Gobierno de Chile, 2017b).

This programme has been a matter of much political and scientific debate since the pilot programme was established in 1985 by the Ministry of Health in the Valparaiso Region in Chile. In 2005, the Health Board of Concepción (VIII Region) stated that there was no scientific evidence to ensure that this programme improves oral health. They expressed that fluoride could act beneficially in the oral cavity without the need to be ingested in the water, as it could be delivered by other means such as toothpaste. However, regular and permanent access to these products is not guaranteed for the entire population (Ministerio de Salud. Gobierno de Chile, 2008).

Likewise, in 2007, the Regional Development Corporation of Region VIII expressed its rejection, arguing that water should not be used as a vehicle to administer medicines (Ministerio de Salud. Gobierno de Chile, 2017b). For these reasons, a measure was adopted by the authorities of the VIII region, so now this Region VIII and Region XVI (formerly part of Region VIII but divided in 2018) are currently without water fluoridation.

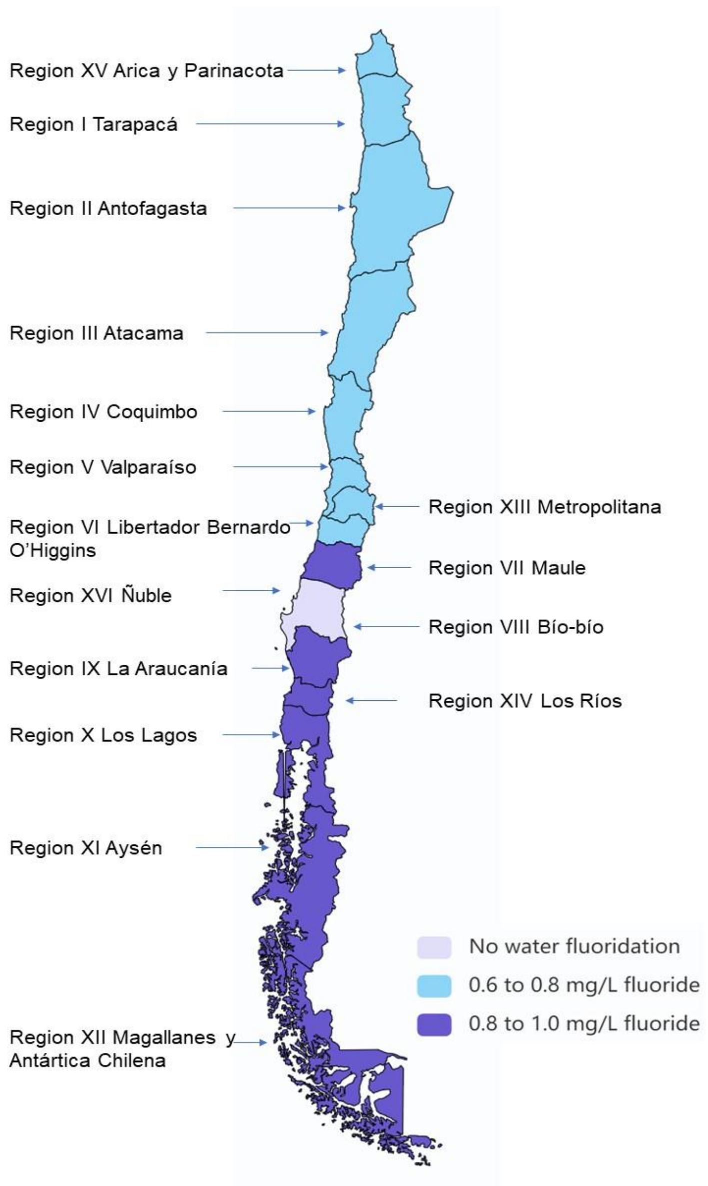


Figure 1.1: Regional division of Chile and its water fluoridation schemes

Despite this, the new national oral health plan includes in its strategic objectives the detection of gaps in coverage of fluoridated drinking water in the urban population throughout the country and the implementation of a plan to increase the coverage of the community water fluoridation programme (Ministerio de Salud. Gobierno de Chile, 2017b).

The national oral health plan established as a goal to the year 2020 the increase of the coverage of large fluoridation programmes (Ministerio de Salud. Gobierno de Chile, 2017b). However, to date, evaluations of the impact of the community water fluoridation programme at the national level in Chile are scarce. In a small study, Olivares-Keller *et al.* (2013) evaluated the prevalence and severity of dental fluorosis and its association with dental caries in 169 seven-year-old children from a municipality in region IX exposed to water fluoridation. They concluded that there was no association between dental fluorosis and caries levels. A multilevel analysis by Del Valle (2016) on the impact of water fluoridation on the urban child population of Chile, including 10,256 individuals, reported that the child population in Chile of 13 years of age or less who attend schools in urban areas with a fluoride concentration of less than 0.5 mg/L showed a 41% higher caries risk in comparison with the child population who attends to schools with a concentration of 0.5 mg/L or higher.

1.7.3 Fluoridated milk programme of Chile

In rural areas where water fluoridation is not feasible due to the lack of drinking water networks, a fluoridated milk programme has been implemented, which benefits children aged six to fourteen years who attend state-funded schools (Ministerio de Salud. Gobierno de Chile, 2017b). Currently, this programme is implemented in the rural schools of the V region to the south, covering ten regions in total. This programme runs only in rural schools without fluoridated drinking water. Before its implementation, the concentration of fluoride in the drinking water of each target school is measured, incorporating only those with a fluoride concentration less than 0.3 mg/L. The companies that elaborate the fluoridated milk must have special authorization from the Chilean Ministry of Health to add fluoride to milk, and this must be exclusively used to supply the school feeding programme. According to the programme guidelines, the recommended fluoride concentration in milk is 3.15 to 4.25 mg/L. Therefore, the amount of fluoride contributed per portion of regular consumption (200 ml) is 0.63-0.85 mg (Ministerio de Salud. Gobierno de Chile, 2018a).

As the target population of the milk fluoridation programme is children in primary education, from 6 years of age onwards, this programme would not generate observable benefits when assessing dental caries levels in six-year-olds due to the temporality of the effect. To date, there has been no formal evaluation of this programme in relation to child oral health.

Only the pilot of the programme, which was implemented in children aged three to six years in a rural municipality of region VI, was evaluated by Mariño *et al.* (1999). They reported that after three years of the implementation of the pilot, the prevalence of caries among children declined between 40% to 60% A follow-up study after three years of the cessation of the pilot by the same researchers reported that the termination of the milk fluoridation programme resulted in a significant increase in caries experience of children aged three to six years (Mariño *et al.*, 2004).

1.7.4 Primary care public clinics

In Chile, dental care is state-funded for children enrolled on the public health system. The activities carried out in primary care centres include preventive and restorative activities according to each patient's needs. Municipal health boards administrate primary public health care clinics, which include dental clinics. Each clinic covers an average of 20,000 inhabitants and has multidisciplinary professional groups, including dentists and dental nurses (Cartes-Velásquez, 2020).

Dental care interventions in six-year-olds and younger children provided in the public primary care centres include a comprehensive clinical examination that must include the evaluation of extraoral soft tissues, temporomandibular joint, intraoral soft tissues, oral hygiene and periodontal status, bone tissue, developing occlusion, caries risk, and child behaviours. If the primary care centre has dental x-ray equipment, these can be used for diagnostic confirmation. According to this examination, necessary preventive measures are carried out, which include education in brushing technique for caregivers, the application of sealants in the primary dentition, and the application of fluoride varnish. If cavitated caries lesions are detected, permanent restorative activities can be provided, including amalgam, glass ionomer and composite fillings. Endodontic treatments are performed on primary teeth in the case of lesions compromising the dental pulp. Finally, in those cases where, according to the diagnosis made by the dentist, it is not possible to perform any of the procedures mentioned above, the extraction of the affected tooth is performed (Ministerio de Salud. Gobierno de Chile, 2009). Dental emergency care for children is also provided in primary care clinics. This consists of providing emergency care for oral conditions that are sudden onset, which causes acute pain and requires immediate and urgent treatment (Ministerio de Salud. Gobierno de Chile, 2017b).

These interventions are described in Clinical Practice Guidelines, which uses the Grading of Recommendations Assessment, Development and Evaluation (GRADE) methodology (Guyatt *et al.*, 2011) to guarantee the performance of activities based on the best available evidence (Ministerio de Salud. Gobierno de Chile, 2021).

Although dental care for children belonging to the public system in Chile seeks to guarantee universal access, this is not always possible, mainly due to the lack of dentists in some areas of the country (Cartes-Velásquez, 2020). In order to improve access to dental care and clinical preventive measures in children in primary care centres, the Chilean Ministry of Health has developed two oral health policies:

1. ‘Comprehensive oral health for six-year-old children’, established in 2005, aimed to guarantee universal access to dental care in this age to educate, prevent and treat six-year-old children and to maintain or recover their oral health. It includes an initial oral health examination, diagnosis, education, preventive interventions and restorative treatment according to the children’s needs (Ministerio de Salud. Gobierno de Chile, 2017b).

2. “Dental assessment with risk approach” (from Spanish: “Control odontológico con enfoque de riesgo” or “CERO”): The CERO programme began in 2017 to increase the proportion of the healthy population and keep it in that condition. It consists of regular follow-up through dental examinations performed by the dentist of children under seven years of age with or without oral pathologies to prevent the development of oral diseases. Children enter this programme at six months of age and leave the programme when they turn seven years of age. The frequency of appointments depends on the individual risk of each child, measured through a guideline that considers factors such as their general health

condition, clinical oral health condition, diet, hygiene, use of fluorides, and family motivation. Each child receives the preventive strategies provided in the primary care clinics according to their risk categorization. The discharge of the CERO programme must coincide with the discharge of the Comprehensive oral health for six-year-old children programme (Ministerio de Salud. Gobierno de Chile, 2017b).

1.7.5 Sembrando Sonrisas programme

“Sembrando Sonrisas” (or, in English, “Sowing Smiles”) was established in 2015, with the aim of contributing to the national oral health plan by maintaining and improving the oral health of the vulnerable child population. It is based on the Scottish “Childsmile” programme (Ministerio de Salud. Gobierno de Chile, 2018c). The specifics objectives of Sembrando Sonrisas are to increase the oral health coverage of preschool children with specific measures of prevention, incorporating dental examinations in a school and nursery setting, and to improve and maintain the oral health of the child population in Chile.

The potential population of Sembrando Sonrisas is defined by children aged two to five years who attend state-funded Chilean nurseries. This group is approximately 400,000 children each year (Ministerio de Salud. Gobierno de Chile, 2018c). Pre-school education in Chile is not mandatory, except for the second level of transition (4-5 years of age), which is a requirement for entry to primary school, and considers children between 3 months and six years of age. These age groups are organized in two cycles: the first cycle, between zero and three years; and the second cycle, between four and up to five years of age (Ministerio de Educacion. Gobierno de Chile, 2014).

1.7.5.1 Sembrando Sonrisas establishment and rollout

In 2006, the “Programme for the Promotion and Prevention of Oral Health for Children under 6-years-old” was established by the Chilean Ministry of Health to improve the oral health of the preschool population (Ministerio de Salud. Gobierno de Chile, 2007b). The planned objective was intended to be achieved through the implementation of 5 strategies: (a) Promote healthy eating habits and oral hygiene, and consumption of fluoridated drinking water; (b) Install the proper use of fluorides; (c) Improve the oral health conditions of the personnel in charge of the care of the children; (d) Encourage self-care in oral health of educational communities through participation in the design of the programme at the local level, and (e) Integrate parents and guardians of children in the care of their teeth (Ministerio de Salud. Gobierno de Chile, 2007b). The programme started as a pilot in seven municipalities. The programme consisted mainly of educational sessions with oral health and diet messages, for teachers working in nurseries. At present, there is no published information on the evaluation of this pilot. Only a qualitative evaluation of the coverage of the educational sessions and their impact on oral health knowledge in parents and the nurseries staff that attended the educational sessions, which was undertaken by Revello and Isler (2013). In that study, 56% of childcare workers and 22.8% of parents and caregivers had participated in oral health workshops offered in preschools. A higher percentage of those who were trained in these workshops passed an oral health knowledge test, compared to their peers who were not trained (Revello and Isler, 2013). Based on this pilot programme, and the robust evidence provided by the evaluations of 'Childsmile' 'Sembrando Sonrisas' was implemented nationally in 2015, to include other components and settings as a multifaceted programme (Ministerio de Salud. Gobierno de Chile, 2018c).

1.7.5.2 Components of the Sembrando Sonrisas programme

"Sembrando Sonrisas" programme consists of three components. The programme includes the option of negative consent to any of its components; therefore, individual consent is not required (Ministerio de Salud. Gobierno de Chile, 2018c).

The three programme components are:

1. The delivery of an intervention performed by the dentist and carried out with the support and coordination of the nursery's educational team to train the nursery staff to implement daily supervised toothbrushing in nurseries. This also includes the delivery of oral health kits with four toothbrushes and one 1000 ppm of fluoride toothpaste tube for each child

annually.

2. An oral health examination of each child each year by a dental team (dentist and dental nurse) through visual inspection with a dental mirror and natural light in the nurseries (classroom or other room of the educational establishment).

3. The application of fluoride varnish (ClinPro©, 3M, 22.600 ppm sodium fluoride) to each child, twice per year, by the dentist in the nurseries.

1.8 Approaches for the evaluation of oral health programmes

Monitoring and evaluation of public health improvement programmes or interventions are essential to determine whether they are effective and cost-effective, as well as supporting implementation and monitorisation of programme delivery, to provide evidence for the continuing support of the programme (Rossi *et al.*, 2018). Evaluation not only can provide feedback on the effectiveness of a programme, but is also a way to determine whether or not the programme is meeting its proposed aims. It can also identify problems with implementation, and help to resolve any concerns that can arise when the programme is implemented (Rossi *et al.*, 2018).

Rossi *et al.* (2018) refer to the evaluation of programmes as "evaluation" or "evaluation research" without distinction. For them, the evaluation of programmes is “the systematic application of procedures and methods of social investigation to evaluate and weigh the conceptualization, design, implementation and utility of social intervention programmes". In other words, the evaluators use research methodology to judge, analyse, evaluate and improve how programmes and policies are conducted, from the earliest stages of definition and design to the stages of development, implementation and outcomes measurement. According to these authors, evaluation is the application of research methods to the analysis of interventions and generates relevant information to policymakers from which public policy decisions and allocation of resources for the planning, design, implementation, and continuity emerge (Rossi *et al.*, 2018).

Programme evaluation is an essential tool for checking the value of either a whole programme or some aspect of a programme (Meyer *et al.*, 1982). However, the extent to which the evaluators achieve both the evaluation goals as well as the programme objectives depends on the theoretical frameworks or models that inform their evaluation (Owston, 2008).

The Medical Research Council (MRC) guidance on the development of complex interventions for health (MRC, 2008), recommends that interventions be systematically developed with attention being paid to the existing evidence as well as any relevant theory. It is also important that researchers consider the programme or intervention reach carefully, and then the evidence of effectiveness that can be gathered (Craig *et al.*, 2008). Evaluation should always consider the ‘best available’ methods, even if they are not theoretically optimum, it may yield useful results (Craig *et al.*, 2008).

In a recent update on the MRC guidelines performed by the National Institute for Health Research of UK (NIHR), an intervention can be considered as ‘complex’ due to the number of components involved; the range of behaviours addressed; the expertise and skills required by the people performing and those receiving the intervention; the number of groups, contexts, or levels targeted; and the permitted level of flexibility of the intervention (i.e. how dynamic or adaptive the intervention is) (Skivington *et al.*, 2021).

A crucial aspect of programme evaluation is the choice of outcome measures or evidence of change. Evaluators should assess which outcomes are most important (primary outcomes) and how to deal with multiple outcomes (secondary outcomes) in the analysis with due consideration of statistical power and transparent reporting. Researchers have many study designs to choose from, and different designs are optimally suited to consider different research questions, circumstances, and resources. Other options or extensions to standard study designs of randomised controlled trials are developed to improve the efficiency of complex intervention research. Among these, non-randomised designs might work best if a randomised design is not practical, for example, in natural experiments or ecological evaluations and in cases where context affects implementation and outcome (Skivington *et al.*, 2021).

1.8.1 Ecological studies for programme evaluation

In clinical practice, evidence-based decision making has now become well-established (Froude, 2012). Randomised controlled trials (RCTs) are often used to evaluate the effectiveness of each intervention and the establishment of organisations such as the Cochrane Collaboration facilitate evidence synthesis (Heller and Page, 2002). However, the gold standard RCT is not always possible, or even appropriate for public health interventions, yet alternative designs have not become well established and are excluded from many guidelines and systematic reviews that aim to provide evidence-based recommendations. Therefore, recommendations are biased towards those interventions that are easier to evaluate, but that may not necessarily be the most effective (Craig *et al.*, 2012). This may mean that resources are not allocated efficiently, and the interventions leading to the most significant health benefits may not always be chosen (Des Jarlais *et al.*, 2004).

Health intervention dissemination is often affected by broader social and environmental circumstances (Lorenc et al., 2013). Therefore, some interventions do not necessarily reduce health inequalities even if randomised controlled trials establish their efficacy. Interventions that depend on individual motivation often increase health inequalities (Schou and Wight, 1994; Lorenc et al., 2013).

In public health, the health problem can be detected at a population level, this could range from a small community to a regional, national or even multinational population. Here, the intervention is often targeted to the population, with the aim of improving health outcomes (for example rates of a disease) within the population as a whole (Richard *et al.*, 2011). Complex public health interventions may affect a range of health outcomes. Furthermore, interventions may also seek to target non-health outcomes, for example a workplace health programme may seek to improve various health outcomes in employees but also save an organisation money by reducing absence, street lighting interventions may seek to reduce road traffic accidents but also reduce crime, the introduction of cycle lanes may seek to increase rates of physical activity but also reduce carbon dioxide emissions (Craig *et al.*, 2012). Besides, many public health interventions target outcomes can occur months, years or even decades into the future. Therefore, programme evaluation that contains diverse strategies to engage several different stakeholders across a range of settings might address health more comprehensively and thus yield better results than an RCT (Craig *et al.*, 2012).

In this context, natural experiments are an essential approach used to answer research questions that would, otherwise, be impossible to address, or employed because of ethical concerns about the use of randomisation to interventions. The UK MRC produced a useful document discussing the nature and significance of natural experiments within medical and public health research (Craig *et al.*, 2012).

According to Dawson and Sim (2015) the term “natural experiment” has not an exact definition. It can be used interchangeably to refer either to the methodological approach of using unplanned or uncontrolled events as a source of variation or to the events themselves. At its broadest, it has been used to distinguish the “comparative method”, i.e. detailed comparisons of contrasting cases, from single case studies, or is used to refer to methodologies in which there is no manipulation of exposure, but the assignment of subjects is “as if” random (Dawson and Sim, 2015).

As stated by the MRC, natural experiments are “events, interventions or policies which are not under the control of researchers, but which are amenable to research which uses the variation in exposure that they generate to analyse their impact” and the studies of these experiments are the research approaches to assess the impact on health or other outcomes of such events. The key to these definitions is that the intervention is not undertaken for research. Also, the variation in exposure and outcomes is analysed using methods that attempt to make causal inferences (Craig *et al.*, 2012). Classic examples given in this guideline are the effects of clean air legislation, indoor smoking bans, and changes in the taxation of alcohol and tobacco.

A possible approach in natural experiments is the use of ecological studies. Ecological studies are frequently used to investigate the spatial patterns of diseases and interventions (Matsuyama *et al.*, 2016). This approach is appropriate when the prevention or intervention implications are at a population level (Gasparrini *et al.*, 2009). Recognition of the importance of considering how broader social, environmental, and biological factors jointly influence health and the integration of a social-ecological systems perspective that acknowledges the complexity and emerging "ecologically inclined multi-level social epidemiological frameworks" is evidence of a paradigmatic shift placing epidemiology "on the track of ecologism" (Marmot *et al.*, 2008).

Ecological models have emerged from developments in many disciplines and fields, not just public health, also sociology, biology, education, and psychology, which in turn converged to form the biological and behavioural foundations of health promotion (Green *et al.*,1996). New developments have reinforced their relevance to the field of public health. In particular, the increased interest into social inequalities in health has directed interest into the central role of broader contextual determinants of health, such as socioeconomic factors, gender, and other social and cultural influences (Marmot *et al.*, 2008). Epidemiologists have debated the limitations of dominant causal models and methods, which emphasise a narrow view of causality and a focus mainly on investigating proximate, individual-level risk factors (McMichael, 1999; Krieger, 2001).

This study design is sometimes criticised for weak causal inference since associations observed on a population level are not necessarily applicable on an individual level. However, this "ecological fallacy" can be avoided when causation has been shown in previous studies, the focus of the study was contextual or based on population effects, and there is no inference to individuals (Idrovo, 2011; Matsuyama *et al.*, 2016).

As mentioned, ecological studies are an alternative for the evaluation of public health policies, especially when these are national/population-wide in scope. In

Mexico, Safdie *et al.* (2014) evaluated the impact of an obesity prevention programme to promote healthy lifestyle behaviours in school in public elementary schools at national and district level. According to their results, the programme was successful in changing student behaviour in the diet at the time of the evaluation, providing new information for the implementation of multifactorial interventions in school-based health promotion programmes.

Arakawa *et al.* (2017) conducted an ecological study for the evaluation at the municipal level of a public health programme for the control of tuberculosis in Brazil. This approach allowed them to conclude that the programme had little coverage in the risk groups, such as families with higher deprivation or HIV positive patients. This information was given to their health teams for the implementation of plans to improve the coverage and effectiveness of the programme.

In Japan, an ecological study was conducted by Matsuyama *et al.* (2016) to evaluate the impact of a school-based fluoride mouth-rinse national programme using aggregated data of children born between 1994 and 2000 in all 47 Japanese prefectures. This ecological study concluded that the fluoride mouth-rinse administered to children in schools of all socioeconomic statuses was associated with lower DMFT at 12 years of age, reducing dental caries inequalities via proportionate universalism.

Macpherson *et al.* (2013) conducted the earlier Childsmile evaluation on an ecological basis, assessing the impact of daily supervised toothbrushing in nurseries on dental caries of the child population of Scotland at the regional level, which led to continued Scottish Government support and funding, and ongoing development of the Childsmile programme.

Despite the increase in the use of ecological studies for the evaluation of public health programmes (Dawson and Sim, 2015), this approach is not yet widespread in the evaluation of oral health interventions, which poses an opportunity for this type of study, especially in policies of national reach, such as the oral health improvement programmes implemented in Chile.

1.8.2 Chilean national oral health programmes evaluation opportunities

The oral health improvement programmes of Chile and their components have the potential to reduce the prevalence of dental caries among the children of Chile. Comprehensive implementation of several evidence-based interventions is considered the main route to achieving this aim (Walsh *et al.*, 2010, McMahon *et al.*, 2011, Marinho *et al.*, 2013). As previously mentioned, in Chile there are few published studies that determine the burden of caries disease in infants (Ministerio de Salud. Gobierno de Chile *et al.*, 2007; Echeverría *et al.*, 2010; Zaror Sánchez *et al.*, 2011; Ministerio de Salud. Gobierno de Chile, 2012), and according to the Chilean Ministry of Health database, and the available scientific literature, there is no study which has evaluated the impact of the national oral health programmes for Chile through the use of routine data on the population.

1.9 Chapter 1 summary

Dental caries remains the most common non-communicable disease of childhood worldwide. Once caries develops in young children, it progresses, commonly resulting in pain, and may harm child development and incur significant costs for healthcare systems. Several approaches exist to prevent the disease, mainly through the exposure of the population to appropriate amounts of fluoride and the decrease in sugar consumption.

Chile is facing up to the dental caries challenge in childhood by developing new public health programmes that aim to improve child oral health and reduce oral health inequalities. These initiatives are in addition to the national drinking water fluoridation programme. Sembrando Sonrisas is one of the most crucial health policies in the community context for the fulfilment of health objectives for children in Chile. This programme was rolled out nationally in 2015.

The utilisation of ecological studies is considered to be important in the evaluation of public health. Such epidemiological research can help inform modifications and the future direction of public health programmes and policies.

This literature review has identified evidence gaps in dental caries trends of the child population in Chile and the impact of the interventions developed to assess this public health challenge. This relates, firstly, to assess the dental caries levels in children at a population level, and secondly to evaluating the impact of the oral health improvement programmes of Chile in relation to child oral health. This information is essential for policymakers and health planners, to further improve the preventive strategies in the country and tackle the oral health related inequalities challenges.

Chapter 2 - Research Aims and Objectives

Chapter 2 describes the overarching aims and objectives of this doctoral research.

2.1 Research Question

Based on the findings of the literature review, the study specifically addressed the following overarching research questions:

What has been the impact of the national oral health improvement programmes of Chile on oral health outcomes of the child population? Additionally, what have been the trends of inequalities in child oral health in Chile?

2.2 Overarching Aim and Objectives

The overarching aim of this study is:

To undertake a quantitative outcome evaluation of the national child oral health improvement programmes for Chile on oral health outcomes and related inequalities.

This overarching aim will be addressed by fulfilling the following objectives:

1. To collect, collate, and manage data from the national oral health programmes, child dental caries, and sociodemographic characteristics at the national, regional, and municipality level in Chile, assessing data quality and completeness.

2. To design and develop an area-based ecological longitudinal cohort to evaluate the trends in dental caries of six-year-old children in Chile at national, regional and municipality levels, related area-based socioeconomic inequalities, and the impact of the municipality's sociodemographic characteristics on child caries levels.

3. To assess the impact of the national oral health programmes, including community fluoridated water and the preventive interventions performed in primary care public clinics, on the caries levels of six-year-old children belonging to the Chilean public health system, and related inequalities.

4. To assess the impact of Sembrando Sonrisas programme interventions on the dental caries outcomes of five-year-old children covered by the programme since its establishment and rollout, its effect over and above community water fluoridation, and related inequalities.

Each of these objectives are respectively addressed in the following Chapters:

Chapter 3: Methods —data collation, indexing, management and quality checks.

The objectives of this chapter are to:

1. Obtain Information Governance approvals to access and analyse multiple datasets from different sources and Data Controllers, through Chilean Government organisations.

2. Identify, collect, and collate the datasets and variables available to be used in the study.

3. Extract, process and translate the datasets into the English language, producing a data dictionary.

4. Undertake quality and completeness assessments of the datasets.

Chapter 4: Caries experience in Chilean children and related inequalities.

The objectives of this chapter are to:

1. Conduct an in-depth descriptive analysis of the datasets, including the dental examination data performed in the primary care clinics of Chile, to measure the quality and completeness of variables and categories and to

assess their potential for evaluating the effectiveness of the national oral health improvement programmes for Chile on child oral health.

2. Identify and create an outcome variable that can be used as a child oral health measure to evaluate the national oral health improvement programmes for Chile.

3. Create a cohort to evaluate the impact of the national oral health improvement programmes for Chile on child oral health.

4. Analyse the trends in child oral health at the national, regional and municipality-level.

5. Investigate the association between potential confounders and the outcome variables in the cohort.

6. Identify the most parsimonious model for assessing the impact of the national oral health improvement programmes for Chile on children's oral health.

7. Assess area-based socioeconomic inequalities in the distribution of dental caries in Chilean children.

Chapter 5: Impact of the national oral health improvement programmes for Chile on six-year-olds caries experience.

The objectives of this chapter are to:

1. Undertake a descriptive analysis of all the variables included in the national oral health improvement programmes datasets.

2. Evaluate each of the national oral health programmes individually to investigate their association with the caries experience of six-year-olds in Chile.

3. Identify a parsimonious model that includes the interventions of the national oral health programmes associated with the caries experience of six-year-olds in Chile.

4. Evaluate the impact of the national child oral health improvement programmes interventions on the Chilean six-year-olds most affected by dental caries.

5. Explore the differences in the reach of each programme according to area-based socioeconomic deprivation.

Chapter 6: Impact of the Sembrando Sonrisas Programme on the oral health outcomes of Chilean children.

The objectives of this chapter are to:

1. Describe the data from the dental examinations performed in nurseries for the Sembrando Sonrisas programme.

2. Identify and create an outcome variable that can be used as an oral health measure for evaluating the Sembrando Sonrisas activities.

3. Create a cohort to evaluate the impact of Sembrando Sonrisas activities on caries levels of covered children at the municipality level.

4. Investigate the association between potential confounders and the outcome variable in the cohort.

5. Identify the most parsimonious model for assessing the impact of Sembrando Sonrisas and the independent effect of each activity on dental caries levels of children covered by the programme at the municipality level.

6. Undertake a descriptive analysis of the intervention and potential confounding variables included in the Sembrando Sonrisas dataset.

7. Evaluate the effect of Sembrando Sonrisas interventions on the caries experience of five-year-olds covered by the programme.

8. Identify a parsimonious model that includes all Sembrando Sonrisas interventions associated with the caries experience of Chilean five-year-olds covered by the programme over and above CWF.

9. Explore the area-based socioeconomic inequalities in the reach of Sembrando Sonrisas programme interventions.

Chapter 7: Discussion, Conclusions, and Recommendations.

The objectives of this chapter are to:

1. Summarise key findings of the thesis as a whole.

2. Compare findings with the literature and explore explanations to the results of this thesis.

3. Discuss thesis strengths and weaknesses.

4. Draw conclusion and implications of the thesis, including proposing recommendations for policy, public health practice, and further research.

Chapter 3 – Methods — Data collation, indexing, management and quality checks

Chapter 3 describes processes of establishing a database including request and collation of national, regional, and municipality level data of the national oral health improvement programmes for Chile interventions and activities; child dental caries outcomes; socioeconomic deprivation levels, and the process of data management and quality and completeness checks.

3.1 Routine administrative data

The rise of "big data", defined as 'Extremely large amounts of data which require rapid and often complex computational analyses to reveal patterns, trends, and associations, relating to various facets of human and non-human entities' (Baro *et al.*, 2015), represents a revolutionary opportunity for both researchers and policymakers. This opportunity has been perhaps best recognised first in some Scandinavian countries, in which national databases – including healthcare and conscription data – have been linked together using unique personal identification numbers, allowing for large and powerful research studies (Ludvigsson *et al.*, 2009).

These studies have significantly improved the knowledge of issues such as cancer, mental health conditions, pre-term birth, cognitive ageing and socioeconomic inequality, and have served as a guide for further research and decision-making in various countries (Ludvigsson *et al.*, 2009).

Administrative data offer much larger sample sizes and have far fewer problems with attrition, non-response, and measurement error than traditional survey data sources. Administrative data are therefore critical for cutting-edge empirical research, and particularly for credible public policy evaluation (Card *et al.*, 2012). However, routine administrative data despite large population-wide sample size are not without their limitations —which are mainly associated with reproposing data for a secondary (often research) purpose. This limitations include the lack additional clinical information about the diseases of interest, health outcomes, and interventions, inconsistency in variable definitions and records, and a large sample size and power may result in overestimating associations, which may lead to incorrect conclusions (Ehrenstein *et al.*, 2017).

Collecting primary clinical data is still considered the gold standard for assessing health-care quality. It is however, an elaborate and expensive approach, primarily if reliable and valid answers must be provided for various groups of patients with various diseases over relatively long periods (Maier *et al.*, 2016).

It is commonly acknowledged that health-related data routinely collected as part of everyday practice, or generated as part of a research study, have great potential to improve patient care, citizens' lives and professional services (Jones *et al.*, 2017). Therefore, data access for research purposes in health should be an easy and fast process, with robust organisations that support and safeguard the management and use of data. However, despite the evidence of the benefits of sharing health administrative data, the road to obtaining data is not always smooth, and it involves navigating the complex legislation and into governance standards which vary considerably across countries (Iveson and Deary, 2019).

3.2 Information Governance regulation of Chile

3.2.1 Law on Transparency and Access to Public Information of Chile

Data routinely collected in Chilean Government organisations can be requested for research through Law No. 20,285, known as the "Transparency Law". A detailed description of this law is shown in Appendix 1. Briefly, after being requested by an individual, the State administration has twenty working days to deliver the information or reserve it according to the cases established by law. In exceptional cases such as difficulty gathering the requested information, the State administration can extend the delivery for a further ten days.

3.2.2 Department of Health Statistics and Information of the Government of Chile

In Chile, the Ministry of Health is responsible for formulating, setting and controlling health policies. This includes processing the data collected in the public health organisations for statistical purposes and keeping records or data banks (Ministerio de Salud. Gobierno de Chile, 2016a). In doing so, the Ministry of Health is responsible for: "Proposing the information technology policies of the sector and ensure its application, proposing the standards of data, codes, and classifications in the information systems of the sector and ensuring that they are observed." (Ministerio de Salud. Gobierno de Chile, 2016a).

To comply with these requirements, the Chilean Ministry of Health had to create a specific department for the registration of all information emanating from the health sector in the country.

Since its creation in 2000, the "Department of Health Statistics and Information" (from the Spanish: "Departamento de Información en Salud" or "DEIS") has, within its roles, to define health information standards to systematically introduce a planned model of continuous improvement for information management; to contribute to decision-making based on valid, comparable, reliable information that support the integral health care at the individual and population level; and to develop clinical management and public health policies (Ministerio de Salud. Gobierno de Chile, 2016a).

3.2.3 Monthly Statistical Records in Health of the Public Health System of Chile

Chile has a structure of health statistic records, including the statistics of activities in the establishments belonging to the National Public Health Centres of the Government of Chile and the statistics of the beneficiary population of all the health programmes at the national, regional and municipal level (Ministerio de Salud. Gobierno de Chile, 2018b). These statistics are constructed through a monthly statistical record (from the Spanish: "Registro Estadístico Mensual" or "REM") that each health centre, whether hospital or primary care clinic, periodically sends to the Ministry of Health, becoming a fundamental tool for monitoring health services, as well as helping to assess the fulfilment of national health objectives (Ministerio de Salud. Gobierno de Chile, 2016a).

Thus, each health centre has a code assigned by DEIS according to the structure indicated by the Ministry of Health of Chile, specifying name, municipality, address and dependence (Ministerio de Salud. Gobierno de Chile, 2018b). According to this, the REM of all public health programmes is referred to the DEIS by establishments and strategies according to this location codes, individually informing each activity according to related categories, as appropriate.

Public health facilities are those defined by the Ministry of Health and DEIS as: a) Public urban primary care clinics; b) Public rural primary care clinics; c) High, medium and low complexity hospitals, all of them with an independent and individual identification code (Ministerio de Salud. Gobierno de Chile, 2018b).

For DEIS, public health programmes are defined as a series of activities that meets technical requirements according to health objectives registered in the National Health Strategy. These must be carried out by health teams registered by the Ministry of Health, and that are executed for the benefit of the population of the country. Each activity carried out in the different health programmes has an independent and specific code to be sent to DEIS through the REM (Ministerio de Salud. Gobierno de Chile, 2016a).

3.3 Ethics approval

By the Chilean law on Data Protection and Private Life, the processing of secondary health data carried out by the Ministry of Health ensures the confidentiality of personal data to users who register as part of the Public Health System. In addition, patients' data are subject to data dissociation procedures, so the information obtained is anonymised and cannot be associated with a specific or determinable person. The law of access to public information establishes that aggregated anonymised routine health data and the non-health information can be publicly accessed under the principle of transparency of the

Chilean Government's public function. Therefore, no specific ethical approvals are needed to use this data.

However, because the evaluation was being led by a research team at the Community Oral Health Department, the University of Glasgow Ethics Committee approval was requested.

An application entitled '*Evaluation of the national child oral health improvement programmes for Chile*' was submitted to the University of Glasgow College of Medicine, Veterinary, and Life Sciences Research Ethics Committee, with ethical approval being granted (Appendix 2).

3.4 Data collation and information governance approvals

To describe the steps involved in accessing the data and the necessary approvals for its use for this research, the process will be divided into five stages: i) data scoping, ii) meetings with key Data Controllers, iii) data requests applications, iv) data access and governance approvals, v) data extraction and indexing.

3.4.1 Data Scoping

An initial scoping exercise was undertaken to identify potential sources of datasets, variables, and to identify the Data Controllers that could be used in the evaluation of the oral health improvement programmes on child oral health. This search was carried out between November 2018 and May 2019. It was based on the grey literature searching and the information obtained in Chapter 1.

Data were identified from six different organisations:

1. Department of Health Statistics and Information, which holds, collates and aggregates health service data and statistics for the REM, which are the primary health care databases with data on all the programmes of the public health system of Chile. This databases included aggregated level data on child dental examinations, dental treatments performed in children aged zero to six years in public primary care clinics, and

Sembrando Sonrisas programme interventions in nurseries (Ministerio de Salud. Gobierno de Chile, 2017a).

2. Superintendence of Sanitary Services of the Ministry of Public Infrastructure of Chile (SISS) for fluoride concentration and coverage of community water fluoridation datasets (Ministerio de Obras Públicas Gobierno de Chile, 2019).

3. Regional Health Services (SEREMI) for the supervision of the community water fluoridation datasets (Ministerio de Salud. Gobierno de Chile, 2019b).

4. National Public Health Insurance (FONASA) for the beneficiary population of the public health system datasets (Ministerio de Salud. Gobierno de Chile, 2019a).

5. National Institute of Statistics of Chile (INE) for Multidimensional Poverty Index and Rurality indexes for each Municipality produced with the information collected from the Chilean National Socioeconomic Characterization Survey (CASEN), and population projections data from the National Census (Instituto Nacional de Estadísticas, 2017).

6. National Observatory of Public Health of the University of Chile for Socioeconomic Development Index (IDSE) datasets (Gattini, 2014).

3.4.2 Identifying and meeting Data Controllers

It was not always clear who the Data Controllers for each dataset were. A number of strategies were used to make contact, including via: i) examining organisations webpages; ii) contacting key representatives within the organisations via email; and iii) holding face-to-face meetings with key representatives from the organisations. These meeting involved explaining the study plans and making the case for data access, and then trying to pin down a timetable on data access.

3.4.2.1 Ministry of Health of Chile (MINSAL)

The primary source of health data in Chile corresponds to the DEIS website, in which it is possible to access and download the REM databases for the years 2008 to 2019, which are aggregated at national, regional and municipal level. According to the Chilean Data Governance protocols and direct transparency, this information is publicly accessible and constitutes an open access database, according to Active Transparency.

The DEIS helpdesk was therefore contacted via email and it was confirmed that all information that is sent to DEIS and processed is delivered in the REM open access database, and that these are updated one month after their registration in public primary care clinics. Specific advice on the impossibility of accessing databases at the individual level was also provided, in accordance with the current data protection laws.

In April 2019, meetings were held with key representatives of the possible data providers of the Oral Health Department of MINSAL. The representatives included the Chief of the Oral Health Division of the Department of Public Health, the National Drinking Water Fluoridation Programme Supervisor and the Community Oral Health Programmes Supervisor, to discuss the completeness and availability of the data related to oral health programmes and caries outcomes in children. In these meetings, the representatives confirmed that the only source of health data in the country related to oral health at a national, regional and Municipality level corresponded to REM records.

They were many delays in data access, which are described in detail in section 3.4.6. Further meetings and contacts via email had to be held between July 2019 and January 2020, with the representative of the community oral health programmes and other representatives of MINSAL, to guarantee the collection of data, in order to address possible solutions, which allowed for the ultimate collection of the data.

3.4.2.2 Regional Health Services (SEREMI)

At the time of this study, there are 16 regions in Chile, each of which has a SEREMI. Therefore, the web pages of each of the SEREMIs were visited. The searched databases were not available for download by direct transparency law, so emails were sent to help desks, receiving the response that the data must be requested online.

3.4.2.3 National Public Health Fund Insurance (FONASA)

The website of FONASA was visited during data scoping. When accessing this webpage, the databases searched were not available for download. An email was sent to the help desk, inquiring about the data availability, to which it was replied that the data could be obtained through a request according to the Transparency law.

3.4.2.4 Superintendence of Sanitary Services (SISS)

The website of the SISS was accessed to search for the databases on fluoride concentration and coverage of community water fluoridation. When accessing the page, following current legislation on direct transparency, the databases from 2010 to 2018 were available for download, without the need for any special permission for their use, analysis, and publication.

An email was sent to the help desk, inquiring about the data for the years 2008 and 2009, to which it was replied that the data could be obtained through a request through the transparency law.

3.4.2.5 National Institute of Statistics of Chile (INE)

The website of the INE was visited during data scoping. The data on this website is anonymized, aggregated and open access and no special permission is required for its download, use, analysis, and publication, following the current data protection laws for direct transparency.

3.4.2.6 University of Chile

During the data scoping stage, the website of the National Observatory of Public Health of the University of Chile was accessed, to find more information regarding IDSE. The researcher responsible for publishing the indicator was contacted by email in March 2019, and a meeting was arranged.

Two meetings were held with a representative of this institution. The first, in April 2019, was to enquire and understand how the database had been designed and request access to the database. In a second meeting, held in October 2019, the approval for the access and use of the database was confirmed.

3.4.3 Data requests applications

For this stage, several data requests were made to five of the key organisations, which are shown in Table 3.1. This involved the preparation of a set of forms. Depending on the organisation, the requests were divided into two types: i) Form for downloading data directly from the open access databases of the webpages for transparency; and ii) Request of data to the institution by Law of Transparency.

Final versions of the forms were submitted between June 2019 and January 2020. In total 24 forms were submitted, along with eight amendments.

Amendments were submitted if the following situations occurred: i) the data were not delivered in the manner in which they were requested or corresponded to incomplete datasets, ii) the requests were not delivered in the period outlined by the Transparency Law (20 business days plus a 10-day extension, reported by email), iii) the request for access was rejected by the institution.

Table 3.1: Organisations, their role, and number of forms required.

Organisations	Role (type of data held)	Forms submitted	Amendments Submitted
Department of Statistics in Health of Chile	Data Controller (Programmes and dmft data) and Research Support	4	1
Regional Health boards	Data Controller (Health and fluoridation data)	15	7
National Public Health Found Insurance	Data Controller (Public health beneficiary data)	1	0
Ministry of Public Infrastructure of Chile	Data Controller (fluoridation data)	2	0
National Institute of Statistics of Chile	Data Controller (Census and deprivation data)	2	0
Total		**24**	**8**

3.4.4 Data access and information governance approvals

The next step was to obtain the data access and information governance approvals. To get to this stage, the study had already considered all legal requirements according to current Chilean regulations, along with the public interest of the research.

Access and governance of datasets from INE, and SISS were obtained relatively quickly, through downloading from open access web data platforms via Active Transparency once the approval of the submitted forms was obtained. In the case of the SISS, it was necessary to wait 18 days from the date of the request to obtain the data for the years 2008 to 2009, which were not included in the website for download, in compliance with the regulations of the Transparency Law. In general, these three organisations complied with the provision of access and governance to data following the protocols established by the Transparency Law of Chile.

Access to health and non-health administrative data from the other organisations, however, proved to be complex.

In the case of the Ministry of Health, the REM databases were available for download as open access data, which were downloaded once the approvals were obtained. For the other administrative health data, that are not found in the REM databases, the access process required much more effort. When the 20 days established by law were fulfilled, the Ministry of Health requested 10 more days for the delivery of the data, which after 12 days were incompletely delivered. The institution was contacted by email to obtain a response, in which they replied that due to the high workload of the personnel in charge of delivering the data, they needed more time to respond satisfactorily to the request.

Finally, access and governance of the requested data were delivered five months after the request date, which did not comply with the protocols established by the Transparency Law of Chile regarding delivery time. It was decided not to take any action in this regard, in order to guarantee good relations with the Ministry of Health, a key stakeholder for this study.

Regarding the requests made to FONASA, once the 20 days for the delivery of response were fulfilled, according to the Transparency Law, an extension of 10 days was requested by the Institution. Seventeen days later, access and governance were received in relation to the requested datasets but the data were incomplete. The Institution was contacted via email, and the response indicated the lack of data was due to FONASA having electronic records and databases of its beneficiaries only from 2010 onwards, so it was not possible to access earlier information. A meeting with the Transparency Officer of FOANSA confirmed that there was no other institution that had access to this information.

The SEREMI Regional Health Boards presented different response times to the request for access and data governance made.

Eight of the sixteen regions submitted the data according to the Transparency Law protocols. Two requested an extension of 10 days in the term; three requested that the delivery of the data should be in-person in each region, together with a meeting to discuss the use of the data, and two did not provide any response.

Since two of the 16 regions did not submit any response within the time stipulated by the Transparency Law, SEREMI was contacted by email and telephone, without receiving any response. In order to obtain the expected data, and following the protocols established in the Chilean Transparency Law, a formal claim was made to the General Comptroller of the Republic of Chile, an institution that, within its powers, must ensure compliance with the Transparency Law.

This procedure consists of the General Comptroller of the Republic issuing a final notice to the Institution so that it may respond to the requests made, and if these are not answered satisfactorily, the Transparency Officers of each Institution risk at least the suspension of their remuneration for at least six months, and in cases where there is no justification, the final dismissal from the Institution (Vial, 2012).

Once this procedure was carried out, six months after making the requests via the Transparency Law, data access and governance was obtained for the datasets requested from these two SEREMI.

Only five of the regions had all of the requested information in the expected time range. In general, all the SEREMI explained that the absence of data were due to the loss of data over time, without providing further details.

3.4.5 Data extraction and indexing

After approval, data needed to be extracted, translated into English, and indexed to ensure it to be available for the study. For this, a protocol was generated for the extraction, indexing and translation of the databases obtained from the Data Controller of the organisations.

This protocol consisted of the following steps:

i) If the dataset of interest for the research corresponded to a subset of the original database, the variables of interest were selected, and the cases filtered according to the age range of interest for the study.

ii) The codebook of the files had to be accessed, and the set of variables selected, and then queried in Structured Query Language (SQL) with a standard code for all datasets from the same origin, to select cases of interest.

iii) They were then exported in .xlsx format from Microsoft Excel Software (Microsoft Corporation, Redmond, WA, USA.)

iv) Once the information was exported, the names of the variables were translated from Spanish to English.

v) Subsequently, the .xlsx file was imported into SAS 9.4 software (SAS Institute Inc., Cary, NC, USA.), where it was processed, indexed, and saved as a .sas7bdat file to be securely transferred and stored using the University of Glasgow Security Transfer Service.

All documents, files, datasets, and the database of this study are stored in the University of Glasgow's secure server, according to the Community Oral Health Section Confidential Data Security Protocol. This is a document that sets out the procedures within the COH section of the University of Glasgow for the handling and processing of confidential data.

This document covers: i) recording/entering of data, including data accuracy and validation; ii) the restricted use of mobile devices; data should not be stored on portable storage devices such as key sticks, CDs, external hard-drives, or smartphones; and iii) storage of password-controlled electronic data in the University of Glasgow's secure server with access to the data on a 'need to use' basis.

3.4.6 Issues

Figure 3.1 provides a Gantt chart with the times taken to complete each of the five stages of the plan designed to obtain the necessary data for this study.

One of the most important issues highlighted by the above narrative is the time taken to achieve health and non-health administrative data from Chilean Organisations, from April 2019 to January 2020. This component of the research took many months and two trips to Chile to gain access to the requested data.

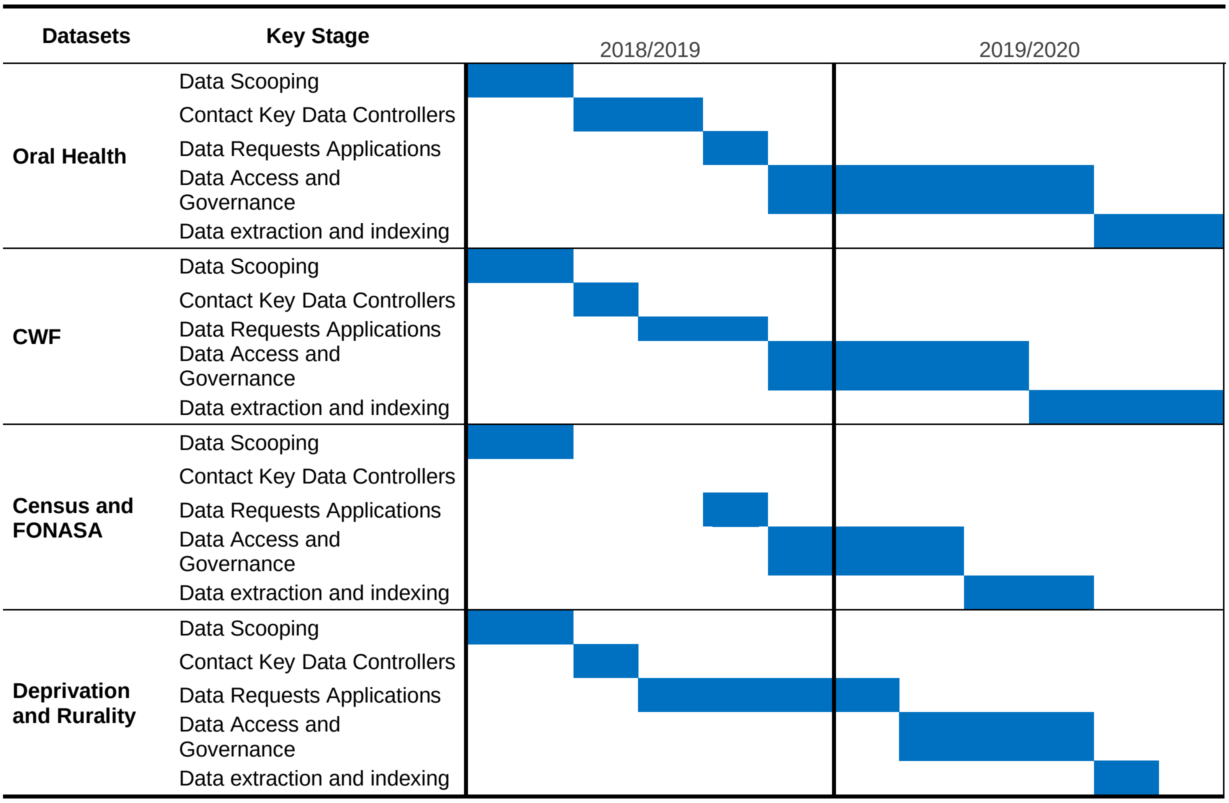


Figure 3.1: Gantt chart demonstrating the time taken to complete key stages for each dataset.

According to the information reviewed in Chapter 1, and to the meetings held with key Data Controllers of the Chilean Organisations, this work constitute the first effort to generate a database for the evaluation of an oral health programme in Chile using administrative data. During the execution of the plan, it became clear that even though the country has robust legislation for the delivery of publicly accessible data from government organisations, the execution of these protocols is not always met. However, complexity was expected given the scale of the data being requested and the resulting risk to privacy and impact of improper use. In addition, the political situation was extremely difficult in Chile in this period, which contributed to some of the delays.

3.5 Source datasets descriptions

The following section describes the datasets that were obtained for this study from the databases provided by the Data Controller organisations. This includes information on the primary function of the dataset, who the Data Controller was, any knowledge relating to the completeness known prior to the data extraction, and inclusion criteria if only a subsample of the dataset was to be used. Information on datasets that have been excluded from the study are also included.

It is relevant to highlight that all the information delivered by the Data Controllers Organisations corresponds to previously anonymized and aggregated data at the National, regional or municipal level. This was in compliance with the Transparency Law of Chile, so that no original dataset or subset that has been used in this study contains any sensitive information according to Chilean regulations.

3.5.1 Source datasets inclusion criteria

The inclusion criteria for all datasets used to configure the database of this study were to contain aggregated data at the national, regional, and municipal levels with information from a time range between 2008 and 2019. Only those records in each of the datasets which met these characteristics were included in the extract of each dataset. If there were no data for all of the years contained in the range then the information was extracted for all the years that were available in the original datasets.

3.5.2 Dental examinations performed in public primary care clinics.

To characterise the oral health of Chilean children, a search was conducted regarding the existence of databases containing the information on child oral health outcomes at the national, regional and municipality level, which is stored through REM, which in its REM09 section, contain the information of dental examinations performed in public primary care clinics for all ages.

The information contained in the REM09 records is obtained from the dental examinations carried out by the dentists who work in the primary care clinics of the public health network in the municipalities throughout the country with the instruction to make this diagnosis according to the WHO criteria (Ministerio de Salud. Gobierno de Chile, 2009; World Health Organisation, 2013).

The dental examination, together with the determination of the dmft index for six-year-olds, constitutes the first step in the protocol for admission to the "Comprehensive Dental Care for the six-year-olds" programme. Therefore, this age range contains more records in comparation with other ages, and was identified as the primary child oral health measure.

The databases of REM per year, which in its REM09 section, contain information of the dental examinations for all ages, were delivered in a .mdb file of total 31GB and saved on the University of Glasgow's secure server. The variables were selected (dental examination), and the cases filtered according to the age range of interest for the study (ages 0 to 6 from 2008 to 2019). The names of the variables and records were indexed, translated, and coded in addition to verifying that the export was made without losing data compared to the record obtained from the query in the original database and transferred via University of Glasgow Secure File Transfer System. Appendix 3 contains a detailed description and the definitions used for the data dictionary of the dataset.

As a measure of the completeness of the dental examination dataset, the total numbers of dental examinations performed on six-year-old children were compared annually with the corresponding FONASA annual six-year-old beneficiary population (Table 3.2). There was a sustained increase in the total numbers of six-year-old children with a dental examination record compared to the population registered in FONASA throughout the years analysed. The coverage reached in the analysed period was 68% of children of that age enrolled in FONASA.

3.5.3 Oral health interventions performed in public primary care clinics

In the same way that the recording of dental inspections is conducted, recording of the oral health interventions carried out by dentists from the public health network in the different municipalities of the country is mandated to be entered as information on electronic records, which are transferred to and processed by DEIS (Ministerio de Salud. Gobierno de Chile, 2018b).

Table 3.2: Frequency of dental examinations on six-year-olds at national-level (2008-2019)

Year	Age six FONASA registrations (a)	Age six dental examinations	
	n	n	% of a
2010	174,001	88,786	51%
2011	173,176	95,958	55%
2012	170,451	107,989	63%
2013	174,354	111,913	64%
2014	174,682	124,278	71%
2015	187,595	140,045	74%
2016	186,347	140,427	75%
2017	189,368	141,753	74%
2018	188,342	153,799	81%
Total	1,618,316	1,400,791	68%

The databases of REM per year, which in its REM09 section, contain information of the oral health interventions performed in public primary care clinics for all ages, were delivered in a .mdb file of total 31GB and saved on the University of Glasgow's secure server. The variables on interventions were selected, including i) preventive interventions: fluoride varnish application, toothbrushing advice, and sealants in primary teeth; ii) restorative interventions: composite fillings, amalgam fillings, glass ionomer fillings; iii) endodontics; and iv) dental extractions. The cases were filtered according to the age range of interest for the study (ages cero to six years from 2008 to 2019). The names of the variables and records were indexed, translated, and coded in addition to verifying that the export was made without losing data compared to the record obtained from the query in the original database. Appendix 3 contains a detailed description and the definitions used for the data dictionary of the dataset.

3.5.4 Sembrando Sonrisas programme interventions

The information obtained in the REM09 records for the Sembrando Sonrisas programme in Chilean children who attend to state-funded nurseries were delivered in a .mdb file of total 31GB and saved on the University of Glasgow's secure server. These data are obtained from the examinations and procedures carried out by the dentists who work specifically for this programme in the public health network and for the municipalities throughout the country. The variables were selected, including dental examinations, fluoride varnish applications, and the delivery of an oral health kit for daily supervised toothbrushing. The names of the variables and records were indexed, translated, and coded in addition to verifying that the export was made without losing data compared to the record obtained from the query in the original database. Appendix 3 contains a detailed description and the definitions used for the data dictionary of the dataset.

As a measure of the completeness of the Sembrando Sonrisas programme dataset, the total number of children included in the datasets were compared with the budget evaluation report of the Sembrando Sonrisas programme, executed by the Ministry of Health in 2017 (Gobierno de Chile, 2017). This is the only data source with which it is possible to make a comparison to determine the completeness of these data.

Table 3.3 indicates that in each year from 2015 to 2017, there is a high consistency between the data reported by the budget evaluation of the Sembrando Sonrisas programme.

Table 3.3: Frequency of children with a dental examination performed for the Sembrando Sonrisas programme, in comparison with the budget evaluation carried out by the Ministry of Health of Chile (2015-2017)

Year	Total Sembrando beneficiary children according to MINSAL budget evaluation (a)	Total Dental examinations records in the dataset of this study	% of a
2015	253,503	246,784	97%
2016	368,382	369,194	101%
2017	480,008	481,886	101%
Total	1,101,893	1,097,864	99%

3.5.5 Census population data

The data contained in this dataset was delivered by the INE and corresponds to the official data used by the State of Chile according to the census carried out in 2017, together with population projections and data from previous years at the national, regional, and municipal level.

The Population and Housing Census carried out by the National Statistics Institute of Chile consists of the count and characterization of all the dwellings and inhabitants of a defined territory, at a certain time. This operation constitutes the main statistical source of a country, which is why it is undertaken regularly and its implementation is encouraged internationally.

In Latin America and the Caribbean, they take place on similar dates, which allows comparison of the changes that occur, and it serves as a key reference for the generation of public policies in the country. This makes it possible to project the distribution of public resources directed to the regions and municipalities, and to provide services to the population, such as education, health and transport, as well as being a solid tool for research: the census data provide information on the total number of the census population, and form a basis for estimating population projections. These make it possible to know the total population of the country in the short and medium term, in addition to its distribution (Instituto Nacional Estadisticas, 2018).

The variables were selected, including the total population and the population projections at the national, regional and municipality level, and the cases filtered according to the age range of interest for the study (ages zero to six years). The names of the variables and records were indexed, translated, and coded in addition to verifying that the export was made without losing data compared to the record obtained from the query in the original database. Appendix 3 contains a detailed description and the definitions used for the data dictionary of the dataset.

3.5.6 FONASA beneficiary population

The databases of the FONASA beneficiary population were delivered in a .xlsx file of total 34MB and saved on the University of Glasgow's secure server. As described in section 3.4.4, in this dataset, there was no information regarding the years 2008 and 2009, because, in that period, there was no electronic registry of the beneficiaries. For 2019, data were not delivered due to the lack of complete records at the date of request. The variables were selected (Total FONASA beneficiary population), and the cases filtered according to the age range of interest for the study (ages zero to six years). The names of the variables and records were indexed, translated, and coded in addition to verifying that the export was made without losing data compared to the record obtained from the query in the original database. Appendix 3 contains a detailed description and the definitions used for the data dictionary of the dataset.

3.5.7 Socioeconomic development index IDSE

Chile has important statistical information, at different levels of the country, on demographic, social and health issues, which includes at the level of municipalities. However, some limitations must be considered when comparing municipal indicators of development and health.

In populous municipalities, especially those located in metropolitan areas, an ecological fallacy occurs since the municipality does not homogeneously represent internal groups whose situation may differ significantly from the average (Gattini, 2014). On the other hand, crucial social aspects related to health - such as those related to poverty and deprivation, rurality, original ethnic groups and sanitation - are concentrated in small municipalities, where few annual events related to health tend to occur (such as births, diseases and deaths from specific causes), which translates into unstable short-term (annual) indicators (Gattini, Sanderson and Castillo-Salgado, 2002).

To systematize the comparison between municipalities in the best possible way, the Socioeconomic Development Index (IDSE) presents composite municipal indicators summarizing socioeconomic development and human development. The conceptual and methodological approach is based on the development of the Human Development Index that is prepared and published annually by the United Nations Development Programme (Gattini, Sanderson and Castillo-Salgado, 2002).

The methodology for preparing the IDSE is adapted to the information at the national, regional, and municipal levels in Chile, and includes the components of (i) economy (monthly per capita income; and poverty), (ii) education (years of average schooling) (iii) housing and sanitation (good and acceptable material for housing; and sewerage or septic tank availability), and (iv) health (life expectancy at birth, infant mortality rate) (Gattini, Sanderson and Castillo-Salgado, 2002).

The data and indicators are secondary and are obtained from official sources of organisations of the Government of Chile, such as the INE and the Ministry of Health (Gattini, 2014).

324 of the 346 municipalities existing in Chile were included for the construction of the IDSE. Two of the 22 excluded municipalities did not have sufficient data, having a population size of fewer than 2,000 inhabitants in 2013. IDSE is a multidimensional indicator including data of the income, poverty, education, sanitary conditions, and health for each municipality, in relation to the Chilean National SocioEconomic Characterization Survey. Each indicator is summarized using measures of central tendency (arithmetic average) and weighted by the total population of the municipality (Gattini, 2014).

The municipalities are ordered from highest to lowest according to the level of the IDSE Index and have been classified into deciles of municipalities according to IDSE level. The municipality deciles include groups ordered according to a progressive level of IDSE, which contain approximately 10% of the accumulated population (from the lowest value of IDSE - decile 1). A weighted average has estimated the value of each indicator and a tenth index according to the size of the municipal population. The most socioeconomic deprived category is “IDSE 1”, and the least socioeconomic deprived category in “IDSE10” (Gattini, 2014).

For data extraction, the original 38 KB .xlsx file delivered by the Public Health Department of the University of Chile was saved on the University of Glasgow's secure server. The variables were selected, including the IDSE index and IDSE tenths. The names of the variables and records were indexed, translated, and coded in addition to verifying that the export was made without losing data compared to the record obtained from the query in the original database. Appendix 3 contains a detailed description and the definitions used for the data dictionary of the dataset.

3.5.8 Multidimensional poverty index

Chile has made significant progress in reducing poverty in recent decades, but there are still many Chilean families who face day-to-day challenges and situations of vulnerability —poverty is mainly concentrated in children, women, indigenous peoples, and the rural municipalities (United Nations, 2018).

The primary purpose of a poverty measure is to monitor living conditions and estimate the size of the population that, according to normative definitions, are excluded or fail to enjoy an adequate level of well-being, allowing related public policy decisions to be made with the design and improvement of policies and programmes and the allocation of public spending aimed at overcoming poverty, along with addressing social gaps and specific needs of vulnerable groups, such as indigenous peoples, children and adolescents, older adults, inhabitants from rural areas or people with disabilities, among others (United Nations, 2018).

According to this, the methodologies and instruments to measure poverty must be adapted to the level of development and the historical, social, and cultural circumstances and conditions of each country, as well as respond to the demands and expectations of citizens. Complementary to the measurement by income, the multidimensional poverty measurement methodology aims to identify households that, regardless of their income level, experience deficiencies in fundamental dimensions of well-being (Gobierno de Chile, 2018).

Multidimensional poverty measurement seeks to directly measure the living conditions of the population, through different dimensions and indicators of deprivation that are considered socially relevant so that people can fight to overcome it and enjoy a decent life. In this way, it allows an analysis of the social reality of the population.

The multidimensional poverty index of Chile (MPI) is based on the analysis of dimensions made up of specific indicators, and for each of the minimum thresholds are defined from which it is considered that a person can have a decent life. The multidimensional poverty index considers four dimensions - Education, Health, Work and Social Security and Housing. All dimensions had the same weight: 25% each. The score ranges from 0 to 100, with an increase in multidimensional poverty with an increase in the score (Gobierno de Chile, 2018).

It was decided to obtain this indicator of deprivation, in addition to IDSE for further analysis, since MPI had the advantage of being available for the entire time range to be analysed in this study, and includes the 346 municipalities in the country, unlike the IDSE, which despite having a more precise methodology, is built with data from a specific moment and excludes 22 municipalities.

For data extraction, the original 2 MB .xlsx file delivered by the INE was saved on the University of Glasgow's secure server. The variables were selected (MPI index). The name of the variable and records were indexed, translated, and coded in addition to verifying that the export was made without losing data compared to the record obtained from the query in the original database. Appendix 3 contains a detailed description and the definitions used for the data dictionary of the dataset.

3.5.9 Community water fluoridation programme fluoride concentrations and coverage

As described in detail in section 1.7.2, drinking water suppliers companies in Chile are adjusting the fluoride concentration through filtering or artificially fluoridating the drinking water network, and they must measure the fluoride concentration daily, deliver monthly analysis with their daily self-control samples and the concentrations of each plant, to the to the Regional Health Boards and the SISS. For its part, the regional health authority must keep a record of the concentration of fluoride delivered in drinking water by the companies. In Chile, the optimum fluoride concentration recommended in drinking water, whether natural or artificial, ranges between 0.6 and 1.0 mg/L.

Two sources were consulted to obtain these data, the Regional Health Boards and the Superintendence of Sanitary Services, according to the information obtained at the data scoping stage. Requests were made individually to each Regional Health Boards for the fluoride concentration at the municipality level, and the same data were requested to the Superintendence of Sanitary Services For the programme coverage, only the Superintendence of Sanitary Services controlled these data, along with the precise information on which municipalities were part of the programme. As explained in detail in section 3.4.6, the data access and governance process for this dataset was highly complex.

It is essential to highlight that the measurements obtained for the delivery of information to the SISS, are carried out directly in the water treatment plant, just before the water enters the drinking water network.

To measure the completeness of the CWF data, the two data sources were compared regarding the total number of municipalities included by year concerning the programme guideline (Table 3.17). This is the only data source with which it is possible to make a comparison to determine the completeness of these data. It was observed that the completeness of the SEREMI datasets was deficient, and in years in which information existed, they corresponded precisely to the same data included in the SISS database. Due to this, it was decided to use the dataset obtained from the SISS for all the analyses in this study.

For data extraction, the original 1 MB .xlsx file delivered by the SISS was saved on the University of Glasgow's secure server. The variables were selected, including CWF coverage and fluoride concentration. The names of the variables and records were indexed, translated, and coded in addition to verifying that the export was made without losing data compared to the record obtained from the query in the original database. Appendix 3 contains a detailed description and the definitions used for the data dictionary of the dataset.

Table 3.4: Frequency of municipalities included in the CWF programme in the datasets delivered by SEREMI and the SISS (2008-2018)

Year	Municipalities included in CWF	Municipalities in SEREMI dataset	Municipalities in SISS dataset
2008	232	82	232
2009	238	82	238
2010	238	93	238
2011	238	153	238
2012	239	177	239
2013	240	178	240
2014	240	206	240
2015	240	206	240
2016	240	219	240
2017	240	219	240
2018	240	219	240

3.5.10 Rurality Indexes

Chile is a country with a wide variety of landscapes and climates that reflect the diversity of those who inhabit it. The particular characteristics of its geography have decisively influenced its population's settlement patterns and economic activity, generating a heterogeneity of urban and rural areas with varied characteristics and challenges. Public policies have emphasized that the provision of goods and services such as housing, education, health, and the design of social programmes needs to be adapted to the socio-cultural and territorial particularities of each community in the country.

Traditionally, rural and urban areas have been defined according to demographic and economic criteria that attempt to segregate the territory. In this context, agriculture is assumed as the main activity of rural populations, while urban ones are mainly linked to industrial production and services. The degree of rurality is understood as the intensity of the rural in a continuous gradient that places each territory within a wide range of possibilities that go from a purely urban to a purely rural extreme (Berdegué *et al.*, 2010).

Among the criteria for evaluating the degree of rurality of a community, the rural population concerning the total population, or proportion of rurality, despite not being perfect, is a good approximation that allows states to recognize the characteristics of the territory, in addition, to allow the comparison of records over time through censuses.

The INE defines the proportion of rurality as the total rural population of a municipality, which corresponds to the population whose settlement belongs to undeclared urban areas, divided by the total population. The information used corresponds to that compiled by the protocols of the Chilean Census (Instituto Nacional Estadísticas, 2007).

During the last decade, there has been a growing and increasingly generalised consensus that this dichotomous or binary differentiation by population may represent a simplification. It provides a segmented view and is, therefore, less practical for adequate public policy. In recognition of this, the Chilean government has raised the need to measure precisely what rurality is.

The National Rural Development Policy is a territorial policy, which is linked to the National Policy for Regional Development, forming a set of strategic guidelines guiding public action, allowing progress towards integrated territorial development and the well-being of inhabitants, regardless of the geographic location where they live, based on an approximation of 'degree of rurality'. With the concept of a type of rurality, the differences in each territory's socioeconomic configurations are realised to distinguish between municipalities with the same degree of rurality but whose economic and social dynamics are notably different.

The National Rural Development Policy defines ‘rural territory’, as the dynamics of the interrelationships between people, economic activity, and natural resources, characterised mainly by its population whose population density is less than 150 inhabitants/km2, with a maximum population of 50,000 inhabitants whose basic unit of organisation and reference is the municipality.

To classify rural municipalities in Chile, an analysis of population density was carried out at the municipal level, proposing three categories for the ‘Rurality Level’: i) Predominantly rural municipality: More than 50% of the population lives in census tracts of less than 150 inhabitants per km2; ii) Mixed municipality: Between 15% and 49% of its population live in census tracts of less than 150 inhabitants per km2; and iii) Predominantly urban municipality: Less than 15% of the population lives in census tracts of more than 150 inhabitants per km2. In addition to the maximum population criterion, the municipalities that are regional capitals are incorporated into this category.

Because each indicator accounts for the characterization of rurality in the country, one with a continuous presentation represented by a proportion, and the other a categorical presentation, and that both indicators are the only ones that are available aggregated at the municipal level for the whole country, information was requested from INE. Both variables for the period analysed, between 2008 and 2019, had only one record of each indicator: for ‘Rurality Proportion’, the indicator was assembled using data from the 2017 Census. The only previous record of the indicator corresponded to the year 2002, therefore, its request was rejected. For ‘Rurality Level’, the National Rural Development Policy was published in 2014, which is why it represents the only available record of the indicator. Prior to its publication, there was a dichotomous characterization through an indicator of rurality, but according to the new policy, it did not accurately represent the reality of each municipality, so its inclusion in the database was discarded.

For data extraction, the original 18 KB .xlsx file delivered by the INE was saved on the University of Glasgow’s secure server. The variables were selected, including rurality proportion and rurality level. The names of the variables and records were indexed, translated, and coded in addition to verifying that the export was made without losing data compared to the record obtained from the query in the original database. Appendix 3 contains a detailed description and the definitions used for the data dictionary of the dataset.

3.6 Database assembly

Once the process of extraction was carried out for all datasets obtained from the Data Controllers Organisations, a merge of all datasets was performed, and a single database was created using SAS 9.4 software, using as key for the merging the Unique Municipal Territorial Codes (Ministerio del Interior Gobierno de Chile, 2018), which was the identification code that was shared among all datasets. Figure 3.2 shows the structure of the database, which will be used for the methods and analyses of the next chapters of this study.

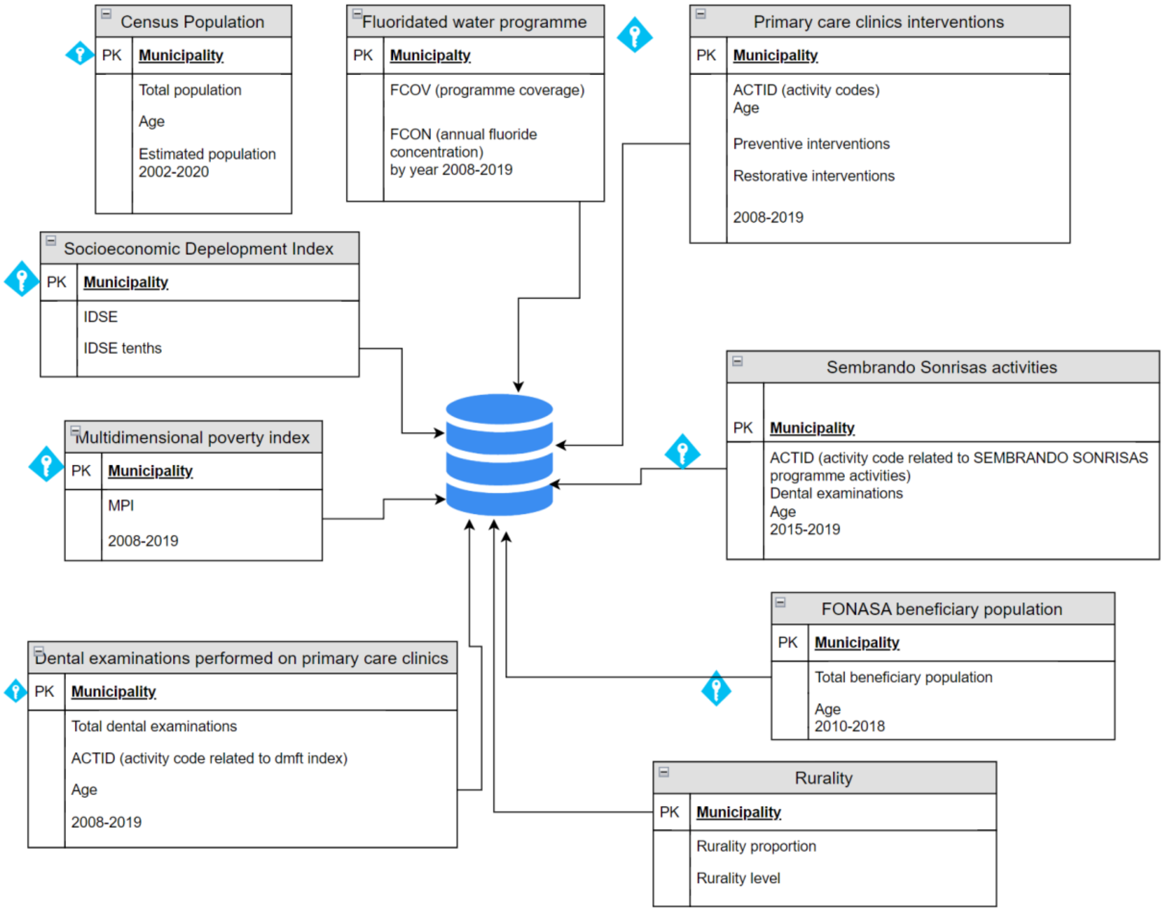


Figure 3.2: Structure of the database for this study.

3.7 Chapter 3 summary

This is the first study aiming to evaluate the impact of oral health programmes on the caries outcomes of children in Chile. Therefore, to develop and implement a strategy to build a database with routine health and non-health related data was a challenge. Multiple information governance processes had to be successfully navigated in order to access the data.

The Chilean legislation for access to public administrative data, through the Transparency Law, is robust and has among its objectives to permit researchers to access complete and quality information, previously anonymized and processed by statisticians, to obtain reliable results in research studies. Although, it is essential to highlight that compliance with protocols highly depends on the workload and priorities of Data Controllers organisations.

Information governance approvals were obtained; data request were submitted and approved; data were received, securely transferred and stored on the University of Glasgow servers; data management and initial quality/completeness checks were performed. In doing so, the database for all the analyses of this study was created.

Chapter 4 - Caries experience in Chilean children and related inequalities

Chapter 4 describes the analysis performed on the database to create an outcome variable and assemble a cohort to evaluate the trends in dental caries of Chilean children. The analysis carried out in the cohort for the effect of potential confounders and modelling for evaluating national oral health programmes interventions and activities on caries levels over time in six-year-olds are also detailed. Additionally, a regional and municipality level analysis on dental caries trends is shown. Finally, a socioeconomic inequality analysis on the distribution of dental caries on six-year-olds in Chile is performed.

4.1 Study design and unit of Analysis

As detailed in Chapter 3, the municipalities are the smallest data aggregation level recorded by Chilean organisations. Chapter 1 discussed how ecological studies are appropriate for evaluating complex interventions at the population level. These study designs also allow assessment of the impact of sociodemographic determinants on the association between programme interventions and measured health outcomes. Consequently, the design of this study corresponds to a completely ecologic analysis because all intervention and outcome variables are ecologic level measures, represented by aggregated observations in each municipality for all years included in the database. Therefore, the unit of analysis developed was **"municipality/years"**.

The municipality/years unit of analysis is based on how the data are recorded according to Chilean regulations, where the municipality is the smallest level of aggregation in which official demographic, social and health statistics are available and reported in Chile.

Due to this data structure, for characterization of the unit of analysis, both a geographical and time grouping is included, which allows two types of comparisons to be made: changes over time and differences among municipality/years.

Since, in Chile, there are 346 municipalities, and 12 years of records were included in the database (from 2008 to 2019), a total of 4152 municipality/years is the maximum possible record, and this maximum will be used when analysing the completeness of the data in further analyses.

4.2 Total children with a dental examination performed in public primary care clinics at municipality level 2008-2019

In the database, there were 4,117,537 aggregated records of dental inspections performed in primary care clinics between 2008 and 2019 nationwide. This included all municipalities and children from 0 to six years of age.

Between 2008 and 2011, the REM only covered the registration of children aged two, four and six years. From 2012 to 2016, the registry of children aged three and five years was also included, and in 2017 the records of children aged 0 and one were incorporated, in addition to making a distinction by sex.

When analysing this pattern of records, it was decided to select for the assembly of the outcome variable only the aggregated records of the six-year-old children, according to the REM records, since that age was the only variable continuously included during all the years included in this study. Additionally, the decision to not perform distinction by sex was made as separation by gender was only incorporated in 2017.

In addition to these reasons, according to information from the Chilean national oral health plan and the reports carried out by MINSAL, the main age for monitoring caries levels of children in Chile is six years (Ministerio de Salud. Gobierno de Chile, 2017b), which reinforces the decision taken for this study.

As stated in section 2.1, the overarching aim of this study is to determine the impact of the national oral health programmes on oral health outcomes among Chilean children, and six-year-olds represents the only age group in which children have had the possibility of being beneficiaries of all interventions and activities included in the database (Ministerio de Salud. Gobierno de Chile, 2017b).

The WHO, in its recommendations for the evaluation of oral health in communities, states that where it is practicable and feasible, children should be examined between their fifth and sixth birthdays. This age is of interest in relation to caries levels in the primary dentition, which may exhibit changes over a shorter period than in the permanent dentition at other index ages, in addition to suggesting that a recommended age for monitoring oral health levels is the age at which children enter primary school, which in Chile corresponds to six years (OECD, 2011; World Health Organization, 2018d).

Once exclusions had been made, there was a total of 1,400,791 dental examinations of six-year-olds performed in primary care clinics between 2008 and 2019 nationwide (defined as **"Total dental examinations"** variable throughout). Figure 4.1 shows a flow diagram of this process and the number of records removed.

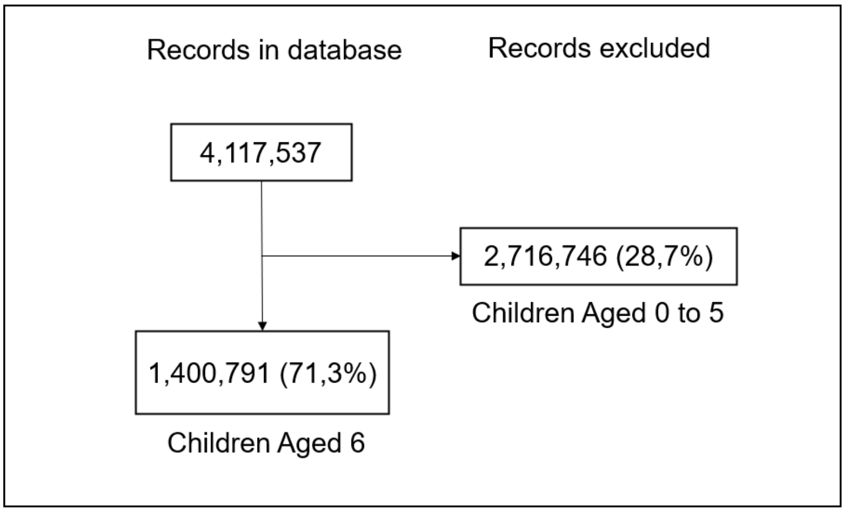


Figure 4.1: Flow chart of the selection of aggregated records of six-year-olds with a dental examination performed in primary care clinics between 2008 and 2019 nationwide in the database

4.2.1 Total dental examinations

Table 4.1 describes the distribution of dental examinations through the years and the percentage of six-year-olds in relation to the population of children aged six. There has been a sustained increase in the percentage of children with a dental examination concerning the six-year-olds population throughout the years analysed. From 2008, higher percentages were observed, reaching 62% of the six-year-olds. It was also observed that there was a decrease in 2019.

Table 4.1: Frequency of dental examinations related to the total six-year-olds population (2008-2019)

Year	Age 6 total population (a)	Total dental examinations	
	N	n	% of a
2008	238,185	77,844	32%
2009	234,252	92,166	39%
2010	232,445	88,786	38%
2011	233,066	95,958	41%
2012	237,840	107,989	45%
2013	245,050	111,913	45%
2014	252,066	124,278	49%
2015	253,299	140,045	55%
2016	252,119	140,427	55%
2017	247,458	141,753	57%
2018	256,809	153,799	62%
2019	249,467	125,833	50%
Total	2,932,056	1,400,791	48%

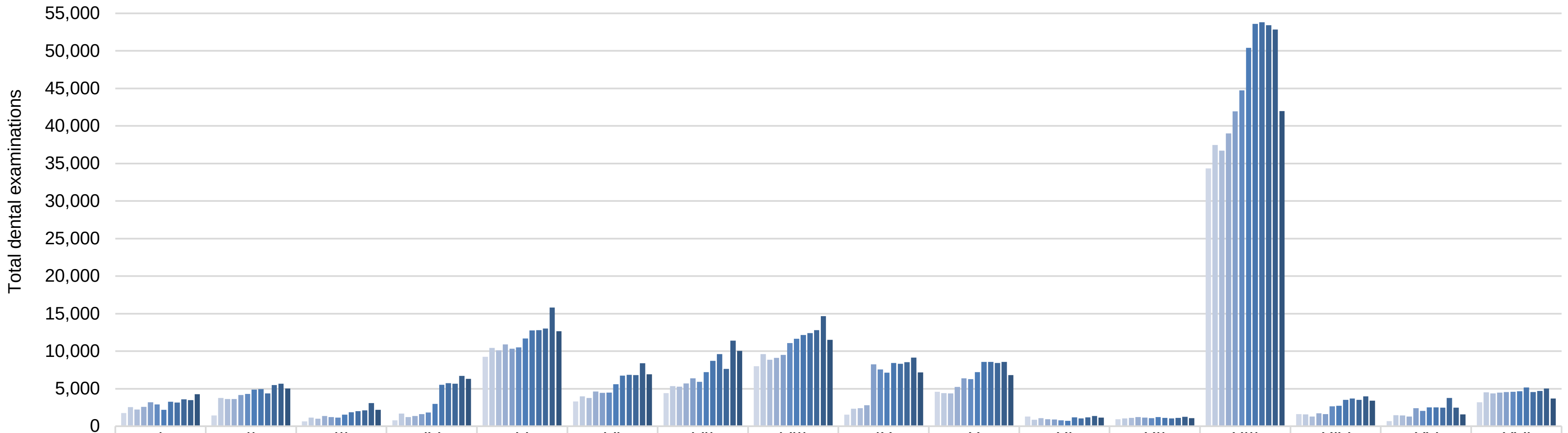
To develop a detailed analysis, the data were disaggregated into regions according to the political-administrative division of Chile. As shown in Table 4.2, total dental examinations data were available from all regions. “Total dental examinations” had a variable representation of each region in the dataset. Region XIII (Metropolitan) comprises the highest number of records (39%). In comparison, regions III and XII only represent 1% of the records each.

Table 4.2: Total dental examinations by region (2008 - 2019)

Region	Region Name	Total dental examinations	% of total records
XV	Arica	24,631	(2%)
I	Tarapacá	34,328	(2%)
II	Antofagasta	51,998	(4%)
III	Atacama	19,408	(1%)
IV	Coquimbo	41,362	(3%)
V	Valparaiso	140,264	(10%)
XIII	Metropolitan	540,283	(39%)
VI	O´Higgins	65,947	(5%)
VII	Maule	87,646	(6%)
XVI	Ñuble	53,474	(4%)
VIII	Biobio	131,299	(9%)
IX	Araucanía	73,613	(5%)
XIV	Ríos	31,389	(2%)
X	Lagos	79,363	(6%)
XI	Aysen	12,458	(1%)
XII	Magallanes	13,328	(1%)

Figure 4.2 shows the trends in the total dental examinations by region. An increase in the total number of records over the years can be observed in most regions, but regions such as XI, XII and XVI maintain a similar number each year. As observed at the national level, and most likely for the same reasons as previously stated, a decrease in the total number of children examined occurred in 2019 in most regions, as opposed to the sustained increase observed in previous years.

Figure 4.3 shows the coverage of dental examinations carried out at the regional level in relation to the regional six-year-olds population. An increase over the years was observed in most regions, except for regions XI, XII, XV and XVI, where variable percentages of coverage were observed through the years.



	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI
2008	1,743	1,421	662	788	9,255	3,315	4,424	7,997	1,548	4,586	1,298	939	34,353	1,625	687	3,203
2009	2,536	3,767	1,151	1,669	10,442	3,994	5,357	9,614	2,312	4,417	857	1,053	37,448	1,594	1,455	4,500
2010	2,209	3,624	998	1,211	10,116	3,755	5,276	8,837	2,386	4,365	1,067	1,113	36,722	1,306	1,424	4,377
2011	2,592	3,632	1,373	1,349	10,889	4,627	5,702	9,120	2,805	5,225	922	1,219	39,003	1,734	1,280	4,486
2012	3,178	4,150	1,234	1,623	10,320	4,430	6,380	9,483	8,251	6,386	905	1,150	41,935	1,624	2,403	4,537
2013	2,903	4,319	1,156	1,834	10,513	4,490	5,909	11,066	7,560	6,290	789	1,072	44,744	2,646	2,043	4,579
2014	2,168	4,868	1,540	2,958	11,674	5,592	7,210	11,641	7,129	7,211	729	1,225	50,424	2,741	2,510	4,658
2015	3,255	4,954	1,854	5,512	12,777	6,742	8,699	12,160	8,420	8,551	1,186	1,127	53,596	3,523	2,517	5,172
2016	3,154	4,373	2,024	5,733	12,789	6,864	9,603	12,404	8,327	8,562	1,055	1,028	53,819	3,677	2,459	4,556
2017	3,570	5,496	2,126	5,681	13,014	6,816	7,637	12,788	8,537	8,413	1,171	1,094	53,407	3,519	3,779	4,705
2018	3,463	5,653	3,087	6,686	15,811	8,389	11,400	14,668	9,157	8,552	1,348	1,240	52,858	3,979	2,482	5,026
2019	4,273	5,025	2,203	6,318	12,664	6,933	10,049	11,521	7,181	6,805	1,131	1,068	41,974	3,421	1,592	3,675

Regions

Figure 4.2: Trends in Total dental examinations by region (2008-2019)

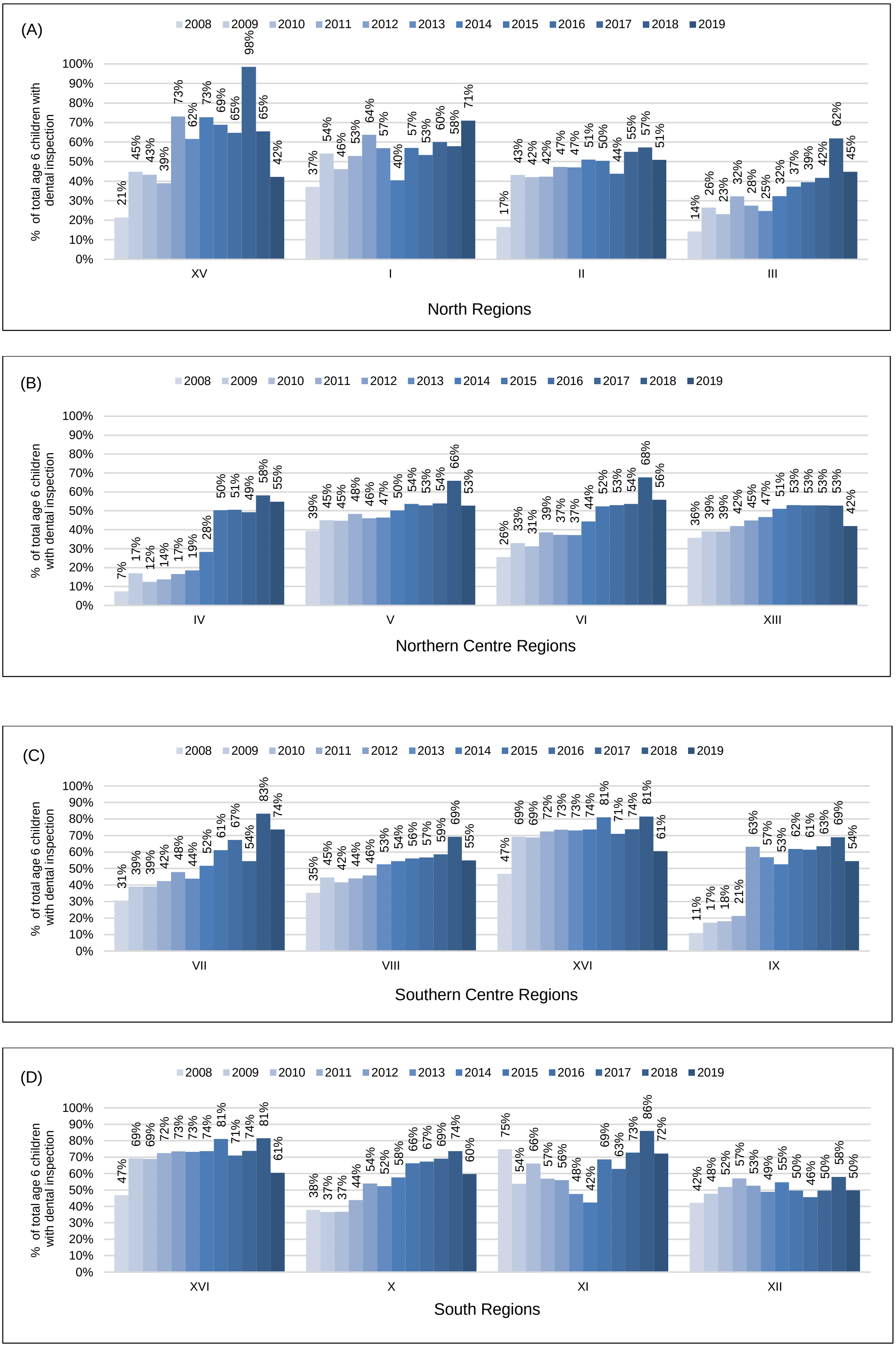


Figure 4.3: Coverage of Dental examinations regarding the total population of six-year-olds by region (2008-2019) (A) North regions. (B) Northern centre regions. (C) Southern centre regions. (D) South regions.

4.2.2 Caries levels by decayed, missing and filled (dmft) index from dental examinations of six-year-old children

Between 2008 and 2013, the dmft index obtained from the dental examination of six-year-olds was registered in the REM in a range of values: “0”, “0-1”, “3-4”, and “5 or more”. In 2014, the number of categories was increased, probably to make a more precise index record, but keeping the category of “5 or more” prevents its use as a continuous variable. Table 4.3 describes the frequency of the dmft categories within the dataset.

Table 4.3: Total aggregated records of dmft categories of the in the database (2008 - 2019)

Category	Total records	Time frame
dmft = 0	450,174	2008-2019
dmft = 1-2	111,504	2008-2013
dmft = 3-4	93,802	2008-2013
dmft = 1	147,859	2014-2019
dmft = 2	121,743	2014-2019
dmft = 3	96,681	2014-2019
dmft = 4	73,046	2014-2019
dmft = 5 or more	305,981	2008-2019

4.2.3 Assembly of ‘No caries experience’ and ‘With caries experience’ variables

To define variables that can be used as oral health measures for the evaluation of the National Child Oral Health Improvement Programmes for Chile, two new variables were created from the dmft records in the database. Using the definitions of the REM dataset (Ministerio de Salud. Gobierno de Chile, 2018b) and the WHO definition of dmft index (World Health Organization, 2018d), the “dmft = 0” records in the dataset were defined as “Total children with no obvious caries experience”, i.e. **“No caries experience”.**

The sum of all other categories was defined as "Total Children with Obvious Caries Experience", so their records were added into a single new variable called **"With caries experience"**. These new variables were incorporated by municipality level for all years in the database.

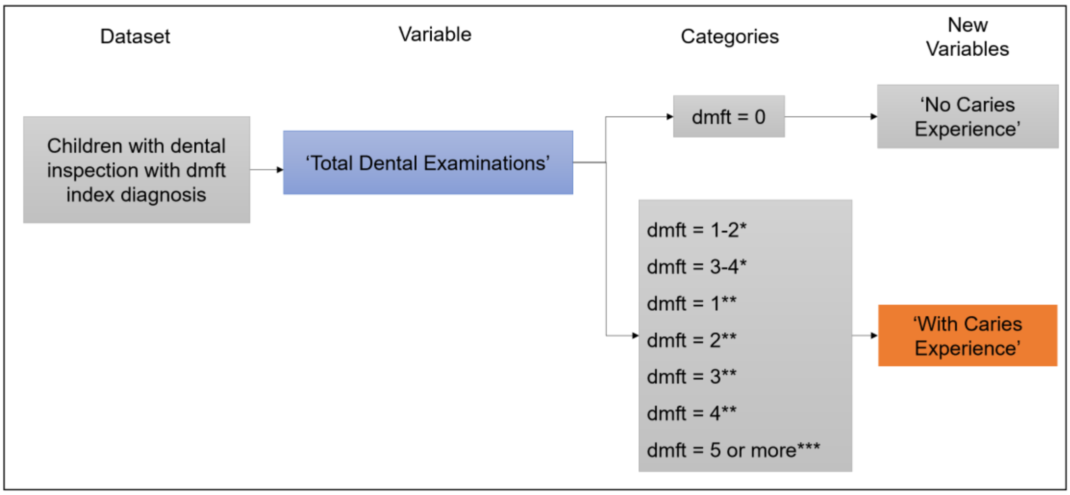


Figure 4.4: Assembly of the 'No caries experience' and 'With caries experience' variables
*Categories for years 2008 to 2013. **Categories for years 2014 to 2019. ***Category included in all years in the dataset.

4.2.4 Summary of "Total dental examinations", "No caries experience" and "With caries experience" variables

The following section describes a summary of each variable used to define the dental caries outcome of this study. All statistical analyses undertaken were completed using SAS Version 9.4.

Regarding the "Total dental examinations" variable, a summary of statistical measures is presented in Table 4.4.

Table 4.4: Statistical measures summary for "Total dental examinations" (2008 - 2019)

Total dental examinations			
Mean	378.7	**Standard Deviation**	580.1
Median	156	**Min**	0
Mode	0	**Max**	4589

Of the total municipality/years, 89.1% (n = 3699) presented records for “Total dental examinations”. Within this total, 2.2% (n = 91) registered no six-year-olds were examined.

As inferred from the mean, median and mode values, data for the “Total dental examination” variable present an asymmetric distribution, along with high variability, reflected in a right-skewed distribution (Figure 4.6).

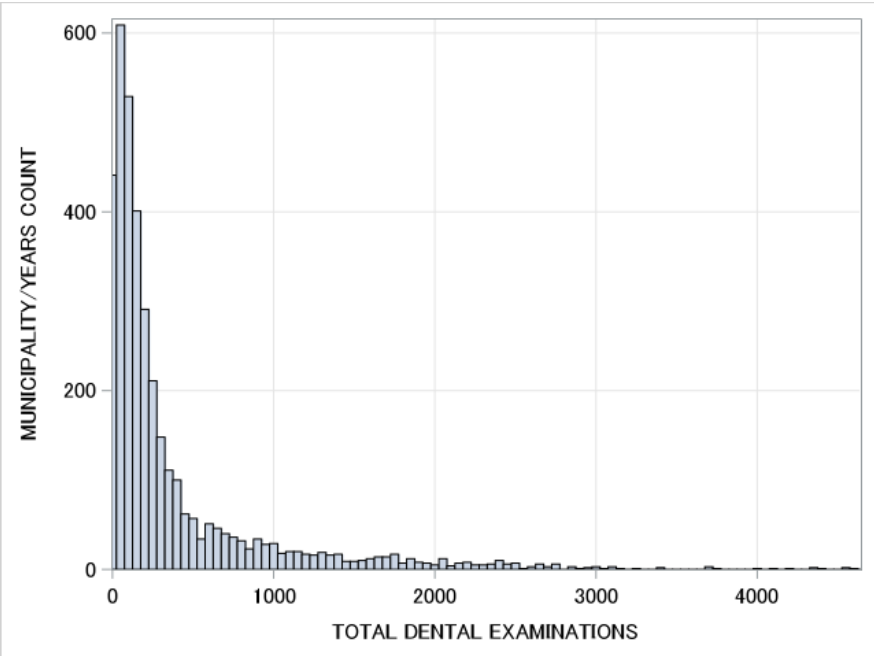


Figure 4.5: Histogram of the distribution of Total dental examinations by municipality/year (2008 - 2019)

The municipality with the highest number of “Total dental examinations” was Puente Alto, from the Metropolitan Region XIII (North Centre) for all years included in the database, where the maximum aggregated records were 4,589 in 2019. This municipality is the community with the largest population in the country, so consistently, it is the municipality with the highest number of records. In addition to Puente Alto, the municipality/years with the highest records of “Total dental examinations” included “Arica/2017” from Region XV (North) with 3,862, “Antofagasta/2017” from Region II (North) with 3,390, “Valparaiso/2018” from Region V (North Centre) with 3,385 and “San Bernardo/2018” of the Region XIII with 3,226.

The municipality/years where no six-year-old children underwent a dental examination (n = 91) included Florida in Region VIII between 2009 and 2013, Ollague of Region II in 2009, 2010, 2012 and 2015 and San Gregorio of Region XII in 2009, 2012, 2013 and 2014.

Most of the municipalities without records for "Total dental examinations" were from the first four years included in the database, then there is a gradual decrease in the number of municipalities without data, reaching only 1% (n = 3) in 2019 (Table 4.5). Two municipalities did not have data for any year: Antartida and Primavera (Region XII).

Table 4.5: Municipalities without "Total dental examinations" records by year

Year	Municipalities without Total dental examinations records	
	n	%
2008	81	23%
2009	83	24%
2010	77	22%
2011	72	21%
2012	49	14%
2013	37	11%
2014	14	4%
2015	15	4%
2016	12	4%
2017	6	2%
2018	4	1%
2019	3	1%
Total	453	11%

Regarding the "No Caries Experience" variable, a summary of statistical measures is shown in Table 4.6.

Table 4.6: Statistical measures summary for "No Caries Experience" variable (2008 - 2019)

No Caries Experience			
Mean	121.7	**Standard Deviation**	216.1
Median	39	**Min**	0
Mode	0	**Max**	1756

This variable was derived from “Total dental examinations”, showing the same trends as the previously described variable. 89.1% (n = 3699) municipality/year presented records of “No Caries Experience”. Within this total, 7.1% (n = 264) registered that no 6-year-old children had “No Caries Experience”.

The “No Caries Experience” variable also presents an asymmetric distribution, along with high variability, reflected in a right-skewed distribution (Figure 4.6).

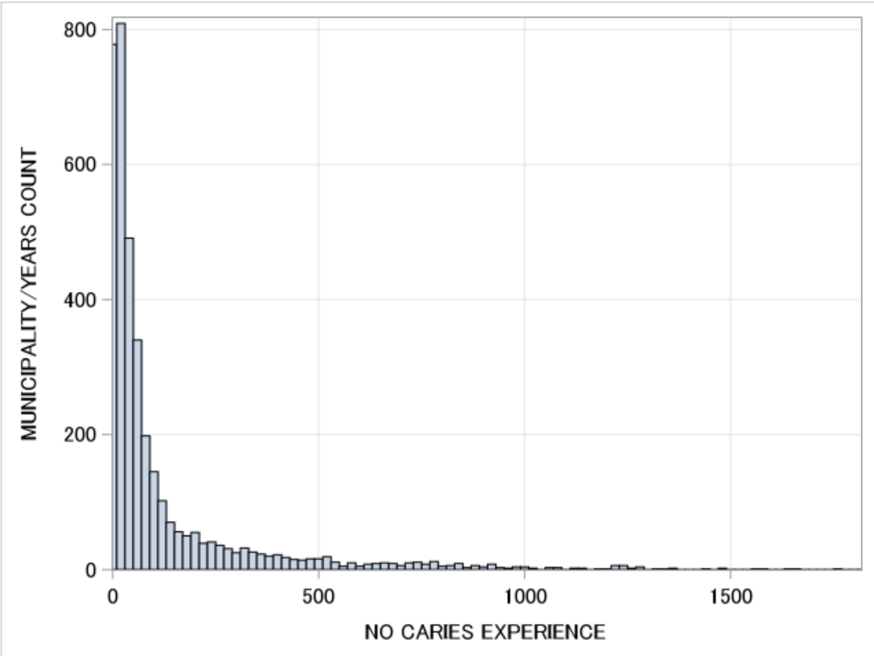


Figure 4.6: Histogram of the distribution of ‘No caries experience’ records by municipality/years (2008 - 2019)

Regarding the “With Caries Experience” variable, a summary of statistical measures is presented in Table 4.7.

Table 4.7: Statistical measures summary for “With Caries Experience” variable (2008 - 2019)

With Caries Experience			
Mean	257	**Standard Deviation**	381.3
Median	111	**Min**	0
Mode	0	**Max**	3315

The variable was derived from “Total Dental Examinations”, showing the same trends and distribution as the previously described variables (Figure 4.7).

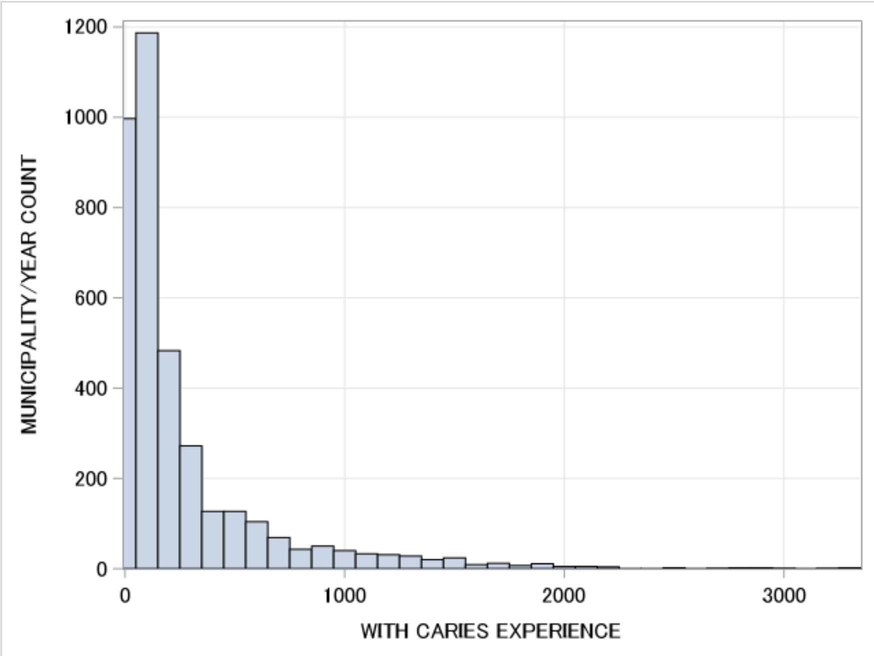


Figure 4.7: Histogram of the distribution of “With Caries Experience” records by municipality/years (2008 - 2019)

4.3 Outcome variable definition

A continuous outcome variable, “Percentage of children with obvious caries experience”, i.e., “**Caries experience**”, was created to analyse trends in caries levels over time and to measure the impact of each national oral health improvement programme on dental caries levels of six-year-olds in Chile. Thus, the primary outcome for this study was developed as six-year-olds caries experience.

Figure 4.8 describes the process of generating the “Caries experience” variable. For the assembly, a proportion was made between total aggregated records of “With Caries Experience” and “Total dental examinations” for each municipality/year. “Caries experience” represented a percentage for each municipality/year, but all analyses considered those percentages a continuous variable and are, therefore, a continuous endpoint. Continuous endpoints are unusual in epidemiology and open a wider choice of analysis techniques (Duke-Margolis Center for Health Policy, 2020).

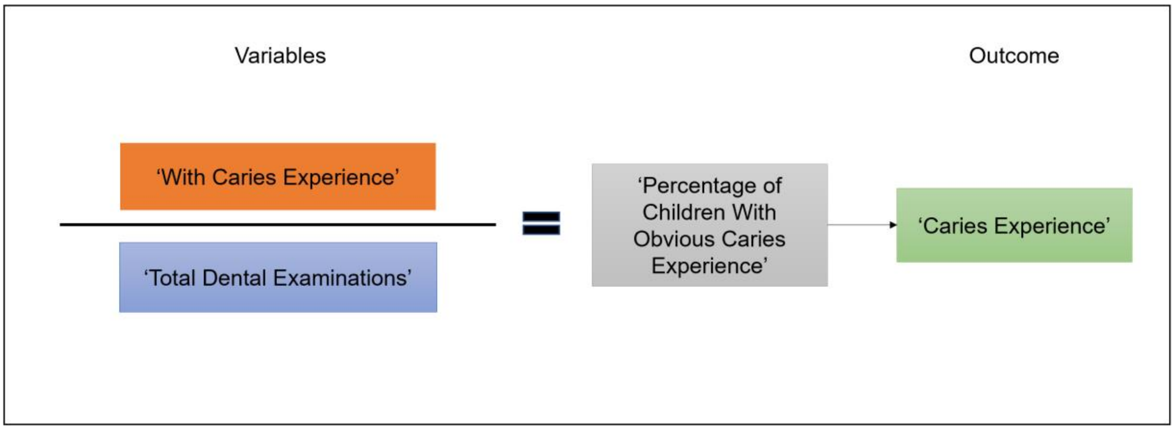


Figure 4.8: Creation of the "Caries Experience" outcome variable

4.4 Trends in caries experience of six-year-old children in Chile

The following section describes the trends in the caries experience of six-year-olds in Chile. All statistical analyses undertaken were completed using SAS Version 9.4.

4.4.1 Caries experience distribution

A summary of statistical measures for the variable "Caries Experience" is presented in Table 4.8.

Table 4.8: Statistical measures summary for "Caries Experience" variable (2008 - 2019)

Caries Experience			
Mean	72.0%	**Standard Deviation**	15.8%
Median	72.2%	**Min**	0%
Mode	100%	**Max**	100%

From the total municipality/years count, in 86.9% (n = 3608), it was possible to calculate the caries experience of six-year-old children. The remaining 13.1% (n = 544) was made up of 10.9% (n = 453) of municipality/years with a lack of data to perform the calculation and a 2.2% (n = 91) in which the two components involved in the assembly of the variable was zero. The mean caries experience in the cohort was 72%. For minimum and maximum values, the full range of percentages was observed, from municipality/years with no children with caries experience to municipality/years where all the examined children had caries experience.

Figure 4.9 shows the distribution of “Caries experience”. Although most of the data were concentrated around the mean and median, which had practically the same value, a left-skewed distribution was observed. Furthermore, it is possible to appreciate a spike in the count of municipality/years in which 100% of the six-year-old children had caries experience.

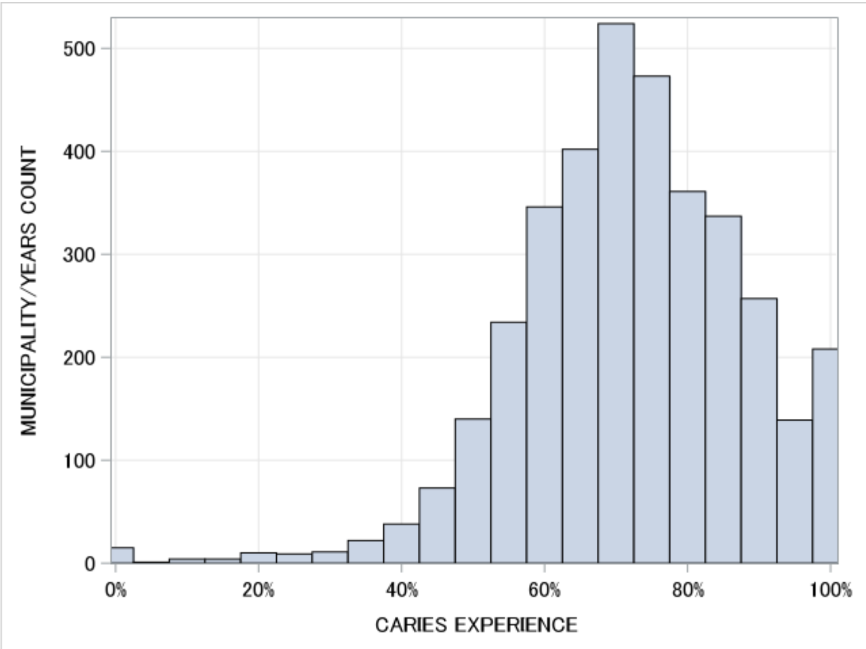


Figure 4.9: Histogram of the distribution of Caries Experience by municipality/years (2008 - 2019)

To observe the influence of the year on “Caries experience” distribution, Figure 4.10 shows a compilation of histograms with the distribution for each year included in the database.

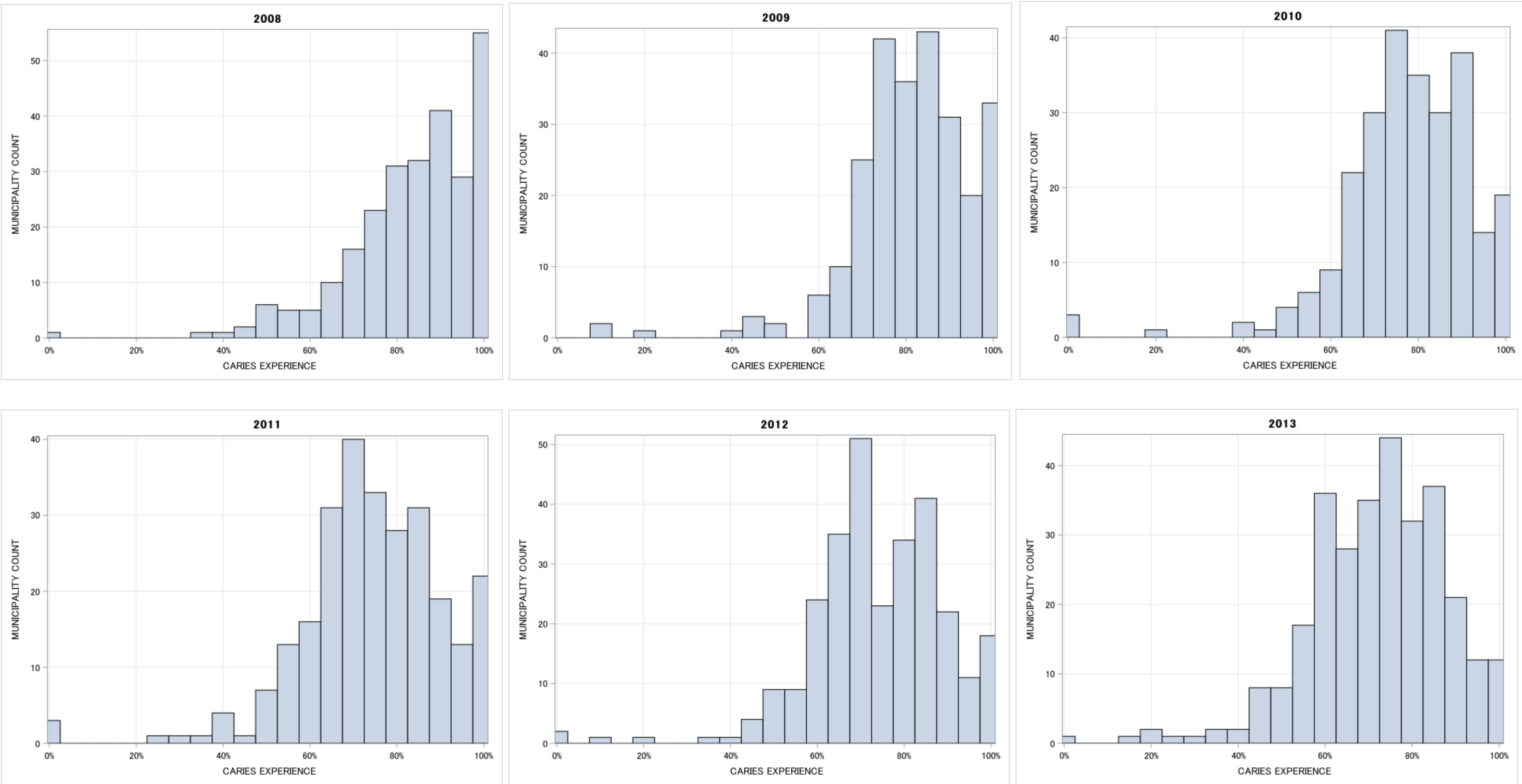


Figure 4.10: Histogram of the distribution of Caries Experience by Municipality for each year (2008 - 2019)

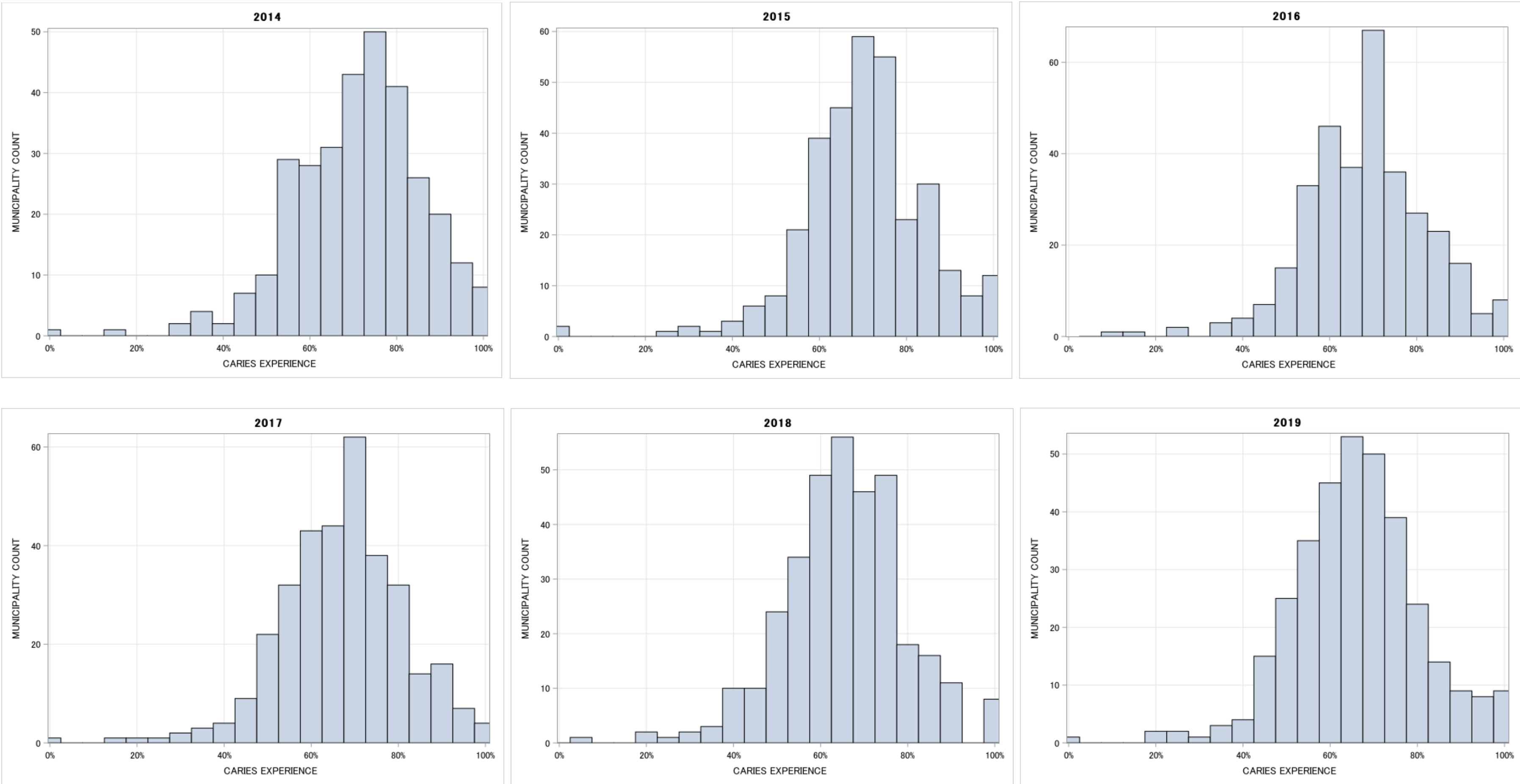


Figure 4.10: Histogram of the distribution of Caries Experience by Municipality for each year (2008 - 2019) (Continued)

When analysing the distribution by year, it was observed that the Municipalities where 100% of the children had Caries Experience were highly prevalent in the first years included in the database. However, over the years, this trend decreased, along with a transformation in the distribution of the data from a left-skewed distribution into a bell-shaped one in 2019.

Since the spike in the municipality/years with 100% caries experience could affect the analysis, tests were carried out to determine the primary source of this spike and the effect of the years on the distribution. For this, different cut-offs were tested, determining that the municipality/years with low total populations presented a high variability in their caries experience, affecting data distribution.

4.4.2 Creation of a municipality/years cohort

The sequence for creating the municipality/years cohort used for the analysis of this study is shown in Figure 4.11. To create the municipality/years cohort that was used in the analysis of this study, first, those municipality/years in which the data did not allow the calculation of Caries Experience (n = 544) were excluded. As stated in 3.5.7, for the assembly of the Socioeconomic Development Index 'IDSE', there were Municipalities in which it was impossible to calculate this variable due to having a population of fewer than 2,000 inhabitants. As this variable was used in the analysis addressed further in this chapter, it was decided to exclude the municipality/years in which there were no data from the IDSE index (n = 239). This decision also solved the problem of the municipality/years with a highly variable caries experience.

After this process, the municipality/years that were used in further analysis constituted 81% (n = 3,369) of the total number of possible municipality/years records. This cohort includes 1,397,377 dental examinations of six-year-olds, which is 99.8% of the total aggregated records included in the original dataset.

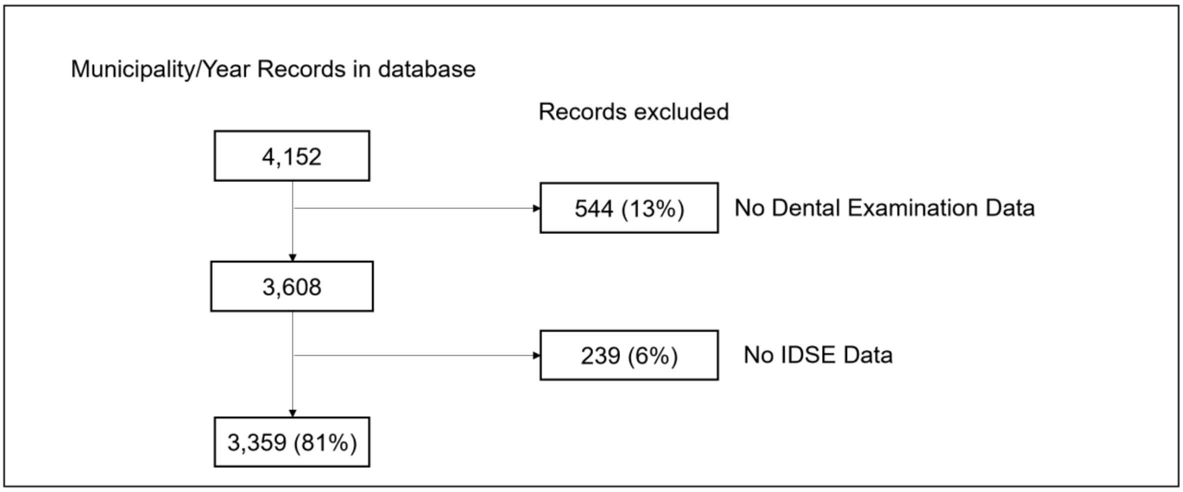


Figure 4.11: Flow chart of the cohort creation

Figure 4.12 shows the distribution of “Caries experience” in the cohort. Most of the data were concentrated around the mean and median, with a left-skewed distribution, but due to the inclusion criteria used for the cohort construction, the spike of municipalities with 100% caries experience was solved. This result makes “Caries experience” a suitable continuous variable to be used as an outcome in further analyses.

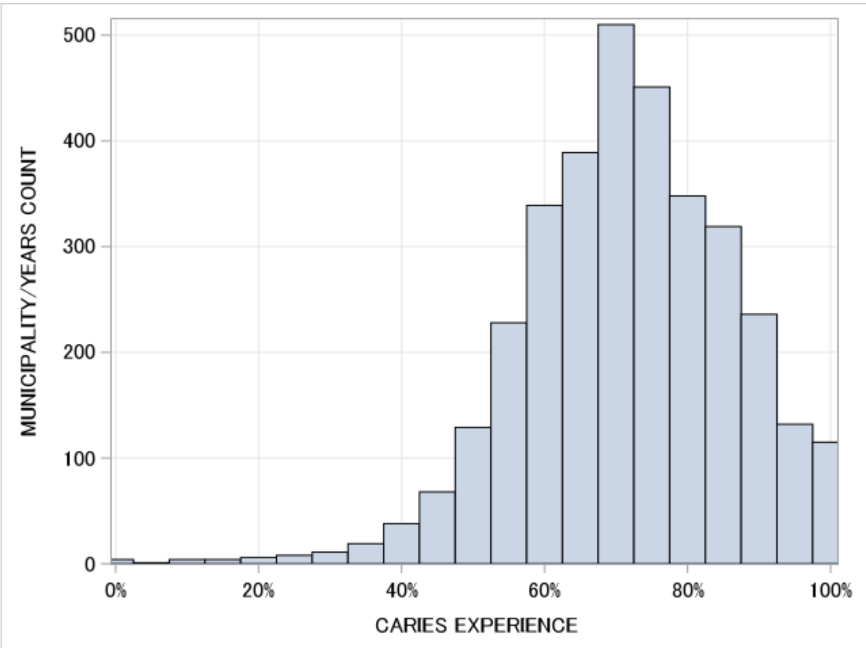


Figure 4.12: Histogram of the distribution of Caries Experience by municipality/years in the cohort (2008 - 2019)

4.4.3 Trends in caries experience by year

A univariate weighted least squares linear regression model was then used to assess the effect of time on the caries experience of six-year-old children in Chile and to analyse the differences between each year. As caries experience in the municipality/years can vary depending on the population, especially for areas where small numbers of children have been examined, all analyses were weighted by municipality/years "Total dental examinations". This variable represents the more precise approximation of the size of the population in the database for the unit of analysis and the outcome selected for this study, in order to make comparisons and assess differences in the outcomes between large and small municipalities.

All results are expressed as differences in the least squares means (LSMean). Wald's p-values with a 5% significant level and 95% confidence intervals were calculated for each LSMean. The association was calculated using the R-Squared coefficient of determination, which measures the degree of linear association between variables and Wald p-values. Note that an R-Squared value of less than 0.04 can suggest that there is no association, between 0.04 and less than 0.25 suggests a small association, between 0.25 and less than 0.64 suggests a medium association, and greater than 0.64 suggests a large association (Sullivan and Feinn, 2012).

The results of the weighted least squares linear regression of "Caries experience" according to "Year", weighted by "Total dental examinations", are presented in Table 4.9. The variable "Year" has twelve categories for each calendar year included in the cohort. The first year with records, 2008, was the referent category.

In 2008, the caries experience of six-year-olds in Chile was 79.0% (95% CI 77.5%, 80.6%). When compared to this year, a significant decrease in caries experience was observed in all subsequent years, except for 2009 (difference = -1.9%; 95% CI -4.1%, 0.2%, p = 0.073). The following years showed a progressive decline. In 2012, the threshold of 70% was crossed, with a caries experience of 68.7% (95% CI 67.3%, 70.0%), this remained stable until 2015, when a reactivation began in the decrease in caries experience, which reached its lowest level in 2018 with 62% (95% CI 60.9%, 63.1%), 17% less than in 2008 (95% CI -19.0%, -15.1%, p <.0001). This percentage was maintained in 2019 (LSmeans difference = -16.2%; 95% CI -18.2%, -14.2%, p <.0001).

Table 4.9: Summary of linear regression for the association between Caries Experience and Time, weighted by Total Dental examinations.

Year	Municipalities Frequency	Caries Experience	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
2008	228	79.0%	77.5%	80.6%	Referent	Referent		Referent
2009	233	77.1%	75.7%	78.5%	-1.9%	-4.1%	0.2%	0.073
2010	237	74.1%	72.6%	75.6%	-4.9%	-7.1%	-2.8%	<.0001
2011	238	70.1%	68.8%	71.6%	-8.9%	-11.0%	-6.7%	<.0001
2012	263	68.7%	67.3%	70.0%	-10.3%	-12.4%	-8.3%	<.0001
2013	278	68.4%	67.1%	69.7%	-10.6%	-12.6%	-8.6%	<.0001
2014	298	68.1%	66.8%	69.3%	-10.9%	-13.0%	-9.0%	<.0001
2015	308	66.8%	65.6%	67.9%	-12.2%	-14.2%	-10.3%	<.0001
2016	312	64.4%	63.2%	65.5%	-14.6%	-16.6%	-12.7%	<.0001
2017	319	64.1%	63.0%	65.3%	-14.9%	-16.9%	-13.0%	<.0001
2018	322	62.0%	60.9%	63.1%	-17.0%	-19.0%	-15.1%	<.0001
2019	323	62.8%	61.6%	64.1%	-16.2%	-18.2%	-14.2%	<.0001

Linear Regression Results:

R-Squared	Df	p-value
0.170	11	<.0001

4.5 Effect of deprivation and rurality on caries experience

Although there are many potential confounding factors for dental caries levels, such as behavioural factors, age, and sex, only the area-based deprivation status via “IDSE” and “MPI” and Rurality via “Rurality Proportion” and “Rurality Level” were available from the data sources. The following section describes the distribution and the effect of deprivation and rurality on the caries experience of Chilean six-year-old children.

4.5.1 Socioeconomic Development Index IDSE

A summary of statistical measures for the variable “IDSE” in a continuous presentation is described in Table 4.10.

Table 4.10: Statistical measures summary for ‘IDSE’ variable

IDSE			
Mean	0.55	**Standard Deviation**	0.119
Median	0.55	**Min**	0.23
Mode	0.66	**Max**	0.99

The IDSE index is included in the database according to the methodology described by the authors (Gattini, 2014), both in a continuous presentation and in its categorical presentation. In its categorical presentation, the variable “IDSE” has ten categories: '1', '2', '3', '4', '5', '6', '7', '8', '9' and '10', with the first category consisting of the 10% most deprived municipalities of Chile up to the tenth category with the 10% least deprived Municipalities of Chile.

In its continuous presentation, the variable represents a rate that can range from 0 to 1. The IDSE index presented a symmetric bell-shaped distribution (Figure 4.13), with a low degree of dispersion of the data.

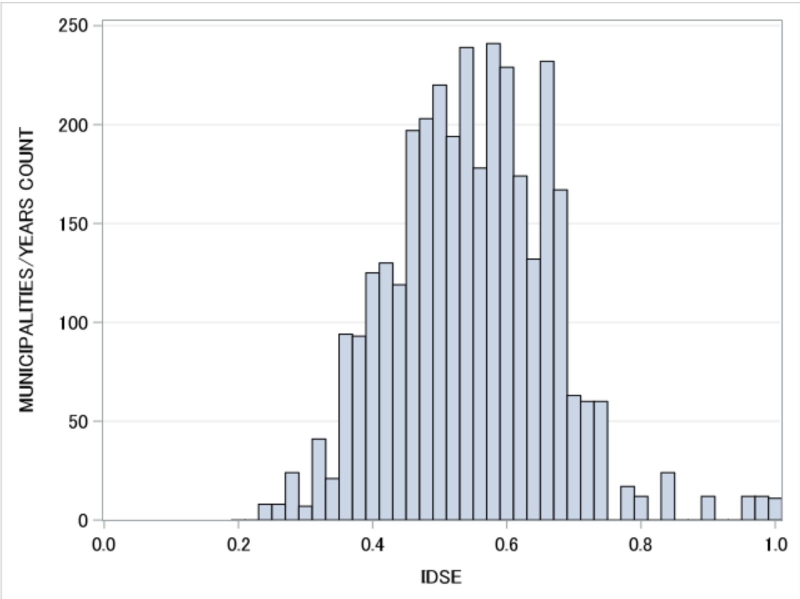


Figure 4.13: Histogram of the distribution of “IDSE” by municipality/years

4.5.1.1 Exploring the association between “IDSE” and “Caries Experience

Table 4.11 describes the average caries experience values according to each IDSE category, weighted by “Total dental examinations”. The municipality/years with a lower level of deprivation according to the “IDSE” presented lower caries experience on average.

Table 4.11: Caries Experience by IDSE categories, weighted by “Total dental examinations” (2008 - 2019).

IDSE Categories	Municipality/years Frequency	Caries Experience Mean	Std Dev
1 (most deprived)	346	79.3%	1.4%
2	336	78.9%	1.5%
3	333	73.2%	2.2%
4	334	74.3%	1.5%
5	341	72.2%	1.7%
6	331	68.6%	1.9%
7	334	69.9%	2.7%
8	358	64.2%	2.7%
9	323	66.4%	3.2%
10 (least deprived)	323	63.0%	2.8%

To consider the association of these variables, an exploration of whether there was a linear relationship between them. Figure 4.14 shows a scatter plot of the “Caries experience” in relation to the continuous presentation of “IDSE”. A negative linear relationship between “Caries experience” and the continuous presentation of “IDSE” was observed, despite the presence of atypical data. The presence of outliers is attributable to the large size of the cohort and the high variability between the different municipality/years records.

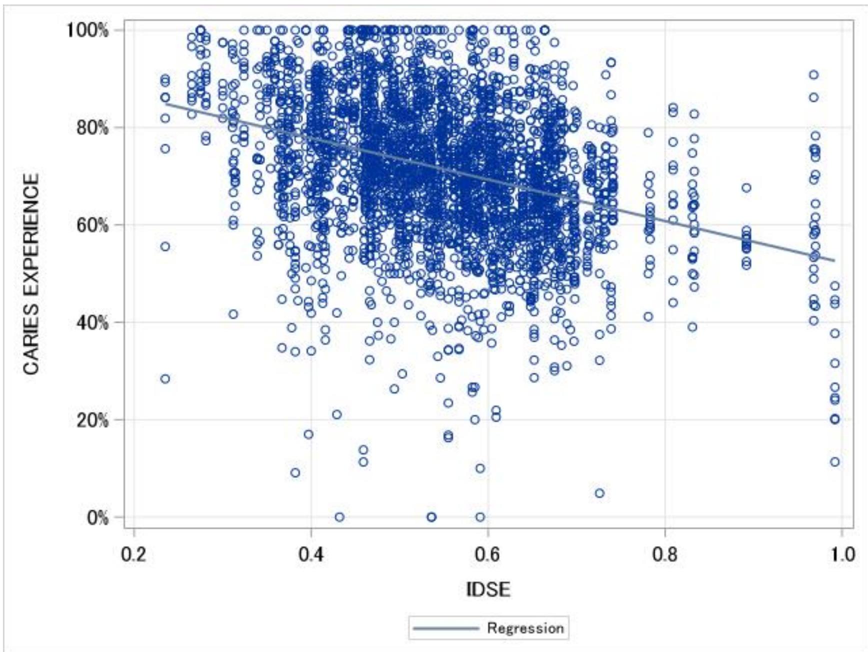


Figure 4.14: Scatter plot for the linear relationship of “IDSE” with “Caries experience” (2008 - 2019).

A univariate weighted linear regression model was then used to test the association between “IDSE” and “Caries experience”. R-Squared, slope and Wald p-values were evaluated. Both the continuous and the categorical presentation of IDSE were analysed independently. Results are presented in table 4.12.

Caries Experience was associated with IDSE, both in its continuous and categorical presentation.

Table 4.12: Summary of linear regression for the association between “Caries experience” and “IDSE”, for categorical and continuous presentation, weighted by “Total dental examinations”

Variable	Slope (Std. Error)	R^2	p-value
Continuous			
IDSE	-0.41 (0.01)	0.121	<.0001
Categorical	**Df**		
IDSE tenths	9	0.143	<.0001

4.5.2 Multidimensional Poverty Index MPI

A summary of statistical measures for the variable “MPI” is described in Table 4.13.

Table 4.13: Statistical measures summary for “MPI”

MPI			
Location		**Variability**	
Mean	17.3	**Std. Deviation**	9.2
Median	15.8	**Min**	0.03
Mode	14.1	**Max**	59.7

“MPI” is a continuous variable representing a proportion that fluctuates between 0 and 100: lower values of “MPI” represent a lower level of deprivation. Figure 4.15 presents the distribution of “MPI” with respect to municipality/years, where a right-skewed distribution was observed.

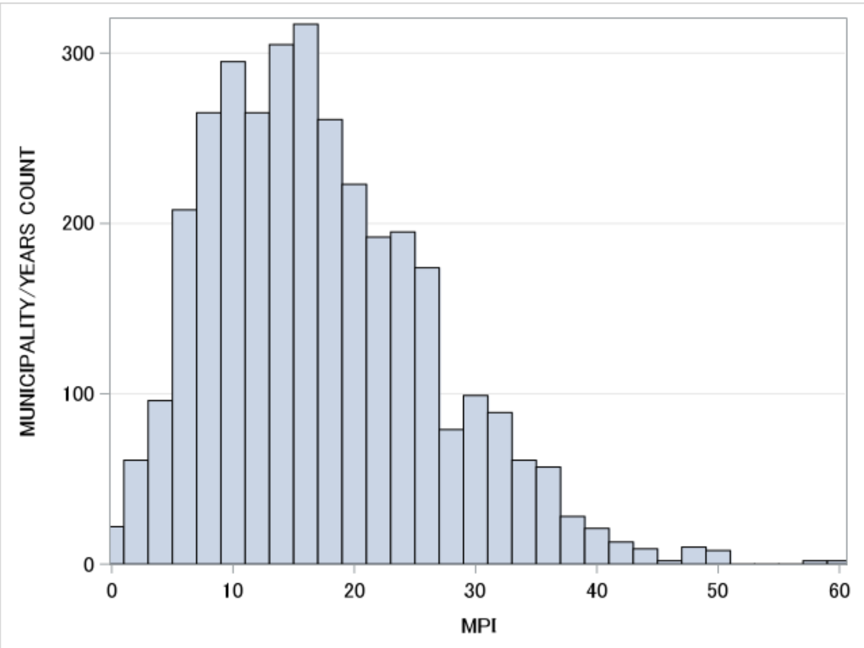


Figure 4.15: Histogram of the distribution of “MPI” by municipality/years

4.5.2.1 Exploring the association between MPI and Caries experience

As was performed for "IDSE", the linear relationship between caries experience and "MPI" was explored (Figure 4.16). A positive linear relationship between "Caries experience" and "MPI" was observed, observing a similar phenomenon as with IDSE, with a high presence of atypical data.

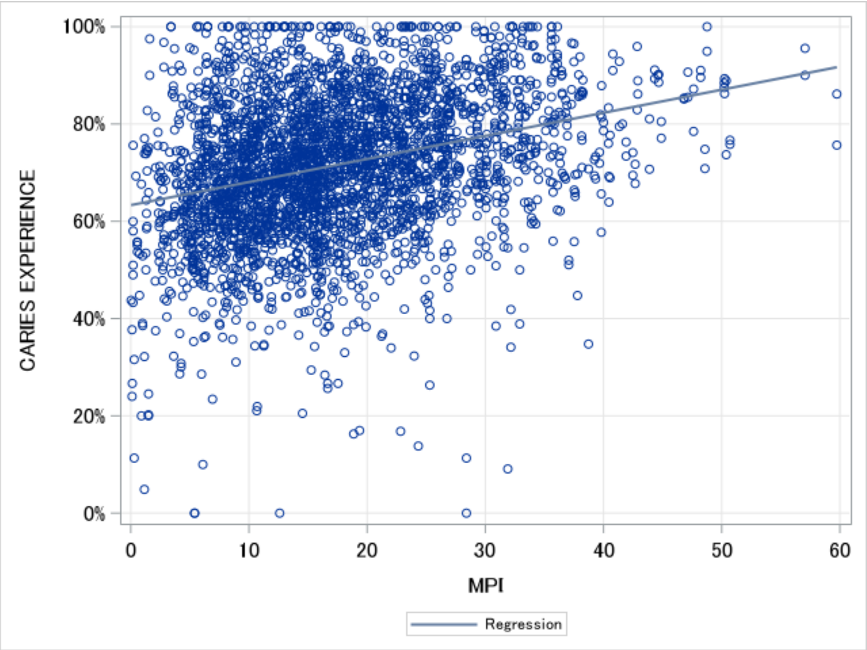


Figure 4.16: Scatter plot for the linear relationship of "MPI" with "Caries experience"

A univariate weighted linear regression was performed to analyse the association between "Caries experience" and "MPI". R-Squared, slope and Wald p-values are presented (Table 4.14). As was observed with "IDSE", an association was found between "MPI" and "Caries experience".

Table 4.14: Summary of linear regression for the association between "Caries experience" and "MPI", weighted by "Total Dental examinations"

Variable	Slope (Std. Error)	R^2	p-value
MPI	0.11 (0.005)	0.109	<.0001

4.5.3 Rurality

The variable “Rurality Proportion” is a continuous variable representing a proportion between the rural population and the total population in a municipality and fluctuates between 0 and 100: lower values represent a lower proportion of rurality. A summary of statistical measures for the variable “Rurality Proportion” is described in Table 4.15.

Table 4.15: Statistical measures summary for “Rurality Proportion”

Rurality Proportion			
Mean	31.4	**Standard Deviation**	25.7
Median	28.1	**Min**	0
Mode	0	**Max**	100

Figure 4.17 shows the distribution of the variable regarding municipality/years, where an asymmetric and multimodal distribution was observed, with a peak in the municipality/years where no rural population was recorded.

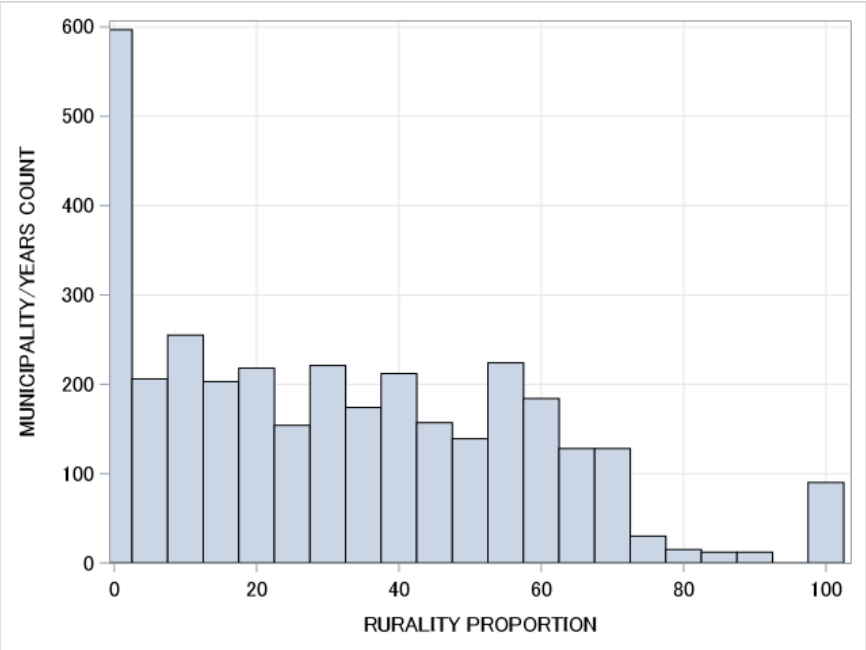


Figure 4.17: Histogram of the distribution of “Rurality Proportion” by municipality/years

4.5.3.1 Exploring the association between Rurality and Caries experience

The variable “Rurality Level” is a categorical presentation of the rurality condition of a municipality designated by the Chilean State for the assignment of various programmes that promote the development of communities in accordance with their territorial and population characteristics. “Rurality Level” presents three categories: “Rural” (more than 50% of the population living in rural conditions), “Mixed” (25% to 50% of the population living in rural conditions), and “Urban” (less than 25% of the population living in rural conditions). Table 4.16 describes the average caries experience values according to each “Rurality Level” category. Urban municipality/years showed lower levels of caries experience compared to rural or mixed municipality/years.

Table 4.16: Caries Experience by Rurality Level categories

Rurality Level	Municipality/years Frequency	Caries Experience Mean	Std Dev
Rural	1637	73.6%	1.7%
Mixed	557	72.5%	2.3%
Urban	1165	66.1%	3.1%

Figure 4.18 shows a scatter plot of “Caries experience” concerning “Rural Proportion”. A positive linear relationship between “Caries experience” and “Rurality Proportion” was observed, with the presence of atypical data.

A univariate weighted linear regression model was then used to test the association between rurality and Caries Experience of six-year-old children in Chile. Intercept, R-Squared, slope and Wald p-values are presented. The continuous “Rural Proportion” and the categorical “Rural Level” were analysed independently. Results are presented in Table 4.17.

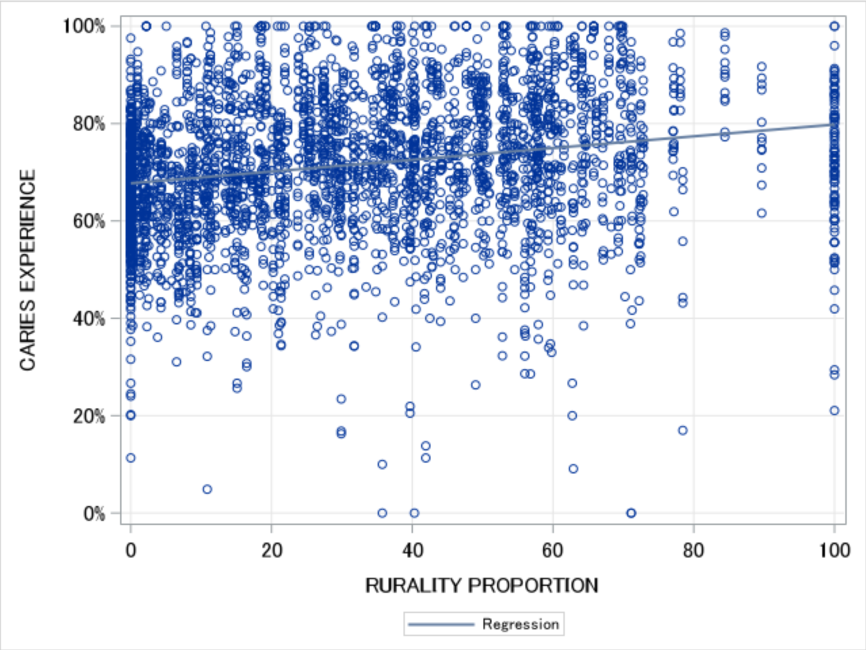


Figure 4.18: Scatter plot for the linear relationship of "Rurality Proportion" with "Caries experience"

"Caries experience" was associated with rurality in both the continuous and categorical presentations.

Table 4.17: Summary of linear regression for the association between "Caries experience" and Rurality, for categorical and continuous presentation, weighted by Total Dental examinations

Variable		R^2	p-value
Continuous	**Slope (Std. Error)**		
Rurality Proportion	0.04 (0.002)	0.076	<.0001
Categorical	**DF**		
Rurality Level	2	0.067	<.0001

In summary, time in years (R^2 = 0.170, p <.0001), IDSE (R^2 = 0.121, p <.0001), MPI (R^2 = 0.109, p <.0001), and rurality proportion (R^2 = 0.076, p <.0001) were all associated with caries experience. Consequently, it was necessary to explore their potential confounding effect on the impact of the national oral health improvement programmes on caries experience.

4.6 Exploring the potential confounding effect of deprivation, rurality and time

To design a model to analyse the effect of time, deprivation, and rurality, in search of the most parsimonious model to consider the main effects of each intervention of the national oral health improvement programmes for Chile in the caries experience of six-year-olds, a forward selection model was undertaken as an exploratory measure to investigate continuous presentation of both “IDSE” and “MPI” deprivation variables, “Rurality Proportion”, and “Year” in a single model.

Forward selection is a modelling procedure that includes variables in a model as long as they make an additional contribution toward explaining changes in the outcome. This is done iteratively until there are no variables left that make any appreciable contribution (Schneider, Hommel and Blettner, 2010). Other procedures were evaluated, such as stepwise and backward selection, determining that the most parsimonious models were the same, independent of the selection procedure.

The criteria for the selection of this model were the Adjusted R-Squared (Adj. R^2), Akaike Information Criterion (AIC), and Mallow's Cp (Cp).

Adj. R^2 explains the proportion of variation in the outcome explained by the variation of the explanatory variables. In multivariate regressions, when adding more variables, R-square always increases due to changes in the degrees of freedom, although variables that do not contribute to explaining the model could be included. Adj. R^2 resolves the reduction in the model's predictive power by adjusting the effect size, even when incorporating new variables that do not contribute to explaining the model. A higher Adj. R^2 value guarantees that contributing variables are being included in the model (informative variables) (Goodenough, Hart and Stafford, 2012).

AIC estimates each model's quality relative to the other models. Given a set of candidate models for the data, the preferred model is the one with the minimum AIC value. Thus, AIC rewards goodness of fit (as assessed by the likelihood function) but also includes a penalty for having too many parameters. The penalty discourages overfitting, which is desired because increasing the number of parameters in the model almost always improves the goodness of the fit. Overfitting a model is a condition where a statistical model begins to describe the random error in the data rather than the relationships between variables. This problem occurs when the model is too complex. Overfitting can produce misleading R-squared values, regression coefficients, and p-values (Goodenough, Hart and Stafford, 2012).

Cp is used to assess the fit of a regression model that has been estimated using ordinary least squares. It addresses overfitting and is especially valid for a large sample size such as the cohort of this study. The closer the Cp is to the number of parameters, the better the fit of the model (Fujikoshi and Satoh, 1997). So, Cp acts as a guard against overfitting (Goodenough, Hart and Stafford, 2012).

The results of the selection model are described in Table 4.18. As each of the variables was incorporated, the Adj. R^2 increased, reaching its maximum value when incorporating the “Rurality proportion” in the model, which can be interpreted as each variable included in every step of the forward selection model until this step contributed to explaining the variations in caries experience. Adj. R-Squared practically did not differ from R-Squared in each step; in addition, the value of Cp decreased, being the same as the number of variables and categories included. The same was observed for the AIC value, which also decreased in each model step. But when the model tested the inclusion of “MPI”, it was determined that the variable did not provide extra explanatory power, increasing the AIC and Cp and not making any increase on the Adj. R-Squared.

It was determined that “IDSE”, which account for deprivation, “Rurality Proportion”, which account for rurality, and “Year”, which accounts for time, were significant explanatory variables. The only factor that did not correspond to a significant explanatory variable was “MPI” ($p = 0.100$). Therefore, the model including “IDSE”, “Rurality proportion”, and “Year” was the most parsimonious, with an Adj. R^2 of 0.307, the smallest AIC of 8123, and the smallest Cp of 15.

Table 4.18: Summary of the forward selection model for the association between "Caries experience" and "IDSE", "MPI", "Rurality Proportion" and "Year" in the cohort.

Forward Selection Summary

Step	Effect Entered	R-Square	Adjusted R-Square	AIC	Cp	*p*-Value
1	**YEAR**	0.170	0.167	9341	688	<.0001
2	**IDSE**	0.306	0.303	8737	33.5	<.0001
3	**RURAL PROPORTION**	0.309	0.307	8123	15	<.0001
Excluded	**MPI**	0.310	0.307	8140	15.7	0.100

One of the conditions for linear regression models to be valid is the assumption of a lack of multicollinearity between explanatory variables. Multicollinearity can be briefly described as the phenomenon in which two or more identified predictor variables in a multiple regression model are highly correlated. The presence of this phenomenon can have a negative impact on the analysis as a whole and can severely limit the conclusions of the research (Miles, 2014).

Therefore, to verify that there was no multicollinearity between "IDSE", "Rurality Proportion", and "Year", the Variance Inflation Factor (VIF) and Tolerance of the model were checked. To determine that there is no multicollinearity between the variables of a model, Tolerance should not have a value less than 0.1, and the VIF should not be greater than 10 (Miles, 2014). The results are described in Table 4.19. Both requirements were met in the model.

Table 4.19: VIF and Tolerance of a model including "IDSE", "Year" and "Rurality proportion"

Variable	Tolerance	VIF
IDSE	0.99	1.01
YEAR	0.58	1.72
RURALITY	0.57	1.73

To evaluate the effect of the adjustment variables of the model on caries experience trends, a weighted least squares linear regression for “Year” adjusted by “Rurality proportion” and “IDSE” was performed (Table 4.20). The year 2008 was used as the reference, which showed a caries experience of 83.0% (95% CI 81.6%, 84.5%), that is, a higher level of caries than that observed in the unadjusted model. The same happened with the rest of the years, where a higher caries experience was observed in the adjusted model. A significant decrease in caries experience was observed throughout all the years in relation to the reference, with a similar trend to the unadjusted model, with a decrease of 17.0% (95% CI -18.8%, -15.2%, $p < 0.001$) for the last year analysed, 2019, which had a caries experience of 66.1% (95% CI: 64.9%, 67.2%). As in the unadjusted model, the lowest caries experience was observed in 2018, 65.3% (95% CI 64.2%, 66.4%).

Table 4.20: Summary of least squares linear regressions for the trends in “Caries experience” by “Year”, adjusted by “IDSE” and “Rurality proportion”, weighted by “Total dental examinations”

Year	Municipalities Frequency	Model* Caries Experience	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
2008	228	83.0%	81.6%	84.5%	Referent	Referent		Referent
2009	233	81.0%	79.6%	82.4%	2.0%	-4.0%	-0.1%	0.040
2010	237	78.1%	76.7%	79.4%	5.0%	-6.9%	-3.0%	<.0001
2011	238	74.2%	72.8%	75.5%	8.9%	-10.8%	-7.0%	<.0001
2012	263	72.2%	70.9%	73.4%	10.9%	-12.7%	-9.0%	<.0001
2013	278	72.0%	70.7%	73.2%	11.1%	-12.9%	-9.2%	<.0001
2014	298	71.7%	70.5%	72.8%	11.4%	-13.2%	-9.6%	<.0001
2015	308	70.1%	69.0%	71.3%	12.9%	-14.7%	-11.1%	<.0001
2016	312	67.7%	66.6%	68.8%	15.3%	-17.1%	-13.5%	<.0001
2017	319	67.6%	66.5%	68.7%	15.4%	-17.2%	-13.7%	<.0001
2018	322	65.3%	64.2%	66.4%	17.7%	-19.5%	-16.0%	<.0001
2019	323	66.1%	64.9%	67.2%	16.9%	-18.8%	-15.2%	<.0001

Linear Regression Results:

Adj. R^2	Df	p-value
0.307	13	<.0001

*Model is adjusted by IDSE and Rurality proportion.

4.7 Oral health socioeconomic inequalities of Chilean six-year-olds

This section describes the analysis that was carried out to measure the socioeconomic inequalities in the distribution of the caries experience of six-year-olds in Chile in the period analysed.

4.7.1 Caries experience by area-based deprivation level

To check the trends in caries experience regarding the socioeconomic deprivation of the municipality/years, the differences in caries experience between “IDSE” tenths were evaluated in the adjusted model (Table 4.21).

Table 4.21: Summary of least squares linear regressions for caries experience by socioeconomic deprivation level, adjusted by “Year” and “Rurality proportion”, weighted by “Total dental examinations”

IDSE tenths	Municipalities Frequency	Model* Caries Experience	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
1 (most deprived)	346	77.8%	76.7%	78.8%	Referent	Referent		Referent
2	336	75.1%	74.0%	76.1%	-2.7%	-4.2%	-1.2%	0.0004
3	333	70.3%	69.2%	71.4%	-7.5%	-9.1%	-5.9%	<.0001
4	334	69.7%	68.5%	70.9%	-8.0%	-9.7%	-6.3%	<.0001
5	341	66.5%	65.3%	67.7%	-11.2%	-12.9%	-9.5%	<.0001
6	331	66.7%	65.4%	68.0%	-11.1%	-12.8%	-9.3%	<.0001
7	334	71.6%	70.2%	73.1%	-6.1%	-8.0%	-4.2%	<.0001
8	358	65.4%	64.0%	66.8%	-12.4%	-14.3%	-10.5%	<.0001
9	323	64.7%	63.4%	66.0%	-13.1%	-14.9%	-11.2%	<.0001
10 (least deprived)	323	65.6%	64.1%	67.0%	-12.2%	-14.1%	-10.2%	<.0001

Linear Regression Results:

Adj. R^2	Df	p-value
0.323	21	<.0001

*Model is adjusted by year and Rurality proportion.

The most socioeconomic deprived municipality/years category (IDSE 1) was used as the referent, with a caries experience of 77.8% (95% CI 76.7%, 78.8%). A significant decrease in caries experience was observed for all other categories, showing the trend of lower caries levels associated with a decrease in the socioeconomic deprivation of the municipality/years.

The least deprived municipality/years (IDSE 10) showed a caries experience of 65.6% (95% CI: 64.1%, 67.0%), with a decrease of 12.2% regarding the reference (95% CI -14.1 %, -10.2%; p <.0001). IDSE 9 showed the lowest caries experience of 64.7% (95% CI: 63.4%, 66.0%), 13.1% lower than the reference (95% CI -14.9 %, -11.2%; p <.0001).

When analysing the trends by year (Figure 4.19), caries experience has decreased in all socioeconomic groups. The most socioeconomic deprived municipality/years showed a caries experience of 89.2% (SD = 11.8%) in 2008, decreasing to 71.4% (SD = 11.7%) in 2019, those in the mid-subgroup in 2008, 86.1% (SD = 12.3%), decreasing to 66.1% (SD = 13.7%) in 2019. The same trend occurred in the least socioeconomic deprived municipality/years. In 2008 they showed a caries experience of 75.1% (SD = 12.2%), decreasing to 57.8% (SD = 12.6%) in 2019.

4.7.2 Summary measures of socioeconomic inequality in the distribution of caries experience of Chilean six-year-olds

In its Health Equity Assessment Toolkit (Hosseinpoor *et al.*, 2018), the WHO states that the selection of summary measures for health inequalities is based on the characteristics of the data and the interpretation of the results sought. Summary measures are calculated by combining estimates of a given health indicator across two or more subgroups in a single numerical figure. They can use simple methods, which compare only two groups, usually the most and least disadvantaged, or complex methods, which look across the whole social gradient, rather than solely at the most and least disadvantaged groups.

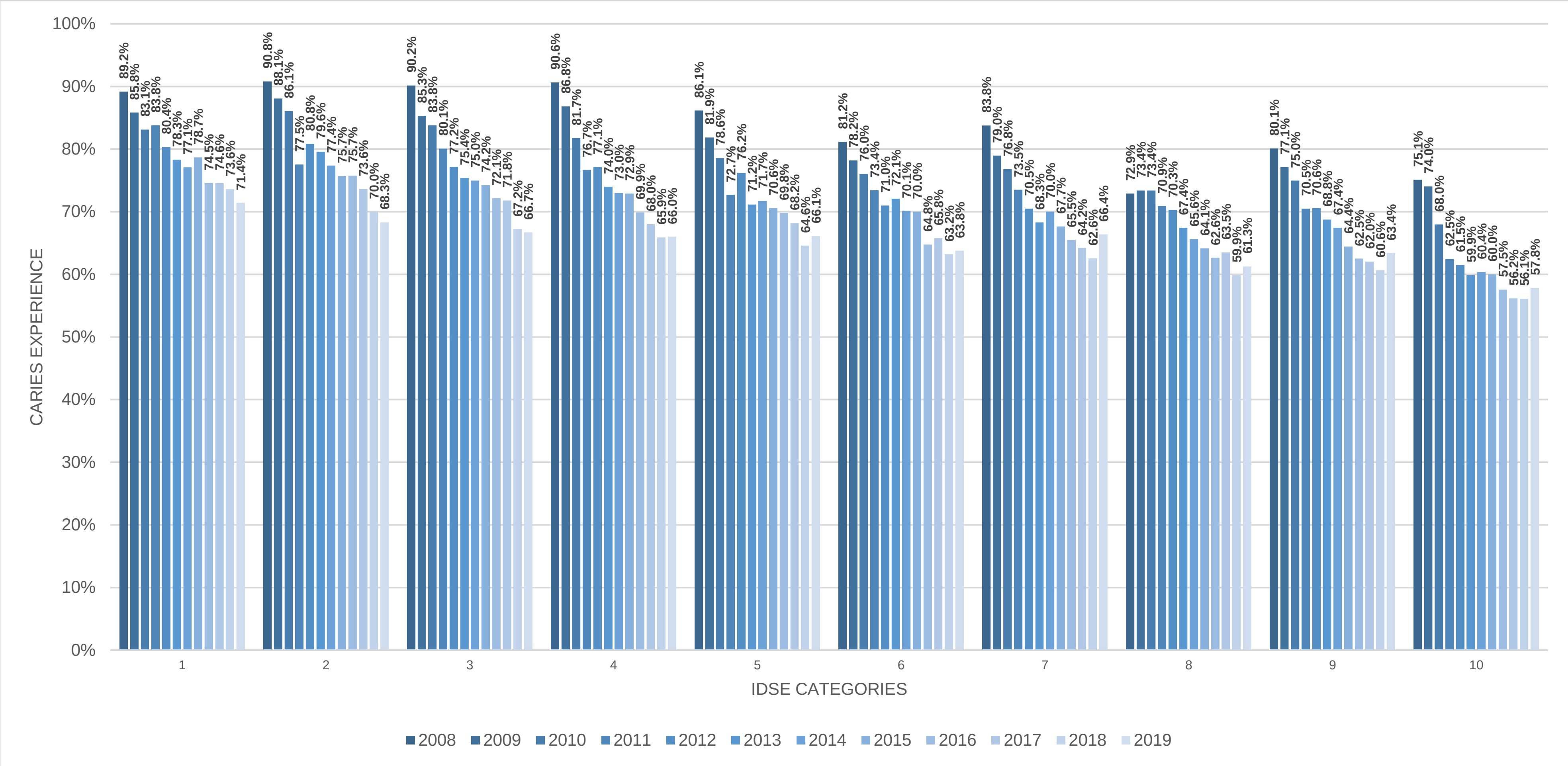


Figure 4.19: Trends in Caries Experience of six-year-olds by area-based deprivation and year

Furthermore, absolute inequality measures indicate the magnitude of difference in health between subgroups for a given health indicator. They retain the same unit as the health indicator. In contrast, relative inequality measures show proportional differences among subgroups and have no unit (World Health Organization, 2018b). Lastly, complex summary measures may be weighted, taking into account the population size of each subgroup (World Health Organization, 2018b).

Four approaches were used to measure the inequities in the distribution of Caries Experience in Chilean six-year-olds by categories of area-based deprivation: two simple measures: i) Absolute Range or Rate Difference and ii) Relative Range or Ratio ; and two complex weighted measures: iii) Slope index of inequality (SII) and iv) Relative index of inequality-linear (RII).

The Absolute Range is the difference between the values of a given health indicator of the most and least advantaged groups, and the Relative Range is the division of both values (Regidor, 2004). For their calculation, the categories IDSE 1 (most deprived) and IDSE 10 (least deprived) were used as subgroups according to the categorical presentation of the Socioeconomic development index.

The SII indicates the absolute difference in estimated values of a health indicator between the most advantaged and most-disadvantaged, accounting for the proportional distribution of the population within each subgroup in a regression model (Regidor, 2004). For calculating SII, the population is ranked from the most-disadvantaged subgroup to the most-advantaged subgroup. The population of each subgroup is considered in terms of its range in the cumulative population distribution and the midpoint of this range. The health indicator is then regressed against this midpoint value using a generalized linear model (Pamuk, 1985).

The RII indicates the ratio of estimated values of a health indicator of the most-advantaged to the most-disadvantaged while considering all the other subgroups (Regidor, 2004). To calculate RII, the SII is divided by the overall value of the health indicator for the whole population.

To calculate both indexes, two assumptions must be fulfilled: the data are ranked and there is a linear relationship between the health indicator and the variable that is used for ranking (Pamuk, 1985).

For the calculation of SII and RII, a linear regression model was weighted by “Total dental examinations” and the IDSE tenths was used to rank by socioeconomic level, which as stated previously in this Chapter, comply with both requirements.

Table 4.22 summarises the analysis for Absolute and Relative Range. The two extreme categories of the IDSE categorical presentation, IDSE 1 (most-deprived) and IDSE 10 (least-deprived), were used. In addition to calculating both summary measures for the period analysed (2008-2019), the years 2008, 2014 and 2019 were selected to evaluate the changes over time.

Table 4.22: Summary of the Absolute and Relative Range summary measures of inequality in the distribution of caries experience in Chilean six-year-olds

Period	IDSE 1 (most) Caries Experience	IDSE 10 (least) Caries Experience	Absolute Range	Relative Range
2008 - 2019	77.1%	59.6%	17.5%	1.29
2008	90.3%	69.2%	21.1%	1.30
2014	76.7%	56.3%	20.4%	1.36
2019	68.6%	53.7%	14.9%	1.28

The caries experience of the six-year-olds in the most deprived municipalities was 1.29 times higher than in the least deprived in the analysed period, with a difference of 17.5%. When analysing the trends in the selected years, 2014 showed an increase in the Absolute and Relative Range compared to 2008. 2019 showed a decrease in the Absolute Range, although the Relative Range remained similar to 2008. Table 4.23 shows a summary of the analysis for SII and RII. Both indexes were calculated for the analysed period (2008 to 2019), and to evaluate the changes over time, three groups of periods of four years each were generated: 2008-2011, 2012-2015 and 2016-2019 to increase the statistical power of linear regression.

Table 4.23: Summary of the SII and RII summary measures of inequality in the distribution of Caries Experience in Chilean six-year-olds

Period	Caries Experience mean	SII	SII 95% CI	p-value	RII
2008 - 2019	68.3%	15.3%	(10.8%, 19.9%)	< 0.001	0.22
2008 - 2011	75.4%	16.3%	(10.0%, 22.6%)	< 0.001	0.22
2012 – 2015	67.9%	17.5%	(11.8%, 23.3%)	< 0.001	0.26
2016 – 2019	63.1%	14.7%	(10.2%, 19.3%)	< 0.001	0.22

In the analysed period, the value of SII was 15.3%; that is, there is a difference of 15.3% in the Caries Experience between the most and less deprived municipalities. The RII value was 0.22 in the same period.

Regarding the changes over time, the SII in the 2016-2019 period was 14.7%, which is an improvement over the 2008-2011 period, although the increase in SII of RII for the 2012-2015 period to 17.5% and 2.6 respectively, is noticeable. The RII did not show improvement when comparing the first and last periods.

4.8 Regional analysis of caries experience of Chilean six-year-olds

As mentioned in section 1.6.1, Chile's territory has been broken down into 16 regions (see Figure 1.1). The trends in caries experience in each region and municipality were examined using choropleth maps performed with QGIS 3.16 software (QGIS Association, 2021). Caries experience in 2019 was selected as the outcome to construct the maps. This was due to 2019 been the year that included the highest number of municipalities, according to the previous analysis (Table 4.5). The maps were constructed using the official geolocation shapes files from the Government of Chile, provided as an open-access resource on the Geospatial Data Infrastructure Bureau of the Ministry of National Assets website

(Ministerio de Bienes Nacionales. Gobierno de Chile, 2021). The municipality name, IDSE tenth category and Rurality level were included in the maps. A dot (.) was included in those municipalities with less than 2,000 total inhabitants, where it is impossible to calculate IDSE.

Maps were constructed by region, including all municipalities, and were grouped into four macrozones: northern, northern centre, south centre, and south. The fact that the country's first region in the northern limit corresponds to XV, and not Region I as logic would order, is that in 2007 Region I was divided into two territories to facilitate the public administration of resources. The same happened with region XIV (divided from region X) and region XVI (divided from region VIII).

4.8.1 Caries experience of six-year-olds from the northern macrozone regions

Figures 4.20 to 4.23 shows the caries experience in the regions of the northern macrozone.

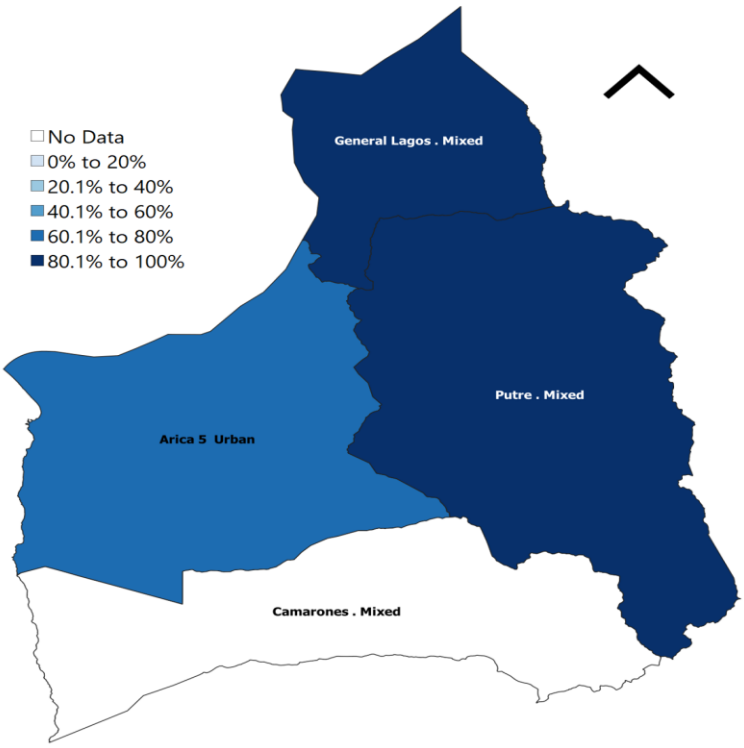


Figure 4.20: Choropleth map for caries experience of six-year-olds in Region XV Arica y Parinacota municipalities (2019)

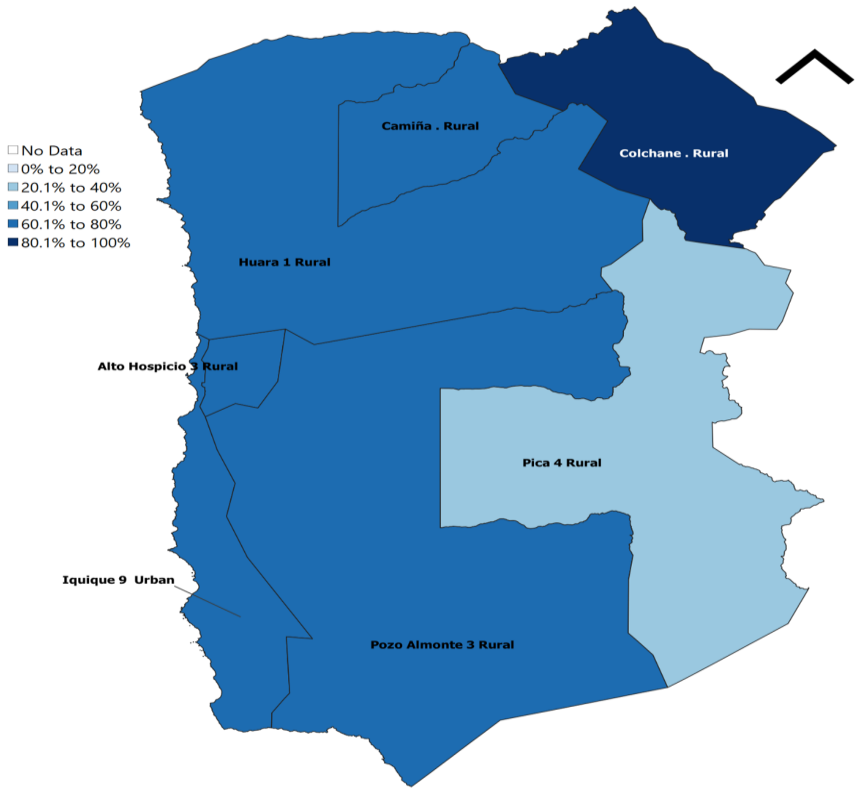


Figure 4.21: Choropleth map for caries experience of six-year-olds in Region I Tarapacá municipalities (2019)

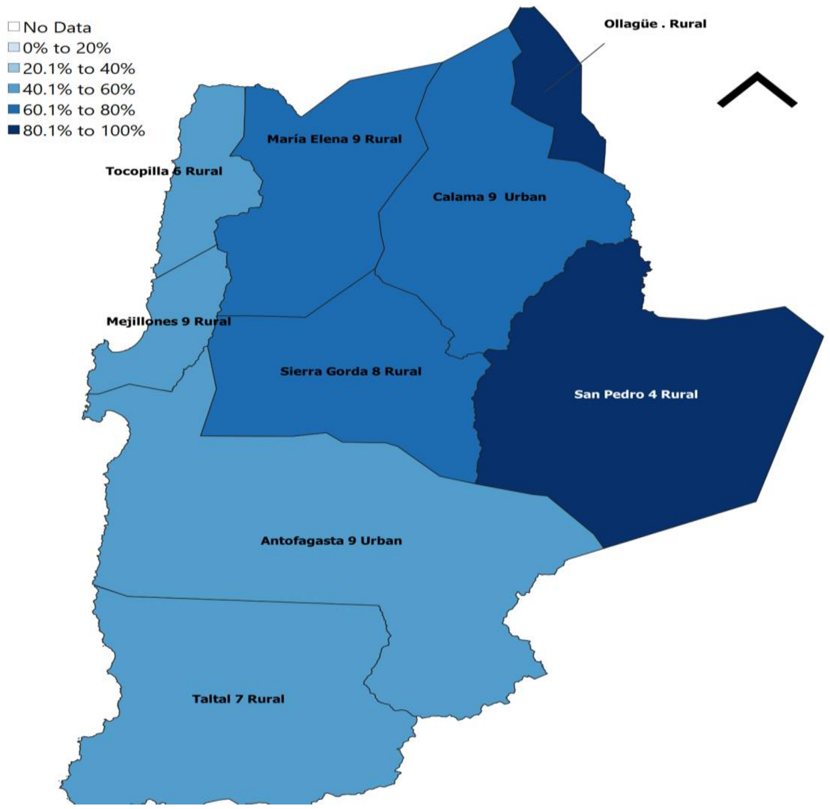


Figure 4.22: Choropleth map for caries experience of six-year-olds in Region II Antofagasta municipalities (2019)

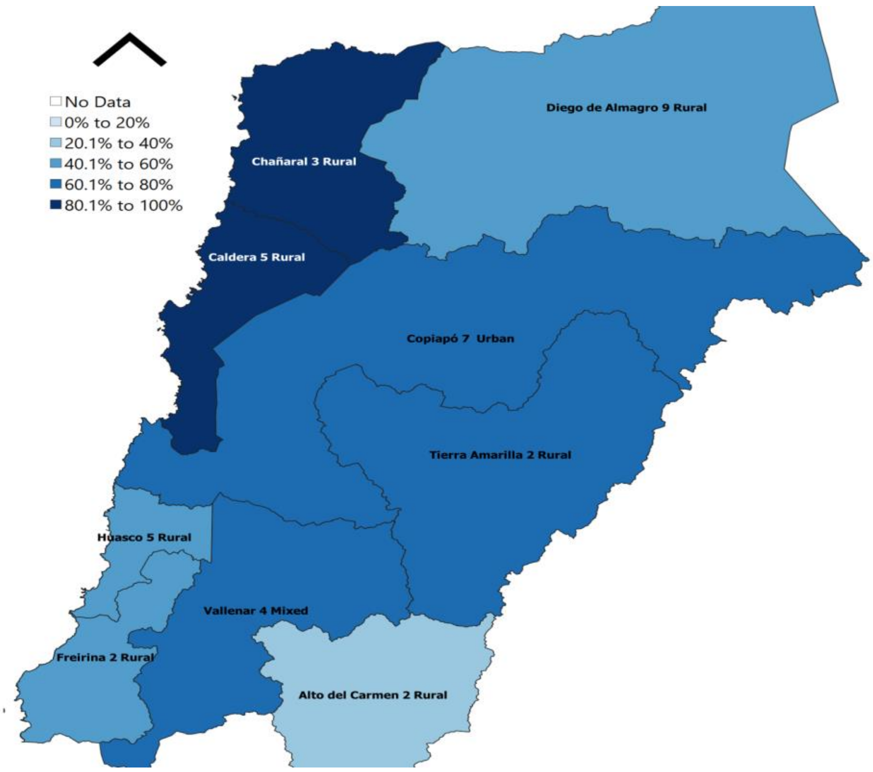


Figure 4.23: Choropleth map for caries experience of six-year-olds in Region III Atacama municipalities (2019)

In region XV, the capital is Arica, the only urban municipality, with a caries experience of 65.5% in 2019. The other municipalities are mixed in their rurality level and have less than 2,000 inhabitants. Two municipalities showed high caries levels, and Camarones did not have data for caries experience calculation.

For Region I, the capital is Iquique, which had a caries experience of 61.8% in 2019; it is also the only urban municipality with the lowest socioeconomic deprivation. All the other municipalities are rural and showed a caries experience between 60% and 80%, except for Colchane, with the highest caries levels of the region with 87.5%, and Pica, with the lowest caries experience of 35.7%.

Antofagasta, with a caries experience of 55.7%, is the capital of Region II. It is noticeable in this region that all the western municipalities had lower caries levels compared to the most eastern ones, despite the IDSE and rurality level.

In Region III, the capital city is Copiapó, which showed a caries experience of 66.8% in 2019. In contrast to region II, two of the municipalities with the highest caries levels are located in the west, and the two municipalities with the lowest caries experience, Diego de Almagro (IDSE 9) and Alto del Carmen (IDSE 2), are located in the east, despite all being rural.

In summary, the municipalities of the regions of the northern macrozone present a high heterogeneity in their contexts and caries levels, with municipalities that are among the most deprived, contrasting with some of those of the 20% least socioeconomic deprived and being a macrozone dominated by rural areas.

4.8.2 Caries experience of six-year-olds from the northern centre macrozone regions

Figures 4.24 to 4.28 shows the caries experience in the regions of the northern centre macrozone. Due to a large number of municipalities in Region XIII, the region was divided into two zones, according to its geographical structure: Santiago, including all the municipalities that conform to the capital of Chile, and Provinces, including those surrounding the capital.

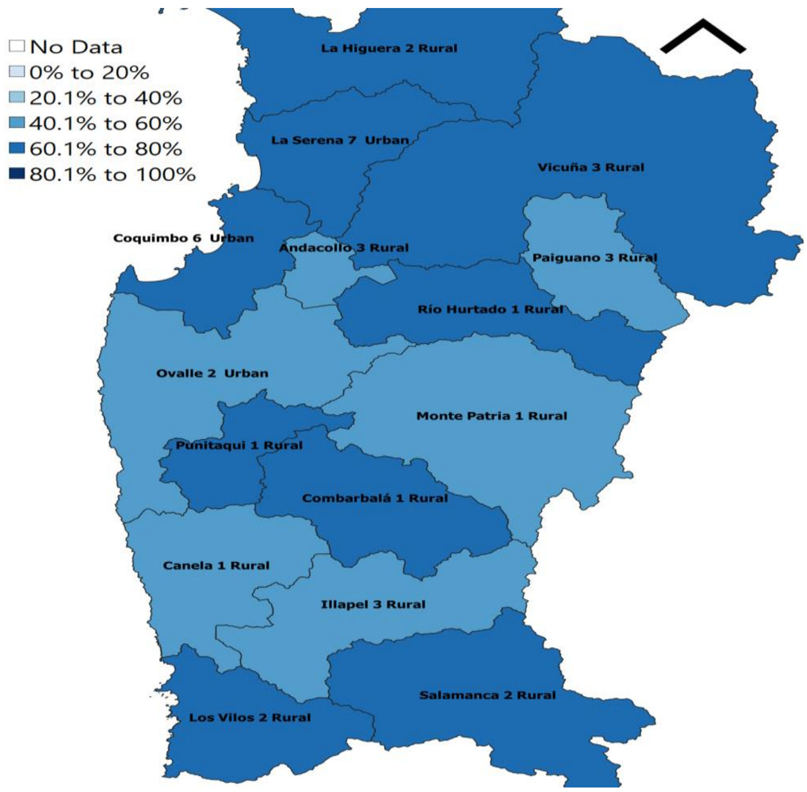


Figure 4.24: Choropleth map for caries experience of six-year-olds in Region IV Coquimbo (2019)

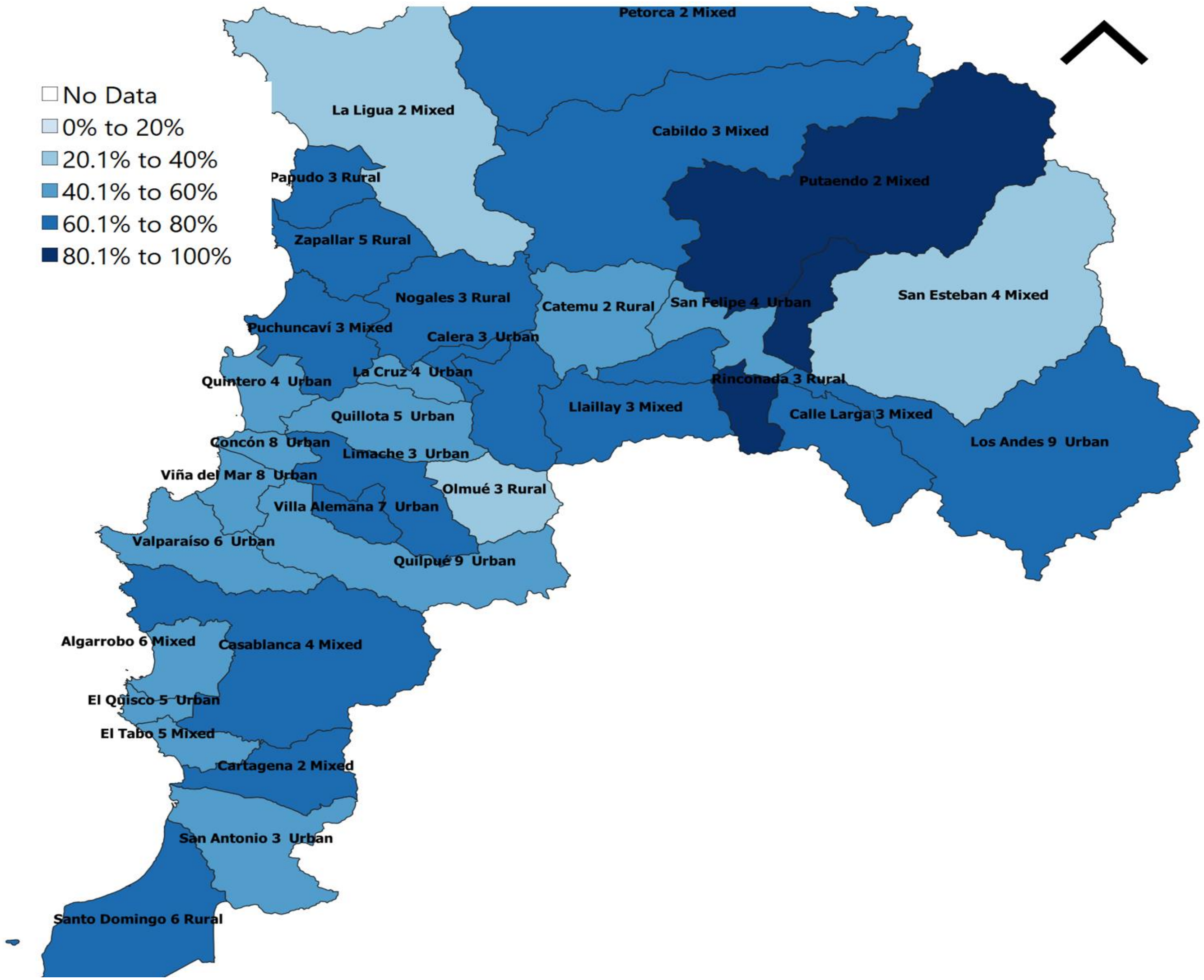


Figure 4.25: Choropleth map for caries experience of six-year-olds in Region V Valparaiso (2019)

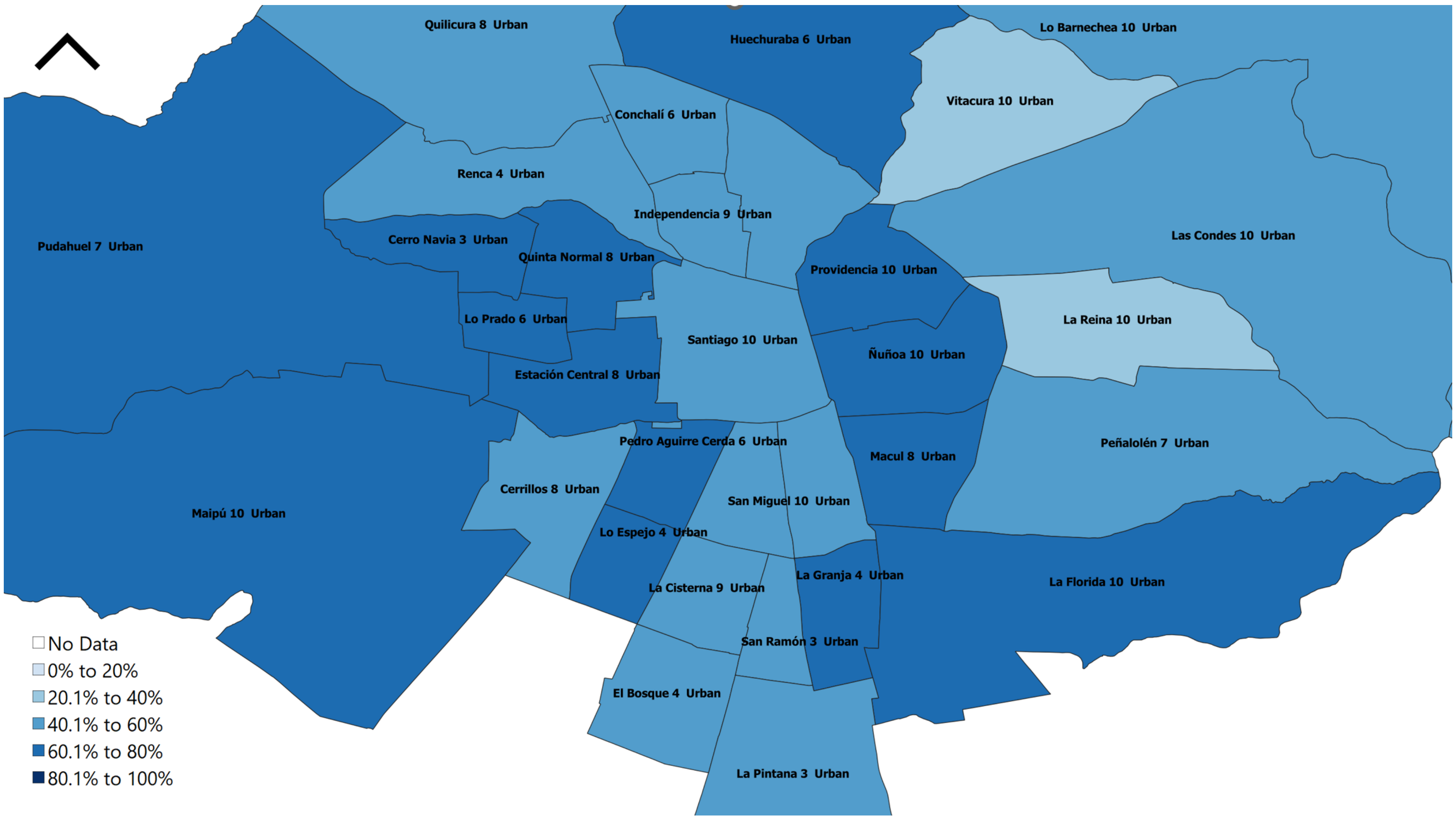


Figure 4.26: Choropleth map for caries experience of six-year-olds in Region XIII Metropolitan-Santiago (2019)

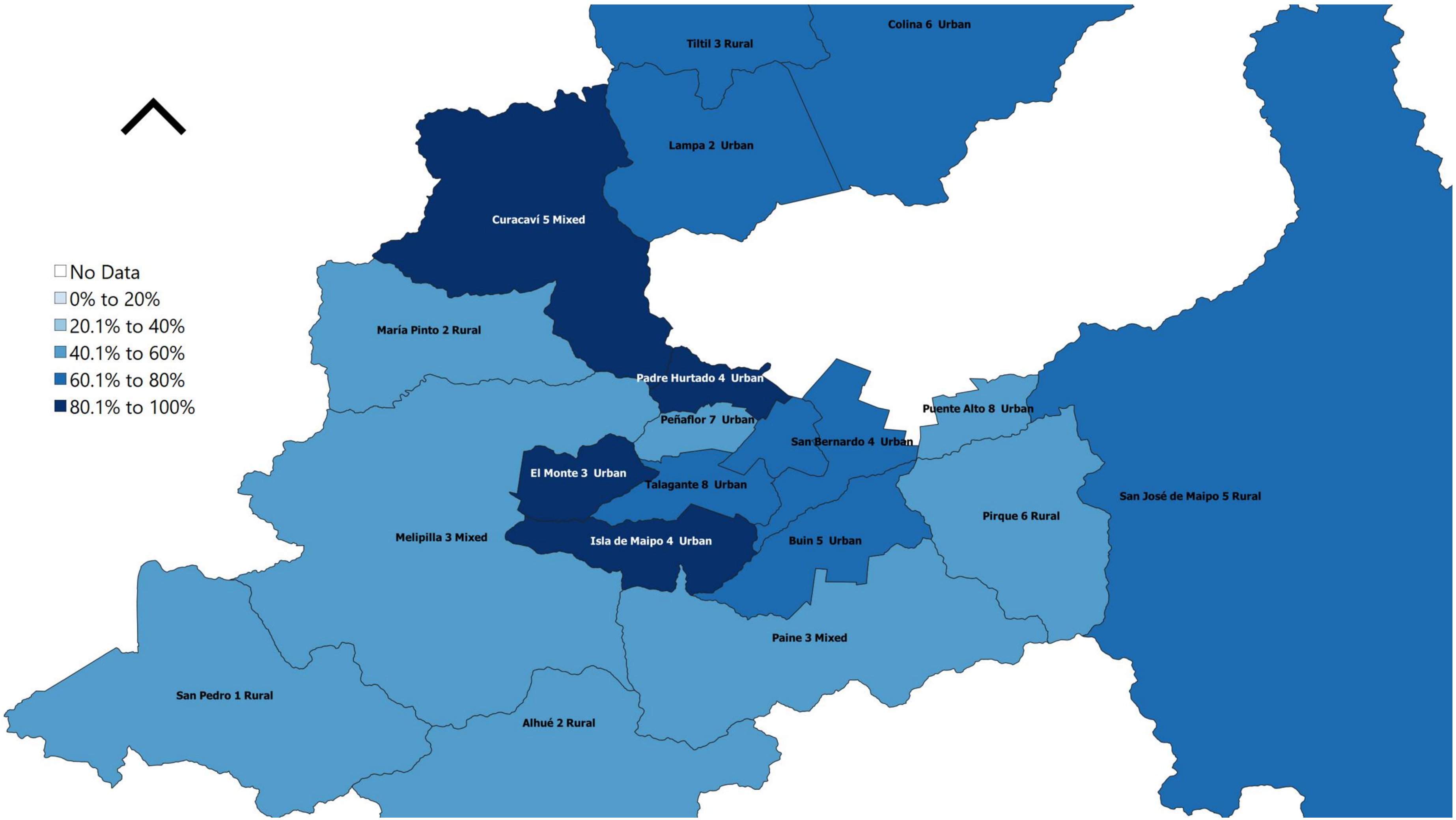


Figure 4.27: Choropleth map for Caries Experience of six-year-olds in Region XIII Metropolitan-Provinces (2019)

Figure 4.28: Choropleth map for caries experience of six-year-olds in Region VI Libertador Bernardo O'Higgins (2019)

La Serena, the capital of Region IV, had a caries experience of 66.5% in 2019. This municipality and Coquimbo are the only urban ones in the region and had the lowest socioeconomic deprivation in a region with a predominance of rural areas and where almost all municipalities are some of the most deprived in the country. Despite this, no municipality with a caries experience of 80% or more was observed.

Region V is a region with a high number of municipalities. Due to this, high heterogeneity in caries levels was observed, along with different IDSE and rurality level contexts. The capital, Valparaiso, showed a caries experience of 51.3% in 2019, and most municipalities had a caries experience of 70% or lower, except Putaendo and Rinconada.

Region XIII has the highest number of municipalities in the country. The capital Santiago is divided into 32 municipalities, and this region concentrates the most IDSE 10 (least deprived) and urban communities in Chile. Santiago Centro, the regional capital, showed a caries experience of 49.7%. Vitacura, the least socioeconomic deprived municipality in the country according to IDSE, had a caries experience of 26.7% in 2019. In the provinces, most municipalities are rural and more deprived than those from the capital, with four municipalities with a caries experience of 80% or more.

Region VI is an area with a predominance of rural and deprived municipalities. The capital is Rancagua, which had a caries experience of 57.8%. Despite the rurality level and deprivation of the municipalities, most had a caries experience between 40% and 65%, with Pichilemu having the highest caries levels in the region.

In summary, the central-north is the macrozone that concentrates most of the least deprived municipalities due to being the productive centre of the country. However, several rural municipalities belong to the most deprived groups with high caries levels. When comparing the caries experience of the regional capitals, the low levels of Santiago and Valparaiso stand out.

4.8.3 Caries experience of six-year-olds from the southern centre macrozone regions

Figures 4.29 to 4.32 shows the caries experience in the regions of the southern centre macrozone.

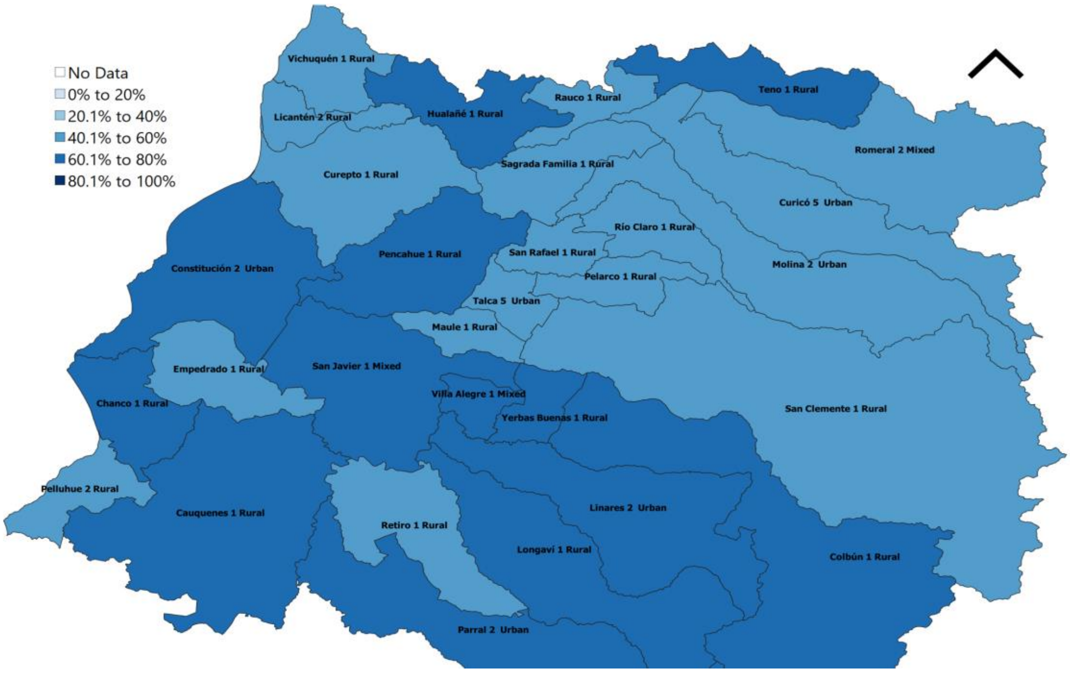


Figure 4.29: Choropleth map for caries experience of six-year-olds in Region VII Maule (2019)

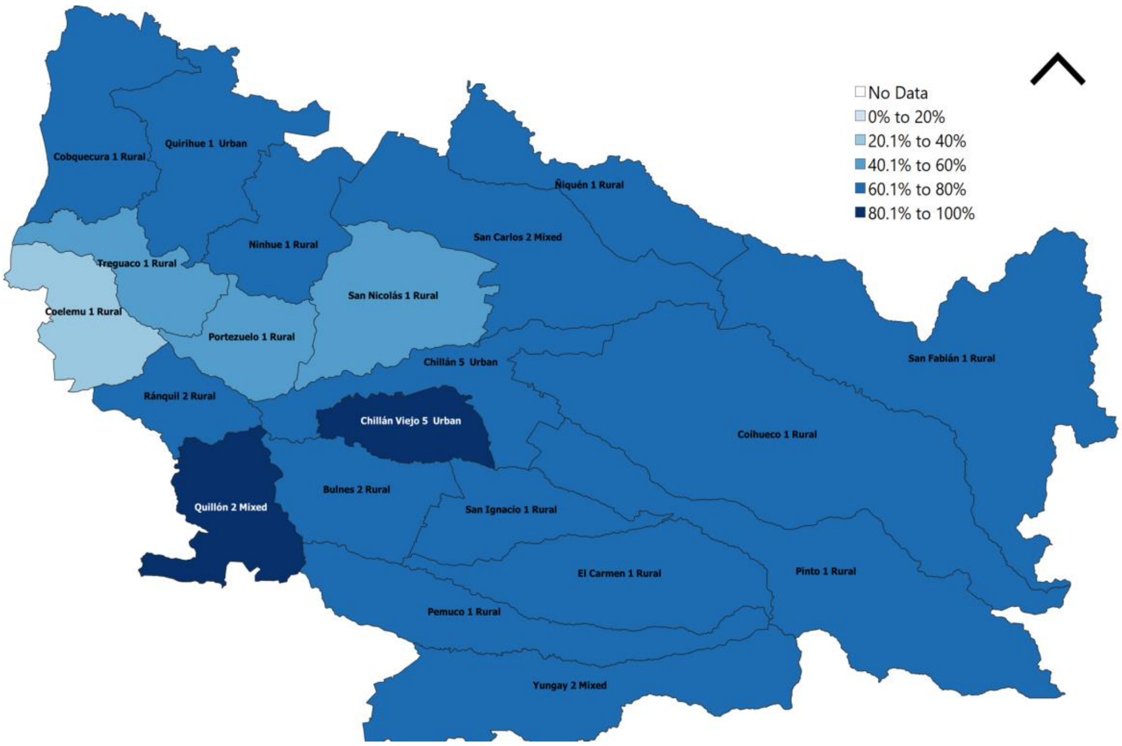


Figure 4.30: Choropleth map for caries experience of six-year-olds in Region XVI Ñuble (2019)

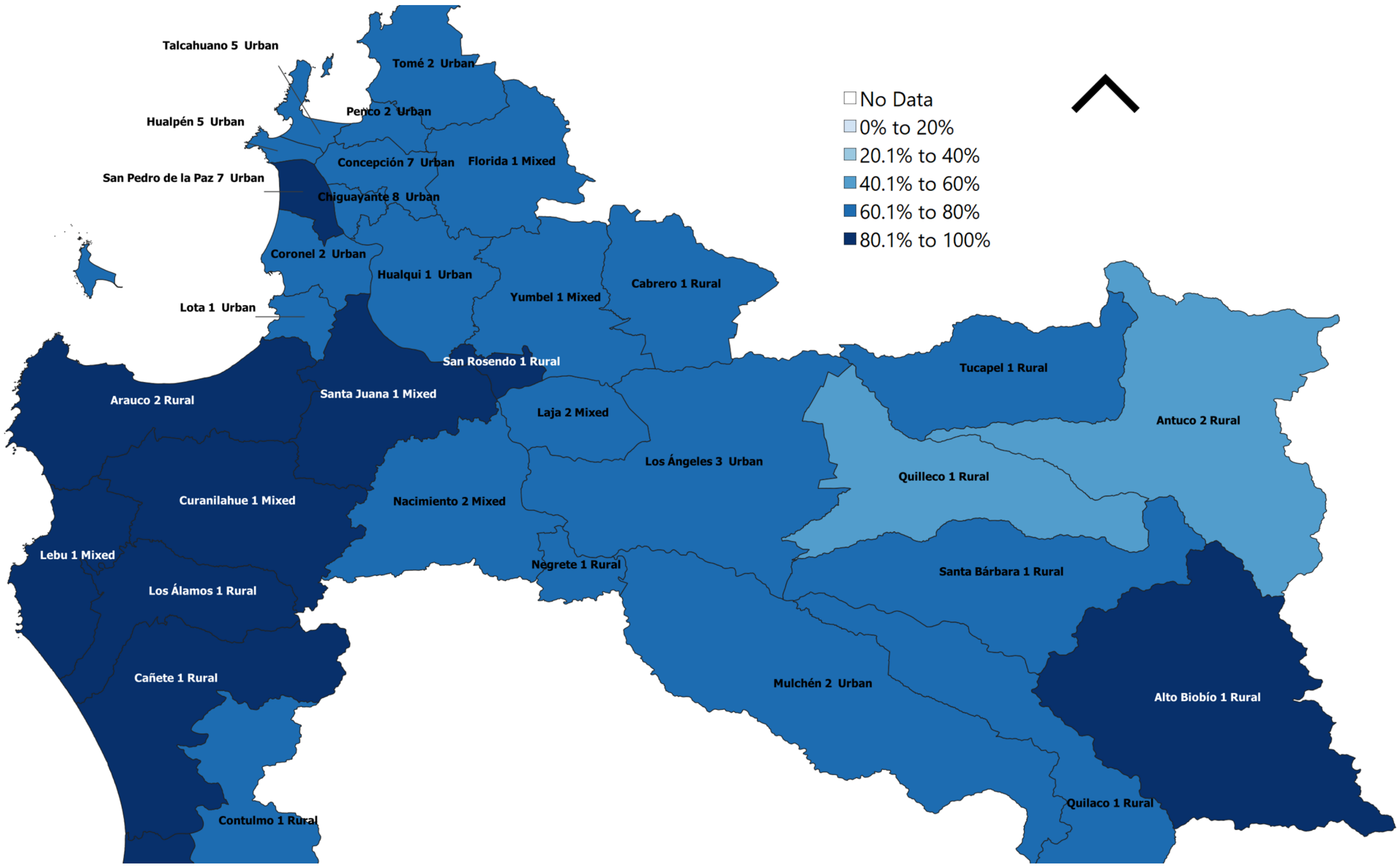


Figure 4.31: Choropleth map for caries experience of six-year-olds in Region VIII Biobio (2019)

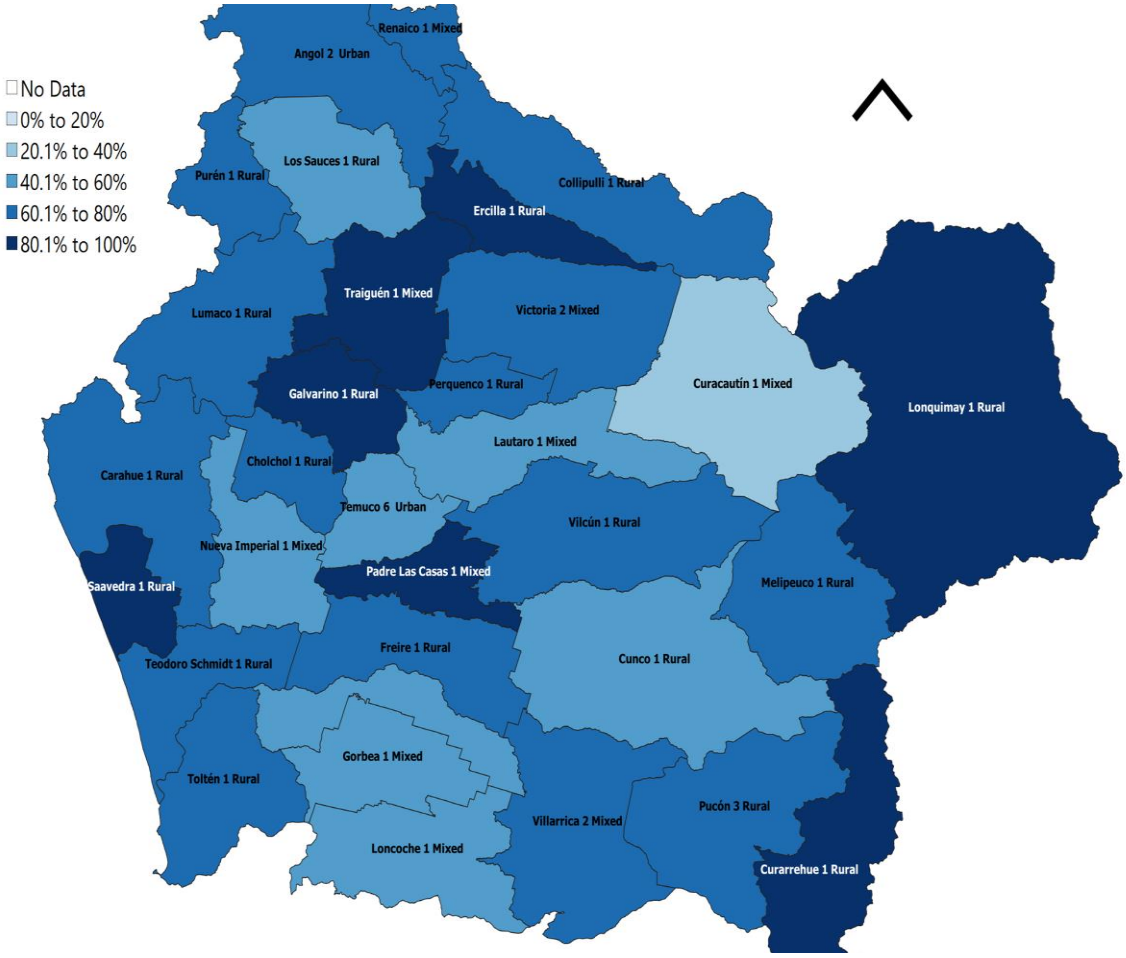


Figure 4.32: Choropleth map for caries experience of six-year-olds in Region IX Araucanía (2019)

Talca is the capital of Region VII and showed a caries experience of 43.3% in 2019, the lowest for all the capitals in the country in 2019, being one of the few urban municipalities in a primarily rural region where no municipalities showed a caries experience over 80% in 2019.

Region XVI is one of the areas where community water fluoridation is not implemented. The capital, Chillan, showed a caries experience of 67.4% in 2019. This region, like all the others of this macrozone, is predominantly rural. Two municipalities showed a caries experience above 80%, being Chillan Viejo and Quillón.

Region VIII is the other region where community water fluoridation is not implemented. The capital is Concepción, which had a caries experience of 69.6%. This region has a clear area with high caries levels, corresponding to the western area where six municipalities had a caries experience of above 80%. They are rural and part of the 20% of most deprived municipalities in the country. Alto Bio Bio, the most deprived municipality in Chile according to IDSE, also showed high caries levels.

Temuco is the capital of Region IX and showed a caries experience of 55% in 2019. In this primarily rural region, seven municipalities showed a caries experience greater than 80%, all being part of the most deprived municipalities in the country, according to IDSE.

In summary, in the south-centre macrozone, two regions do not have community water fluoridation, with a greater representation of rural areas. Another aspect to highlight is that the vast majority of the municipalities that belong to the most socioeconomic deprived 10%, according to the IDSE index are from this macrozone, and all showed high caries levels.

4.8.4 Caries experience of six-year-olds from the south macrozone regions.

Figures 4.33 to 4.36 shows the caries experience in the regions of the south macrozone.

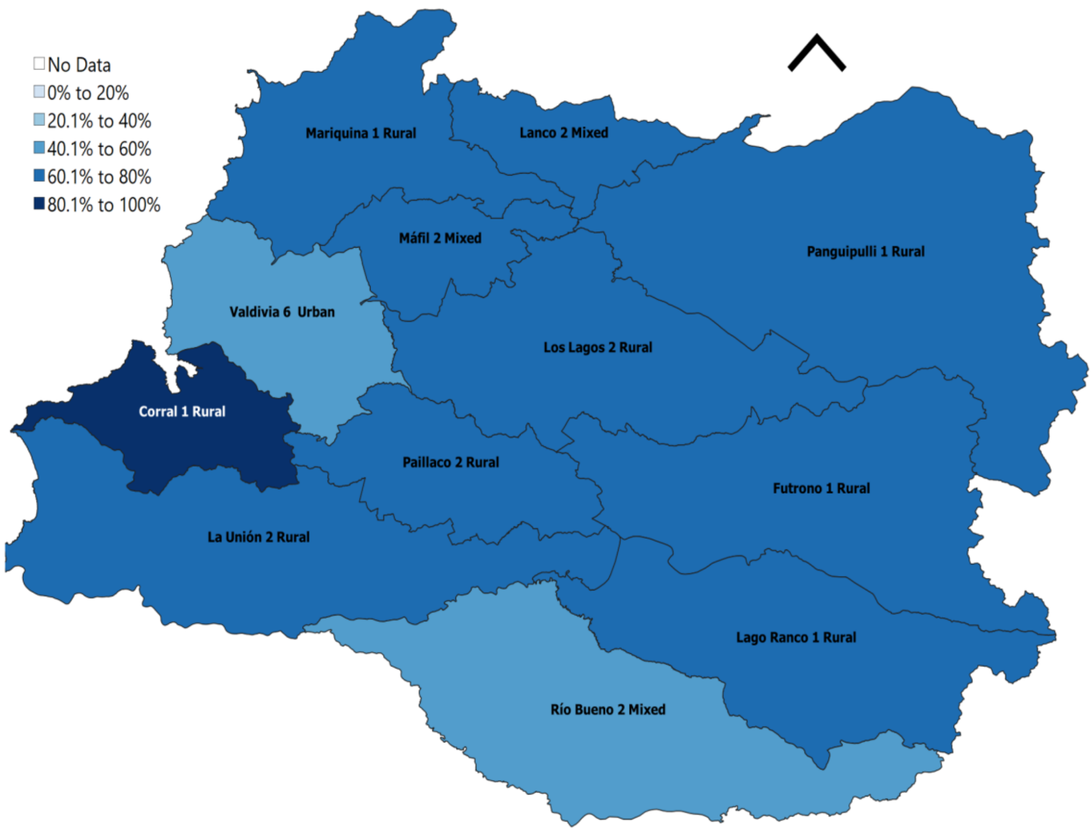


Figure 4.33: Choropleth map for caries experience of six-year-olds in Region XIV Los Rios (2019)

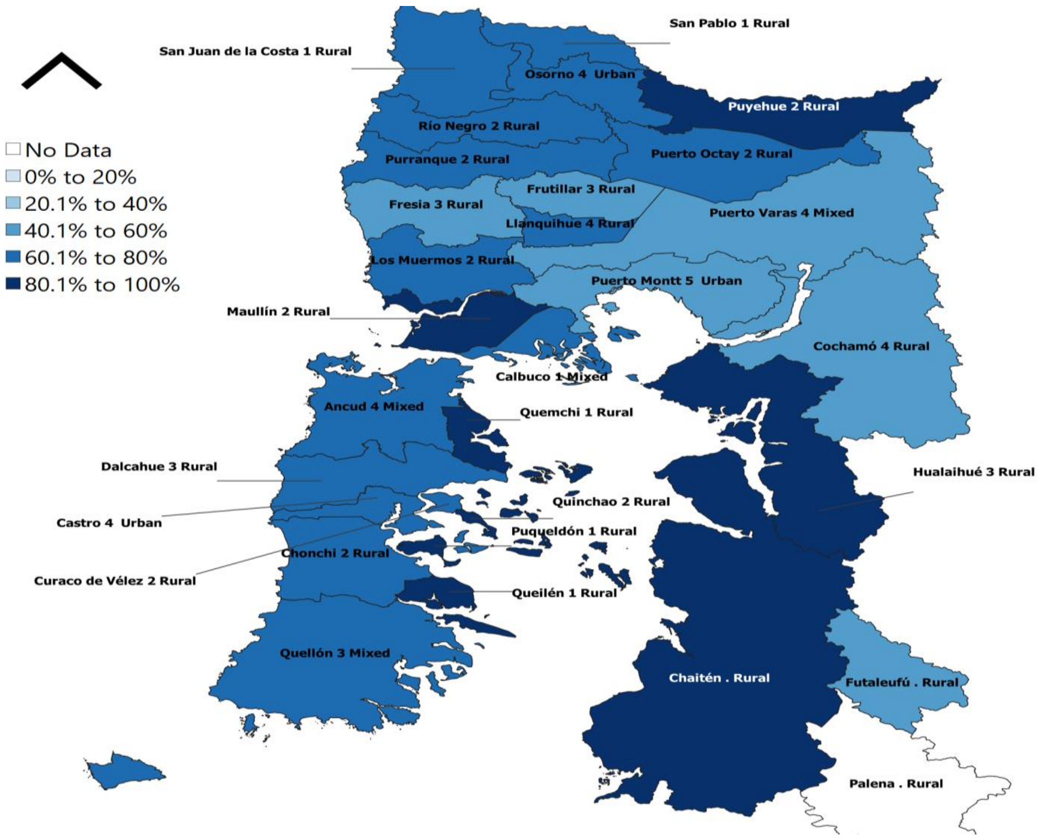


Figure 4.34: Choropleth map for caries experience of six-year-olds in Region X Los Lagos (2019)

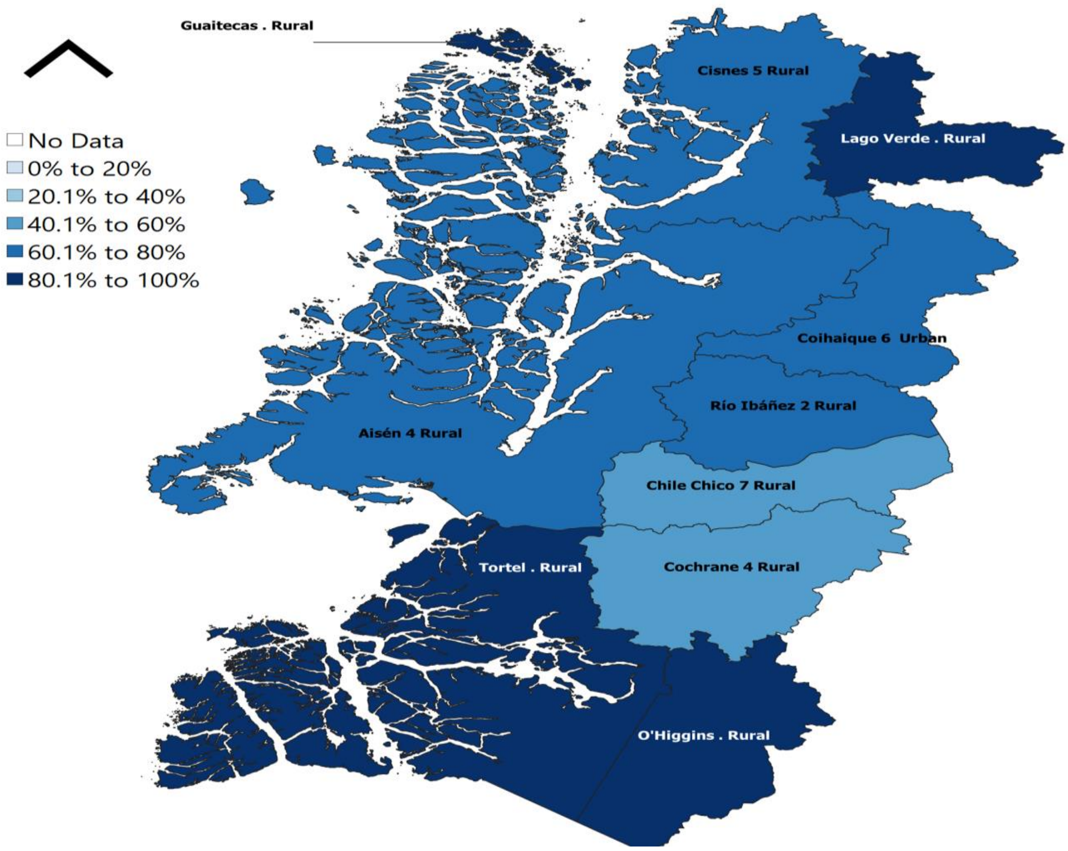


Figure 4.35: Choropleth map for caries experience of six-year-olds in Region XI Aysen (2019)

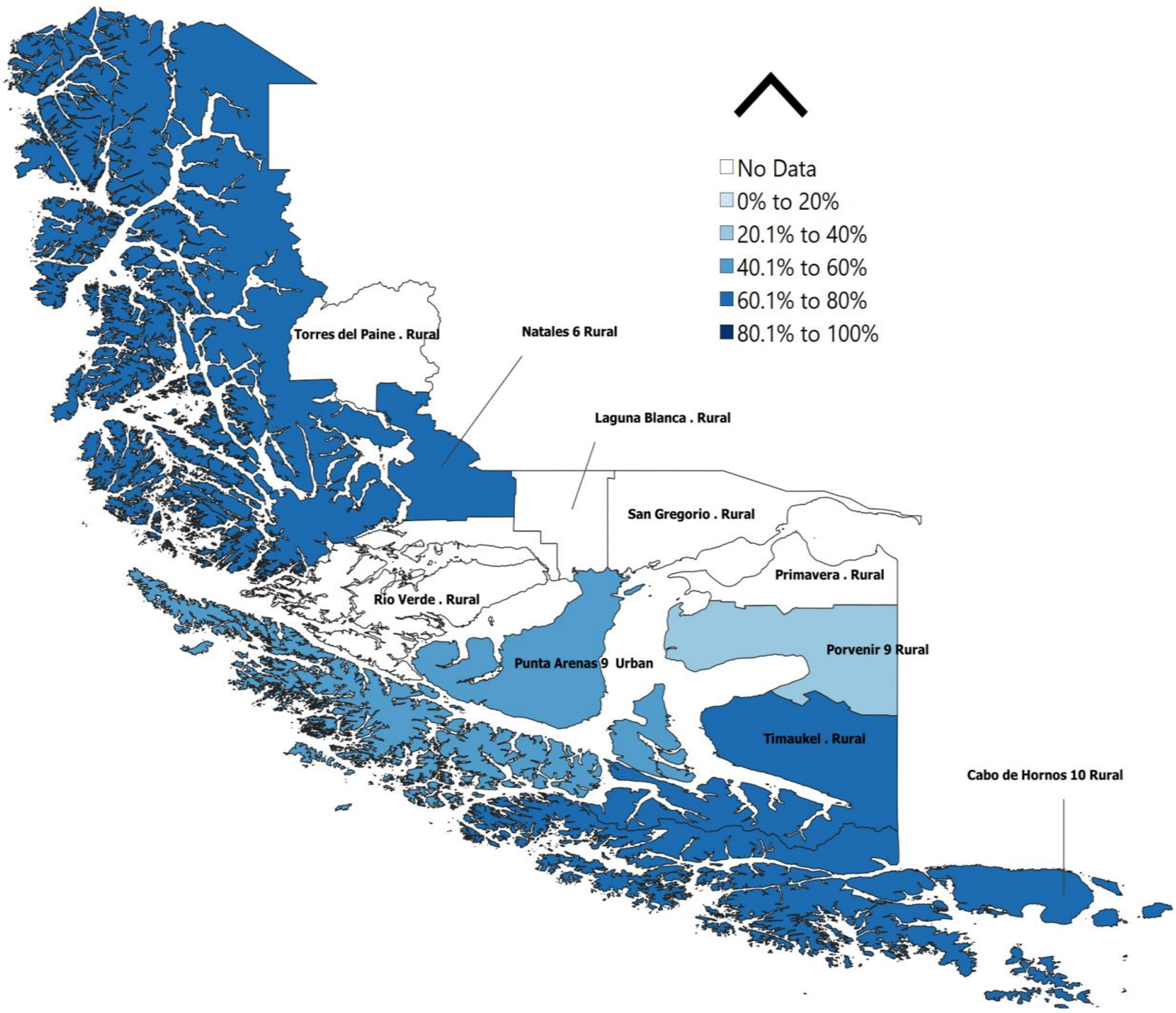


Figure 4.36: Choropleth map for caries experience of six-year-olds in Region XII Magallanes (2019)

Valdivia, the capital of Region XIV, is the only urban municipality in this region and had a caries experience of 57% in 2019. All the other municipalities are mixed or rural and part of the 20% most deprived communities. Only one municipality, Corral, a rural and IDSE 1 municipality, showed a caries experience above 80%.

In Region X, the capital is Puerto Montt, the only urban area. Puerto Montt had a caries experience of 57.6% in 2019. Eight municipalities showed a caries experience of above 80% in 2019, all being rural and mainly from the 10% most deprived according to IDSE.

Coyhaique is the capital of Region XI and showed a caries experience of 75.4% in 2019, the highest among the capitals in the country. Four municipalities in this region showed a caries experience of above 80%, all rural and with less than 2,000 inhabitants.

Finally, despite being the biggest region in size, Region XII has the lowest number of inhabitants in Chile. The capital is Punta Arenas, which showed a caries experience of 47.7%, and along with the other two municipalities with more than 2,000 inhabitants in this region, are part of the 20% least deprived communities in the country. Due to this region's low number of inhabitants, five municipalities did not have records of caries experience in six-year-olds.

In summary, the municipalities of the southern macrozone show a predominance of rural and deprived areas. Different situations of Caries Experience characterized this macrozone, where Punta Arenas stands out with the lowest caries levels in the zone.

4.8.5 Trends in caries experience by region

Figure 4.37 shows the distribution of Caries Experience of six-year-olds in the period 2008-2019 by region.

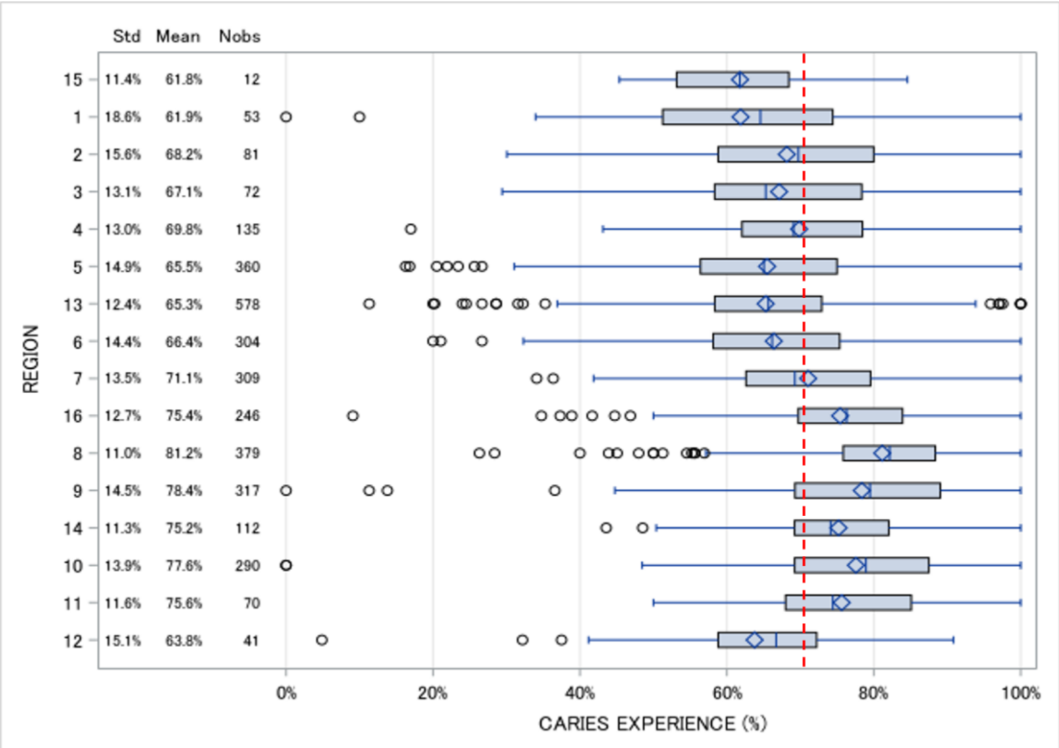
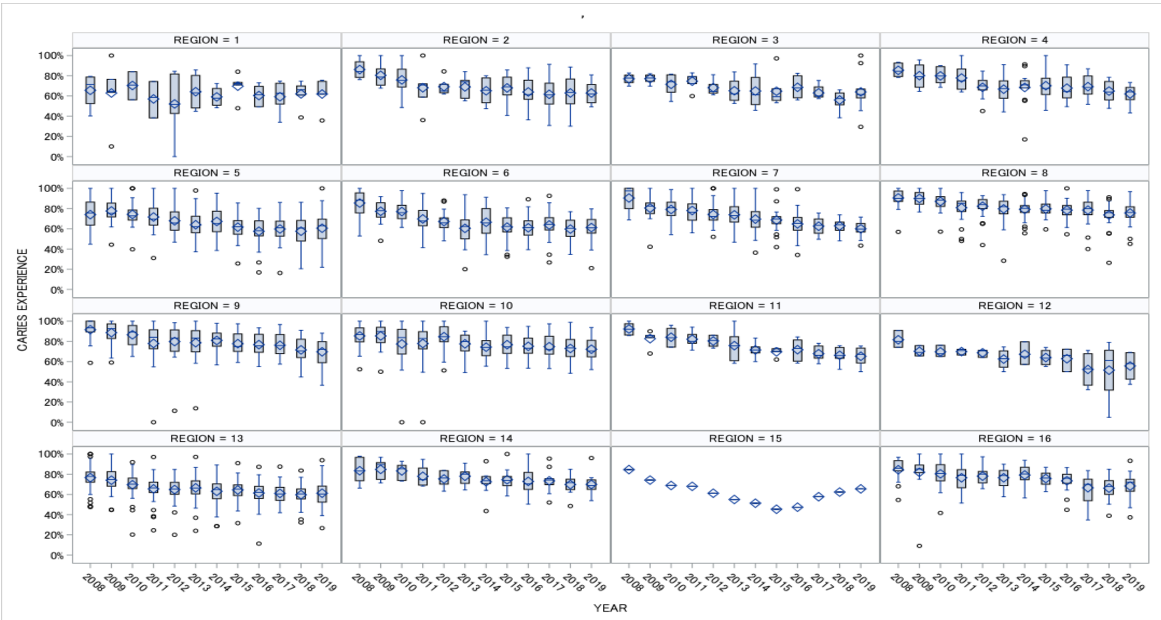


Figure 4.37: Distribution of caries experience of six-year-old children in Chile by region (2008 – 2019) *The red line is the unadjusted mean caries experience at national level (72%)

The regions with the lowest Caries Experience were Region XV (61.8%; SD = 11.4%), Region I (61.9%; SD = 18.6%) and Region XII (63.8%; SD = 15.1%). In contrast, the regions with the highest caries experience were Region X (77.6%; SD = 14.0%), Region IX (78.4%; SD = 14.5%) and Region VIII (81.2%; SD = 11.0%). It is noteworthy that the region with the highest caries experience in the analysed period corresponds to one of those that does not have the community water fluoridation programme. When evaluating by macrozone, the north macrozone shows the lowest levels of caries in six-year-olds, with a tendency to increase towards the south of the country, with the central-south macrozone concentrating the highest levels. In this trend, the exception was Region XII, which, as mentioned, is among the regions with the lowest caries experience.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
I	65.6%	62.9%	70.3%	57.0%	52.1%	64.2%	59.1%	69.7%	60.4%	59.2%	62.1%	61.9%
II	86.2%	80.4%	75.9%	68.1%	69.2%	69.0%	65.1%	68.0%	64.0%	61.7%	63.0%	62.9%
III	77.0%	77.1%	71.5%	74.6%	68.2%	65.1%	64.9%	64.7%	68.5%	63.1%	56.0%	64.0%
IV	85.4%	80.1%	79.9%	77.8%	68.5%	66.7%	68.4%	70.2%	67.8%	69.2%	64.8%	62.0%
V	74.0%	77.6%	74.2%	71.7%	67.9%	64.0%	67.3%	61.6%	57.6%	59.8%	57.6%	60.6%
VI	85.5%	77.3%	77.0%	69.8%	67.2%	60.5%	66.5%	61.7%	61.0%	63.8%	59.7%	61.2%
VII	90.5%	80.5%	79.1%	78.0%	74.2%	73.8%	69.6%	68.6%	64.8%	62.6%	62.9%	60.0%
VIII	90.6%	90.0%	87.1%	80.8%	82.3%	79.7%	79.2%	79.7%	78.4%	78.5%	73.6%	75.6%
IX	91.6%	88.7%	86.6%	78.0%	79.8%	78.7%	81.0%	77.8%	76.8%	76.2%	71.6%	69.7%
X	85.4%	85.4%	77.5%	77.9%	84.7%	77.6%	74.3%	76.8%	75.2%	74.8%	73.0%	72.2%
XI	92.3%	82.7%	84.1%	82.1%	80.4%	75.8%	71.6%	69.7%	71.8%	67.8%	66.2%	65.3%
XII	81.7%	70.2%	69.7%	69.9%	68.7%	62.5%	67.3%	64.0%	62.8%	52.3%	51.5%	55.7%
XIII	76.6%	74.1%	69.6%	65.5%	64.8%	66.5%	63.1%	64.4%	61.4%	61.0%	59.7%	61.2%
XIV	83.5%	84.8%	83.3%	77.9%	75.4%	78.0%	72.6%	74.6%	72.9%	73.5%	69.8%	69.9%
XIV	84.6%	74.2%	68.9%	68.0%	61.2%	55.0%	51.3%	45.4%	47.4%	57.8%	62.4%	65.5%
XVI	84.4%	81.9%	80.4%	76.5%	78.1%	76.5%	79.2%	75.8%	73.5%	66.6%	66.2%	68.3%

Figure 4.38: Trends in caries experience of six-year-old children in Chilean regions by year

When analysing the trends by year (Figure 4.38), most regions showed a continuous decrease in Caries Experience over time compared to 2008. However, an increase in recent years in Region XV is especially noticeable, the region with the lowest caries experience in the period analysed. The greatest decrease in caries experience of 30.5% was observed in region VII. In contrast, region XIII, the most populated region with most municipalities being among the least deprived, showed a decrease of 15.4%. Region VIII, the region with the highest caries experience in the period analysed, showed a decrease of 15.1%. Also, Region I, despite being among the regions with lower caries levels, showed a decrease in caries experience of only 3.7%.

4.9 Chapter 4 summary

From the database created in Chapter 3, through the analysis of the information related to the Dental examinations performed in primary health care clinics in Chile, a variable was created to evaluate the levels of dental caries in Chilean six-year-olds.

A primary outcome was assembled from the data of the dental examinations performed on six-year-olds in the primary care clinics of each municipality to assess the oral health of children in Chile, “Caries experience”. This continuous variable met the distribution requirements to be used as an outcome in linear regression models.

Due to the country's legislation, the municipalities are the smallest data aggregation level. This determined the creation of a cohort that included all the municipalities with the necessary data to evaluate the trends in caries experience and the impact of Chile's national oral health improvement programmes in the years analysed. The unit of analysis that was selected was municipality/years. There were n = 3,369 municipality/years included in the developed cohort.

When exploring the trends in the caries experience of Chilean six-year-olds between 2008 and 2019, it was observed that there was a significant decrease in dental caries levels in the analysed period. This was noticeable in the notorious transformation in the distribution of the caries experience, from a left-skewed shape in 2008 to a bell-shape distribution in 2019.

Additionally, the association with potential confounders included in the database was explored: time, deprivation, and rurality, observing that the three variables were associated with the Caries Experience of the six-year-olds in the cohort. With the information from the analysis of the potential confounders, the most parsimonious model for evaluating the impact of the national oral health programmes for Chile on the cohort was selected through selection procedures for linear regression analysis. This model includes the variables “IDSE” for socioeconomic deprivation, “Rurality proportion” for rurality, and “Year”, for time and will be used in the analyses of Chapter 5.

There is a socioeconomic gradient in the distribution of Caries Experience in Chile, where the most deprived communities have significantly higher caries levels. Although there has been a decrease over the years in all socioeconomic deprivation groups, this gradient still exists. When evaluating the inequality measures in oral health, despite the decrease in caries experience in the most and least deprived groups, no meaningful changes in absolute and relative inequality were observed. Six-year-old children from most deprived communities had 14.3% higher caries experience compared to those living in the least deprived municipalities.

In the analyses by region, it was noticeable that there is high heterogeneity in the distribution of dental caries of Chilean six-year-olds according to the geographic area, but that those that belong to the most socioeconomic deprived 20% municipalities, according to the IDSE index, with more than 50% of the population living in rurality, and from the central-southern macrozone are the most affected, especially those that do not have the community water fluoridation programme (Regions VIII and XVI).

Chapter 5 - Impact of the national oral health improvement programmes for Chile on six-year-olds caries experience

Chapter 5 describes the analysis performed on the cohort to assess the independent effect of each programme, including the development of a model that includes all the interventions to evaluate the independent effect on the oral health of six-year-old children and related inequalities.

5.1 Analysis methods

This section describes the different analytical approaches and models used to address the effect on caries experience of each component of the national oral health improvement programmes for Chile in the cohort. All statistical analysis undertaken were completed using SAS 9.4.

Community water fluoridation and preventive interventions performed at primary care clinics were selected to assess their impact on caries levels in six-year-old children. Sembrando Sonrisas, the Dental Assessment with Risk Approach CERO programme and fluoridated milk programme were not included.

Sembrando Sonrisas was not included because its interventions are performed in nurseries, and it has its own dental examinations. Hence, as there is no data at the individual level, a data link cannot be made to determine if the children who attend the primary care clinics are the same as those who attend the nurseries in the municipalities/years. Therefore, it will be evaluated in Chapter 6 with the data collected in nurseries.

Regarding the CERO programme, since its establishment and rollout was in 2017 and the database of this study includes information up to 2019, there is still no birth cohort that has completely benefited from this programme, so it was considered that CERO is not yet sufficiently established to be evaluated.

Regarding fluoridated milk, its target population is children in primary education, from six years of age onwards, so this programme would not generate observable benefits when assessing dental caries levels in six-year-olds due to the temporality of the effect.

Therefore, this analysis had to focus on the community water fluoridation (CWF) programme and the preventive interventions delivered in primary care clinics. Each variable was described through a summary of statistical measures and their distribution in the cohort. From this analysis, it was inferred whether each variable in its continuous presentation was suitable for categorization. Cut-offs points were chosen for pragmatic reasons making sure that there were enough municipality/years in each category.

Weighted univariate linear regressions were conducted to establish the associations between each programme activity or intervention (individually) and Caries Experience. R-Squared, and Wald p-values were presented for each variable.

Subsequently, each variable adjusted by deprivation (“IDSE”), rurality (“Rurality Proportion”), and time (“Year”) (Model 1) was analysed using weighted multivariable least squares linear regression models. In addition, the interaction of each variable with “Year” was explored. Results were expressed as differences in the least square means. Wald p-values with a 5% significant level and 95% confidence intervals were calculated.

5.2 Community water fluoridation programme

This section analyses the CWF programme. As described in section 3.5.9, two variables of this programme were collected in the database for each municipality/years in the cohort: the annual average concentration of fluoride in drinking water expressed in mg/L determined by the companies supplying the drinking water, i.e., **“Fluoride concentration”**, and the percentage of the population covered by the programme, i.e., **“Fluoride coverage”**.

5.2.1 Fluoride concentration

A summary of statistical measures for the variable “Fluoride concentration” is described in Table 5.1.

Table 5.1: Statistical measures summary for “Fluoride Concentration” variable

Fluoride Concentration			
Location		**Variability**	
Mean	0.55 mg/L	**Std Deviation**	0.38 mg/L
Median	0.66 mg/L	**Max**	1.80 mg/L
Mode	0 mg/L	**Min**	0 mg/L

“Fluoride concentration” represents how much fluoride is contained in each litre of water that leaves the drinking water supply companies, either natural (mainly in the northern macrozone of Chile) or added artificially. Figure 5.1 presents the distribution of “Fluoride Concentration” with respect to municipality/years.

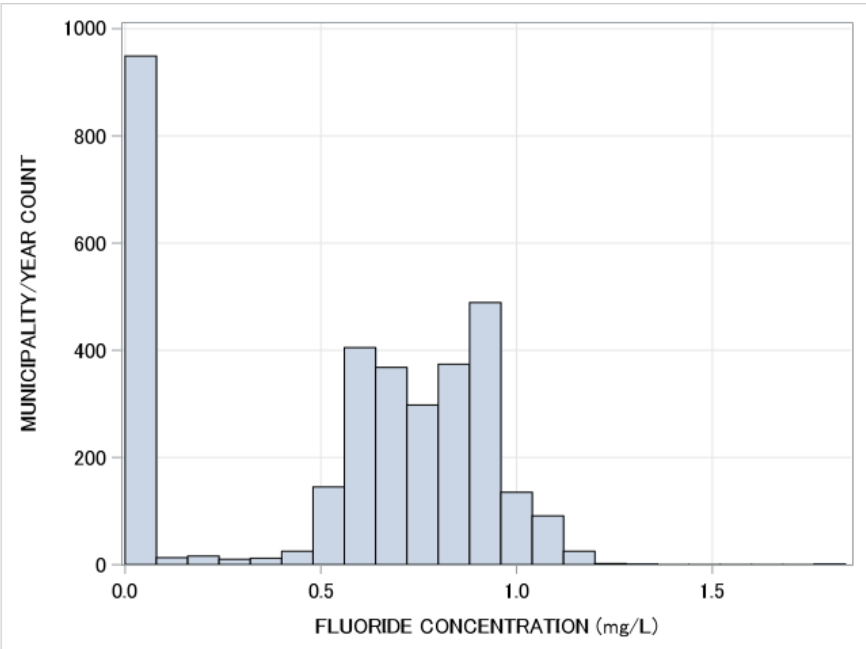


Figure 5.1: Histogram of the distribution of “Fluoride Concentration” by municipality/years

“Fluoride concentration” clearly showed multimodal distribution, with a peak in the municipality/years with a concentration of 0 mg/L, then a group with low frequencies, with concentrations between 0 and 0.5 mg/L, the main group with concentrations between 0.6 and 1.0 mg/L, and finally a group with concentrations greater than 1.0 mg/L. This result is related to the guidelines of the programme, so five groups were observed: the municipality/years without the programme, those that did not meet the concentration indicated in the guidelines, those that had concentrations in the lower range of the guidelines, those that had concentrations in the higher range of the guidelines, and those in which the concentration of fluoride was higher than indicated in the guidelines.

With this information, the construction of a categorical presentation of this variable was carried out, i.e., **“Fluoride concentration level”**. This variable has five categories: “No CWF”; “< 0.6 mg/L”; “0.6 - 0.8 mg/L”; “>0.8 - 1.0 mg/L”; and “> 1.0 mg/L”.

5.2.1.1 Fluoride concentration and caries experience

Table 5.2 describes the mean caries experience values according to each “Fluoride concentration level” category in the cohort, weighted by “Total dental examinations”. The municipality/years with fluoride in the drinking water had lower levels of caries experience on average. The lowest caries experience was observed in those municipality/years where fluoride concentration level was in the lower range indicated in the guidelines, that is, between 0.6 mg/L and 0.8 mg/L.

Table 5.2: Caries experience by “Fluoride concentration level”

Fluoride Concentration Level	Municipality/years Frequency	Caries Experience Mean	Std. Dev.
No CWF	958	76.7%	13.8%
< 0.6 mg/L	468	66.7%	13.0%
0.6 - 0.8 mg/L	816	62.9%	14.4%
> 0.8 - 1.0 mg/L	934	69.2%	14.0%
> 1.0 mg/L	183	67.2%	12.0%

5.2.1.2 Association between fluoride concentration and caries experience

For the univariate analysis (Table 5.3), an association was observed between "Fluoride concentration level" and "Caries experience" (R^2 = 0.146). A marked increase in the association was observed when adjusting the variables to Model 1 ("IDSE", "Rural Proportion", and "Year"). An interaction was observed between "Fluoride concentration level" and "Year" (p = 0.011) (Figure 5.2).

Table 5.3: Linear regressions for the association between "Caries experience" and "Fluoride concentration level", weighted by "Total dental examinations": univariate and adjusted

Variable	Univariate DF	Univariate R^2	Univariate p-value	Model 1* Adjusted R^2	Model 1 p-value	Year interaction p-value
Fluoride Concentration Level	4	0.146	<.0001	0.379	<.0001	0.011

*Model 1 is adjusted by IDSE, Rurality proportion and Year

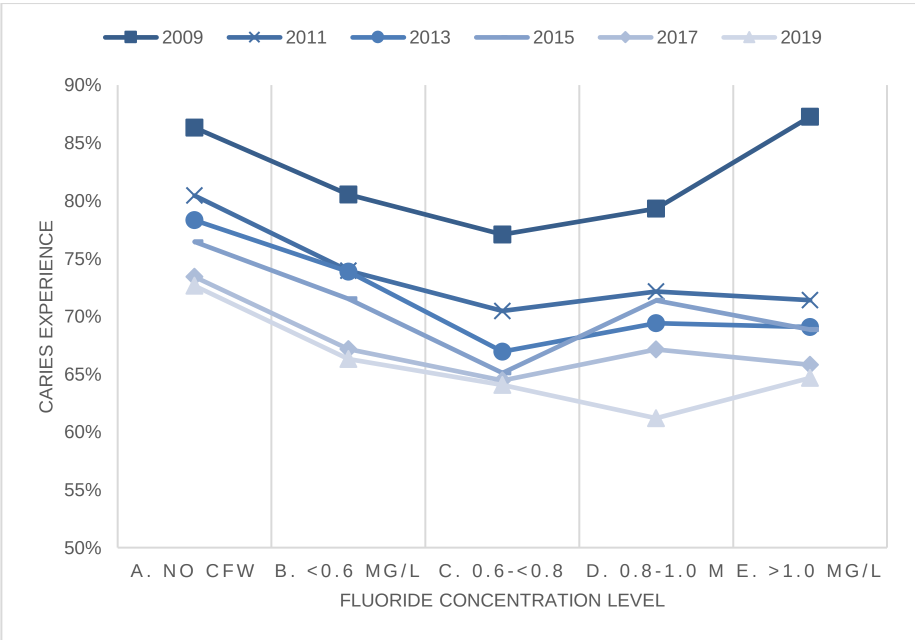


Figure 5.2: Interaction between "Fluoride concentration level" and "Year"

The results of the multivariate weighted least-squares linear regression of "Caries experience" according to "Fluoride Concentration level" are presented in Table 5.4. The "No CWF" category was used as the referent so that the differences in caries experience could be compared in relation to this baseline.

Table 5.4: Least squares linear regressions for the association between "Caries experience" and "Fluoride concentration level", adjusted by deprivation, rurality and time, weighted by "Total dental examinations"

Fluoride Concentration Level	Municipality/ years freq.	Model1* Caries Experience	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
No CWF	958	78.3%	77.5%	79.1%	Referent	Referent		Referent
< 0.6 mg/L	468	73.0%	72.1%	73.8%	5.3%	-6.3%	-4.3%	<.0001
0.6 - <0.8 mg/L	816	68.4%	67.7%	69.2%	9.9%	-10.9%	-8.8%	<.0001
0.8 – 1 mg/L	934	70.8%	70.1%	71.6%	7.5%	-8.5%	-6.4%	<.0001
> 1 mg/L	183	71.1%	69.5%	72.7%	7.2%	-9.0%	-5.4%	<.0001

Linear Regression Results:

Adj. R^2	DF	p-value
0.379	17	<.0001

*Model 1 is adjusted by IDSE, Rurality proportion and Year

The "No CWF" municipality/years had a caries experience of 78.3% (95% CI 77.5%, 79.1%) in the analysed period. Compared to this category, a significantly lower caries experience was observed in all municipality/years with some fluoride concentration.

The municipality/years where the programme had the recommended concentration at its lower threshold, between 0.6 to 0.8 mg/L showed the lowest caries experience of 68.4% (95% CI 67.7%, 69.2%) , a difference of 9.9% with respect to the referent (95% CI -11.0%, -8.9%, p = <.0001). Those with concentrations within the guidelines but at their highest limit, 0.8 to 1 mg/L of fluoride, showed a caries experience of 70.8% (95% CI 70.1%, 71.6%).

When the concentrations were greater than those indicated in the guidelines, that is, greater than 1 mg/L of fluoride, the municipality/years of this category showed a caries experience of 71.1% (95% CI 69.5%, 72.7%]), with a difference from the “No CWF” of 7.2% (95% CI -9.0%, -5.4%, p = <.0001).

From these results, it was possible to highlight the important effect of the adjustment for rurality, time, and the level of deprivation, concerning the analysis of the average caries experience presented in Table 5.2, and that the lowest caries experience was observed in the municipality/years with concentrations of fluoride between 0.6 and 0.8 mg/L.

5.2.2 Fluoride coverage

A summary of statistical measures for the variable “Fluoride coverage” is described in Table 5.5.

Table 5.5: Statistical measures summary for “Fluoride coverage”

Fluoride Coverage

Location		Variability	
Mean	58.4%	**Std Deviation**	39.7%
Median	75.2%	**Max**	99.84%
Mode	0%	**Min**	0

“Fluoride coverage” represents the percentage of the population covered by the drinking water supply network, which, according to the regulations of the Ministry of Health of Chile, must include fluoride as a preventive measure for dental caries.

Figure 5.3 presents the distribution of “Fluoride coverage” in the cohort.

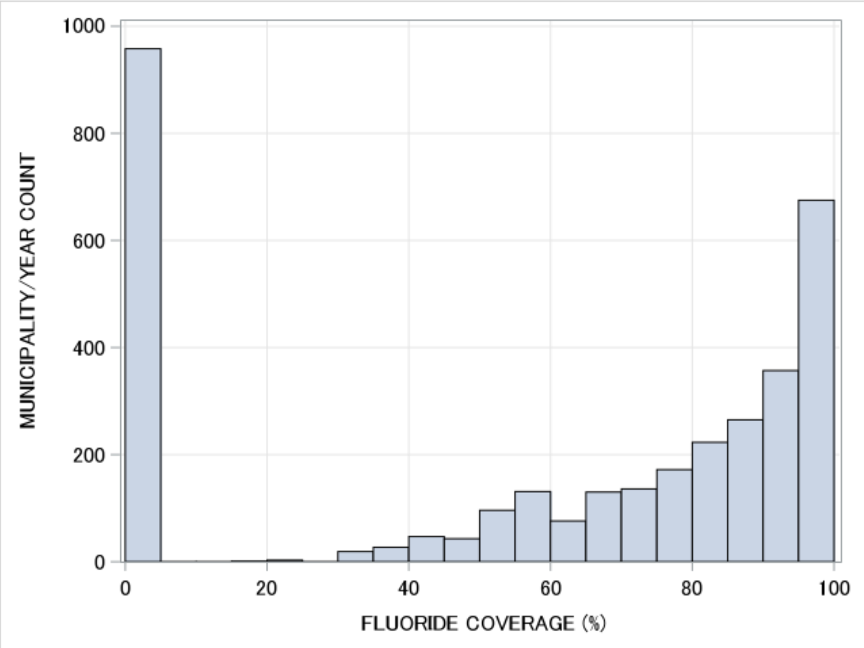


Figure 5.3: Histogram of the distribution of "Fluoride coverage" by municipality/years

"Fluoride coverage" showed a left-skewed distribution, with a peak in the municipality/years with 0% of coverage, represented by the data mode. This group of municipality/years represents those where either there is no drinking water supply network and those from regions VIII and XVI that, as stated previously, do not have fluoride in the drinking water by law. Along with the large number of municipality/years that did not have coverage because they were not part of the programme, it was observed that the largest number of municipalities had coverages above 75%, and a second peak of municipality/years with close to 100% coverage.

Due to the observed distribution, the construction of the categorical presentation of this variable, i.e., **"Fluoride coverage level"** was performed. This variable has four categories: "No CWF"; "<75%"; "75% - 90%"; and "> 90%".

5.2.2.1 Fluoride coverage and caries experience

The mean caries experience of the "Fluoride coverage level" categories are shown in Table 5.6. The "No CWF" municipality/years showed the highest caries experience, and as coverage increases, a decrease in caries experience was observed.

Table 5.6: Caries experience by “Fluoride coverage level”

Fluoride coverage level	Municipality/years Frequency	Caries experience Mean	Std. Dev.
No CWF	958	76.7%	13.6%
< 75%	709	74.5%	14.3%
75% - 90%	660	71.3%	14.9%
> 90%	1032	63.9%	12.2%

5.2.2.2 Association between Fluoride coverage and caries experience

The univariate analysis showed an association between “Fluoride coverage level” and “Caries experience” (R^2 = 0.197; p <.0001). As observed for “Fluoride concentration level”, in the cohort, a marked increase in the association with “Caries experience” was observed when adjusting the variables by deprivation, rurality and time (Table 5.7). No interaction was observed between “Year” and “Fluoride coverage level” (p = 0.525) (Figure 5.4).

Table 5.7: Linear regressions for the association between “Caries experience” and “Fluoride coverage level”, weighted by “Total dental examinations”: univariate and adjusted

Variables	Univariate DF	Univariate R^2	Univariate p-value	Model 1* Adjusted R^2	Model 1 p-value	Year interaction p-value
Fluoride Coverage Level	3	0.197	<.0001	0.385	<.0001	0.467

*Model 1 is adjusted by IDSE, Rurality proportion and Year

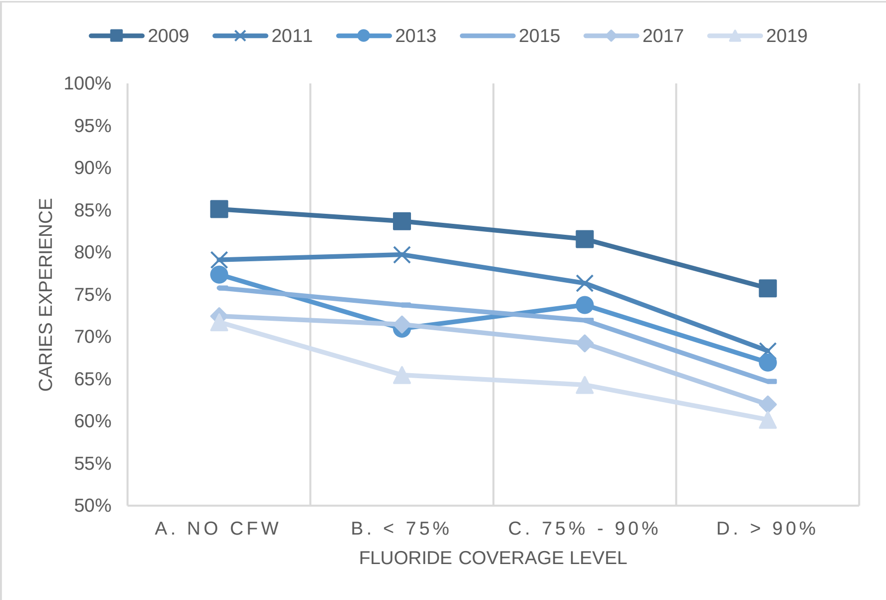


Figure 5.4: Interaction between "Fluoride coverage level" and "Year"

The least-squares linear regression results for "Fluoride coverage level" are presented in Table 5.8. The "No CWF" category was again used as the referent.

Table 5.8: Least squares linear regression for the association between "Caries experience" and "Fluoride coverage level", adjusted by deprivation, rurality, and time, weighted by "Total dental examinations"

Fluoride Coverage Level	Municipality/ years freq.	Model1* Caries Experience	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
No CWF	958	77.3%	76.5%	78.1%	Referent	Referent		Referent
< 75%	468	74.2%	73.0%	75.4%	-3.1%	-4.5%	-1.6%	<.0001
75% - 90%	816	73.0%	72.1%	73.9%	-4.3%	-5.5%	-3.1%	<.0001
> 90%	934	67.1%	66.4%	67.9%	-10.2%	-11.1%	-9.2%	<.0001

Linear Regression Results:

Adj. R^2	**DF**	**p-value**
0.385	16	<.0001

*Model1 is adjusted by IDSE, Rurality proportion and Year

The "No CWF" municipality/years had a caries experience of 77.3% (95% CI 76.5%, 78.1%) in the model. A significantly lower caries experience was observed in all the other municipality/years categories.

In the municipality/years in which there was a coverage of more than 90%, the lowest level of caries Experience was observed, with 67.1% (95% CI 66.4%, 67.9%), with a difference from the referent of 10.2% (95% CI -11.3%, -9.2%, p = <.0001).

5.2.3 Association between community water fluoridation delivery and caries experience

Due to the impact determined in the previously presented analyses, to evaluate the effect of a variable that included both the coverage and the fluoride concentration of CWF in the cohort, a new variable was created that combined the categorical presentations of both: **"CWF delivery"**. This was to help determine the best scenario to optimize the effect of the CWF programme in reducing the caries experience according to the data. Table 5.9 presents the mean caries experience in each "CWF delivery" category.

Table 5.9: Caries experience by "CWF delivery"

CWF Delivery Categories	Municipality/years Frequency	Caries Experience Mean	Std. Dev.
No CWF	958	76.7%	13.8%
< 75% - <0.6 mg/L	28	70.3%	16.3%
< 75% - 0.6-< 0.8 mg/L	81	67.8%	15.6%
< 75% - 0.8-1.0 mg/L	475	75.6%	14.1%
< 75%- > 1.0 mg/L	125	74.1%	11.9%
75%-90% - <0.6 mg/L	55	70.8%	19.2%
75%-90% -0.6- < 0.8mg/L	292	69.8%	15.6%
75% - 90% - 0.8-1.0 mg/L	270	73.3%	13.0%
75%-90% - > 1.0 mg/L	43	69.4%	9.6%
> 90% - < 0.6 mg/L	385	66.4%	11.5%
> 90% - 0.6 - <0.8 mg/L	443	61.0%	12.9%
> 90% - 0.8 - 1.0 mg/L	189	62.8%	11.9%
> 90% - > 1.0 mg/L	15	57.6%	8.6%

Those municipality/years that did not have the CWF programme were those with the highest caries levels, in contrast to those with coverage greater than 90% and concentrations of at least 0.6 mg/L, which presented the lowest levels. However, it can be seen that the category with the lowest caries levels corresponds to that with concentrations greater than 1.0 mg and > 90% coverage.

The univariate analysis (Table 5.10) showed an association between “CWF delivery” and “Caries experience” (R^2 = 0.233; p <.0001). An increase in the association with “Caries experience” was observed when adjusting the variables by deprivation, rurality and time. The interaction between “CWF delivery” and “Year” was significant (p = 0.002) (Figure 5.5).

Table 5.10: Linear regressions for the association between “Caries experience” and “CWF delivery”, weighted by “Total dental examinations”: univariate and adjusted

Variable	Univariate DF	Univariate R^2	Univariate p-value	Model 1 Adjusted R^2	Model 1 p-value	Year interaction p-value
CWF Delivery	12	0.233	<.0001	0.413	<.0001	0.002

*Model 1 is adjusted by IDSE, Rurality proportion and Year

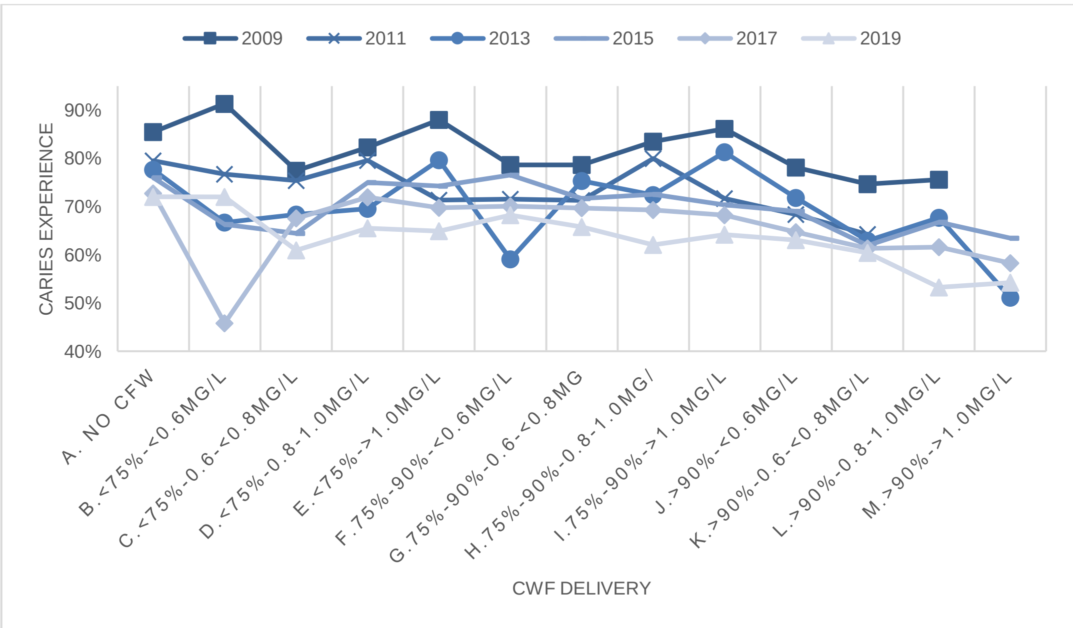


Figure 5.5: Interaction between “CWF delivery” and “Year”

Least-squares weighted linear regression results for “CWF delivery” and “Caries experience” are presented in Table 5.11. The “No CWF” category was used as the reference.

Table 5.11: Summary of least squares linear regressions for the association between “Caries experience” and “CWF delivery”, adjusted by deprivation, rurality, and time, weighted by “Total dental examinations”

Fluoride Concentration Level	Municipality/ years freq.	Model 1* Caries Experience	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
No CWF	958	77.5%	76.7%	78.3%	Referent	Referent		Referent
< 75% - <0.6 mg/L	28	72.8%	65.4%	80.2%	-4.7%	-12.2%	2.7%	0.214
< 75% - 0.6-< 0.8 mg/L	81	67.7%	64.0%	71.5%	-9.8%	-13.6%	-5.9%	<.0001
< 75% - 0.8-1.0 mg/L	475	74.0%	72.7%	75.4%	-3.5%	-5.1%	-1.8%	<.0001
< 75%- > 1.0 mg/L	125	75.8%	73.3%	78.3%	-1.7%	-4.3%	0.9%	0.201
75%-90% - <0.6 mg/L	55	76.0%	73.4%	78.6%	-1.5%	-4.2%	1.2%	0.286
75%-90% -0.6- < 0.8mg/L	292	72.0%	70.6%	73.4%	-5.5%	-7.1%	-3.9%	<.0001
75% - 90% - 0.8-1.0 mg/L	270	73.7%	72.3%	75.1%	-3.8%	-5.4%	-2.2%	<.0001
75%-90% - > 1.0 mg/L	43	73.4%	70.4%	76.3%	-4.1%	-7.2%	-1.1%	0.008
> 90% - < 0.6 mg/L	385	70.3%	69.4%	71.2%	-7.2%	-8.3%	-6.1%	<.0001
> 90% - 0.6 - <0.8 mg/L	443	65.3%	64.4%	66.2%	-12.2%	-13.3%	-11.1%	<.0001
> 90% - 0.8 - 1.0 mg/L	189	65.8%	64.6%	67.0%	-11.7%	-13.0%	-10.4%	<.0001
> 90% - > 1.0 mg/L	15	62.2%	59.5%	64.9%	-15.3%	-18.1%	-12.6%	<.0001
Linear Regression Results:								
Adj. R^2	**DF**	**p-value**						
0.413	25	<.0001						

*Model 1 is adjusted by IDSE, Rurality proportion and Year

The “No CWF” municipality/years had a caries experience of 77.5% (95% CI 76.7%, 78.3%). When coverage was less than 75% of the population and concentration was below the guidelines recommendations, a caries experience of 72.8% (95% CI 65.4%, 80.2%) was observed, with a difference of 4.7% with the reference. However, this difference was not significant, probably due to the size of the category (95% CI -12.7%, 2.7%, p = 0.214). The same occurred in the group with coverage less than 75% and concentrations greater than 1.0 mg/L (p = 0.201).

The category with coverage between 75% and 90% with concentrations lower than that determined in the guidelines showed a caries experience of 76.0% (95% CI 73.4%, 78.6%), without significant differences concerning the reference (p = 0.235). However, all those with concentrations equal to or greater than 0.6 mg of fluoride showed a significantly lower caries experience.

The lowest caries experiences were observed in those municipality/years with coverage greater than 90%, where the category with a concentration greater than 1.0 mg showed the lowest caries experience, with 62.2% (95% CI 59.5%, 64.9%), with a difference of 15.3% compared to the reference (95% CI -18.1%, -12.6%, p < .0001).

5.2.4 Community water fluoridation effect on caries experience of Chilean six-year-olds

Because both the concentration of fluoride and the coverage of the programme presented an association with "Caries experience", both variables were included to analyse the effect of community water fluoridation on the caries experience of Chilean six-year-olds, evaluated via forward selection models (Table 5.12).

Table 5.12: Summary of the forward selection model of the impact of the community fluoridated water programme on "Caries experience", adjusted by deprivation, rurality, and time, weighted by "Total dental examinations"

Forward Selection Summary

Step	Effect Entered	R-Square	Adjusted R-Square	AIC	CP	*P*-Value
1	YEAR	0.170	0.167	8737	1392	<.0001
2	IDSE	0.306	0.303	8140	622	<.0001
3	RURALITY	0.309	0.307	8123	601	<.0001
4	FLUORIDE COVERAGE LEVEL	0.388	0.384	7728	166	<.0001
5	FLUORIDE CONCENTRATION LEVEL	0.414	0.410	7586	20	<.0001

The Adj. R^2 value increased when incorporating each variable, reaching its maximum value when incorporating both variables of community water fluoridation into the model; therefore, both the concentration and the coverage of fluoride in the programme contribute to explaining the differences in caries experience among the municipality/years. Mallow's Cp also decreased in each step, reaching a final value equal to the number of parameters included in the model. The same was observed for the AIC value, which also decreased in each step of the model. It was observed that a model including rurality, deprivation, time, and the interventions of the community fluoridated water programme could explain 41.4% (p <.0001) of the differences in caries experience in six-year-olds between municipalities in the analysed period.

5.3 Preventive interventions performed in primary care clinics

This section analyses the preventive interventions performed in the primary care clinics of the Chilean public healthcare system. As described in sections 1.7.4 and 3.5.3, these interventions are delivered to children according to the diagnosis performed via dental examinations and to their individual cariogenic risk. The information relating to these activities are then recorded in the REM datasets to be anonymised and aggregated at the municipality level.

As the objective of this study is to evaluate the impact of preventive intervention on caries levels of six-year-olds, only those variables that corresponded to preventive interventions or activities were selected since other activities such as restorations, extractions or pulp treatments represents an outcome of the disease.

From the analysis in Chapter 1 and the activities available in the dataset, the fluoride varnish applications performed in primary care clinics, i.e., **"Clinical fluoride varnish"**, individual toothbrushing advice delivered by a dentist to parents and caregivers in primary care clinics, i.e., **"Toothbrushing advice"**, and the application of pit and fissure preventive sealants in primary teeth performed in public clinics, i.e., **"Sealants"** were selected for this evaluation.

For the creation of variables that could explain the interventions and activities received by children in primary care clinics over the years, and that had an impact on the caries experience at six years of age in each municipality/years, it was decided that the sum of the total activities of each variable performed on children in the years before they were six years old would be incorporated. This methodology is explained in Figure 5.6.

In the database, there is only REM data from 2008 to 2019. As explained in 4.2, some ages were incorporated over the years. For the analyses, only those birth cohorts with records of the received interventions for the whole period, that is, since they were two years of age up to five years of age were incorporated. Therefore, the years included were from 2015 to 2019. As an example, to evaluate the impact of preventive activities in six-year-olds in 2019, the activities delivered in the previous relevant years were used, this was: five-year-old children in 2018, four-year-old children in 2017, three-year-olds in 2016 and 2-year-olds in 2015 (Figure 5.6 A).

Taking these factors into account to construct the variables, it was decided to generate a rate using as denominator the "Total dental examinations" in the relevant years (Figure 5.6 B).

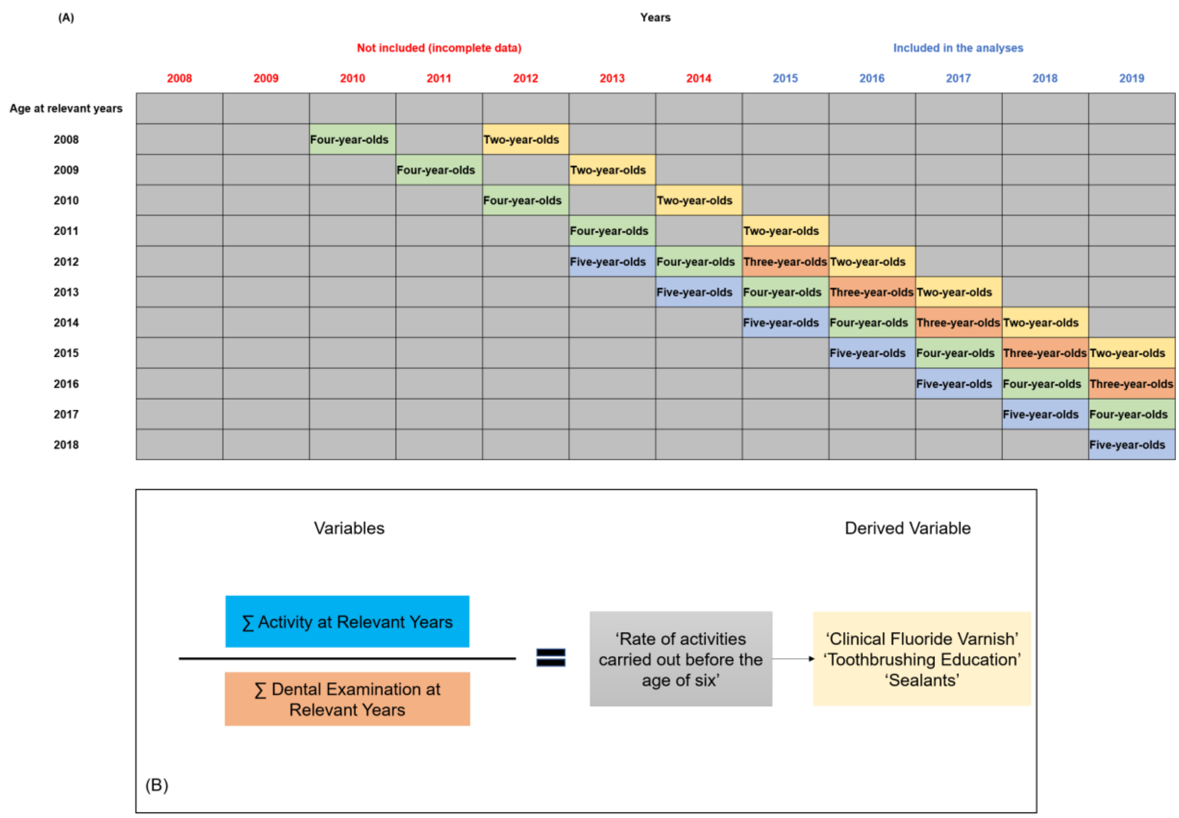


Figure 5.6: Creation of the variables for preventive interventions performed in primary care clinics (A) Ages and relevant years included in the analyses (B) Methodology used to create the variables

5.3.1 Fluoride varnish applications performed in primary care public clinics

This section describes the analyses of the impact of the fluoride varnish performed in primary care clinics before age six over time on the caries experience of six-year-olds. A summary of statistical measures for the variable “Clinical fluoride varnish rate” is described in Table 5.13 and its distribution in Figure 5.7.

Table 5.13: Statistical measures summary for “Clinical fluoride varnish rate”

Clinical fluoride varnish rate			
Location		**Variability**	
Mean	3.46	**Std. Dev.**	12.8
Median	1.29	**Min**	0
Mode	0	**Max**	237

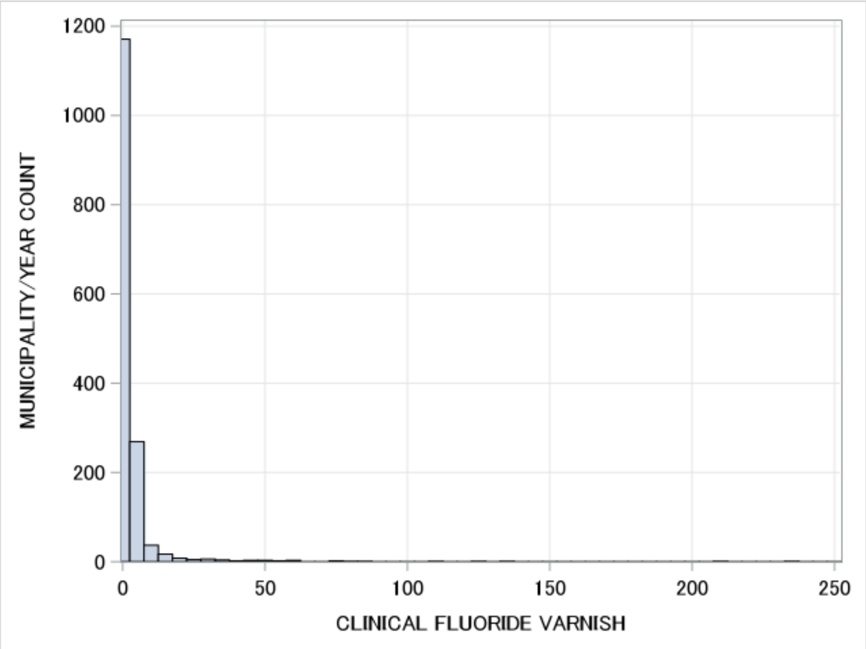


Figure 5.7: Histogram of the distribution of ‘Clinical fluoride varnish rate’ by municipality/years

“Clinical fluoride varnish rate” shows high variability and an asymmetric left-skewed distribution. Due to this distribution, especially marked by some municipality/years where the number of applications of fluoride varnish was very high concerning the number of children attended, it was decided to generate a categorical presentation by dividing the continuous variable into tenths, creating the variable **"Clinical fluoride varnish rate tenths"**.

5.3.1.1 Clinical fluoride varnish and caries experience

The mean caries experience of each "Clinical fluoride varnish rate tenths" category in the cohort are shown in Table 5.14. An increase in caries experience of six-year-olds was observed with a higher clinical fluoride varnish rate.

Table 5.14: Caries experience by "Clinical fluoride varnish tenths"

Clinical Fluoride Varnish Tenths cut-offs	Municipality/years Frequency	Caries Experience Mean	Std Dev
1 (up to 0.33)	155	63.3%	11.8%
2 (0.34 - 0.53)	153	65.1%	10.9%
3 (0.54 – 0.79)	154	65.2%	10.9%
4 (0.80 - 0.10)	154	64.2%	12.9%
5 (0.11 - 1.30)	154	66.2%	14.4%
6 (1.31 - 1.65)	154	63.4%	12.3%
7 (1.66 - 2.11)	154	65.8%	12.5%
8 (2.12 – 2.92)	154	68.9%	12.7%
9 (2.93 – 5.17)	154	70.3%	15.0%
10 (> 5.17)	153	70.9%	14.0%

5.3.1.2 Association between Clinical fluoride varnish and caries experience

The results of the analysis to evaluate the association between "Clinical fluoride varnish rate tenths" and "Caries experience" are shown in Table 5.15. The univariate analysis showed an association between "Clinical fluoride varnish rate tenths" and "Caries experience" (R^2 = 0.079; p <.0001). A marked increase in the association with "Caries experience" was observed when adjusting the variables by deprivation, rurality, and time (Adj. R^2 = 0.229; p <.0001).

An interaction was observed between "Year" and "Clinical fluoride varnish rate tenths" (p = 0.0002) (Figure 5.8).

Table 5.15: Linear regressions for the association between "Caries experience" and "Clinical fluoride varnish rate tenths", weighted by "Total dental examinations": univariate and adjusted

Variable	Univariate DF	Univariate R^2	Univariate p-value	Model 1 Adj. R^2	Model 1 p-value	Year interaction p-value
Clinical fluoride varnish rate tenths	10	0.079	<.0001	0.229	<.0001	0.001

*Model 1 is adjusted by IDSE, Rurality proportion and Year

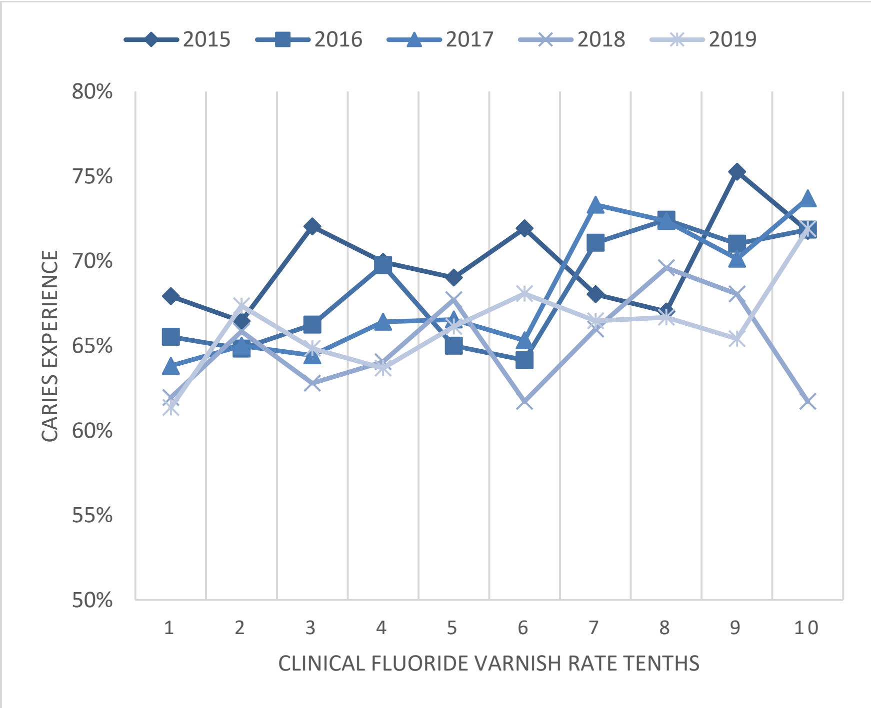


Figure 5.8: Interaction between "Clinical fluoride varnish rate tenths" and "Year"

The results of the weighted least-squares linear regression of "Caries experience" according to "Clinical fluoride varnish rate tenths", adjusted by deprivation, rurality and time, and weighted by "Total dental examinations", are shown in Table 5.16. The category of municipality/years with the lowest rate of fluoride varnish applications in primary care clinics was the referent, showing a caries experience of 64.1% (95% CI 62.7%, 65.5%).

Table 5.16: Least squares linear regression for the differences in caries experience of "Clinical fluoride varnish rate tenths", adjusted by deprivation, rurality, and time, weighted by "Total dental examinations"

Clinical fluoride varnish rate tenths	Municipality/ years freq.	Model 1* Caries Experience	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
1 (up to 0.33)	155	64.1%	62.7%	65.5%	Referent	Referent		Referent
2 (0.34 - 0.53)	153	65.7%	64.3%	67.0%	1.5%	-0.2%	3.2%	0.076
3 (0.54 – 0.79)	154	65.8%	64.4%	67.1%	1.6%	-0.1%	3.4%	0.643
4 (0.80 - 0.10)	154	66.6%	65.0%	68.1%	2.4%	0.5%	4.4%	0.013
5 (0.11 - 1.30)	154	67.0%	65.4%	68.6%	2.9%	0.9%	4.8%	0.045
6 (1.31 - 1.65)	154	66.1%	64.6%	67.7%	2.0%	0.1%	3.9%	0.042
7 (1.66 - 2.11)	154	69.2%	67.4%	71.1%	5.1%	2.9%	7.3%	<.0001
8 (2.12 – 2.92)	154	70.2%	68.6%	71.9%	6.1%	4.0%	8.2%	<.0001
9 (2.93 – 5.17)	154	70.2%	68.3%	72.1%	6.1%	3.7%	8.4%	<.0001
10 (> 5.17)	153	69.6%	67.7%	71.5%	5.4%	3.1%	7.8%	<.0001

Linear Regression Results:

Adj. R^2	DF	p-value
0.229	15	<.0001

*Model 1 is adjusted by IDSE, Rurality proportion and Year

A significant increase in caries experience was associated with an increase Clinical fluoride varnish rate. The highest difference concerning the reference was observed for the categories 8 and 9, with a rate between 2.12 and 5.17, that showed a caries experience of 70.2% (95% CI 68.3%, 72,1%), 6.1% higher than the reference (95% CI 3.7%, 8.4%; p = <.0001).

5.3.2 Individual toothbrushing advice delivered in primary care clinics

This section describes the analyses of the impact of the individual advice in toothbrushing delivered by dentist to parents of children before age six over time on the caries experience of six-year-olds. A summary of statistical measures for the variable "Toothbrushing advice rate" is described in Table 5.17 and its distribution in Figure 5.9.

Table 5.17: Statistical measures summary for "Toothbrushing advice rate"

Toothbrushing advice			
Location		**Variability**	
Mean	7.55	**Std. Dev.**	29.0
Median	2.61	**Min**	0
Mode	3	**Max**	653

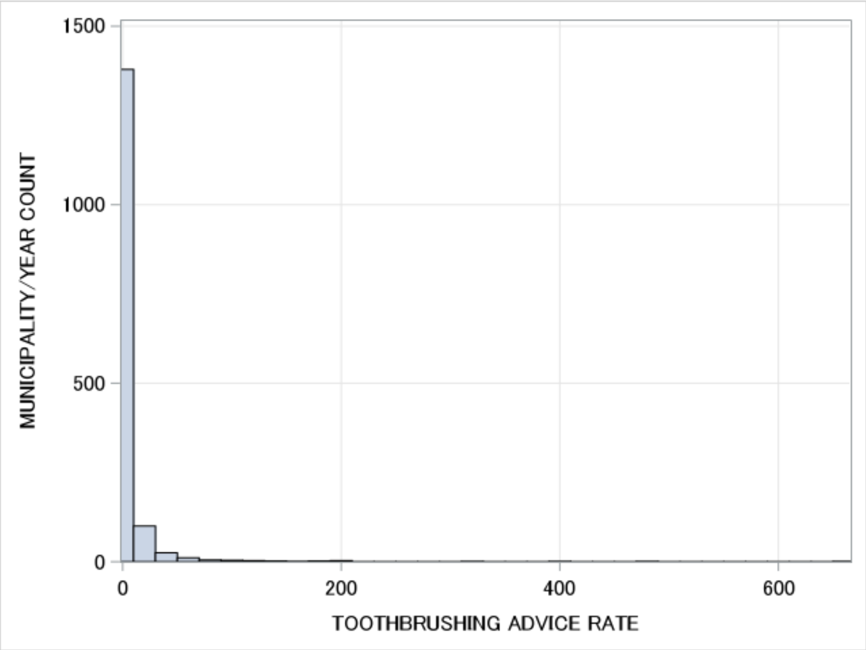


Figure 5.9: Histogram of the distribution of "Toothbrushing advice rate" by municipality/years

Like "Clinical fluoride varnish rate", "Toothbrushing advice rate" showed high variability and an asymmetric left-skewed distribution. The same procedure was followed for this variable: generate a categorical presentation by dividing the continuous presentation into tenths, creating the variable **"Toothbrushing advice rate tenths"**.

5.3.2.1 Toothbrushing advice and caries experience

Caries experience means of the "Toothbrushing advice rate tenths" categories in the cohort are shown in Table 5.18. An increase in caries experience of six-year-olds was observed with a higher toothbrushing advice rate.

Table 5.18: Caries experience by "Toothbrushing advice rate tenths"

Toothbrushing advice rate tenths cut-offs	Municipality/years Frequency	Caries Experience Mean	Std Dev
1 (up to 1.37)	154	62.7%	12.2%
2 (1.38 - 1.74)	154	60.8%	12.7%
3 (1.75 - 1.98)	154	62.8%	12.7%
4 (1.99 – 2.26)	154	65.6%	12.1%
5 (2.26 - 2.61)	154	65.3%	12.0%
6 (2.61 - 3.03)	154	68.2%	12.6%
7 (3.04 - 3.78)	154	68.7%	11.7%
8 (3.79 – 5.18)	154	69.6%	12.3%
9 (5.18 – 10.43)	154	71.7%	12.6%
10 (> 10.43)	153	72.0%	14.2%

5.3.2.2 Association between toothbrushing advice and caries experience

The results of the analysis to evaluate the association between toothbrushing advice and caries experience are shown in Table 5.19. The univariate analysis showed an association between "Toothbrushing advice rate tenths" and "Caries experience" (R^2 = 0.103; p <.0001). An increase in the association with "Caries experience" was observed when adjusting the variables by deprivation, rurality, and time (Adj. R^2 = 0.248; p <.0001). An interaction with "Year" was observed (p <.0001) (Figure 5.10).

Table 5.19: Linear regressions for the association between "Caries experience" and "Toothbrushing advice rate tenths", weighted by "Total dental examinations": univariate and adjusted

Variable	Univariate DF	Univariate R^2	Univariate p-value	Model 1* Adjusted R^2	Model 1 p-value	Year interaction p-value
Toothbrushing advice rate tenths	10	0.103	<.0001	0.248	<.0001	<.0001

*Model 1 is adjusted by IDSE, Rurality proportion and Year

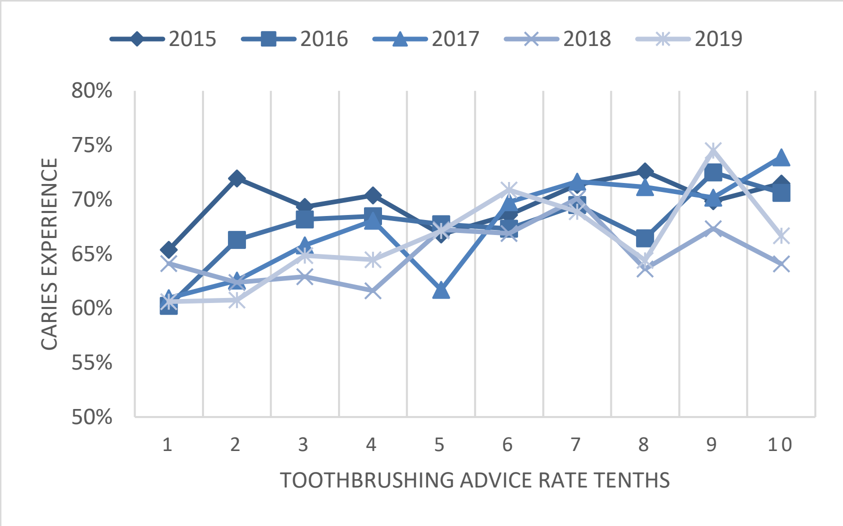


Figure 5.10: Interaction between "Toothbrushing advice rate" tenths and "Year"

Results for the weighted least-squares linear regression of Caries Experience according to Toothbrushing advice rate tenths, adjusted by deprivation, rurality and time and weighted by Total dental examinations are shown in Table 5.20.

Table 5.20: Least squares linear regression for the differences in caries experience of "Toothbrushing advice rate tenths", adjusted by deprivation, rurality, and time, weighted by "Total dental examinations"

Toothbrushing advice rate tenths	Municipality/ years freq.	Model 1* Caries Experience	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
1 (up to 1.37)	154	62.4%	60.9%	63.9%	Referent	Referent		Referent
2 (1.38 - 1.74)	154	64.3%	62.8%	65.9%	1.9%	0.0%	3.9%	0.056
3 (1.75 - 1.98)	154	65.8%	64.3%	67.2%	3.4%	1.4%	5.3%	0.0006
4 (1.99 – 2.26)	154	66.6%	65.2%	67.9%	4.2%	2.3%	6.0%	<.0001
5 (2.26 - 2.61)	154	66.8%	65.3%	68.3%	4.4%	2.4%	6.4%	<.0001
6 (2.61 - 3.03)	154	68.8%	67.3%	70.3%	6.4%	4.4%	8.4%	<.0001
7 (3.04 - 3.78)	154	70.5%	69.0%	72.1%	8.1%	6.1%	10.2%	<.0001
8 (3.79 – 5.18)	154	68.1%	66.5%	69.8%	5.7%	3.6%	7.9%	<.0001
9 (5.18 – 10.43)	154	70.3%	68.5%	72.0%	7.9%	5.6%	10.1%	<.0001
10 (> 10.43)	153	69.5%	67.7%	71.4%	7.1%	4.8%	9.5%	<.0001

Linear Regression Results:

Adj. R^2	DF	p-value
0.248	15	<.0001

*Model 1 is adjusted by IDSE, Rurality proportion and Year

The category of municipality/years with the lowest rates of individual toothbrushing advice performed by a dentist in primary care clinics was the referent, showing a caries experience of 62.4% (95% CI 60.9%, 63.9%). Compared to this category, significantly higher levels of caries experience were observed in all subsequent categories, with significant differences from rates higher than 1.37.

The highest caries level was observed in the category with a rate of toothbrushing advice between 3.04 - 3.78, with a caries experience of 70.5% (95% CI 69.0%, 72.1%), and a difference of 8.1% to the reference (95% CI 6.1%, 10.2%; p <.0001).

5.3.3 Application of pit and fissure sealants in primary teeth performed in primary care clinics

This section describes the analyses of the impact of the application of pit and fissure sealants in primary teeth performed in primary care clinics before age six over time on the caries experience of six-year-olds.

A summary of statistical measures for the variable “Sealants rate” is described in Table 5.21 and its distribution in Figure 5.10.

Table 5.21: Statistical measures summary for “Sealants rate”

Sealants rate

Location		Variability	
Mean	6.17	**Std. Dev.**	23.8
Median	2.08	**Min**	0
Mode	1	**Max**	708

“Sealants rate” showed a high variability and an asymmetric left-skewed distribution. Therefore, a categorical version was generated by dividing the continuous presentation into tenths, creating the **“Sealants rate tenths”** variable.

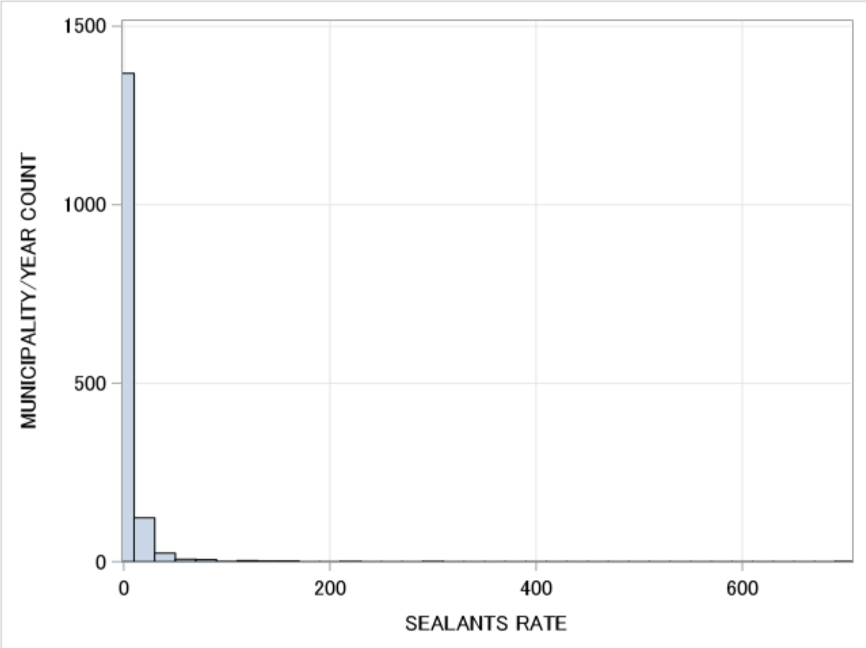


Figure 5.10: Histogram of the distribution of "Sealants rate" by municipality/years

5.3.3.1 Sealants and caries experience

The mean caries experience for each "Sealants rate tenths" category is shown in Table 5.22. The municipality/years with lower rates of sealants applications in the clinics showed lower levels of caries experience.

Table 5.22: Caries Experience by "Sealants rate tenths"

Sealants rate tenths cut-offs	Municipality/years Frequency	Caries Experience Mean	Std Dev
1 (up to 0.35)	154	60.3%	12.3%
2 (0.36 - 0.62)	154	61.9%	13.2%
3 (0.63 - 0.93)	154	62.7%	12.3%
4 (0.94 – 1.39)	154	65.0%	12.2%
5 (1.40 - 2.08)	154	65.3%	13.1%
6 (2.09 - 3.02)	154	68.2%	11.6%
7 (3.03 - 4.07)	154	69.7%	11.7%
8 (4.08 – 6.20)	154	68.7%	12.8%
9 (6.21 – 10.96)	154	69.9%	10.5%
10 (> 10.96)	153	75.7%	13.2%

5.3.3.2 Association between sealants and caries experience

The results of the regressions for “Sealants rate tenths” and “Caries experience” are shown in Table 5.23. The univariate analysis showed an association between “Sealants rate tenths” and “Caries experience” (R-Square = 0.180; p <.0001).

An increase in the association with “Caries experience” was observed when adjusting the variables by deprivation, rurality, and time. An interaction with “Year” was also observed (p <.0001) (Figure 5.11).

Table 5.23: Linear regressions for the association between “Caries experience” and “Sealants rate tenths”, weighted by “Total dental examinations”: univariate and adjusted

Variables	Univariate DF	Univariate R^2	Univariate p-value	Model 1* Adjusted R^2	Model 1 p-value	Year interaction p-value
Sealants rate tenths	10	0.099	<.0001	0.239	<.0001	<.0001

*Model 1 is adjusted by IDSE, Rurality proportion and Year

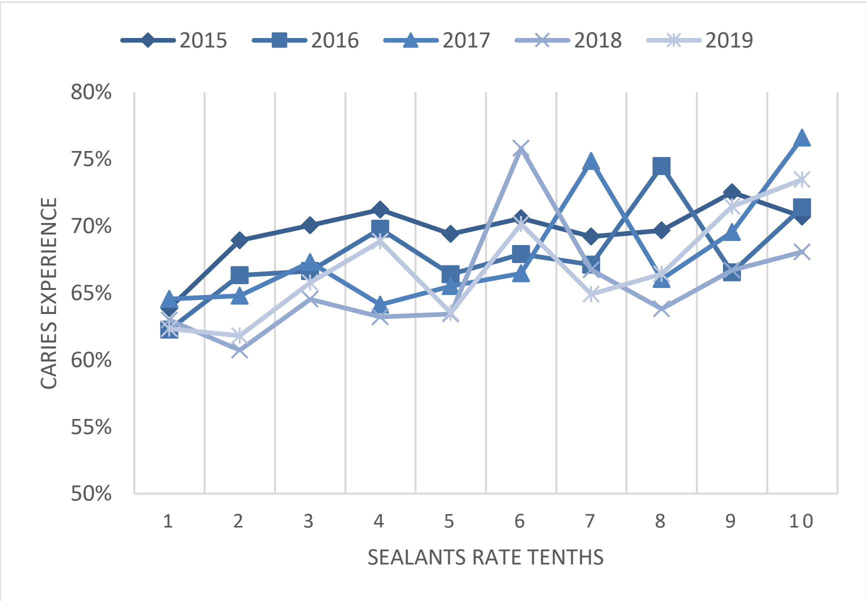


Figure 5.11: Interaction between “Sealants rate tenths” and “Year”

Table 5.24 shows the results of the least-squares linear regression of the association of “Caries experience” and “Sealants rate tenths”, adjusted by deprivation, rurality and time, and weighted by “Total dental examinations”. The category with the lowest rates of preventive sealants delivered in primary teeth in primary care public clinics was used as the referent, which showed a caries experience of 63.5% (95% CI 62.0%, 64.9%).

A higher sealants rate was associated with an increase in caries experience. The municipality/years with the highest rate, 10 (> 10.96) that showed a caries experience of 70.6% (95% CI 68.6%, 72.7%) had the highest difference regarding the reference of 7.1% (95% CI 4.6%, 9.7%; p <.0001).

Table 5.24: Least squares linear regression for the differences in caries experience of "Sealants rate tenths", adjusted by deprivation, rurality, and time, weighted by "Total dental examinations"

Sealants rate tenths	Municipality/ years freq.	Model 1* Caries Experience	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
1 (up to 0.35)	154	63.5%	62.0%	64.9%	Referent	Referent		Referent
2 (0.36 - 0.62)	154	64.4%	63.1%	65.8%	0.9%	-0.8%	2.7%	0.290
3 (0.63 - 0.93)	154	66.8%	65.4%	68.2%	3.3%	1.5%	5.1%	0.0002
4 (0.94 – 1.39)	154	67.2%	65.6%	68.9%	3.8%	1.8%	5.7%	0.0002
5 (1.40 - 2.08)	154	65.7%	64.2%	67.2%	2.2%	0.3%	4.1%	0.023
6 (2.09 - 3.02)	154	70.1%	68.5%	71.6%	6.6%	4.7%	8.5%	<.0001
7 (3.03 - 4.07)	154	68.7%	67.2%	70.3%	5.3%	3.3%	7.2%	<.0001
8 (4.08 – 6.20)	154	67.6%	65.8%	69.5%	4.1%	1.8%	6.5%	0.0004
9 (6.21 – 10.96)	154	69.1%	67.1%	71.0%	5.6%	3.1%	8.0%	<.0001
10 (> 10.96)	153	70.6%	68.6%	72.7%	7.1%	4.6%	9.7%	<.0001

Linear Regression Results:

Adj. R^2	**DF**	**p-value**
0.239	15	<.0001

*Model 1 is adjusted by IDSE, Rurality proportion and Year

5.3.4. Preventive interventions performed in primary care clinics effect on caries experience of Chilean six-year-olds.

As determined from the analysis carried out on the preventive interventions delivered in primary care clinics variables, there is a positive association between each intervention and "Caries experience"; that is, higher levels of caries in six-year-olds are associated with a higher rate of exposure to the activities in the years prior to the age of six, unlike what was observed in the variables of the community water fluoridation programme.

Therefore, no forward selection model including these interventions or also including community water fluoridation was performed to assess the best model to explain the reduction in the caries experience of six-year-olds in Chile in the period analysed.

5.4 National oral health improvement programmes for Chile impact on Chilean six-year-olds with high caries experience

As mentioned in section 4.3, the primary outcome for this study was six-year-old caries experience. Based on the results of the analysis shown in this Chapter, it was decided to explore the programme's impact on the child population most affected by the disease, that is, those six-year-old children with the highest dmft in each municipality/years included in the cohort ("dmft = 5 or more"). A continuous secondary outcome variable, **"High caries experience"**, was created to analyse the trends in caries levels over time and to measure the impact of the national oral health improvement programmes interventions in this specific group.

Figure 5.12 describes the process to generate the "High caries experience" variable. For the variable assembly, a proportion was made between the "dmft = 5 or more" total aggregated records and "Total dental examinations" for each municipality/years included in the cohort. As was explained for the "Caries experience" variable in Chapter 4, "High caries experience" is a percentage for each municipality/years, but those percentages were considered as a continuous variable for all analyses.

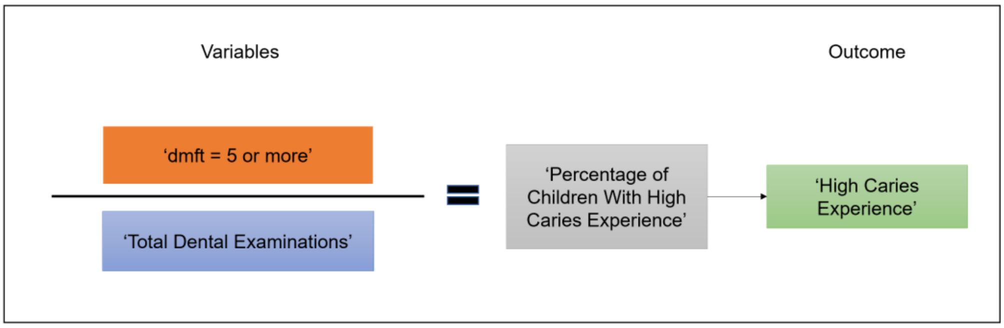


Figure 5.12: Assembly of the "High caries experience" variable

5.4.1 High caries experience distribution

A summary of statistical measures for the variable “High caries experience” is presented in Table 5.25.

Table 5.25: Statistical measures summary for “High caries experience”

High caries experience			
Mean	36.0%	**Std. Dev.**	16.6%
Median	33.4%	**Min**	0%
Mode	33.3%	**Max**	100%

High caries experience showed a mean of 36.0%, close to the median of 33.4%. Figure 5.13 shows the distribution of the variable, which was roughly bell-shaped.

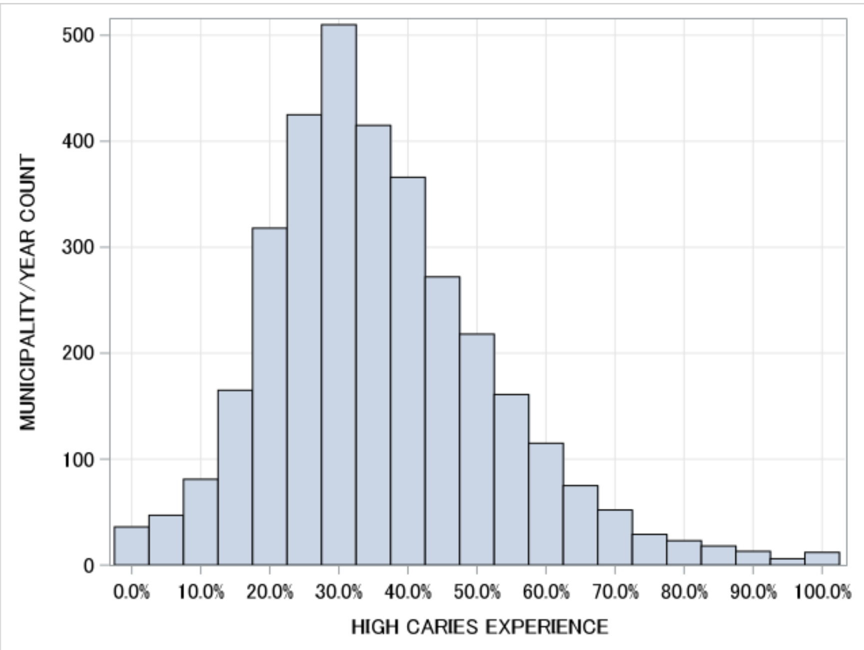


Figure 5.13: Histogram of the distribution of high caries experience by municipality/years

5.4.2 Exploring the effect of deprivation, rurality and time on high caries experience.

As performed for the primary outcome, to analyse the effect on high caries experience of time, deprivation, and rurality, a forward selection model was performed, including “IDSE”, “Rurality Proportion”, and “Year” in a single model. The results of the selection model are described in Table 5.26. As each of the variables were incorporated, Adj. R-Squared increased, reaching its maximum value when incorporating all three variables in the model. Adj. R^2 practically did not differ from R^2 in each step, and both the AIC value and Mallow's Cp also decreased in each step of the model. Therefore, “IDSE”, “Rurality proportion” and “Year” were significant explanatory variables.

Table 5.26: Summary of the forward selection model for the effect on High Caries Experience of “IDSE”, “Rurality Proportion, and “Year”

Step	Effect Entered	R^2	Adjusted R^2	AIC	Cp	P-Value
1	IDSE	0.111	0.110	9269	516	<.0001
2	YEAR	0.226	0.224	8824	19	<.0001
3	RURALITY PROPORTION	0.228	0.225	8818	14	0.006

5.4.3 Association of the national oral health improvement programmes for Chile and high caries experience

To evaluate the association between each of the interventions of the national oral health improvement programmes and “High caries experience”, both univariate weighted linear regression and weighted linear regression adjusted for deprivation, rurality and time were performed.

As each of the programme variables had already been described in detail, best performing presentations from the primary outcome analysis were selected. R-Squared was considered for the univariate analysis, Adj. R^2 for the adjusted model, along with the Wald's p values. Results are shown in Table 5.27. All variables were associated with “High caries experience” in both the univariate and adjusted analyses.

As for “Caries experience” the most explanatory variable for the differences in high caries experience among municipalities was “Fluoride coverage level” (Adj.R^2 = 0.362).

Table 5.27: Summary of linear regressions for the association between “High caries experience” and each intervention of the programmes, weighted by Total dental examinations: univariate and adjusted

Variables	Univariate R^2	Univariate p-value	Model 1* Adjusted R^2	Model 1 p-value
Fluoride concentration level	0.220	<.0001	0.354	<.0001
Fluoride coverage level	0.249	<.0001	0.362	<.0001
Clinic fluoride varnish rate tenths	0.069	<.0001	0.155	<.0001
Toothbrushing education rate tenths	0.101	<.0001	0.180	<.0001
Sealants rate tenths	0.079	<.0001	0.163	<.0001

*Model 1 is adjusted by IDSE, Rurality proportion and Year

To evaluate the effect of each intervention in the differences in “High caries experience”, weighted least squares linear regressions adjusted by deprivation, rurality and time were performed (Tables 5.28 and 5.29).

Table 5.28: Least squares linear regressions for the differences in high caries experience by the community water fluoridation variables categories, adjusted by deprivation, rurality, and time, weighted by “Total dental examinations”

Variable	Categories	Municipality/ year freq.	Model 1* High Caries Experience	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
Fluoride concentration level	No CWF	958	46.0%	45.1%	46.8%	Referent	Referent		Referent
	< 0.6 mg/L	468	35.2%	34.3%	36.1%	-10.8%	-11.9%	-9.6%	0.040
	0.6 - 0.8 mg/L	816	31.7%	30.9%	32.5%	-14.2%	-15.3%	-13.1%	<.0001
	> 0.8 - 1.0 mg/L	934	35.4%	34.6%	36.2%	-10.5%	-11.7%	-9.4%	<.0001
	> 1.0 mg/L	183	34.3%	32.6%	36.1%	-11.6%	-13.5%	-9.7%	<.0001
Fluoride coverage level	No CWF	958	45.1%	44.2%	45.9%	Referent	Referent		Referent
	< 75%	709	39.2%	37.9%	40.4%	-5.9%	-7.4%	-4.3%	<.0001
	75% - 90%	660	35.2%	34.2%	36.2%	-9.9%	-11.2%	-8.6%	<.0001
	> 90%	1032	30.7%	29.9%	31.6%	-14.4%	-15.4%	-13.3%	<.0001

*Model 1 is adjusted by IDSE, Rurality proportion and Year

Table 5.29: Least squares linear regressions for the differences in high caries experience by the preventive interventions in primary care clinics variables categories, adjusted by deprivation, rurality, and time, weighted by “Total dental examinations”

Variable	Categories	Municipality/ year freq.	Model 1* High Caries Experience	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
Clinic fluoride varnish rate tenths	1 (up to 0.33)	155	28.4%	27.0%	29.8%	Referent	Referent		Referent
	2 (0.34 - 0.53)	153	30.2%	28.8%	31.6%	1.8%	0.1%	3.5%	0.038
	3 (0.54 – 0.79)	154	29.6%	28.2%	30.9%	1.2%	-0.6%	2.9%	0.181
	4 (0.80 - 0.10)	154	30.7%	29.2%	32.3%	2.3%	0.4%	4.3%	0.016
	5 (0.11 - 1.30)	154	32.7%	31.1%	34.3%	4.3%	2.4%	6.3%	<.0001
	6 (1.31 - 1.65)	154	31.3%	29.8%	32.9%	2.9%	1.0%	4.9%	0.003
	7 (1.66 - 2.11)	154	33.5%	31.7%	35.3%	5.1%	2.9%	7.3%	<.0001
	8 (2.12 – 2.92)	154	34.5%	32.9%	36.2%	6.1%	4.1%	8.2%	<.0001
	9 (2.93 – 5.17)	154	33.9%	31.9%	35.8%	5.5%	3.1%	7.8%	<.0001
	10 (> 5.17)	153	34.7%	32.7%	36.6%	6.3%	3.9%	8.6%	<.0001
Toothbrushing advice rate tenths	1 (up to 1.37)	154	27.0%	25.5%	28.5%	Referent	Referent		Referent
	2 (1.38 - 1.74)	154	28.0%	26.5%	29.5%	1.0%	-1.0%	3.0%	0.330
	3 (1.75 - 1.98)	154	29.4%	27.9%	30.8%	2.4%	0.5%	4.3%	0.016
	4 (1.99 – 2.26)	154	31.1%	29.8%	32.5%	4.1%	2.3%	6.0%	<.0001
	5 (2.26 - 2.61)	154	32.0%	30.5%	33.5%	5.0%	3.0%	7.0%	<.0001
	6 (2.61 - 3.03)	154	33.2%	31.8%	34.7%	6.2%	4.3%	8.3%	<.0001
	7 (3.04 - 3.78)	154	34.7%	33.2%	36.3%	7.7%	5.7%	9.8%	<.0001
	8 (3.79 – 5.18)	154	32.8%	31.1%	34.4%	5.8%	3.6%	7.9%	<.0001
	9 (5.18–10.43)	154	34.6%	32.9%	36.4%	7.6%	5.4%	9.9%	<.0001
	10 (> 10.43)	153	34.8%	32.9%	36.6%	7.8%	5.4%	10.1%	<.0001
Sealants rate tenths	1 (up to 0.35)	154	27.8%	26.4%	29.3%	Referent	Referent		Referent
	2 (0.36 - 0.62)	154	28.7%	27.4%	30.1%	0.9%	-0.9%	2.6%	0.318
	3 (0.63 - 0.93)	154	31.5%	30.1%	32.9%	3.7%	1.9%	5.5%	<.0001
	4 (0.94 – 1.39)	154	31.3%	29.7%	32.9%	3.5%	1.5%	5.5%	0.0006
	5 (1.40 - 2.08)	154	31.4%	29.9%	32.9%	3.6%	1.6%	5.5%	0.0003
	6 (2.09 - 3.02)	154	35.0%	33.5%	36.5%	7.2%	5.3%	9.1%	<.0001
	7 (3.03 - 4.07)	154	32.5%	31.0%	34.1%	4.7%	2.7%	6.7%	<.0001
	8 (4.08 – 6.20)	154	32.8%	31.0%	34.7%	5.0%	2.7%	7.3%	<.0001
	9 (6.21 – 10.96)	154	33.6%	31.6%	35.6%	5.8%	3.3%	8.2%	<.0001
	10 (> 10.96)	153	34.1%	32.0%	36.1%	6.3%	3.7%	8.8%	<.0001

*Model 1 is adjusted by IDSE, Rurality proportion and Year

For CWF, a similar trend to the primary outcome was also observed, but the impact of both fluoride concentration and coverage was larger for “High caries experience” in comparison to “Caries experience”.

For “Fluoride concentration level”, a reduction in high caries experience of 14.2% (95% CI -15.3%, -13.1%; p >.0001) was observed for the municipality/years with a concentration between 0.6 to 0.8 mg/L of fluoride in relation to the “No CWF” category. In contrast, in the primary outcome analysis, the difference between the same groups was 9.9%.

For “Fluoride coverage level”, the municipality/years with coverage greater than 90% shower a high caries experience of 30.7% (95% CI 29.9%, 31.6%), that is, 14.4% (95% CI -15.4%, -13.3%; p >.0001) lower than the “No CWF” category. In the caries experience analysis, this difference was 10.2%. Therefore, the CWF programme had a greater impact on reducing the caries levels of the most affected children at the municipality level.

For the variables of preventive activities performed in primary care clinics, it was observed that, as for the primary outcome, a higher rate of interventions delivered was associated with a significantly greater high caries experience.

For the fluoride varnish applications delivered in primary care clinics, the category the highest rate showed a high caries experience of 34.7% (95% CI 32.7%, 36.6%), being 6.3% higher than the referent (95% CI 3.9%, 8.6%; p >.0001).

The category with the highest rate of toothbrushing advice showed a high caries experience of 34.8% (95% CI 32.9%, 36.6%), 7.8% (95% CI 5.4%, 10.1%; p >.0001) higher than the category with the lowest rate.

Finally, for “Sealants rate tenths”, a high caries experience of 34.1% (95% CI 32.0%, 36.1%) was observed, 6.3% (95% CI 3.7%, 8.8%; p >.0001) higher than the referent.

5.5 National oral health improvement programmes inequalities analysis

This section describes the analyses to assess the inequalities in the distribution of the national oral health improvement programmes by area-based socioeconomic deprivation. Univariate weighted least-squares linear regressions were used to assess socioeconomic inequalities in the distribution of the programmes interventions variables by IDSE tenths, using as outcome the continuous presentation of each variable. For the community water fluoridation programme variables, only the municipality/years that had the programme were included.

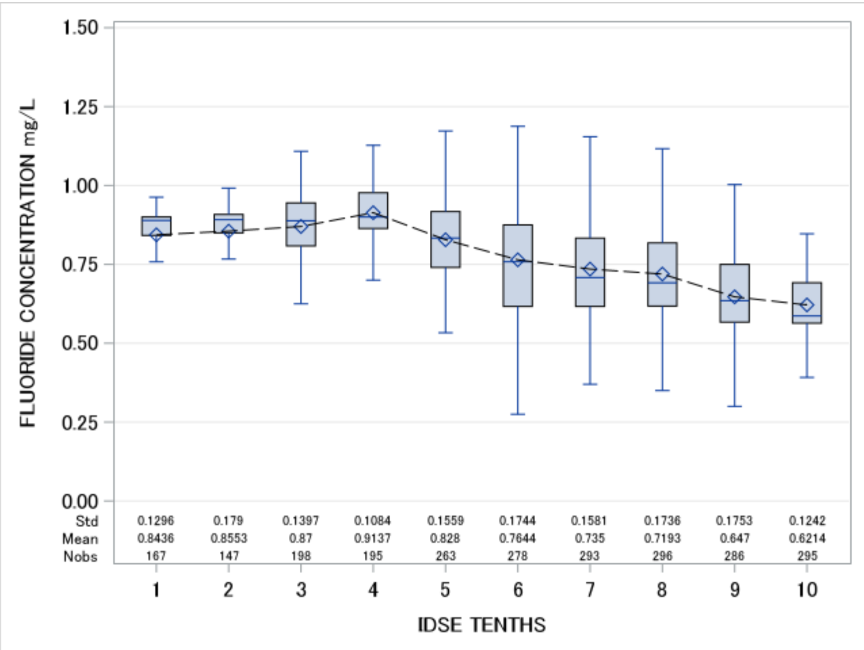


Figure 5.14: Distribution of fluoride concentration of the CWF programme by IDSE tenths (2008 – 2019)

For fluoride concentration (Figure 5.14), the most socioeconomically deprived areas showed significantly higher fluoride concentrations. The highest concentration of 0.91 mg/L of fluoride (95% CI 0.89 mg/L, 0.94 mg/L) was observed for the “IDSE 4” category. When comparing the “IDSE 1” category (0.84 mg/L; 95% CI 0.82 mg/L, 0.87 mg/L) with “IDSE 10” (0.62 mg/L; 95% CI 0.60 mg/L, 0.64 mg/L), a significant difference in the fluoride concentration of 0.22 mg/L (95% CI -0.25 mg/L, -0.19 mg/L) was observed.

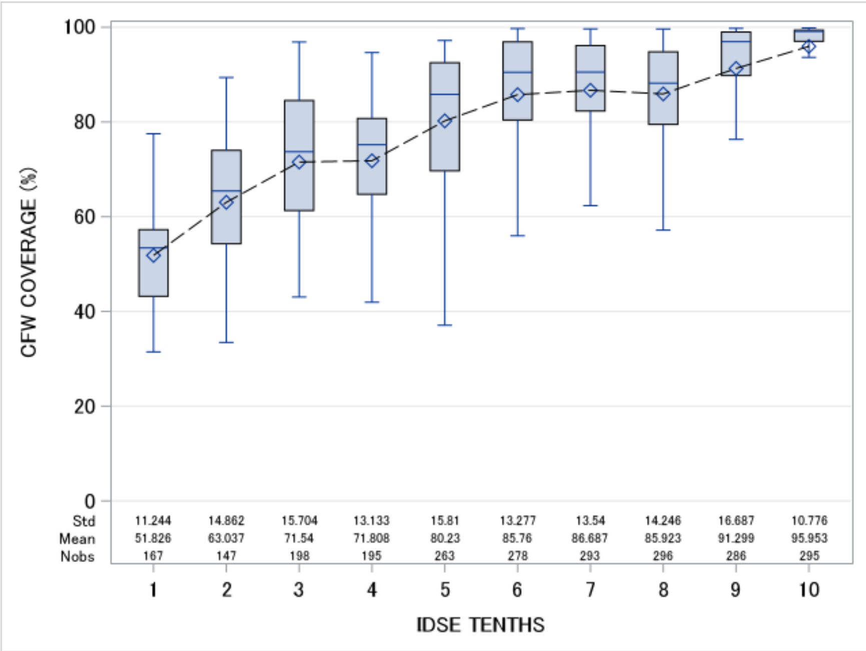


Figure 5.15: Distribution of the CWF programme coverage by IDSE tenths (2008 - 2019)

For fluoride coverage (Figure 5.15), a socioeconomic gradient was observed. Using “IDSE 1” (most deprived) category as referent, which showed coverage of 51.8% (95% CI 49.7%, 54.0%), all the other municipality/year groups showed significantly higher coverages of CWF. The “IDSE 10” (least deprived) category showed coverage of 96% (95% CI 94.3%, 97.6%), with a significant difference of 44.2% (95% CI 41.5%, 46.8%) regarding the coverage of the referent.

Furthermore, the number of municipality/years with the programme increased as deprivation decreased. For “IDSE 1” category, only 167 municipality/years out of 346 have CWF. In contrast, in the least deprived group, this increases to 295 out of 323 municipality/years.

Figure 5.16 shows the results for the fluoride applications delivered in primary care clinics. The “IDSE 5” showed the highest fluoride varnish rate of 5.5 (95% CI 4.0, 7,1). When comparing the most and least socioeconomic deprived categories, “IDSE 10” showed a fluoride varnish rate of 1.1 (95% CI -0.4, 2.7), being 2.5 (95% CI -4.7, -0.4; p = 0.022) lower than the “IDSE 1” category. No significant differences were observed for the other categories using “IDSE 1” as the referent.

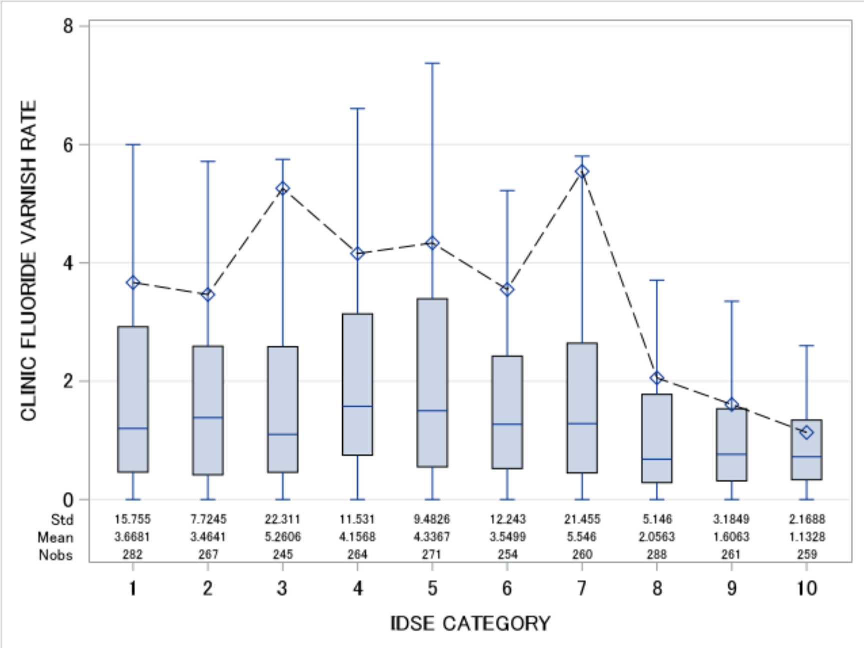


Figure 5.16: Distribution of "Clinics fluoride varnish rate" by IDSE tenths (2008 - 2019)

For toothbrushing advice (Figure 5.17), the "IDSE 3" category showed the highest rate of 12.6 (95% CI 8.9, 16.3). This rate was significantly higher (p = 0.017) than the rate of 6.4 (95% CI 3.0, 9.9) shown by "IDSE 1". No significant differences were observed between the toothbrushing advice rates of "IDSE 1" and "IDSE 10" (p = 0.243), despite that "IDSE 10" showed a lower rate of 3.5 (95% CI -0.6, 7.1).

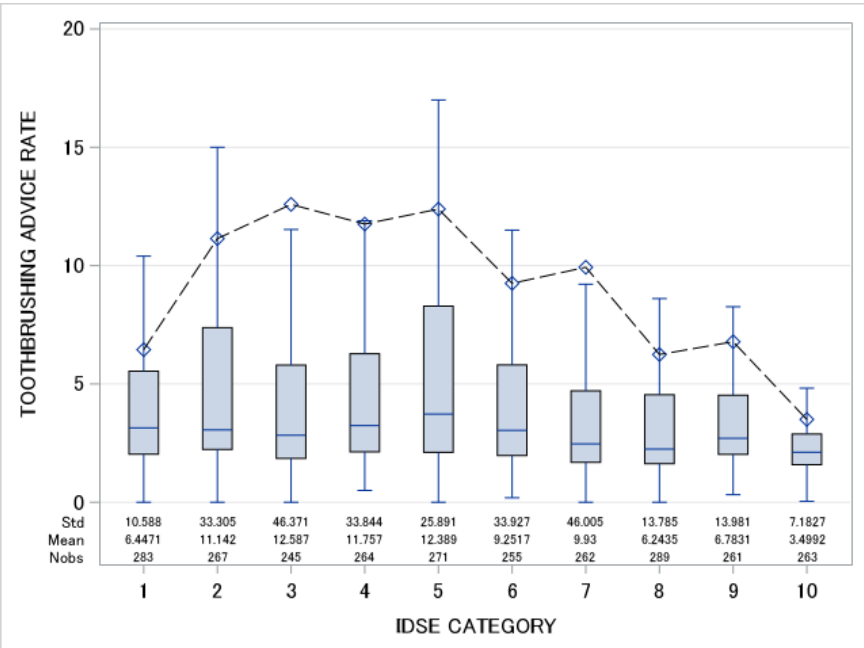


Figure 5.17: Distribution of "Toothbrushing advice rate" by IDSE tenths (2008 - 2019)

Finally, for the sealants delivered in primary care clinics (Figure 5.18), the highest rate was shown by the "IDSE 2" category (13.6; 95% CI 10.0, 17.2). "IDSE 10" showed a sealants rate 6.7 (95% CI -11.7, -1.6; p = 0.001) lower than the "IDSE 1" category.

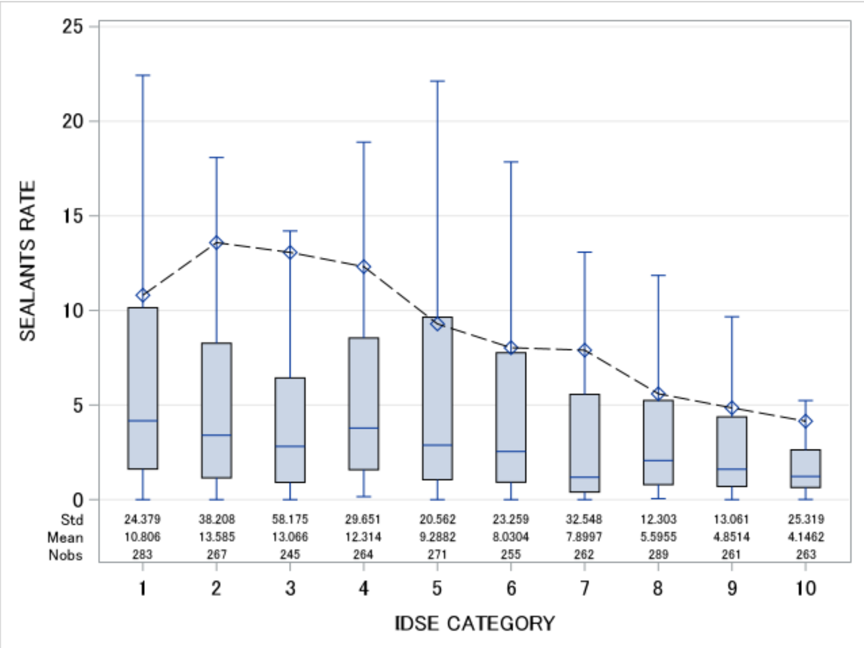


Figure 5.18: Distribution of "Sealants rate" by IDSE tenths (2008 – 2019)

5.6 Chapter 5 summary

When analysing the effects of the national oral health improvement programmes for Chile interventions on caries experience, the variables associated with changes in caries levels in Chilean six-year-olds in the period analysed were determined.

Regarding the community water fluoridation programme, both the annual average concentration of fluoride and the coverage of the programme were associated with a decrease in caries experience of six-year-olds in Chile, where those municipality/years with coverage of over 90% of its population and that with a mean annual concentration equal to or higher than 0.6 mg/L of fluoride presented 12% lower caries experience in comparison with those areas not exposed to community water fluoridation.

The effect of the community water fluoridation variables on reducing caries experience of six-year-olds remained significant even after adjusting by deprivation, rurality and time in the cohort.

The preventive interventions delivered in primary care clinics showed an association between caries experience and fluoride varnish application, education in brushing technique, and the application of sealants in primary teeth. This association was positive —a higher rate of these interventions was associated with higher caries levels in both univariate and adjusted analyses.

Similar results were found when analysing the caries levels trends including only the six-year-olds most affected by dental caries —with a dmft of 5 or more. Those children in areas not exposed to community water fluoridation were the most affected, and the impact of fluoride concentration and coverage was higher in the most affected group compared to all six-year-olds at the municipality level. In this analysis, the preventive interventions performed in primary care clinics were also associated with increased caries levels in the most affected children.

A socioeconomic gradient was observed when assessing the inequalities in the distribution of the community water fluoridation variables. The most socioeconomically deprived municipalities had significantly higher fluoride concentration and, most notoriously, significantly lower coverages compared with the least deprived areas. The water fluoridation coverage in most deprived municipalities was 52%, in contrast to the least deprived, which showed a coverage of 96%.

For the preventive interventions delivered in primary care clinics, the socioeconomic gradient was not so clear. Despite this, a significantly lower rate of fluoride varnish applications and sealants in primary teeth was observed in the least deprived municipalities, in comparison with the most socioeconomic deprived areas.

Chapter 6 – Sembrando Sonrisas In-depth Analysis

Chapter 6 describes the construction of a cohort from the Sembrando Sonrisas programme data, and the analyses undertaken to evaluate the impact of its interventions in children between two and four years of age since programme establishment and rollout on caries experience of five-year-olds; to assess the related inequities; and to investigate its effect over and above the community water fluoridation programme.

6.1 Sembrando Sonrisas impact on dental caries of children in Chile

This section describes the different analytical approaches and models that were used to address the effect of Sembrando Sonrisas on the dental caries levels of children covered by the programme. All statistical analyses undertaken were completed using SAS 9.4.

As explained in Chapter 5, it was decided to perform an in-depth analysis of Sembrando Sonrisas with the data collected in nurseries due to the lack of individual-level records or a protocol that allowed linkage of this information this information with the data that was collected in primary care clinics, according to the Chilean data legislation. Therefore, a more precise evaluation of Sembrando Sonrisas can be achieved by using the data that was directly collected from the interventions performed for the programme.

6.2 Dental examinations performed in nurseries for Sembrando Sonrisas programme

In the database, there were 2,091,719 aggregated records of children with a dental examination that was performed in nurseries for the Sembrando Sonrisas programme between 2015 and 2019 nationwide, including all municipalities and children aged two to five years. In contrast to the dental examinations in primary care clinics, the electronic records of **"Total Sembrando examinations"** only differentiate between children with no obvious caries experience, i.e. **"Sembrando with no caries experience"** (as defined in section

4.2.3, with a dmft = 0), and children with obvious caries experience, i.e. **"Sembrando with caries experience"** (with a dmft greater than 0). Table 6.1 shows the distribution of the dental examinations of the Sembrando Sonrisas programme in the dataset by age.

Table 6.1: Distribution of dental examinations performed in nurseries for Sembrando Sonrisas programme by age.

Age	Total Sembrando With No Caries Experience Records	Total Sembrando With Caries Experience Records	Total Sembrando dental examinations Records
Two-year-olds	275,617	84,569	358,140
Three-year-olds	316,631	191,051	506,157
Four-year-olds	310,835	283,994	594,245
Five-year-olds	291,360	342,310	633,177
Total	1,194,443	901,925	2,091,719

6.3 Sembrando Sonrisas outcome variable definition and unit of analysis

A continuous outcome variable, the "Percentage of **five-years-old** children with obvious caries experience from Sembrando Sonrisas programme", i.e. **"Sembrando caries experience"** was created to analyse the trends in caries levels over time and to measure the impact of the Sembrando Sonrisas interventions on the levels of dental caries of the children that were covered by the programme.

This decision was made because five years of age represents the only age where it is possible to accurately evaluate the impact of all the interventions delivered by the programme in its entire duration. Since the Sembrando Sonrisas establishment and rollout, only two birth cohorts had been exposed to the programme in the dataset: the children aged two in 2015 and five in 2018, and children aged two in 2016 and five in 2019 (Figure 6.1). It was decided to use the data of both the 2018 and 2019 five-year-olds to increase the statistical power of the analyses.

As for "Caries experience" in Chapter 4, "Sembrando caries experience" is a percentage for each municipality/year, but all analyses considered those percentages as a continuous endpoint.

Figure 6.1: Selection of the birth cohorts of Sembrando Sonrisas for further analyses. In yellow the 2015-2018 birth cohort, in orange the 2016-2019 cohort, and in blue the two points selected for the assembly of the outcome variable.

2015	2016	2017	2018	2019
Two-year-olds	Two-year-olds			
	Three-year-olds	Three-year-olds		
		Four-year-olds	Four-year-olds	
			Five-year-olds	Five-year-olds

Figure 6.2 describes the process to construct the "Sembrando caries experience" variable. For the assembly, a proportion was made between total aggregated records of "Sembrando With Caries Experience" and "Total Sembrando examinations" on five-year-olds for each municipality in 2018 and 2019; therefore, the unit of analysis, as it was for previous chapters, was defined as **"municipality/years"**.

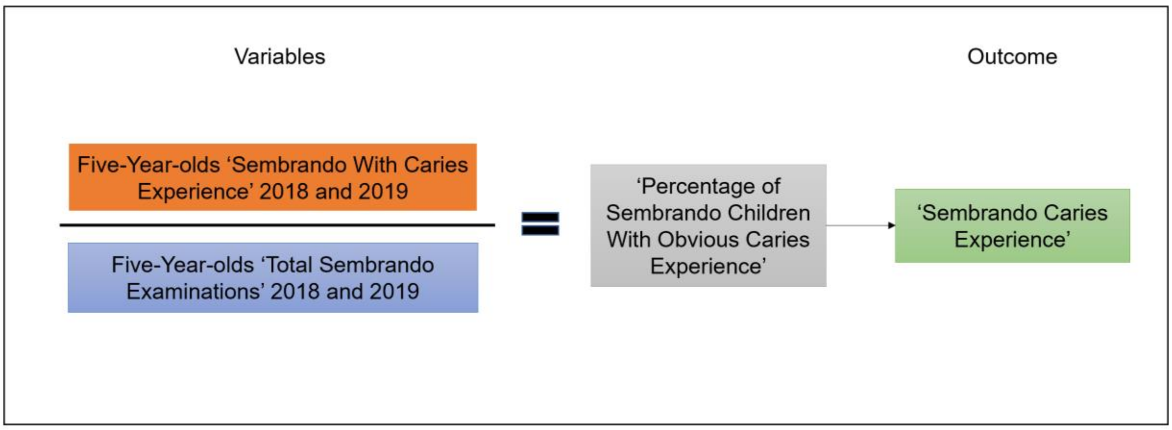


Figure 6.2: Creation of the outcome variable for Sembrando Sonrisas programme analysis.

As stated in section 4.3.1, Chile has 346 municipalities, and the years 2018 and 2019 were included for the analyses. Therefore, a total of 692 municipality/years is the maximum possible record and will be used to analyse the completeness of the data.

6.3.1 Summary of "Total Sembrando examinations" and "Sembrando with caries experience" variables

The following section describes a summary of each variable that was used to define the outcome of this chapter. All statistical analyses undertaken were completed using SAS Version 9.4.

Regarding the "Total Sembrando examinations" in five-year-olds, a summary of statistical measures is shown in Table 6.2, and its distribution in Figure 6.2.

Table 6.2: Statistical measures summary for "Total Sembrando examinations"

Location		Variability	
Mean	485.7	**Std. Dev.**	750.9
Median	185	**Max**	7222
Mode	71	**Min**	10

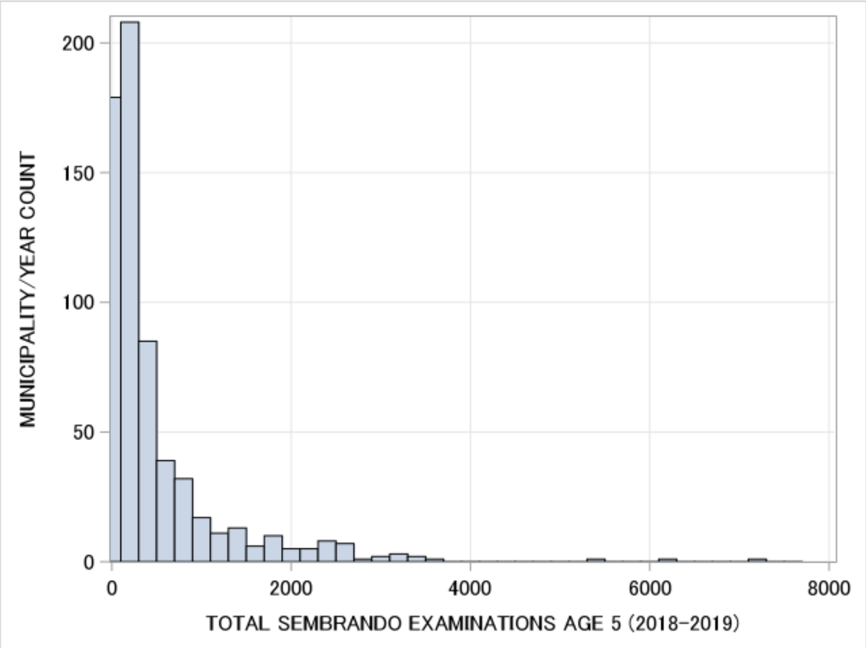


Figure 6.3: Histogram of the distribution of "Total Sembrando examinations" of five-year-olds by municipality/years

From the data presented, “Total Sembrando Examinations” in five-year-olds presented a clear asymmetric distribution with high variability, reflected in a right-skewed form of the histogram.

A summary of statistical measures for “Sembrando With Caries Experience” in five-year-olds is presented in Table 6.3, and its distribution in Figure 6.3. A high variability, and a right-skewed distribution were observed.

Table 6.3: Statistical measures summary for Sembrando With Caries Experience in five-year-olds (2018 - 2019).

Location		Variability	
Mean	253.4	**Std. dev.**	396.8
Median	106	**Max**	3697
Mode	0	**Min**	0

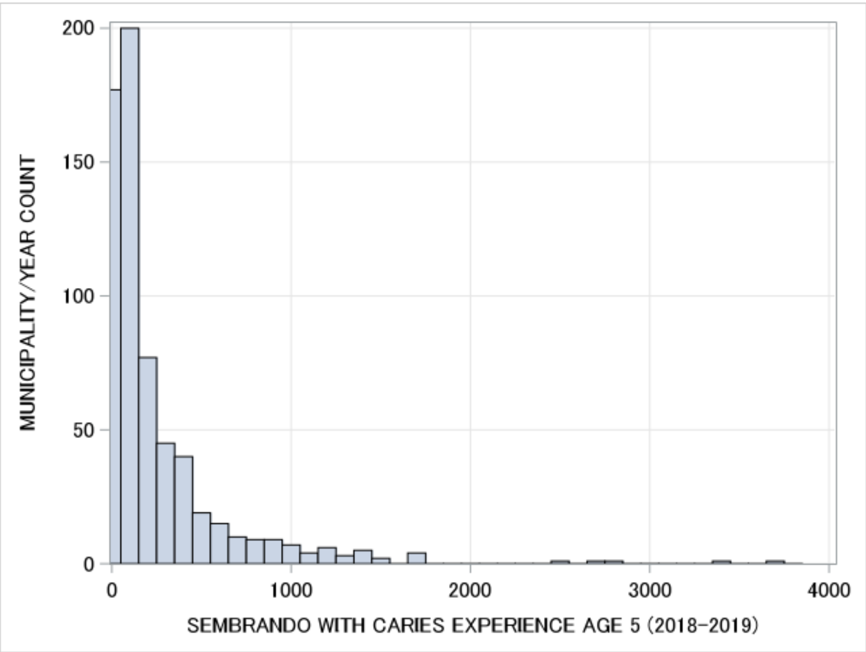


Figure 6.4: Histogram of the distribution of “Sembrando with caries experience” of five-year-olds by municipality/years

6.3.2 Outcome variable and cohort assembly for Sembrando Sonrisas analysis

The sequence for creating a new municipality/years cohort specifically for the analysis of this Chapter is shown in Figure 6.5. The same criteria were used as for the cohort of six-year-olds described in section 4.4.2, but with the data of the Sembrando Sonrisas programme: (1) Have records to calculate "Sembrando caries experience", and (2) have records on the Socioeconomic Development Index ("IDSE").

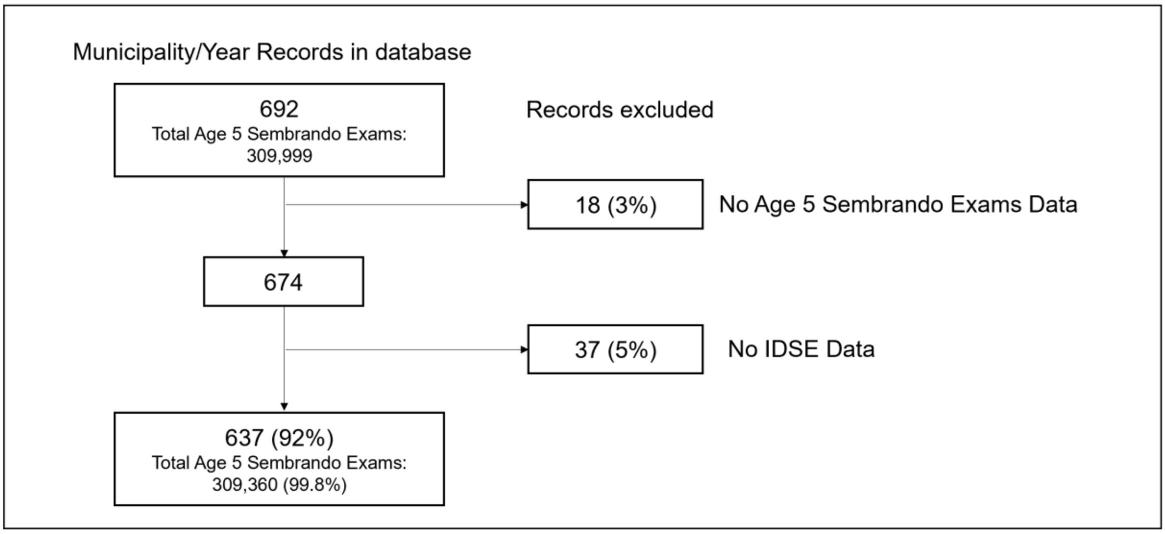


Figure 6.5: Flow Chart of the creation of the new cohort for Sembrando Sonrisas analysis.

After this process, the new municipality/years cohort used in further Sembrando Sonrisas analysis included 92% (n = 637) of the total number of possible municipality/years records for five-year-olds. For the "Sembrando caries experience" assembly, the cohorts included 309,360 "Total Sembrando Examinations" five-year-olds records, that is, 99.8% of the total aggregated records were included in the analysis.

6.4 Sembrando caries experience distribution

A summary of statistical measures for “Sembrando caries experience” in the new cohort is presented in Table 6.4, and its distribution is shown in Figure 6.6.

Table 6.4: Statistical measures summary for the “Sembrando caries experience” variable (2018 - 2019)

Location		Variability	
Mean	54.9%	**Std. dev.**	17.3%
Median	55.1%	**Max**	100%
Mode	0%	**Min**	0%

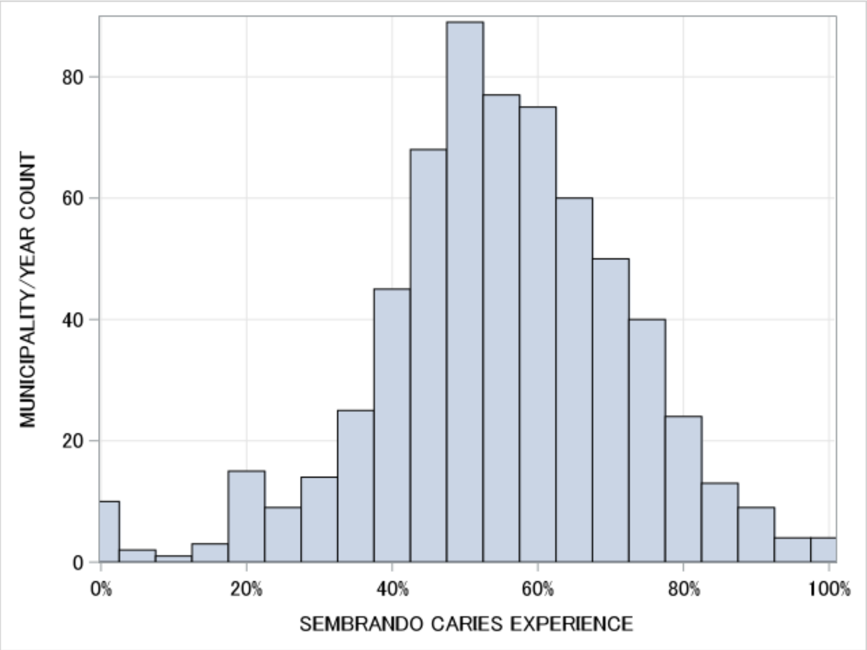


Figure 6.6: Distribution of “Sembrando caries experience” by municipality/years

“Sembrando caries experience” showed a mean of 54.9%, and a similar median of 55.1%, with a bell-shaped distribution. This results makes “Sembrando caries experience” a highly suitable variable to be used as outcome in further regression-based analyses.

6.5 Effect of deprivation, rurality and time on Sembrando caries experience

The association between “Sembrando caries experience” and the potential confounders available in the database: deprivation with the “IDSE” variable, rurality with the “Rurality proportion”, and time with “Year” was evaluated using univariate weighted (by “Total Sembrando Examinations”) linear regressions. A detailed description on the regression methods used for this analysis is provided in sections 4.4.3 and 4.6.

Briefly, “Total Sembrando examinations” was selected to weight the analyses, to compare municipalities with small populations with those with larger populations. For each linear regression for the association between “Sembrando caries experience” and the potential confounders, R^2 and Wald’s p-value were calculated.

Table 6.5. shows the results for the univariate weighted linear regression analysis performed for each potential confounder.

Table 6.5: Univariate weighted linear regression analysis for the association of “Sembrando caries experience” and potential confounder variables

IDSE		Year		Rurality Proportion	
R^2	p-value	R^2	p-value	R^2	p-value
0.075	<.0001	0.003	0.119	0.061	<.0001

“IDSE” (p <.0001) and “Rurality Proportion” (p <.0001) were associated with “Sembrando Caries Experience” in the univariate analysis, but “Year” was not (p = 0.119). This result for ‘Year’ showed that there was no difference in Sembrando caries experience between five-year-olds of 2019 and 2018, which strengths the decision to join them for analysis.

To search for the most parsimonious model to evaluate the Sembrando Sonrisas interventions effect on Sembrando Caries Experience, a forward selection model was performed including IDSE, Rurality proportion and Year (Table 6.6).

Table 6.6: Forward selection model for the association between “Sembrando caries experience” and “IDSE”, “Rurality Proportion” and “Year”

Step	Effect Entered	Adjusted R-Square	AIC	Cp	*P*-Value
1	**IDSE**	0.086	2101	2	<.0001
Excluded	**Rurality Proportion**	0.087	2101	3	0.128
Excluded	**Year**	0.085	2104	5	0.649

The criteria used to define the model's 'goodness of fit' were the Adj. R^2, AIC and Mallow’s Cp values (see a detailed description of this criteria on section 4.6). The incorporation of “Year” had no statistical significance in the model and increased the AIC and Cp values. For Rurality proportion, even though its inclusion slightly increased the Adj. R^2 and did not increased AIC, Cp was greater than the model with only IDSE and also was not a significant explanatory variable. These results indicate that the most parsimonious model is the one that only includes “IDSE”, leaving aside the incorporation of “Rurality proportion” and “Year”. The most parsimonious model was confirmed by backwards and step-wise selection methods, showing the same results.

6.5.1 Sembrando caries experience by area-based socioeconomic deprivation

To evaluate the differences in the distribution of “Sembrando caries experience” by area-based socioeconomic deprivation, univariate weighted least squares linear regressions were performed, using the categorical presentation IDSE tenths. Table 6.7 shows a summary of the results.

Table 6.7: Univariate weighted least squares linear regressions for "Sembrando Caries Experience" by IDSE tenths

IDSE tenths	Municipality/Year Frequency	Sembrando Caries Experience	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
1 (most)	66	59.9%	53.2%	66.7%	Referent	Referent		Referent
2	64	61.0%	55.3%	66.7%	1.0%	-7.7%	9.8%	0.818
3	64	58.1%	52.5%	63.7%	-1.8%	-10.6%	6.9%	0.682
4	63	58.4%	52.9%	63.8%	-1.5%	-10.2%	7.1%	0.726
5	62	53.8%	49.4%	58.2%	-6.1%	-14.1%	1.9%	0.134
6	67	57.5%	53.5%	61.5%	-2.4%	-10.2%	5.3%	0.538
7	62	55.5%	51.9%	59.2%	-4.4%	-12.0%	3.2%	0.259
8	61	53.7%	50.9%	56.5%	-6.2%	-13.5%	1.1%	0.095
9	66	48.4%	46.0%	50.8%	-11.5%	-18.6%	-4.4%	0.002
10 (least)	62	47.1%	44.8%	49.4%	-12.8%	-19.9%	-5.7%	0.0004

A significant difference was observed for area-based socioeconomic deprivation between the most socioeconomic deprived category "IDSE 1", that showed a Sembrando caries experience of 59.9% (95% CI 53.2, 66.7%), with the two least deprived groups. The largest difference regarding the referent was observed for IDSE 10, which showed a Sembrando caries experience of 47.1% (95% CI 44.8%, 49.4%), which was 12.8% (95% CI -19.9%, -5.7%; p = 0.0004) lower than the referent.

6.6 Effect of community water fluoridation in Sembrando caries experience

One of the objectives of this Chapter includes evaluating the impact of Sembrando Sonrisas interventions over and above the effect of community water fluoridation. According to the results of Chapter 5, community water fluoridation was strongly associated with a decrease in caries experience of six-year-olds at the municipality level. Therefore, it was decide to explore its impact on caries levels in children covered by the Sembrando Sonrisas programme in the new cohort.

Since the number of municipality/years in the new cohort created for the Sembrando analyses (n = 637) is considerably lower than the Chapters 4 and 5 cohort (n = 3,359), which would lead to each “CWF delivery” category (see section 5.2.3 for a detailed description of this variable) having a representation that would make the analyses challenging and less clear, it was decided to create a new categorical variable: **“CWF exposure”**, to include the community water fluoridation programme in the Sembrando Sonrisas analyses, with two categories: **“No CWF”**, including all municipality/year in the cohort unexposed to community water fluoridation; and **“CWF”**, including those exposed to water fluoridation.

Univariate and adjusted (by “IDSE”) weighted least-squares linear regressions were performed to assess the association between “CWF exposure” and “Sembrando caries experience” (Table 6.8).

Table 6.8: Least-squares weighted linear regressions for the association between Sembrando Caries Experience and CWF exposure: univariate and adjusted

Variable	Category	Municipality/Year Frequency	Sembrando Caries Experience	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
CWF Exposure	No CWF	176	60.5%	57.4%	63.6%	Referent	Referent		Referent
	CWF	461	51.0%	49.8%	52.2%	-9.5%	-12.8%	-6.1%	<.0001
Adjusted Model 1	No CWF	176	60.5%	57.5%	63.5%	Referent	Referent		Referent
	CWF	461	54.1%	52.6%	55.6%	-6.4%	-9.7%	-3.0%	0.0002

*Model 1 is adjusted by IDSE

In both analyses, univariate and adjusted for deprivation, it was observed that Sembrando caries experience was significantly lower in those municipalities/years exposed to CWF. The “No CWF” category showed a Sembrando caries experience of 60.5% (95% CI 57.4%, 63.6%) in the univariate model. In contrast, the communities with exposed CWF showed a Sembrando caries experience of 51% (95% CI 49.8%, 52.2%), being 9.5% lower than the reference (95% CI -12.8%, -6.1%, p <.0001). For the model adjusted for deprivation, the difference was 6.4% (95% CI -9.7%, -3.0%, p = 0.0002).

6.7 Effect of Sembrando Sonrisas interventions on Sembrando caries experience

This section describes the analytical approaches and models that were used to address the effect of each component of the Sembrando Sonrisas programme on the caries experience of five-year-olds covered by the programme at the municipality level.

A similar approach to that used for the variables of preventive interventions delivered in public primary care clinics in Chapter 5 (section 5.5) was adopted to create variables that could explain the impact of the interventions delivered in nurseries to children covered by the Sembrando Sonrisas programme on Sembrando caries experience, where a sum of the interventions received by children in nurseries before the age of five at municipality-level was used as the numerator and the sum of “Total Sembrando examinations” before the age of five at municipality-level was used as the denominator to create a rate of exposure to the interventions through the programme (Figure 6.6).

The interventions received by two-year-old in 2015 summed with those performed in three-year-olds in 2016 and four-year-olds in 2017 were used as the numerator for the rate of exposure to that intervention for the 2018 five-year-olds, and then divided with the same sum for the ‘Total Sembrando Examinations’ to finally create the rate. The same calculations were used a year later for the 2019 endpoint.

From the literature review performed in Chapter 1 and the data available in the dataset, the fluoride varnish applications delivered in nurseries, i.e. **“Sembrando fluoride varnish rate”,** and the delivery of an oral health kit that includes four toothbrushes and one toothpaste with 1000 ppm of fluoride in the Sembrando Sonrisas programme, i.e. **“Sembrando kits rate”,** were selected to evaluate their impact on caries levels of five-year-old children covered by the programme.

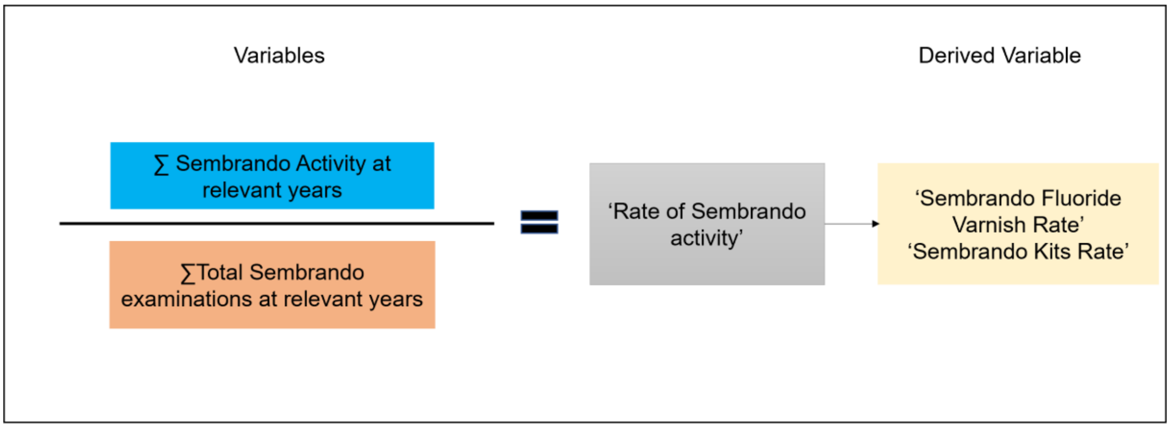


Figure 6.7: Description of the assemble of variables from the Sembrando Sonrisas programme

First, each variable was described by summarising statistical measures and their distribution. This analysis inferred whether the variable in its continuous presentation was suitable for assembling a categorical presentation, deciding the cut-offs values according to the results.

Weighted univariate linear regressions were conducted to establish the association between each intervention (individually) and Sembrando Caries Experience.

Subsequently, a model adjusted by deprivation (IDSE) was analysed using multivariate weighted least squares linear regression models for the differences between categories of each variable of the programme. Results were expressed as differences in the least squares means. Wald p-values with a 5% significant level and 95% confidence intervals were calculated.

Finally, the independent effects of each intervention, adjusted by deprivation, and over and above the effect of community water fluoridation was assessed.

6.7.1 Sembrando oral health kits

Oral health kits, including four toothbrushes and a toothpaste with 1000 ppm of fluoride, are delivered annually to each child aged two to five years in state-funded nurseries for the daily supervised toothbrushing component of the Sembrando Sonrisas programme.

Table 6.9 shows a summary of statistical measures for the variable "Sembrando kits rate", and its distribution in Figure 6.7. "Sembrando kits rate" shows a bell-shaped distribution, with a peak of the municipality/years with a rate of one, explained by a mean, median and mode with a value of one, representing those municipality/years where all children received the kit.

Table 6.9: Statistical measures summary for "Sembrando kits rate" variable.

Sembrando kits rate				
	Location		**Variability**	
Five-year-olds	**Mean**	1.02	**Std Dev.**	0.21
	Median	1	**Max**	2.15
	Mode	1	**Min**	0.34

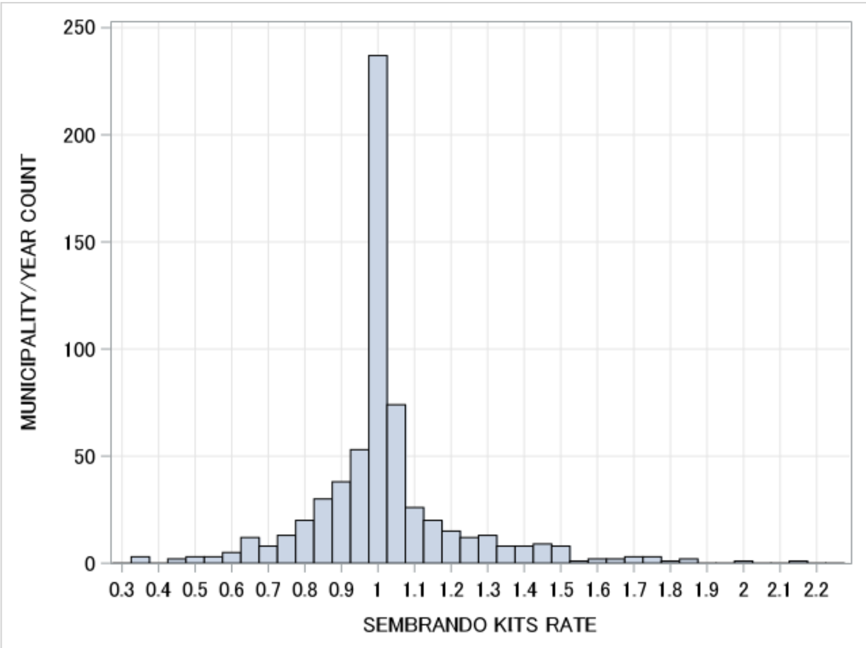


Figure 6.8: Histogram of the distribution of 'Sembrando kits rate'

Due to this distribution, it was decided to generate a categorical version of the variable by dividing the continuous variable into two categories creating the **"Sembrando kits rate delivery"** variable: (1) "**Partial**", with a rate of less than one; and (2) "**Complete**", with a rate greater equal to one. This cut-off was selected in order to compare those municipality/year where all children received the kits with those were this did not occur.

6.7.1.1 Association between Sembrando kits and Sembrando caries experience

Table 6.10 presents the results of the linear regressions performed to evaluate the association between “Sembrando kits rate delivery” and “Sembrando Caries experience”.

Table 6.10: Linear regressions for the association between “Sembrando caries experience” and “Sembrando kits rate delivery”, weighted by “Total Sembrando examinations”: univariate and adjusted

Variable	Univariate R^2	Univariate p-value	Model 1* Adj. R^2	Model 1* p-value
Sembrando Kits Rate Delivery	0.026	<.0001	0.109	0.0004

*Model 1 is the multivariate linear regression adjusted by IDSE

Univariate analyses showed an association between “Sembrando kits rate delivery” and Sembrando Caries Experience (p <.0001), that remained in the adjusted model (p = 0.0004).

Table 6.11 shows the results of the least-squares linear regression of “Sembrando caries experience” according to “Sembrando kits rate delivery” categories, both univariate and adjusted by deprivation, weighted by “Total Sembrando examinations”.

Table 6.11: Least-squares linear regressions for the association between “Sembrando caries experience” and “Sembrando kits rate delivery”, weighted by “Total Sembrando examinations”: univariate and adjusted

	Sembrando kits rate delivery	Municipality/Year Frequency	Sembrando Caries Experience	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
Univariate	Partial (< 1)	248	55.0%	53.3%	56.7%	Referent	Referent		Referent
	Complete (>= 1)	389	50.1%	48.6%	51.7%	-4.9%	-7.2%	-2.5%	<.0001
Adjusted Model 1*	Partial (< 1)	248	58.1%	56.2%	60.1%	Referent	Referent		Referent
	Complete (>= 1)	389	54.1%	52.2%	56.0%	-4.0%	-6.3%	-1.8%	0.0003

*Model 1 is the multivariate linear regression adjusted by IDSE

The category of municipality/years with a “Partial” (less than one) delivery rate of Sembrando kits was used as referent. Sembrando caries experience was significantly lower in those municipality/years where all children received the kits for daily supervised toothbrushing in nurseries in both univariate and adjusted analyses. Also there were 248 municipality/years where not all children received the kits, against 389 where this was achieved.

In the univariate analysis, the municipalities/year with a partial delivery showed a Sembrando caries experience of 55.0% (95% CI 53.3%, 56.7%), while those with a complete delivery was 50.1% (95% CI 48.6%, 51.7%), and the difference was 4.9% (95% CI -7.2%, -2.5%, $p < .0001$) less than the referent.

In the model adjusted for deprivation, the Sembrando caries experience in both groups was slightly higher, with a significant difference in Sembrando caries experience between kit delivery rate groups of -4.0% (95% CI -6.3%, -1.8%, $p = 0.0003$).

6.7.2 Sembrando fluoride varnish applications

As part of the Sembrando Sonrisas programme, twice-per-year fluoride varnish applications are performed by a dentist in nurseries. Table 6.12 shows a summary of statistical measures for the variable “Sembrando fluoride varnish rate”, and its distribution in Figure 6.9.

Table 6.12: Statistical measures summary for “Sembrando fluoride varnish rate”

Location		Variability	
Mean	1.60	**Std Dev.**	0.33
Median	1.62	**Min**	0.70
Mode	2.0	**Max**	2.92

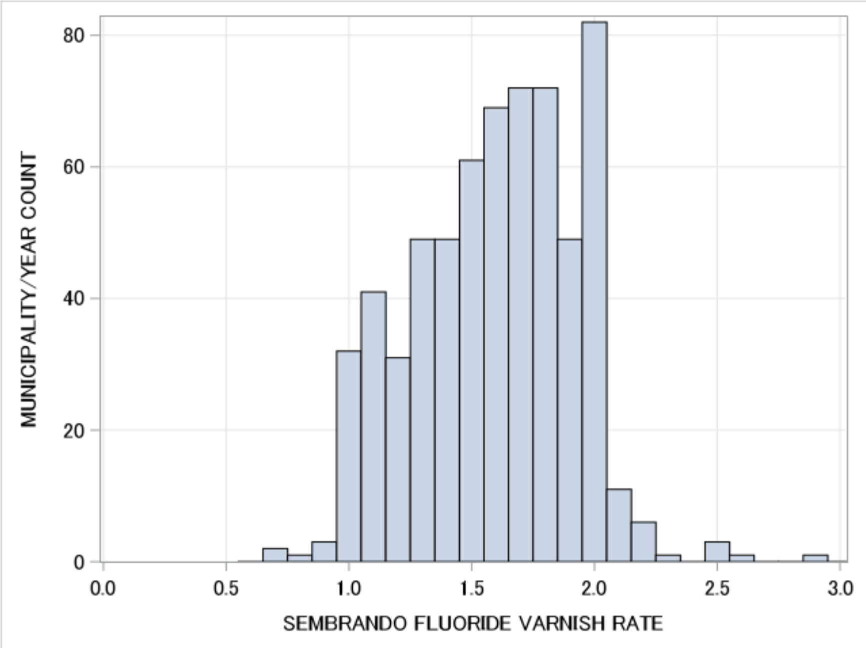


Figure 6.9: Histogram of the distribution of "Sembrando fluoride varnish rate"

What is expected from this intervention is that the children have two applications of fluoride varnish during the year, so for this to happen, the rate should have a value of 2.0. Sembrando fluoride varnish rate showed a mean and a median of 1.6, with a mode of 2.0. No municipality/years were observed with a rate lower than 0.7. The distribution was quite close to a bell-shaped one, but with the peak in the municipalities/years with a rate of 2.0, explained in the value of the mode.

Due to this distribution, it was decided to test the association with Sembrando caries experience in both continuous version and in a categorical version in fifths of the distribution, i.e. **"Sembrando fluoride varnish rate fifths"**.

6.7.2.1 Association between Sembrando Fluoride Varnish and Sembrando Caries Experience

The results of the linear regressions performed to evaluate the association between both the continuous and categorical presentations of Sembrando fluoride varnish rate and Sembrando caries experience are shown in Table 6.13.

Table 6.13: Linear regressions for the association between "Sembrando caries experience" and "Sembrando fluoride varnish rate" and "rate fifths", weighted by "Total Sembrando examinations": univariate and adjusted

Variable	Univariate R^2	Univariate p-value	Model 1* Adj. R^2	Model 1* p-value
Sembrando FV Rate	0.002	0.301	0.091	0.947
Sembrando FV Rate Fifths	0.011	0.130	0.095	0.582

*Model 1 is the multivariate linear regression adjusted by IDSE

The linear regression results showed no association between "Sembrando caries experience" and the continuous (p = 0.301) and categorical (p = 0.130) presentation of "Sembrando fluoride varnish rate" in the univariate analysis. This result remained not significant after adjustment by IDSE.

Table 6.14 shows the results of the least-squares linear regression of Sembrando Caries Experience according to Sembrando Fluoride Varnish Rate Fifths, both univariate and adjusted by deprivation, weighted by Total Sembrando examinations.

The lowest Sembrando fluoride varnish rate fifth category (0.70 – 1.27) was used as referent, that had a Sembrando caries experience of 54.6% (95% CI 51.7%, 57.5%) in the univariate analysis. The only fifth category that showed a significantly lower Sembrando caries experience in the univariate analysis was 4 (1.72 - 1.90) with a 49.7% (95% CI 47.2%, 52.3%), with a difference of 4.8% (95% CI -8.7%, -1.0%, p = 0.015), but this significant difference did not remain in the model adjusted by deprivation.

Table 6.14: Least-squares linear regressions for the association between Sembrando Caries Experience and Sembrando fluoride varnish rate fifths, weighted by Total Sembrando Examinations: univariate and adjusted

	Sembrando Fluoride Varnish Rate Fifths	Municipality/Year Frequency	Sembrando Caries Experience	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
Univariate	1 (0.70 – 1.27)	128	54.6%	51.7%	57.5%	Referent	Referent		Referent
	2 (1.28- 1.52)	127	51.8%	49.4%	54.2%	2.8%	-6.5%	1.0%	0.146
	3 (1.53- 1.71)	127	52.6%	50.3%	55.0%	2.0%	-5.7%	1.8%	0.302
	4 (1.72 - 1.90)	127	49.7%	47.2%	52.3%	4.8%	-8.7%	-1.0%	0.015
	5 (1.91 – 2.92)	127	53.6%	50.6%	56.5%	1.0%	-5.2%	3.1%	0.627
Adjusted Model 1*	1 (0.70 – 1.27)	128	55.9%	53.0%	58.7%	Referent	Referent		Referent
	2 (1.28- 1.52)	127	54.9%	52.5%	57.4%	-1.0%	-4.6%	2.7%	0.619
	3 (1.53- 1.71)	127	56.3%	53.9%	58.8%	0.4%	-3.1%	4.1%	0.791
	4 (1.72 - 1.90)	127	53.7%	51.0%	56.4%	-2.2%	-5.8%	1.6%	0.266
	5 (1.91 – 2.92)	127	56.0%	53.0%	58.8%	0.1%	-3.9%	4.0%	0.978

*Model 1 is the multivariate linear regression adjusted by IDSE

6.8 Effect of Sembrando Sonrisas programme interventions on Sembrando caries experience over and above community water fluoridation

Since the variable related to the delivery of kits for daily supervised toothbrushing in the nurseries was associated with Sembrando caries experience and no association was observed that was related to the application of fluoride varnish in the nurseries of the Sembrando Sonrisas programme, the variables “IDSE”, “CWF exposure” and “Sembrando kits rate delivery” were modelled together to discover the most parsimonious model that explains the differences in the caries levels of the five-year-olds covered by the programme since its establishment and rollout at the municipality-level.

Table 6.15 shows the results of the forward selection model including the aforementioned variables.

Table 6.15: Forward selection model summary of the impact of “Sembrando Sonrisas kits delivery”, “IDSE”, and “CWF exposure” on “Sembrando caries experience”, weighted by “Total sembrando examinations”

Step	Effect Entered	Adjusted R-Square	AIC	Cp	*P*-Value
1	**IDSE**	0.086	2101	34	<.0001
2	**CWF exposure**	0.107	2088	21	0.0002
3	**Sembrando kits**	0.128	2073	6	<.0001

All the variables included were significant explanatory variables in the forward model, showing the largest Adj. R^2 and the lowest values of Cp and AIC, so the most parsimonious model includes the three variables analysed. As before, Mallow’s Cp was the clearest and most decisive metric to assess the model. In addition, “Sembrando kits rate delivery” continues to be a significant explanatory variable for the changes in “Sembrando caries experience” even when “CWF exposure” is included in the model. The results were confirmed by backwards and step-wise selections.

Multivariate weighted least-squares linear regressions were performed, evaluating the effect on “Sembrando caries experience” of three variables included in the model: “Sembrando kits rate delivery”, “CWF exposure”, and “IDSE” (Table 6.16).

The municipality/years with a “Partial” delivery of Sembrando kits showed a Sembrando caries experience of 60.2% (95% CI 58.1%, 62.3%), while those with a “Complete” delivery showed a 55.3% (95% CI 53.5%, 57.2%), being 4.9% lower than the reference (95% CI -7.1%, -2.6%, p <.0001).

For “CWF exposure”, the “No CWF” category showed a Sembrando caries experience of 61.5% (95% CI 58.5%, 64.5%). In contrast, the “CWF” category showed a Sembrando caries experience of 54.0% (95% CI 52.5%, 55.5%). A difference of 7.5% (95% CI -10.9%, -4.2%, p < .0001) was observed between the two categories.

Table 6.16: Least-squares linear regressions for “Sembrando caries experience” in a model including “Sembrando kits rate delivery”, “CWF exposure” and “IDSE”, weighted by “Total Sembrando examinations”

Variable	Category	Municipality/ Years Frequency	Model 2 * Sembrando Caries Experience	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
Sembrando kits rate delivery	Partial (< 1)	248	60.2%	58.1%	62.3%	Referent	Referent		Referent
	Complete (>= 1)	389	55.3%	53.5%	57.2%	-4.9%	-7.1%	-2.6%	<.0001
CWF Exposure	No CWF	176	61.5%	58.5%	64.5%	Referent	Referent		Referent
	CWF	461	54.0%	52.5%	55.5%	-7.5%	-10.9%	-4.2%	<.0001

*Model 2 is the multivariate linear regression including IDSE, Sembrando kits rate delivery and CWF exposure

In addition, a combination of “Sembrando kits rate delivery” and “CWF exposure” was also tested in the model (Table 6.17) due to an interaction observed between “CWF exposure” and “Sembrando caries experience” in the tested model (p <.0001).

Table 6.17: Least-squares linear regressions for “Sembrando caries experience” and a combined variable of “Sembrando kits rate delivery” and “CWF exposure”, adjusted by “IDSE”, and weighted by “Total Sembrando examinations”

Variable	Category	Municipality/ Years Frequency	Model 1 * Sembrando Caries Experience	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
Combined	Partial - No CWF	53	65.1%	59.5%	70.6%	Referent	Referent		Referent
	Complete – No CWF	123	58.7%	54.5%	58.2%	-6.4%	-13.0%	0.1%	0.055
	Partial - CWF	195	56.3%	55.2%	62.2%	-8.8%	-14.6%	-2.9%	0.004
	Complete – CWF	266	51.7%	49.8%	53.6%	-13.4%	-19.3%	-7.5%	<.0001

*Model 1 is the multivariate linear regression adjusted by IDSE

For the combined variable of “Sembrando kits rate delivery” with “CWF exposure”, the municipality/years with a “Partial” delivery and with “No CWF” showed the highest Sembrando caries experience of 65.1% (95% CI 59.5%, 70.6%) and were used as the referent.

No significant differences were observed between the referent and the category with complete kit delivery and without CWF (p = 0.055).

The category with partial kit delivery and exposed to CWF and the category with complete delivery and exposed to CWF showed significantly lower caries levels in five-year-olds covered by Sembrando Sonrisas. The group with the best performance was the one with complete kit delivery and exposed to CWF, with a Sembrando caries experience of 51.7% (95% CI 49.8%, 53.6%), being 13.4% (95% CI -19.3%, -7.5 %, p <.0001) lower than the referent.

6.9 Area-based deprivation analysis of Sembrando Sonrisas interventions

Univariate weighted least-squares linear regression models were performed to assess whether there were differences in the exposure rates of both interventions of the Sembrando Sonrisas programme included in the database, according to the socioeconomic deprivation of the municipality/years, using the continuous presentation of the interventions as dependent variables. Table 6.18 shows the results for ‘Sembrando Kits Rate’.

Table 6.18: Univariate least-squares linear regressions for “Sembrando kits rate” by “IDSE tenths”, weighted by “Total Sembrando Examinations”

IDSE	Municipality/ Year Frequency	Sembrando kits rate	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
1 (most deprived)	66	1.00	0.92	1.08	Referent	Referent		Referent
2	64	1.00	0.93	1.07	0.00	-0.11	0.11	0.995
3	64	1.03	0.96	1.10	-0.03	-0.07	0.14	0.572
4	63	1.05	0.98	1.11	-0.04	-0.06	0.15	0.400
5	62	1.01	0.96	1.07	-0.01	-0.08	0.11	0.790
6	67	1.00	0.95	1.04	0.00	-0.10	0.09	0.926
7	62	0.93	0.89	0.97	0.07	-0.16	0.02	0.124
8	61	0.92	0.89	0.96	0.08	-0.16	0.01	0.085
9	66	1.04	1.01	1.07	-0.04	-0.05	0.12	0.405
10 (least deprived)	62	0.98	0.95	1.01	0.02	-0.10	0.07	0.665

Using the most socioeconomically deprived municipality/years group as referent ("IDSE 1"), no significant differences were observed in the rate of Sembrando kits with any category of "IDSE tenths", even the least deprived.

Table 6.19 shows the results for "Sembrando fluoride varnish rate".

Table 6.19: Univariate least-squares linear regressions for "Sembrando fluoride varnish rate" by "IDSE tenths", weighted by "Total Sembrando examinations"

IDSE	Municipality/ Years Frequency	Sembrando fluoride varnish rate	95% CI		Difference Between LSMeans Δ	Δ 95% CI		p-value
1 (most deprived)	66	1.52	1.38	1.65	Referent	Referent		Referent
2	64	1.46	1.35	1.57	-0.06	-0.23	0.12	0.510
3	64	1.62	1.51	1.74	0.10	-0.07	0.28	0.243
4	63	1.58	1.47	1.69	0.06	-0.12	0.23	0.513
5	62	1.55	1.46	1.63	0.03	-0.13	0.19	0.726
6	67	1.66	1.58	1.74	0.14	-0.02	0.30	0.081
7	62	1.46	1.38	1.53	-0.06	-0.21	0.09	0.434
8	61	1.58	1.53	1.64	0.07	-0.08	0.21	0.370
9	66	1.64	1.60	1.69	0.13	-0.02	0.27	0.822
10 (least deprived)	62	1.62	1.57	1.66	0.10	-0.04	0.24	0.165

As was observed for Sembrando kits, when using the most socioeconomic deprived category as the reference, no significant differences were observed in the rate of fluoride varnish applications from the Sembrando Sonrisas programme with any of deprivation categories. This result indicates that socioeconomic inequities were not observed in the rate of the interventions of the Sembrando Sonrisas programme at the municipality level.

6.10 Chapter 6 Summary

A series of analyses were performed to evaluate the impact of Sembrando Sonrisas interventions on five-year-old children covered by the programme since its establishment and rollout in 2015 in Chile, starting with creating a bespoke cohort of municipality/years with a specific outcome variable —"Sembrando caries experience". The five-year-old children of the two birth cohorts exposed to the programme since its establishment and rollout in 2015 showed a caries experience of 54.9%.

In order to design the most parsimonious model to evaluate the Sembrando Sonrisas interventions on the caries experience of five-year-olds linear regression models were used. These determined that deprivation (measured through IDSE) was associated with the caries experience of five-year-olds, therefore representing a potential confounder on the effects of Sembrando interventions.

The impact of community water fluoridation on the caries experience of five-year-olds was assessed in the cohort. The analysis showed that exposure to community water fluoridation was also associated with a significant reduction in caries levels of five-year-olds covered by the programme.

Sembrando Sonrisas presented information on two interventions in the database: fluoride varnish application in nurseries, which should be done twice per year, and the delivery of oral health kits with four toothbrushes and one toothpaste tube with 1000 ppm of fluoride annually for daily supervised toothbrushing in nurseries.

The delivery of Sembrando oral health kits showed an association with a reduction in the caries experience of five-year-olds. Those municipality/years where all children received an oral health kit for daily supervised toothbrushing in nurseries each year before the age of five showed a 4% lower caries experience of five-year-olds compared with those where this was not achieved in a model adjusted by deprivation. No association was observed between Sembrando caries experience and the levels of fluoride varnish applications performed in nurseries in univariate and adjusted analyses.

In an analysis including Sembrando oral health kits for supervised toothbrushing in nurseries, deprivation, and the exposure to community water fluoridation of the municipality/years, Sembrando oral health kits continued to be a significant explanatory variable of the differences in the caries levels of five-year-olds covered by the Sembrando Sonrisas programme, with a reduction of 5% in caries experience in those municipality/years where all children received a Sembrando oral health kit in comparison with those where this did not occur. These results provide early evidence that this Sembrando Sonrisas intervention has contributed to reducing the caries experience of five-year-olds over and above the presence of community water fluoridation in Chile.

Those municipalities exposed to community water fluoridation and where all children received a Sembrando oral health kit for daily supervised toothbrushing in nurseries showed the lowest caries experience, being 13% lower than those municipalities not exposed to community water fluoridation and where not all children had received the Sembrando oral health kits for daily supervised toothbrushing in nurseries.

Finally, when analysing area-based socioeconomic inequalities in the rate of Sembrando oral health kits for daily supervised toothbrushing in nurseries and the application of fluoride varnish in nurseries at the municipality level, no significant differences were observed between the groups, using the most socioeconomic deprived category as a reference for each Sembrando Sonrisas programme intervention.

Chapter 7 – Discussion, conclusion and recommendations

Chapter 7 discusses explanations of the findings derived from this research and its methodological aspects and implications, compared with the literature. It also evaluates the strengths and weaknesses of the thesis analyses. Recommendations for policymakers from Chile and beyond in relation to oral health improvement programmes, along with future research opportunities arising from the research findings, are made.

7.1 Key findings

This thesis sought to evaluate the impact of the oral health programmes of Chile on the dental caries outcomes of young children and assess related inequalities between 2008 and 2019. In doing so, this thesis identified important findings:

i. A cohort of municipalities was created, including secondary health and non-health related datasets, representing the first effort in Chile to generate a cohort database resource for the evaluation of oral health programmes. This involved substantial efforts to navigate for data approval and access, following current data protection regulations. A variable was created to evaluate the impact of national oral health programmes in Chile on area-based caries levels of six-year-olds through a novel longitudinal cohort methodology.

ii. A continuing and significant improvement in caries experience among six-year-olds was observed when assessing trends over time, from 83% in 2008 to 66% in 2019. Area-based deprivation and rurality, which represented potential confounders for evaluating the impact of the programmes, were independently associated with caries experience.

iii. Although an improvement in caries experience was observed in all socioeconomic deprivation categories over the study period, both relative and absolute inequalities in the distribution of caries experience among six-year-old children in Chile were still observed — with children from the most deprived municipalities having a significantly greater disease burden.

iv. When analysing the trends in the caries experience of six-year-olds at the regional and municipal levels, it was observed that children in the most deprived municipalities, with a higher rural population, and those belonging to the south-central macrozone had higher levels of caries than those from the rest of the country.

v. Both the coverage of homes connected to the drinking water network, which according to the regulations of the Ministry of Health of Chile, must include fluoride as a preventive measure for dental caries, and the average annual fluoride concentration in mg/L that leaves the drinking water supply companies, either natural or added artificially, was associated with a decrease in caries experience levels among six-year-old children. In the case of coverage, a dose-dependent effect was observed, where municipalities with coverage greater than 90% had a 10% lower caries experience than those not exposed to community water fluoridation. For fluoride concentration, the lowest caries experience was observed in communities with concentrations between 0.6 and 0.8 mg/L, with a caries experience 10% lower than those not exposed to community water fluoridation. These results remained significant even when adjusting for deprivation, rurality and time.

vi. The preventive interventions delivered in primary care clinics (fluoride varnish application, individual toothbrushing advice to parents and caregivers, and the application of sealants in primary teeth) showed an association with caries experience. In six-year-olds, a higher rate of these interventions was associated with higher caries levels in both univariate and adjusted analyses.

vii. When evaluating the impact of the national oral health improvement programmes interventions on the caries levels of only the most affected six-year-old children (high caries experience), similar results were observed in relation to the caries experience of all six-year-olds.

Community water fluoridation coverage and concentration were shown to be associated with a decrease in high caries experience. For fluoride concentration, those municipalities with a concentration between 0.6 to 0.8 mg/L of fluoride had a high caries experience 14% lower than those not exposed to community water fluoridation. A similar result was observed for coverage, where areas with a coverage of 90% or more had a 14% lower high caries experience than those not exposed to water fluoridation. For the preventive interventions delivered in primary care clinics, a higher rate of these interventions was associated with higher high caries experience levels.

viii. The interventions of the community water fluoridation programme showed a socioeconomic gradient, where the most deprived municipalities had 44% lower coverage and 0.22 mg/L higher fluoride concentrations than the least deprived municipalities.

ix. A new cohort was assembled to evaluate the impact of the Sembrando Sonrisas programme on the caries experience of five-year-old children covered by the programme since its rollout and establishment in 2015, using data collected in nurseries. The caries experience of five-year-olds covered by the programme since its establishment and rollout was 4% lower in municipalities where all children received an oral health kit with materials for daily supervised toothbrushing in nurseries before age five in comparison with those areas where this did not occur, even after adjusting for area-based socioeconomic deprivation and community water fluoridation. However, univariate and adjusted analyses found no association between five-year-olds caries experience and the rate of fluoride varnish applications delivered in nurseries.

x. Those municipalities exposed to community water fluoridation and where all children received a Sembrando oral health kit for daily supervised toothbrushing in nurseries had 13% lower caries experience among five-year-olds than those areas that are not exposed to community water fluoridation and where not all children received and Sembrando oral health kit for daily supervised toothbrushing in nurseries. No differences were observed in the delivery of the Sembrando Sonrisas interventions between socioeconomic deprivation subgroups.

xi. Collectively, the thesis results included a novel national ecological cohort approach. General improvements in dental health of six-year-olds where observed over the last decade in Chile, but the high childhood caries levels and inequalities observed, despite the presence of the community water fluoridation programme, remain a public health challenge. The toothbrushing component of Sembrando Sonrisas programme showed early promising results on its impact on caries experience of five-year-old children, especially over and above community water fluoridation.

7.2 Data collection and cohort creation

According to the information that was collected during the data scooping stage, this work constitutes the first effort to create a database to perform a quantitative impact evaluation of an oral health programme in Chile. When investigating the current legislation in the country, the existence of a law that guarantees access to information collected by public organisations meant that it was feasible to generate a database that would allow the completion of the objectives of this study.

Despite this, the data collection was a complex and laborious process, which involved using all the protocols available in the Chilean data regulation and direct advocacy with Data Controllers. Nevertheless, all the necessary approvals and governance processes were successfully navigated and all of the datasets available were accessed, collected, securely transferred and collated.

There is evidence that access to routine data, especially in health, is usually a convoluted process, with navigating legislation requirements (Iveson and Deary, 2019). Therefore, complexity was expected given the scale of the data being requested and the resulting risk and impact of improper use. This study is a precedent that may be relevant for future researchers who need access to public information available in Chile to evaluate oral health improvement programmes and even other policies that may require area-based analysis.

One of the main reasons for the methodology developed in this thesis was the structure of data collection in Chile, where the smallest level of data aggregation is the municipalities. This data structure is based on territorial municipality codes (Ministerio del Interior Gobierno de Chile, 2018), which allowed the linkage of all of the collected datasets, even those non-health data, such as the Socioeconomic Development Index and the rurality indexes.

Other methodological alternatives include the use of data at the individual-level or multilevel analysis, for which databases aggregated at the individual level or at a level smaller than that of the municipalities are needed (Richard *et al.*, 2011). To date, there are no datasets available at the individual-level regarding the programmes to be evaluated or regarding the non-health variables included, so this possibility was discarded when planning the study methods. Despite this, there is still the option to merge the database of this study with future data sources that may include individual-level data.

Although assembling cross-sectional databases from aggregated data is a common methodology (Richard *et al.*, 2011), generating an area-based cohort which contains more than a decade of information, rich in size, breadth, and scope, is a more novel approach. When creating the unit of analysis for this study (municipality/years), the goal was that the cohort was the most representative of the Chilean situation, providing a national/population-level picture. For this, methodology was developed that would allow the inclusion of the largest number of municipalities/years and records in the analyses, to obtain complete and quality databases even within the complex political and social context of Chile during the period of this study (Méndez, Greer and McKee, 2020), and the impact of the pandemic on Chilean public institutions (Schöngut-Grollmus *et al.*, 2021).

Even though a percentage of the municipality/years did not present data that would allow the necessary calculations to be made in the analyses, a high percentage of the total possible records was included, 81% for the analysis of the six-year-olds cohort and 91% for Sembrando Sonrisas programme evaluation cohort.

7.3 Caries experience trends in Chilean six-year-olds

There was a continuing and significant improvement in caries experience of Chilean six-year-olds over the study period, which is evident in the transformation of caries experience in the municipality/year from a marked left-skew in 2008, with a predominance of municipalities where all children had caries experience, to a more symmetrical one in 2019, with a bell-shaped distribution and without the spike in the municipalities where all children had caries experience (see section 4.4.1).

As mentioned in section 1.3.1, dental caries remains the most common non-communicable disease globally, and 532 million children suffer from caries of primary teeth (Bernabe *et al.*, 2020). According to the last cross-sectional national oral health survey of six-year-old children commissioned by the Chilean Ministry of Health in 2007, 70% of children had a history of dental caries (Ministerio de Salud. Gobierno de Chile, 2012). In comparison, this study showed a caries experience in six-year-olds of 79% in 2008 (the first year of registration included in the analyses) in the univariate analysis and 83% when adjusting for deprivation and rurality. This difference can be explained mainly by the applied methodologies, since the national oral health survey corresponds to an analysis at the individual level of a representative sample of 2,220 six-year-olds recruited via cluster sampling (Ministerio de Salud. Gobierno de Chile, 2007a). However, it is relevant to highlight that both results supports the fact that the caries experience in Chilean children was and remains a public health challenge in Chile. Therefore, the need for interventions to tackle this public health challenge and the call for action to the policymakers was urgent. This call for action was beyond the merely epidemiological implications since the impact of oral health on the development of children, especially at six years of age, has been widely described (Casamassimo *et al.*, 2009; Çolak *et al.*, 2013; Peng and McGrath, 2020).

Even with the 17% decrease in caries experience over the study period, the high caries levels observed in six-year-olds continue to be of concern. Chile is considered a high-income country, based on its gross national income (The World Bank, 2020), but its sociodemographic characteristics, health system, oral health programmes and outcomes, and geographic location make it difficult to directly compare with other countries. Thus, comparisons with countries that have areas with community water fluoridation such as New Zealand, which has also shown improvements in children's caries levels in recent years, but have a higher income, less socioeconomic inequalities, and have lower caries levels at baseline (Schluter and Lee, 2016) are difficult. However, in the context of the Latin American region - where comparisons may be more justified – countries such as Brazil, where there is also evidence of the positive impact of water fluoridation in reducing caries prevalence and severity (Belotti and Frazão, 2021), show a similar trend over the same period, with a decrease in the levels of the disease in children, but high caries levels and wide inequalities still remaining (Karam *et al.*, 2022).

All of the variables in the database that were considered to be potential confounders — deprivation, time, and rurality — were associated with caries experience in six-year-olds. Regarding rurality, in the study period, the urban municipalities had a significantly lower caries experience than the rural municipalities, both in the univariate model, with a difference of 7.5%, and multivariate model adjusted for deprivation and time, with a difference of 2%. This finding supports the idea that rural populations carry a higher burden of the disease in comparison to the population in urban areas. A study performed on 485 Chilean six-year-old children from Region VII at the individual level also showed this association, where children living in urban areas had a 13% lower caries prevalence in comparison with those living in rural areas of Region VII (Giacaman *et al.*, 2015).

In Latin American countries, rurality is strongly associated with socioeconomic deprivation (Organización de las Naciones Unidas para la Alimentación y la Agricultura, 2018). Despite this, it is not possible to rule out a direct effect of rurality beyond socioeconomic deprivation, because rurality constituted a significantly informative variable in the adjusted model. It has been suggested that lower oral health knowledge, low maternal educational levels, inappropriate dietary habits among rural children, along with the lack of access to health services and water fluoridation, could explain this association (Kamińska *et al.*, 2016).

Since the association between dental caries and socioeconomic deprivation has been widely described in different populations and systematic reviews (Schwendicke *et al.*, 2015; Singh *et al.*, 2019), it is not surprising to see this association in Chilean children. However, this study represents one of the first efforts to assess relative and absolute socioeconomic inequalities in the distribution of dental caries and its trends over time in children in the Latin American region.

The potential mediation mechanisms for the relationship between caries and socioeconomic deprivation have been suggested in a systematic review by Schwendicke *et al.* (2015). Children from the most socioeconomic deprived groups had parents with low education level, that is associated with having worse health literacy, worse dietary and oral health behaviours and lower health service utilization. Additionally, social position influences social engagement, support, stability, cohesion, access to services, and healthy choices, all of which positively impact health and healthy behaviour (Schwendicke *et al.*, 2015).

In this thesis, a difference of 15.3% in the caries experience of six-years-old children was observed between the most deprived and least deprived municipalities in the SII absolute inequality analysis. For relative inequality, a RII of 0.22 was observed in the study period. If the RII is multiplied by 0.5 and expressed as a percentage (Moreno-Betancur *et al.*, 2015) it can be interpreted as that the caries experience of six-year-olds is around 11% higher in the most socioeconomic deprived municipalities relative to the mean rate in the population. Also, no substantial changes in the inequalities of the distribution of caries experience in six-year-olds were observed between 2008 and 2019.

These results support the need to evaluate the interventions over time to understand the decrease in the caries experience, and why, despite all of the efforts in providing preventive interventions, caries levels and socioeconomic inequalities in the distribution of the disease are still a major public health challenge in Chile. However, it highlights that a large part of the differences observed at the municipality-level can be explained by the level of socioeconomic deprivation and rurality of the communities.

By evaluating the regional and municipality level trends in caries experience, it was possible to observe the different contexts in the oral health of six-year-old children in Chile. The most deprived municipalities, which also tend to be those with a higher proportion of rural population, had the highest caries experience in all regions. Therefore, the place of residence and area socioeconomic and demographic circumstances have a strong influence on the oral health of Chilean six-year-old children.

When evaluating the differences by region, the territory with the worst caries levels corresponded to the two regions without the community water fluoridation programme. In addition, a geographic trend was observed where the regions of the northern and central northern macro zones have lower caries experience, and that caries levels increase towards the south of the country. The only exception is the southernmost area of the country, region XII, which showed the third-lowest caries experience of the country. This can be explained by the fact that the municipalities of this region are among the least deprived in the country and also have access to community water fluoridation. The first region to implement a community water fluoridation pilot in the country, 36 years ago, was Region V, which had a 15% lower caries experience than Region VIII, which does not have water fluoridation.

There is a lack of updated national survey data regarding caries of six-year-olds in Chile. However, the last available national oral health survey of 2007 showed results that supports the findings of this thesis, where the south-central macrozone showed the highest levels of caries experience, and the northern regions showed better oral health in six-year-old children (Ministerio de Salud. Gobierno de Chile, 2007a). Moreover, Danke *et al.* (2022) evaluated the trends in “caries-free” children in Chilean health services between 2012 and 2019, showing that health services in Region VIII had the lowest prevalence (Danke *et al.*, 2022).

7.4 Impact of the national oral health improvement programmes on caries experience of six-year-olds

7.4.1 Community fluoridated water programme

Among the factors analysed in this study, the coverage of community water fluoridation was shown to be the intervention that most explains the decrease in caries experience of six-year-olds over the study period. A significantly lower caries experience was observed in those areas with community water fluoridation, with a dose-dependent association, where the group of municipality/years with a coverage greater than 90% had the lowest caries experience.

Similarly, those areas that were exposed to some level of fluoride concentration also had a significantly lower caries experience than those that were unexposed, where the best-performing groups were those with a concentration between 0.6 and 0.8 mg/L of fluoride. According to the guidelines of the community water fluoridation programme in Chile (Ministerio de Salud. Gobierno de Chile, 2008), it was decided that those regions most affected by dental caries should receive a higher concentration of fluoride, within the range of 0.8 to 1.0 mg/L, in contrast to those areas with lower caries levels, where the optimal range should be between 0.6 to 0.8 mg/L.

When creating a combined variable and adjusting for time and deprivation, as could be expected, community water fluoridation delivery was found to be optimal with a coverage above 90% and at least 0.6 mg/L of fluoride. These findings may suggest that adding fluoride in the water supply has been important in preventing dental caries in Chilean six-year-old children at the municipality-level. Although other contexts may be challenging to compare with Chile, this result is consistent with other international studies (Schluter and Lee, 2016; Weston-Price *et al.*, 2018).

Despite the impact on public health and dentistry of fluorides on caries prevention, community water fluoridation has been the subject of intense ethical discussions (Denbesten and Li, 2011; Romero *et al.*, 2017). There are arguments against water fluoridation, mainly the violation of the principle of autonomy (Awofeso, 2012), and the potentially toxic effects of fluoride (Mendoza, 2007). However, evidence supporting these arguments presents methodological flaws, so it is considered low quality (Song and Kim, 2021). Conversely, the evidence is clear in supporting the position that at the concentrations used in Chile (up to 1 mg/L), there are no health risks, along with the bulk of evidence supporting its effectiveness in reducing caries levels (Iheozor-Ejiofor *et al.*, 2015).

The thesis findings are relevant in providing updated evidence of the impact that the community water fluoridation programme has had in caries levels of children at the population level. The results will not resolve the controversy in Chile or globally due to, among other factors, the lack of data on adverse effects of water fluoridation, such as dental fluorosis (Abanto Alvarez *et al.*, 2009). However, it provides evidence on its caries preventive effect to policymakers and dentists who have defended this programme in Chile and other countries. In recent years, a group of medical general practitioners in Chile have questioned the Chilean Ministry of Health governance on the subject (Romero *et al.*, 2017), suggesting that there is a need for training or education initiatives regarding both water fluoridation and evidence-based dentistry for other members of the health teams. The results of this thesis could contribute to this.

It has been suggested that the inclusion of community water fluoridation may reduce inequalities in the distribution of dental caries in children. A systematic review by Shen *et al.* (2021) on interventions aiming to reduce inequalities in caries among children included four studies on the impact of water fluoridation. They concluded that water fluoridation had a consistent impact on reducing inequalities compared with target population interventions (Shen, Bernabé and Sabbah, 2021). However, the role of water fluoridation, including the coverage and optimal fluoride concentrations in closing the gap in oral health among populations with different socioeconomic backgrounds needs to be investigated further (Iheozor-Ejiofor *et al.*, 2015). Studies in Brazil, the United States, Canada and Australia have shown area-based inequalities in water fluoridation coverage (O’Mullane *et al.*, 2016).

In this study, the water fluoridation coverage in the most socioeconomic deprived municipalities was 52%, in contrast to the least deprived, which showed a coverage of 96%, so the potential benefit that community water fluoridation could have in the most deprived communities has not been fully realized by the different levels of access to the water supply network across municipalities. This finding can provide an opportunity to improve caries levels in six-year-old children by increasing access to fluoridated water in the most deprived communities of the country, although this can bring difficulties beyond health policies (Mota and Frazão, 2021) due to the provision of fluoridated water being linked to sanitation service coverage, water provider characteristics, the percentage of the urban population, and the municipality's geographic location (da Silva *et al.*, 2021). Therefore, evaluating the incorporation of other upstream and midstream preventive oral health initiatives in contexts where it is not feasible to cover the entire population with fluoridated water becomes especially important to reduce socioeconomic inequalities in the burden of the disease (Filho *et al.*, 2021).

7.4.2 Discussion of preventive interventions delivered in primary care public clinics

In Chile, preventive dental care is state-funded for children in the public health system. The three preventive activities provided by dentists in the primary care clinics to children six years of age or younger were included in this study: sealants in primary teeth, the application of fluoride varnish, and individual toothbrushing advice to parents and caregivers. Bhaskar *et al.* (2014) reviewed the effectiveness of preventive dental visits for children aged six and under, concluding that the evidence for the effectiveness of early preventive dental visits and the year of the first dental visit is weak, and that only high-risk children or those with existing dental diseases benefited from preventative dental consultations before the age of three (Bhaskar *et al.*, 2014).

The results of this study showed that a higher rate of these preventive interventions in clinics received by children before the age of six was associated with a higher caries experience at the municipal level.

7.4.2.1 Fluoride varnish application

According to the clinical guidelines for primary care in the country, 5% sodium fluoride topical varnish has been used for more than 20 years in primary care clinics in Chile (Ministerio de Salud. Gobierno de Chile, 2009).

In the study period, the average municipality rate of fluoride varnish applications was 3.5 per child per year, and the median was 1.3. However, it was evident that there are outliers in the data, with records that probably are not correct, mainly due to the maximum rate observed at the municipal level of 237. These cases were infrequent, but they determined, together with the right-skewed distribution of the variable, the need to create a categorical presentation of the rate. In the univariate analyses, the subgroup with the lowest rate (≤ 0.33) showed the lowest caries experience, showing a trend toward higher caries experience in the categories with higher rates.

As covered in the literature review, the more recent Cochrane review on the effect of fluoride varnish on caries levels in children suggests that fluoride varnish has a significant caries-preventing effect in both permanent and primary teeth. However, the quality of the evidence was rated as moderate because it mainly consisted of studies with a high risk of bias and much variability. In a 2017 review on the subject, Mishra *et al.* suggested that professionally applied fluoride varnish two to three times a year had a more consistent effect on preventing new lesions, but acknowledging that the evidence from the studies reviewed in this review was of limited value (Mishra *et al.*, 2017).

It is impossible to determine the reason for this positive association from the data included in this study. It is suggested that future studies should include data with an individual-level of aggregation and other experimental designs. It is feasible that children who attended dental care in primary care clinics already had the disease (with attendance to primary care clinics driven by treatment need), so this intervention, which should fulfil a preventive effect, may instead be being applied to children with caries. Therefore, the application of fluoride varnish may have prevented future caries development, but the metrics used in this thesis would not pick this up — i.e. recording caries outcomes as just caries experience in a municipality/year rather than the individual caries incidence over time. In addition, children with higher dental caries risk are more likely to be prescribed with fluoride varnish and have it applied (NHS Health Scotland, 2018). This fact was supported with the differences observed in the distribution of fluoride varnish applications by area-based socioeconomic deprivation, where children from most deprived municipalities received 2.5 more fluoride varnish applications than those living in the least deprived areas.

7.4.2.2 Sealants in primary teeth

In the most recent Cochrane review of the effectiveness of sealants in primary teeth (Ramamurthy *et al.*, 2022), the available evidence did not allow for a recommendation to be made. This lead to the conclusion that there is an important gap in the evidence regarding the caries-preventive effect and retention of sealants in primary teeth, which should be addressed through robust research (Wright *et al.*, 2016). The effectiveness in preventing caries of the sealants depends on their retention in the long term, which is subject not only to the application technique but also to the degree of the eruption of the tooth, the use of adhesive agents, and the use of fluid resins (Freitas *et al.*, 2014).

A mean rate of 6.2 per children per year for sealant application on primary teeth was observed in this study at the municipality level, although with a high standard deviation. The median showed a more logical value of two sealants per child per year. The very high rate of sealants observed may be due to several causes, which escape the objectives of this study, but it is possible to propose that the intervention is not only being used as a preventive measure but also as a restorative intervention. Also, as mentioned for fluoride varnish application, if a child had caries in their teeth is more likely that other teeth are sealed. These suggestions are supported by the findings of the association of sealants rate with caries experience, where a higher rate was associated with higher caries levels, along and the finding that the most socioeconomic deprived communities had significantly higher rate of sealants applied to children in primary care clinics, in comparison to the children from least deprived municipalities.

Unfortunately, there are no other studies published on the Chilean population about the effect of sealants on primary teeth, which prevents a comparison with the results of this thesis. However, according to the results obtained and with the evidence of the Cochrane review, it is necessary to review their effectiveness in the primary care clinics in Chile, even more so knowing that the clinical guidelines on dental care in children between two to five years of age in primary care centres in Chile from 2009 recommend the use of sealants in primary teeth only in those cases where there are deep pits or non-cavitated occlusal caries lesions (Ministerio de Salud. Gobierno de Chile, 2009).

7.4.2.3 Individual toothbrushing advice

Long-term oral health requires assisting parents in developing suitable home-based oral health behaviours for their children (Filho *et al.*, 2021). Parental brushing of teeth and supervision of older children is essential for ensuring proper toothbrushing with fluoride toothpaste, and to ensure that children do not eat or swallow the toothpaste. A recent systematic review by Aliakbari *et al.* (2021) reported a wide range, 9%-72%, of young children, between one and five years old, brushing their own teeth without parental assistance, and that active toothbrushing takes very little time when preschool children are left alone to brush their teeth.

According to a recent systematic review, there is insufficient evidence to support the effectiveness of home-based toothbrushing interventions for parents of young children in reducing dental caries. Even though some studies showed increases in parents' self-reported toothbrushing practises for their young children, the outcomes were more mixed, with some studies even suggesting an increase in caries prevalence after the interventions (Aliakbari *et al.*, 2021).

Our findings for this intervention were similar to the other two clinical preventive interventions evaluated, with a high mean rate of 7.6 per children per year, and a median of 2.6, that would more logically reflect the actual number of interventions delivered in the primary care clinics of each municipality.

All three preventive interventions that were evaluated from primary care clinics are complex interventions due to the interaction of diverse behaviours, individual differences, and the effect of the environment. Also, all three were positively associated with caries experience of six-year-olds. Although it is not the objective of this study to know why such results could have emerged, it is possible to suggest some options.

First, results could be due to methodological limitations, mainly because the variables used only accounted for the number of interventions delivered at the municipality-level, without considering the variability of individual circumstances and even the possible unintended consequences that can occur as a result of intervening. Secondly, the time that the children received these interventions was probably related to going to the dentist for pain or the need to receive restorative treatment, causing these interventions to be performed more frequently in children with caries experience.

Based on these findings, and taking into account the limitations of the present study, we suggest the need for further studies in Chile, in order to better understand how these activities are being implemented and delivered in the context of primary dental care across Chile.

7.4.3 Further discussion of the national oral health programmes

The findings of this thesis showed that a model that includes community water fluoridation coverage and annual fluoride concentration, adjusted by deprivation, rurality, and time, was the most parsimonious in explaining the differences in caries experience among six-year-olds between the municipalities over time. For the preventive interventions delivered in primary care clinics, a higher rate of the interventions was associated with higher caries levels of six-year-olds, but limitations in the methodology prevented assessment of the impact of these interventions in preventing future caries development.

Only one study has evaluated some of the interventions that were included in this thesis in the Chilean population, and it only assessed the cost-effectiveness of the interventions. Mariño *et al.* (2012) performed a cost-effectiveness analysis, using two hypothetical populations, of three community-based programmes in Chile: water fluoridation, salt fluoridation and dental sealants; and four school-based programmes: milk fluoridation, fluoridated mouth rinses, topical application of fluoride gel, and supervised toothbrushing with fluoride toothpaste. They concluded that most community and school-based dental caries interventions were cost-effective, with salt fluoridation being the best performing in the simulated models (Mariño *et al.*, 2012). However, the models used in the study only assessed the cost that was required to prevent one carious tooth among school children, thus, underestimating the effect of each intervention.

In the thesis analysis, the impact of the national oral health improvement programmes on those children with the most burden of dental caries was also assessed (Chapter 5, section 5.4). For this, the variable “High caries experience” was assembled, including the children with a dmft of five or more. The results observed in these analyses where similar to those of the primary outcome, showing the same trends and associations but highlighting that the size effect of community water fluoridation coverage and fluoride concentration was higher in children with a higher disease burden in the municipalities.

Finally, based on the results, it would appeal that the community fluoridated water programme has contributed to reduced caries levels in six-year-olds at the municipality-level in Chile. However, despite being associated with caries experience, the results for the preventive interventions delivered in primary dental care were not so clear, so further research is need to better understand their impact on caries experience of six-year-olds.

7.5 Sembrando Sonrisas

It is feasible to assume that the children living in a municipality attend both the public primary care clinics and the state-funded nurseries of that municipality. However, according to the data regulation and collection structure of Chile, there is no way to link the data collected in nurseries with the data collected in primary care clinics at the individual level, to corroborate that they do constitute the same children attending both services in the same municipality/year. This was the main reason why it was decided to perform an analysis with the data collected directly from the interventions of the Sembrando Sonrisas programme, and to create a new municipality/years cohort with a new outcome variable —Sembrando caries experience—, that, as mentioned, would lead to a focus on five-year-olds caries outcomes, collected as part of the dental examinations component of the programme.

From its establishment and rollout in 2015 until 2019, the last year included in the database of this study, two birth cohorts were covered by the programme between two and five years of age, which is the target age of Sembrando Sonrisas. The analyses were then carried out to evaluate the impact of exposure to the two programme interventions: (1) the delivery of an oral health kit for daily supervised toothbrushing in nurseries; and (2) fluoride varnish applications in nurseries— on caries levels at five years of age.

Of the two evaluated interventions, only the delivery of oral health kits for daily supervised toothbrushing in nurseries was associated with a lower caries experience at the municipality level, both in the univariate and deprivation-adjusted models. This variable does not necessarily account for children brushing their teeth in nurseries every day. However, for this to happen, each of them must at least have the necessary materials to do it. This result represents the first preliminary evidence that a component of the Sembrando Sonrisas programme is helping to reduce caries levels in the child population of Chile.

When evaluating the distribution of the variable “Sembrando kits rate”, it was also possible to observe that in many municipalities all children did not receive the Sembrando oral health kit for daily supervised toothbrushing in nurseries. Because rurality was not a significant informative variable in the model, and no differences were observed in the delivery of the kits between socioeconomic deprivation level of municipalities, further studies involving primary data collection are warranted to investigate further issues around distribution. Moreover, work to assess and optimise daily supervised toothbrushing in nurseries to maximise the number of days and children brush their teeth would be useful in the Sembrando Sonrisas programme. It is also necessary to explore under what conditions daily supervised toothbrushing is being carried out in nurseries, and whether teachers have the tools to support and supervise children in their oral health care. The context where daily supervised toothbrushing is delivered is essential for this intervention to succeed. According to a recent systematic review on the subject, daily monitoring, the timing of the communication of the programme, inadequate transfer of information among staff, frequent staffing turnover, lack of parental support, and staff feelings towards oral health, were reported as barriers to daily supervised toothbrushing in nurseries (Chandio *et al.*, 2022).

The association between the variable relating to oral health kits for daily supervised toothbrushing of Sembrando Sonrisas and a lower caries experience suggests the importance of incorporating this intervention in reducing the high caries levels among children in Chile. In this thesis, a significant 4% reduction in caries experience of five-year-olds was observed in those municipalities where all children received the Sembrando oral health kit for daily supervised toothbrushing annually before the age of five. This is relevant because the bulk of the evidence supporting the incorporation of daily supervised toothbrushing comes mainly from populations in high-income and European countries (Ghaffari *et al.*, 2018; Ladewig *et al.*, 2018; Kidd *et al.*, 2020), including Scotland and its experience with the Childsmile programme which was used as a reference for the development of Sembrando Sonrisas in Chile (Ministerio de Salud. Gobierno de Chile, 2020).

As discussed in Chapter 1, since its establishment and rollout, the daily supervised toothbrushing component of the Childsmile programme has been strongly associated with a decrease in caries levels among preschool children in Scotland and having greater effect in reducing caries among children from most socioeconomic deprived areas than the fluoride varnish applications in nurseries component of the programme (Macpherson *et al.*, 2013; Kidd *et al.*, 2020). The results of this thesis suggest that the Childsmile model can be reproduced in other countries with high levels of caries and with different sociodemographic contexts, even in those areas with community water fluoridation. Also, according to the cost-effectiveness evaluation by Anopa *et al.* (2015), the inclusion of daily supervised toothbrushing in Scotland decreased the need for dental treatments in five-year-olds, and in eight years the estimated savings were more than two and a half times the cost of supervised toothbrushing implementation. A rapid review performed by the York Health Economics Consortium (2016) requested by Public Health England on the evidence published since 2013 on the cost-effectiveness of interventions to improve the oral health of children aged zero to five years concluded that in recent years there had been few published studies that assessed the cost-effectiveness of these interventions to suggest the cost-effectiveness of supervised toothbrushing in nurseries, apart from the study undertaken by Anopa *et al.*(2015). In contrast, the authors did not find robust information on the cost-effectiveness of fluoride varnish applications (Public Health England, 2016b).

Sembrando Sonrisas also includes twice-per-year fluoride varnish applications in nurseries. In this study, the mean number of fluoride applications in children before five years of age was 1.6, implying that not all children in the municipalities in Chile since the establishment and rollout of the programme received two varnish applications per year. However, the mode was a rate of 2, so the most frequent context in the municipalities was that this was achieved. Despite this high level coverage, no association was observed between the fluoride varnish applications rate and a lower caries level in children.

A significantly lower caries experience of five-year-olds was only seen in the univariate model in those municipalities where the rate was between 1.7 and 1.9, in comparison to those with a rate between 0.7 and 1.3. However, this result did not remain in the deprivation-adjusted model, which was the most parsimonious according to the forward selection. In this model, municipalities with a lower rate of fluoride varnish applications showed virtually the same caries experience as children with the highest rate.

There is evidence of the preventive effect of fluoride varnish in the primary dentition (Marinho *et al.*, 2013). Nevertheless, the most recent systematic review by De Sousa *et al.* (2019) concluded that fluoride varnish application had a modest and uncertain anticaries effect in preschool children, even in the context of wider preventive programmes. This is especially relevant for Sembrando Sonrisas, where this intervention represents the most significant part of the programme's budget since, as mentioned in Chapter 1, in addition to the costs involved in purchasing the fluoride varnish, its application is delivered exclusively by dentists (Ministerio de Salud. Gobierno de Chile, 2020).

The results of this evaluation of Sembrando Sonrisas align with recent evidence regarding the impact of fluoride varnish in a nursery setting. Kidd *et al.* (2020), in their evaluation of the Scottish Childsmile programme, determined that the component of fluoride varnish application in nurseries was not independently associated with the caries experience of children; instead, nursery toothbrushing and regular dental visits were associated strongly with a reduction in the caries levels of the children participating in the programme (Kidd *et al.*, 2020). McMahon *et al.* (2020) found in a high-quality randomised controlled trial that fluoride varnish provided a modest and non-significant reduction in dental caries experience at a relatively high cost when delivered in a nursery setting twice a year from 3 years of age, over and above the multiple-component treatment as usual preventive interventions delivered in the Childsmile programme. Anopa *et al.* (2022) conducted an economic evaluation of the randomized controlled trial by McMahon *et al.* (2020). They concluded that the application of fluoride varnish applications in addition to the other components of Childsmile would not be deemed cost-effective.

Studies from South America included a randomised controlled trial conducted by Oliveira *et al.* (2014). They found that the professional application of fluoride varnish twice a year for two years did not significantly reduce the incidence of caries in pre-schoolers from areas with fluoridated water in Brazil (Oliveira *et al.*, 2014). A randomised controlled trial by Muñoz-Millán *et al.* (2018) assessed a twice-per-year fluoride application intervention versus placebo in rural children of Chile without access to water fluoridation that were already receiving supervised toothbrushing. They concluded that biannual fluoride varnish application was not effective in preschool children from rural non-fluoridated communities at a high risk of caries in Chile.

Palacio *et al.* (2019) used a simulated decision-analytic model to evaluate whether fluoride varnish application might increase the proportion of caries-free Chilean children aged four to six years at an acceptable cost by comparing two fluoride application settings: preschool and a well-child programme appointment in a primary care setting. They found that both interventions may increase the caries-free population, with the applications in a primary care setting being the most cost-effective strategy, assuming that all children receive the twice-per-year fluoride application.

This evidence, together with the findings of this thesis, suggests that there is a need for a review and appraisal of the application of fluoride varnish to preschool children in nursery settings as part of population oral health improvement policies and programmes, including the Sembrando Sonrisas programme.

This is relevant since the economic resources currently allocated to fluoride varnish applications could be used to improve access to materials for daily supervised toothbrushing.

An important initial result of the thesis evaluation was the synergistic action observed in those municipalities where all children received oral health kits for daily supervised toothbrushing in nurseries and were exposed to community water fluoridation. First, the delivery of daily supervised toothbrushing oral health kits was a significant informative variable in the model adjusted for deprivation and exposure to community water fluoridation, where a significant 4.9% reduction in caries experience of five-year-olds was observed in the model adjusted by deprivation and community water fluoridation when comparing the municipalities where all children received the oral health kits for daily supervised toothbrushing in nurseries in comparison with those municipalities where this did not occur, suggesting that this component of Sembrando Sonrisas contributes to reducing caries levels over and above the access to fluoridated water in the communities. Secondly, the best results were observed in those municipalities that were exposed to both programmes, with a difference of 13.4% in caries experience of five-year-olds when comparing the municipalities with complete delivery of oral health kits for daily supervised toothbrushing and exposure to community water fluoridation with those where not all children received the oral health kits and not exposed to community water fluoridation.

Despite the presence of daily supervised toothbrushing programmes in nurseries in many countries, some of them in areas with access to fluoridated water (Dickson-Swift *et al.*, 2017), just a few have undergone extensive evaluation of their impact, including the Scottish Childsmile programme (Macpherson *et al.*, 2013; Kidd *et al.*, 2020). Scotland does not have water fluoridation, and, to date, no other daily supervised programme evaluation has provided evidence of a synergistic effect of implementing this intervention in nurseries over and above the presence of water fluoridation. Therefore, the results of this study provide, to our knowledge, the first evidence of the importance of including daily supervised toothbrushing in high caries communities, improving the caries levels in conjunction with the presence of community water fluoridation.

These findings may help to counter some of the antifluoridation lobby´s arguments that Childsmile/supervised toothbrushing programmes should replace community water fluoridation, and support the additional improvement of daily supervised toothbrushing to community water fluoridation, but also indicating both programmes have room for improvement.

It has been suggested that nursery-based toothbrushing with fluoride toothpastes may contribute to reducing inequalities in the distribution of dental caries in children. Children from lower socioeconomic backgrounds are perhaps less likely to have home toothbrushing with fluoride toothpaste for multiple reasons including social factors, while those from higher socioeconomic backgrounds may already be regularly brushing with fluoride toothpaste at home (Acuña-González *et al.*, 2022). Therefore, those from lower socioeconomic status are more likely to benefit from the availability of community-based fluoride provision interventions (Shen *et al.*, 2021).

In this thesis, a socioeconomic gradient was observed in the caries levels of the five-year-olds covered by Sembrando Sonrisas, where children from the least socioeconomically deprived municipalities had a 13% lower caries experience than those from the most deprived communities. In the forward selection model, IDSE (the variable that was used to measure socioeconomic deprivation) was a significant explanatory variable for the differences in Sembrando caries experience. In the deprivation-adjusted model, delivery of Sembrando oral health kits for daily supervised toothbrushing in nurseries significantly reduced caries levels, so it is possible to infer that this intervention impacts all socioeconomic levels.

Because the “Year” variable was not a significant explanatory variable, it was impossible to assess whether there was a decrease in oral health inequalities over time due to Sembrando Sonrisas interventions. In addition, it has only been eight years since the programme establishment and rollout (of which three have been during the current pandemic). Therefore, an evaluation of the impact of Sembrando interventions on decreasing inequalities in the distribution of dental caries should be carried out in the future, and this thesis provides a framework for such an evaluation.

No differences were found in the delivery of the Sembrando oral health kits and the fluoride varnish application amongst the socioeconomic groups. Sembrando Sonrisas proposes universal coverage in state-funded nurseries; that is, it benefits all children from aged two to five who attend these establishments (Ministerio de Salud. Gobierno de Chile, 2020). So knowing that there is no unequal distribution of its interventions between municipalities despite their socioeconomic level is an important finding.

Nevertheless, if evaluated from a national point of view, by only benefiting state-funded nurseries, Sembrando Sonrisas corresponds to an intervention with proportionate universalism (Marmot, 2010; Macpherson, Rodgers and Conway, 2019b) since the inclusion of this programme has not yet been considered in private nurseries (Ministerio de Salud. Gobierno de Chile, 2020). Despite being a free right, not all children in Chile attend pre-school education. According to OECD data, only 44.79% of three-year-old children attend nurseries. Of this, 42.6% attend state-funded nurseries, and 57.4% attend private nurseries, that are not included in Sembrando Sonrisas. The rest of the children do not attend any pre-school education (OECD, 2011; Alarcón *et al.*, 2015). Therefore, increasing access to fluoride toothpaste and materials for daily toothbrushing among children in Chile should represent a priority for public policies in oral health in Chile and policy makers should consider how it is possible to expand the programme's coverage to those children who do not attend state-funded nurseries, especially in the most deprived municipalities and those without access to community water fluoridation.

Due to the high child caries levels observed in this study, despite the interventions made, further consideration should be given to factors such as the age of commencement of the programme. Additionally, optimising daily supervised toothbrushing, increasing its coverage and, in the light of the most recent evidence, an increase in toothpaste fluoride concentration of fluoride in the from 1000 ppm to 1450 ppm (Walsh *et al.*, 2019; Kidd *et al.*, 2020) could also be explored. Furthermore, the need for further upstream (policy) and midstream (community-level) preventive interventions must be evaluated, particularly upstream sugar control strategies (Watt *et al.*, 2019).

7.6 Limitations of the thesis studies

7.6.1 Limitations of data available

In most databases, there are missing data. This makes it difficult to describe the studied phenomena with precise statistics. In the database constructed for this study, the progressive incorporation of electronic health records may introduce missing data, as despite being mandatory since 2008 not all of the municipalities had the proper infrastructure and access to the network due to, among other reasons, geographic isolation and the technical feasibility of the internet.

This phenomenon must be distinguished from the information not being captured, which could also account for some records being missing from the datasets. Of the total municipalities included (n = 346) and years analyzed (12 years, from 2008 to 2019), there were a total of 4152 possible records of each variable included in which 81% of municipality/years had records for all variables in the database. In addition, the lack of official reports by the Data Controller organizations in Chile makes it challenging to assess the completeness of the data.

Moreover, municipality-level data were not available for important variables known to impact on caries levels, such as sugar consumption and the home-based access to toothbrushing with fluoride toothpaste (Filho *et al.*, 2021).

A problem detected when working with the database was the transformation of the dmft index from a discrete-continuous variable to a categorical variable. In addition, the lack of records of all ages from the beginning of electronic health records only allowed the evaluation of the impact of preventive activities in the last five years included in the study period.

Since Chile has a health system where public primary care clinics and private providers coexist (Rotarou and Sakellariou, 2017), and the data included in this study only includes (non-calibrated) clinical dental examinations performed in the public health system (which covers approximately 75% of the population) (Koch, Cid Pedraza and Schmid, 2017), caries outcomes and related inequalities may be underestimated.

Regarding the data from Sembrando Sonrisas, this programme includes the option of negative consent to any of its components; therefore, individual consent is not required, but there are no records of how many parents refuse to allow their children to participate in the programme. In addition, this programme includes an educational session on oral health carried out by dentists for teachers in nurseries once a year, but this intervention was not recorded until 2020.

No variable was available in the original datasets specifying that children are indeed performing the daily supervised toothbrushing. This is common in evaluations of daily supervised toothbrushing programmes in nurseries, so in this study, we decided to go a step further and not assume that all children were brushing just for being included in the programme but rather assess whether they had the materials for this. However, we recognize that this does not necessarily indicate that children do indeed brush their teeth every day.

7.6.2 Analytical limitations

The findings of this study should be interpreted in the light the of limitations of an ecological study design and the inherent limitations of the data available. Therefore, the findings may not be exactly inferred at the sub-population or individual level.

Another critical factor is that the information collected in primary care clinics and in nurseries is not primarily intended for research, along with the fact that the dentists are not calibrated in their diagnoses and treatments. Hence, it is possible to assume an inherent variability due to the complexity of the aggregated records from routine health information.

An ecological methodology can introduce misclassification bias in terms of area-based socioeconomic deprivation level not necessarily representing individual socioeconomic status and does not account for intermunicipal migration. Individual household level socioeconomic index data is not available from the data sources of Chile. Therefore, two area-based socioeconomic deprivation indexes were used to characterize each municipality, and only IDSE was a significant explanatory variable in the models included in this study. Despite the precise methodology used to construct this index, it is impossible to avoid the possibility of the 'ecological fallacy' because the individual household socioeconomic status may vary across households within the same municipalities grouped in the same level of area-based deprivation (Macintyre, Maciver and Sooman, 1993).

Furthermore, an ecological methodology can introduce misclassification bias in community water fluoridation status and does not represent individual water consumption or fluoride exposure from other sources. There were no data in this study accounting for possible adverse effects of water fluoridation schemes. Temporal changes in water quality, zone boundaries and fluoride levels, 'halo' effects from neighbouring areas, and the presence of varying levels of natural fluoridation can all introduce additional misclassification bias (Griffin *et al.*, 2001).

Using the calendar year variable to account for the timing of the interventions makes it impossible to accurately assess when the interventions were performed, which also could have an impact on the caries outcomes.

Finally, the main analytical limitations of this study were the lack of data at different levels of aggregation (individual, schools, or others). This prevented using multi-level or more complex multivariate analysis approaches that would complement this thesis's results. Also, it may be too early for evaluation of some programmes, with only two birth cohorts for Sembrando Sonrisas and no birth cohort exposed to the CERO programme for all years before the age of six since its rollout and establishment in 2017. It is, therefore, not the definitive findings on the effectiveness of the national oral health programmes; instead, it provides an initial assessment of the relationship between its interventions, the caries levels in the child population of Chile, and related inequalities.

7.7 Strengths of the study

7.6.1 Novel ecological cohort approach

This study has several strengths, which include the use of a large database that comprises a cohort of municipalities over time, representing a novel longitudinal ecological study design that was able to assess the impact of the national oral health improvement programmes for Chile on child dental caries and consider relevant area-based potential confounders such as deprivation and rurality. The use of municipality-level aggregated data were considered appropriate because of the area-level implications and population-wide coverage, with the uniqueness of being from the Latin American region, where this information is scarce.

In addition, as described in Chapter 1, using ecological studies for evaluating public policies is a common approach in the literature. However, this thesis provides a novel approach, through a longitudinal ecological study, following an area-based cohort on time, which allows for assessing not only the area-based differences, but also the changes over time in the measured outcomes. Moreover, caries experience represented a percentage for each municipality/year, but all of the analyses considered those percentages a continuous variable. Therefore, creating a continuous outcome in ecological studies expands the availability of superior and useful model fitting techniques, especially Mallow’s Cp.

7.6.2 Dataset size and scope

As mentioned above, one of the main strengths of this study was the creation of a database wide in size, breadth, and scope, containing more than a decade of information. The database, to date, includes aggregated data from more than 4 million child records collected on primary public health clinics between 2008 and 2019, along with the activities and dental interventions received from the national oral health improvement programmes, including all municipalities from the beginning of the mandatory electronic registry. This is the first big data effort to link this routine dental health information with non-health records in Chile. However, caution is required in studies of this size when using the p-value to measure significance, and within this study, the 95% confidence interval and indexes like Mallow´s Cp and Akaike Information Criteria were more often utilised as the measure of significance and goodness of fit of the models.

Although some municipalities did not have sufficient data or population size to perform the analyses, more than 98% of the dental examination records included in the database were used to calculate the caries outcomes evaluated in this study.

The quality of the dataset that was constructed for this thesis was secured by the organisations that compile and make them available following current Chilean regulations, based on international standards to deliver comparable, reliable information that favours the integral wellbeing of the Chilean population and the development of public policies (Comision Nacional de Productividad, 2017).

7.8 Conclusions

This section describes the conclusions from this research's findings in relation to meeting the objectives (Chapter 2). To the author's knowledge, this study is the first population-wide impact evaluation of Chile's national oral health programmes of Chile on the oral health of the young child population, using routine databases with a national scope and over time, that were linked to non-health databases.

The overarching aim of this study was to undertake a quantitative outcome evaluation of the national child oral health improvement programmes for Chile on the oral health outcomes and related inequalities. This research obtained funding from the “Development of Advanced Human Capital for Chile” programme of the National Research and Development Agency of Chile.

The decision of the National Research and Development Agency of Chile to provide funding for this thesis was based on the fact that despite the Chilean Ministry of Health having records of caries levels in children over the last decade, there was neither any formal evaluation of the impact of the oral health improvement policies implemented in order to reduce the high levels of caries in children, nor has there been analysis performed on socioeconomic inequalities in the distribution of the disease detected in the last national oral health survey of 2007, or how each of the components of the national oral health improvement programmes was associated with the caries experience of children.

As mentioned in section 1.8, the lack of information regarding the impact of public health programmes prevents the evolution and adaptation of the interventions and hinders an optimal allocation of resources. Therefore, this thesis fulfils the vital role of providing data for better decision-making in dental health policies that benefit the child population of Chile.

Four objectives were defined to fulfil this study's overarching aim, and each of them was addressed in a chapter of this thesis.

7.8.1 Data collation, indexing, management and quality checks

The first objective was to collect, collate and manage data from the national oral health programmes, child dental caries and sociodemographic characteristics at Chile's national, regional and municipality levels, assessing data quality and completeness. Despite the difficulties previously raised, the objective of creating a database for evaluating the national oral health programmes was completed. This process, described in detail in Chapter 3, will be a resource that will also provide support for future research not only for the evaluation of public policies in dental health in children but also to evaluate other dental programmes in different age ranges and even other health policies that have nothing to do with dentistry.

7.8.2 Caries experience in Chilean children and related inequalities

The second objective was to design an area-based ecological longitudinal cohort to evaluate the trends in dental caries of six-year-old children in Chile at national, regional and municipality levels, related area-based socioeconomic inequalities and the impact of the sociodemographic characteristics of the municipalities on child caries levels. The municipality/years cohort created in Chapter 4 made it possible to evaluate (with a novel ecological cohort approach) the differences in caries levels of six-year-olds between municipalities and the changes over time, along with the association between caries experience and relevant potential confounders.

A continuing and significant decrease in the caries experience of six-year-old children at the municipality level was observed during the study period in Chile. The caries experience observed in the study period in the model adjusted for socioeconomic deprivation and rurality was 83% in 2008, decreasing to 67% in 2019. Despite this significant decrease, the high childhood caries levels and inequalities observed remain a public health challenge.

Socioeconomic inequalities were evaluated using linear regression models and summary measures. In all the analyses, a strong association was observed between deprivation and caries levels with a clear socioeconomic gradient, where the most deprived municipalities presented a significantly higher caries experience in six-year-olds compared to less deprived areas. Although a decrease in caries experience was observed in all socioeconomic groups over time, there was no significant decrease in the inequalities of the distribution of the disease. In addition, rural and mixed municipalities had significantly higher caries levels than those classified as urban. These associations were evident when evaluating caries levels by region and municipality. The rural and most deprived areas showed the highest levels of caries, especially in the central-south macrozone of the country, including the two regions that do not have fluoridated water. These findings calls for action for further upstream (policy) and midstream (community-level) interventions, delivered via a proportionate universal approach, that focus especially on preschool children from rural and socioeconomic deprived areas.

7.8.3 Impact of the national oral health improvement programmes for Chile on six-year-olds caries experience

The third objective was to assess the impact of the national oral health programmes, including community fluoridated water and the preventive interventions that are performed in primary care public clinics, on the caries levels of six-year-old children. Univariate regressions revealed an strong association between both annual fluoride concentration and coverage of the community water fluoridation programme and a lower caries experience among six-year-olds in Chile at the municipality-level, which persisted in a multivariate regression model adjusted for socioeconomic deprivation, rurality and time.

Despite the significant impact of this programme in contributing to the reduction of caries levels in children in Chile, socioeconomic inequalities were observed for the distribution of community water fluoridation, with the most deprived municipalities having a coverage 44.2% lower and a fluoride concentration 0.22 mg/L higher than the least deprived higher municipalities. Therefore, inequalities in the caries burden also mirror the inequalities in the coverage of community water fluoridation, which could help explain why there was no decrease in the gap in caries experience between the most and least deprived municipalities in the study period.

These findings calls for action to optimise community water fluoridation delivery in Chile, but it is also clear that further interventions are required, including upstream and midstream preventive oral health initiatives.

For the preventive interventions performed at primary care clinics, a positive association was observed between higher exposure to these interventions prior to age six and caries experience. Also, a higher rate of these interventions was observed in the most socioeconomic deprived municipalities, in comparison with the least deprived communities. Although we consider that an ecological methodology may not represent the most precise approach to evaluate these clinical interventions that depend on many factors at the individual level, it is essential to investigate how and in what contexts they are being carried out to assess their relevance in clinical settings and to update guidelines in Chile, especially in light of the findings of this study and newly available evidence.

7.8.4 Impact of the Sembrando Sonrisas Programme on the oral health outcomes of Chilean children

Finally, the fourth objective of this thesis was to assess the impact of Sembrando Sonrisas programme interventions on the dental caries outcomes of five-years-old children covered by the programme since its establishment and rollout, its effect over and above community water fluoridation, and related inequalities. Sembrando Sonrisas includes two interventions evaluated in this thesis, the delivery of kits with toothbrushes and 1000 ppm fluoride toothpaste for daily supervised toothbrushing and the twice-a-year application of fluoride varnish in state-funded nurseries.

The provision of materials for daily brushing was associated with a lower caries experience in five-year-olds covered by the programme since its establishment and rollout. This association remained in a model adjusted for socioeconomic deprivation and even over and above the presence of community water fluoridation. The best results were observed in those municipalities that had access to fluoridated water and in which all children had access to daily toothbrushing materials in nurseries before the age of five. Hence, there was a synergy between both programmes.

These findings support the importance of incorporating a midstream policy of daily toothbrushing with a proportionate universalism approach, along with providing the necessary materials for its implementation in reducing caries levels in the child population in Chile. Therefore, it is imperative to seek strategies to increase its coverage, mainly since it was observed that in many municipalities not all children are receiving toothbrushing materials, and also the coverage of preschool education in Chile at the age of three is less than 50%.

Furthermore, these findings suggest that a model based on the Scottish Childsmile programme can be successfully replicated in other sociodemographic contexts.

The findings regarding the fluoride varnish application showed that a higher rate of exposure to this intervention had no impact on reducing caries levels in the five-year-olds covered by the programme since its establishment and rollout. These results are similar to the current evidence that proposes that fluoride applications in nurseries may not be an effective or cost-effective addition to population programmes, where even Childsmile, the programme that served as a reference for the incorporation of Sembrando Sonrisas in Chile, has provided high-quality randomised and epidemiological evidence suggesting the need for an appraisal of the application of fluoride varnish to pre-school children at an increased risk in nurseries settings as part of population oral health improvement policies and programmes.

7.9 Recommendations

Based on the findings of this thesis, the recommendations have been organised into two sections — those related to further research and those directed toward policymakers and stakeholders.

7.9.1 Recommendations for further research

- Multilevel analysis with updated data that allow further assessment of the impact of the national oral health improvement programmes of Chile, including data at the individual level. Ideally, these evaluations should incorporate other potential confounders such as ethnicity, sugar consumption and exposure to different sources of fluoride in the Chilean child population, as well as comparison with other conditions with common risk factors.

- An economic evaluation is required to determine programme interventions and activities' cost-effectiveness.

- Continuous updates to the database created for this study will allow further evaluation of the impact of the national oral health improvement programmes on caries levels and the related inequalities in the future.

- Consider alternative approaches for programme evaluation, including high-quality RCT and qualitative evaluations, to assess the impact the interventions on the prevalence and severity of dental caries in the child population of Chile.

- It is also suggested to evaluate the impact of the programmes on vulnerable groups in society and in children with special health needs.

- As the years since the start of the SARS-Cov-2 virus pandemic were not included on this study, we suggest evaluating its effects on caries trends, the impact on the national oral health programmes, and the post-pandemic recovery of health services to re-implement these interventions in the child population of Chile.

7.9.2 Recommendations for policymakers and stakeholders

- It is necessary to update the official information with which decisions are made for implementing public policies in dental health, ideally through a national oral health survey at least every ten years.

- Improve electronic health records, which allow the evaluation of the impact of the interventions of the national oral health improvement programmes. This mainly implies modifying the dmft and DMFT registry so that it can be used as a discrete-continuous variable, which will allow evaluating both the prevalence and severity of caries in the population through routine health information.

- Incorporate evaluation as a fundamental pillar of all dental health programmes from the initial stages of development and implementation, together with allocating resources to carry them out.

- It is necessary to develop state policies to increase access to fluoridated drinking water, especially in the country's most socioeconomic deprived and rural communities. Due to the inherent difficulties of expanding access to the water network, upstream and midstream policies should focus on municipalities with a lower socioeconomic level and with a higher proportion of rural population in the central-south and south macrozones of Chile.

- Due to the existence of a fluoridated milk programme in schools for children six years of age or older in Chile, this intervention needs to be evaluated further, and it is relevant to discuss whether this intervention should be implemented at earlier ages to increase access to other sources of fluoride.

- It is necessary to assess the impact at the individual level of clinical preventive interventions carried out in primary care centres in Chile, along with updating the clinical guidelines for the dental care of preschool children following international standards and evidence-based recommendations.

- It is important to improve the delivery of Sembrando Sonrisas oral health kits, to guarantee that each child participating in the programme receives toothbrushes and fluoride toothpaste for daily supervised toothbrushing.

- Due to the limited coverage of preschool education in Chile, it is necessary to discuss whether this health policy should expand its coverage through the delivery of toothbrushes and toothpaste in primary care centres of Chile for families with children who do not attend state-funded nurseries in rural municipalities, without access to community water fluoridation, and with low socioeconomic status.

- An appraisal of the application of fluoride varnish to preschool children at an increased risk via nursery settings as part of population oral health improvement policies and programmes is necessary due to current evidence suggesting that this is not a cost-effective intervention in reducing caries levels in the population.

- Even with optimal levels of community water fluoridation delivery and Sembrando Sonrisas in place, still high levels of caries among children were observed at the municipality level in Chile. This support the need to look at complementary non-fluoride-based interventions, particularly sugar control strategies at both upstream and community levels.

Finally, the author intends that the findings of this thesis and its recommendations can provide valuable information that serves as a guide and support for the future directions of the national oral health improvements programmes of Chile, in addition to serving as a reference for the implementation of similar dental public health policies in other countries of the Latin American region and the developing world. It is a priority for health professionals to face the challenge of dental caries in children, and contribute to improve child health from the early stages of life.

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Appendices

Appendix 1: Chilean Transparency Law description

The provisions established in Law No. 20,285 are applicable to the Organisations and services of the central administration of the State (ministries, public services, corporations, and foundations generated by the public administration such as those of the Presidency of the Republic). In the same way, so are the municipalities, government, regional governments and Armed Forces of Order and Security. They can be grossly summarized in obligations of active transparency (publication of relevant background of the service on a regular and updated basis) and response to requests for access to public information.

After being requested by an individual, the State administration considers twenty working days to deliver the information or reserve it according to the cases established by law; within them, due compliance with the functions of the service, the rights of the people, national security, national interest or exceptions established by qualified quorum laws. In exceptional cases such as the difficulty in gathering the requested information, the State administration can exceptionally extend the delivery for ten business days.

The Law of the Republic of Chile No. 20,285 on Access to Public Information establishes in its article 5: “Under the principle of transparency of the public function, the acts and resolutions of the organs of the State Administration, its foundations, the documents that support them or direct and essential complement, and the procedures that are used for their dictation, are public, except for the exceptions established by this law and those provided for in other laws of qualified quorum ”.

Chilean Article 7 of Law No. 20,285 establishes what is called Active Transparency, which is the action of each agency to publish certain information established by law during the first ten days of each month. Among them are the organic structure of the service, the administrative acts that have effects on third parties, the hired staff, the budget, the purchases made, the activities and the data they may collect, among others. Active transparency can be achieved by delivering reports, or optimally, on the digital platforms of the agencies.

After being requested by an individual, the State administration considers twenty working days to deliver the information or reserve it according to the cases established by law; within them, due compliance with the functions of the service, the rights of the people, national security, national interest or exceptions established by qualified quorum laws. In exceptional cases such as the difficulty in gathering the requested information, the State administration can exceptionally extend the delivery for ten business days.

Article 12 of Law 20,285 regulates the form of the request for information, indicating that it must be in writing or by electronic websites of the Organisations, and must contain: a) Name, surname and address of the applicant; b) Clear identification of the information required; c) Signature of the applicant stamped by any means enabled, and d) Administrative body to which it is addressed.

In this regard, the regulation of the law states, in its article 28, that a request will be identified as requested when it indicates the essential characteristics of it, such as its subject, date of issue or period of validity, origin or destination.

If the request does not meet the requirements indicated, the applicant will be required to correct the fault within five days of the respective notification, indicating that, if he does not do so, he will be withdrawn from his request. The petitioner may express in the request to be notified by electronic communication for all actions and resolutions of the administrative procedure of access to information, indicating for this, under his responsibility, an enabled email address.

By the provisions of article 19 No. 4 of the Political Constitution of the Republic of Chile and the relevant norms of the law No. 19.628 on Data Protection and Private Life, the processing of health data carried out Ministry of Health is governed by the following rules:

- The Ministry of Health ensures the confidentiality of personal data to users who register as part of the Public Health System.

- The personal data of the users will be subject to procedures of dissociation of data, understood as any treatment of personal data so that the information obtained is anonymized and cannot be associated with a specific or determinable person.

- The Ministry of Health may also communicate to third parties statistical information prepared from the data, without the express consent of the owner, when it is not possible to identify the owners individually, following the law.

Also, Law No. 20,635 establishes the principle of purpose in the processing of sensitive personal health data. This law introduced said principle establishing that "health providers, social security organisations, the National Health Fund or other entities, both public and private, that prepare, process or store data of health origin may not sell, transfer or transfer, for any title, databases containing sensitive information regarding their users, beneficiaries or patients, if they do not have for this, with the consent of the owner of such data, in the terms provided in law No. 19.628 or in other special regulations that regulate said matter, unless it concerns the granting of the corresponding health benefits, as well as compliance of their respective legal objectives, for which such consent will not be required".

Appendix 2: Ethics approval

University of Glasgow

21st April 2022

Dear Professor David Conway,

MVLS College Ethics Committee

Project Title: Evaluation of the national child oral health improvement programmes for Chile
Project No: 200210122

The College Ethics Committee has reviewed your application and has agreed that there is no objection on ethical grounds to the proposed study. It is happy therefore to approve the project, subject to the following conditions:

- Project end date: As stated in application
- The data should be held securely for a period of ten years after the completion of the research project, or for longer if specified by the research funder or sponsor, in accordance with the University's Code of Good Practice in Research: https://www.gla.ac.uk/media/media_490311_en.pdf
- The research should be carried out only on the sites, and/or with the groups defined in the application.
- Any proposed changes in the protocol should be submitted for reassessment, except when it is necessary to change the protocol to eliminate hazard to the subjects or where the change involves only the administrative aspects of the project. The Ethics Committee should be informed of any such changes.
- You should submit a short end of study report to the Ethics Committee within 3 months of completion.
- For projects requiring the use of an online questionnaire, the University has an Online Surveys account for research. To request access, see the University's application procedure at https://www.gla.ac.uk/research/strategy/ourpolicies/useofonlinesurveystoolforresearch/.

Yours sincerely

Jesse Dawson
MD, BSc (Hons), FRCP, FESO
Professor of Stroke Medicine
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Appendix 3: Data dictionary

Data Set Information Sheet: National Child Oral Health Improvement Programs for Chile

General information

Title of the dataset

National Child Oral Health Improvement Programs for Chile

Author's information

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Date of data collection

The data was collected between March 2019 and February 2020.

Data sources

(i) National Public Health Found Insurance (FONASA) for the beneficiary population of the public health system datasets, (ii) Superintendence of Sanitary Services of the Ministry of Public Infrastructure of Chile for Fluoride Concentration and Coverage from the National Drinking Water datasets, (iii) National Institute of Statistics of Chile (INE) for Multidimensional Poverty Index produced with the information collected from the Chilean National Socioeconomic Characterization Survey and population projections data from the National Census, and (iv) the Public Health Department of the University of Chile for Socioeconomic Development Index. (v) Department of Health Statistics and Information of the Government of Chile for electronic oral health data.

License/restrictions placed on the data

All data included in this dataset has a Creative Commons license.

Data from Chilean Observatory of Public Health, School of Public Health, Faculty of Medicine, University of Chile is licensed under CC BY NC ND 4.0: https://creativecommons.org/licenses/by-nc-cd/4.0/

No alterations or transformations were made to the original source.

Data dictionary

DATASET NAME	National Child Oral Health Improvement Programs for Chile		
FILE NAME	DATASET.csv		
FILE TYPE	.csv		
DESCRIPTION	The dataset consists of aggregated electronic dental healthcare routine data from all the 346 Chilean Municipalities from the year 2008 to 2019, constructed with the ‘municipality/year’ unit of analysis, including dental examinations of children aged 0 to 6 years old and primary care and child oral health programmes activities and interventions linked to non-health data including population, community water fluoridation levels and coverage and area-based deprivation indexes.		
LEVEL	National, regional and municipality.		
ROWS	4152		
VARIABLES	186		
UNIT OF ANALYSIS	Municipality/Year		
VARIABLE NAME	DESCRIPTION	TYPE	Time range and (observations)
MUNID	Municipality ID code (Unique Territorial Code)	Categorical	2008-2019 (346 municipalities)

YEAR	Calendar year	Numeric	2008-2019
REGION	Code assigned to each region of Chile (Unique Territorial Code)	Categorical	2008-2019 (16 regions)
MUNNAME	Name of each municipality	Categorical	2008-2019
AGE0CENPOP	Total age 0 children population according to Census data	Numeric	2008-2019
AGE1CENPOP	Total age 1 children population according to Census data	Numeric	2008-2019
AGE2CENPOP	Total age 2 children population according to Census data	Numeric	2008-2019
AGE3CENPOP	Total age 3 children population according to Census data	Numeric	2008-2019
AGE4CENPOP	Total age 4 children population according to Census data	Numeric	2008-2019
AGE5CENPOP	Total age 5 children population according to Census data	Numeric	2008-2019
AGE6CENPOP	Total age 6 children population according to Census data	Numeric	2008-2019
AGE0FONPOP	Total age 0 children population beneficiary of FONASA (public health system)	Numeric	2010-2018
AGE1FONPOP	Total age 1 children population beneficiary of FONASA (public health system)	Numeric	2010-2018
AGE2FONPOP	Total age 2 children population beneficiary of FONASA (public health system)	Numeric	2010-2018
AGE3FONPOP	Total age 3 children population beneficiary of FONASA (public health system)	Numeric	2010-2018
AGE4FONPOP	Total age 4 children population beneficiary of FONASA (public health system)	Numeric	2010-2018
AGE5FONPOP	Total age 5 children population beneficiary of FONASA (public health system)	Numeric	2010-2018
AGE6FONPOP	Total age 6 children population beneficiary of FONASA (public health system)	Numeric	2010-2018
IDSEDCL	Decile of each municipality according to the socioeconomic development index	Ordinal	2008-2019 (the decile is the same for all years to each municipality)
IDSERNK	Ranking of each municipality according to the socioeconomic development index	Ordinal	2008-2019 (the ranking is the same for all years to each municipality)

IDSE	Socioeconomic development index score of each municipality	Numeric	2008-2019 (the score is the same for all years to each municipality)
MPI	Multidimensional Poverty index score for each municipality	Numeric	2008-2019
FCOV	Percentage of coverage of the drinking water program in houses of each municipality	Numeric	2008-2019 (%)
FCON	Annual fluoride concentration of each municipality	Numeric	2008-2019 (mg / L)
AGE0DMFT00	Total age 0 children with dmft = 0	Numeric	2017-2019
AGE1DMFT00	Total age 1 children with dmft = 0	Numeric	2017-2019
AGE2DMFT00	Total age 2 children with dmft = 0	Numeric	2008-2019
AGE3DMFT00	Total age 3 children with dmft = 0	Numeric	2012-2019
AGE4DMFT00	Total age 4 children with dmft = 0	Numeric	2008-2019
AGE5DMFT00	Total age 5 children with dmft = 0	Numeric	2012-2019
AGE6DMFT00	Total age 6 children with dmft = 0	Numeric	2008-2019
AGE0DMFT01	Total age 0 children with dmft = 1	Numeric	2017-2019
AGE1DMFT01	Total age 1 children with dmft = 1	Numeric	2017-2019
AGE2DMFT01	Total age 2 children with dmft = 1	Numeric	2014-2019
AGE3DMFT01	Total age 3 children with dmft = 1	Numeric	2014-2019
AGE4DMFT01	Total age 4 children with dmft = 1	Numeric	2014-2019
AGE5DMFT01	Total age 5 children with dmft = 1	Numeric	2014-2019
AGE6DMFT01	Total age 6 children with dmft = 1	Numeric	2014-2019
AGE0DMFT02	Total age 0 children with dmft = 2	Numeric	2017-2019
AGE1DMFT02	Total age 1 children with dmft = 2	Numeric	2017-2019

AGE2DMFT02	Total age 2 children with dmft = 2	Numeric	2014-2019
AGE3DMFT02	Total age 3 children with dmft = 2	Numeric	2014-2019
AGE4DMFT02	Total age 4 children with dmft = 2	Numeric	2014-2019
AGE5DMFT02	Total age 5 children with dmft = 2	Numeric	2014-2019
AGE6DMFT02	Total age 6 children with dmft = 2	Numeric	2014-2019
AGE0DMFT03	Total age 0 children with dmft = 3	Numeric	2017-2019
AGE1DMFT03	Total age 1 children with dmft = 3	Numeric	2017-2019
AGE2DMFT03	Total age 2 children with dmft = 3	Numeric	2014-2019
AGE3DMFT03	Total age 3 children with dmft = 3	Numeric	2014-2019
AGE4DMFT03	Total age 4 children with dmft = 3	Numeric	2014-2019
AGE5DMFT03	Total age 5 children with dmft = 3	Numeric	2014-2019
AGE6DMFT03	Total age 6 children with dmft = 3	Numeric	2014-2019
AGE0DMFT04	Total age 0 children with dmft = 4	Numeric	2017-2019
AGE1DMFT04	Total age 1 children with dmft = 4	Numeric	2017-2019
AGE2DMFT04	Total age 2 children with dmft = 4	Numeric	2014-2019
AGE3DMFT04	Total age 3 children with dmft = 4	Numeric	2014-2019
AGE4DMFT04	Total age 4 children with dmft = 4	Numeric	2014-2019
AGE5DMFT04	Total age 5 children with dmft = 4	Numeric	2014-2019
AGE6DMFT04	Total age 6 children with dmft = 4	Numeric	2014-2019
AGE0DMFT05	Total age 0 children with dmft greater or equal to 5	Numeric	2017-2019

AGE1DMFT05	Total age 1 children with dmft greater or equal to 5	Numeric	2017-2019
AGE2DMFT05	Total age 2 children with dmft greater or equal to 5	Numeric	2008-2019
AGE3DMFT05	Total age 3 children with dmft greater or equal to 5	Numeric	2012-2019
AGE4DMFT05	Total age 4 children with dmft greater or equal to 5	Numeric	2008-2019
AGE5DMFT05	Total age 5 children with dmft greater or equal to 5	Numeric	2012-2019
AGE6DMFT05	Total age 6 children with dmft greater or equal to 5	Numeric	2008-2019
AGE2DMFT12	Total age 2 children with dmft = 1 or 2	Numeric	2008-2013
AGE3DMFT12	Total age 3 children with dmft = 1 or 2	Numeric	2012-2013
AGE4DMFT12	Total age 4 children with dmft = 1 or 2	Numeric	2008-2013
AGE5DMFT12	Total age 5 children with dmft = 1 or 2	Numeric	2012-2013
AGE6DMFT12	Total age 6 children with dmft = 1 or 2	Numeric	2008-2013
AGE2DMFT34	Total age 2 children with dmft = 3 or 4	Numeric	2008-2013
AGE3DMFT34	Total age 3 children with dmft = 3 or 4	Numeric	2012-2013
AGE4DMFT34	Total age 4 children with dmft = 3 or 4	Numeric	2008-2013
AGE5DMFT34	Total age 5 children with dmft = 3 or 4	Numeric	2012-2013
AGE6DMFT34	Total age 6 children with dmft = 3 or 4	Numeric	2008-2013
AGE0AMAL	Total number of amalgam restorations delivered to age 0 children in public clinics and hospitals	Numeric	2017-2019
AGE1AMAL	Total number of amalgam restorations delivered to age 1 children in public clinics and hospitals	Numeric	2017-2019
AGE2AMAL	Total number of amalgam restorations delivered to age 2 children in public clinics and hospitals	Numeric	2008-2019
AGE3AMAL	Total number of amalgam restorations delivered to age 3 children in public clinics and hospitals	Numeric	2012-2019

AGE4AMAL	Total number of amalgam restorations delivered to age 4 children in public clinics and hospitals	Numeric	2008-2019
AGE5AMAL	Total number of amalgam restorations delivered to age 5 children in public clinics and hospitals	Numeric	2012-2019
AGE6AMAL	Total number of amalgam restorations delivered to age 6 children in public clinics and hospitals	Numeric	2008-2019
AGE0BRUSH	Total number of individual educations in brushing technique delivered to age 0 children in public clinics and hospitals	Numeric	2017-2019
AGE1BRUSH	Total number of individual educations in brushing technique delivered to age 1 children in public clinics and hospitals	Numeric	2017-2019
AGE2BRUSH	Total number of individual educations in brushing technique delivered to age 2 children in public clinics and hospitals	Numeric	2008-2019
AGE3BRUSH	Total number of individual educations in brushing technique delivered to age 3 children in public clinics and hospitals	Numeric	2012-2019
AGE4BRUSH	Total number of individual educations in brushing technique delivered to age 4 children in public clinics and hospitals	Numeric	2008-2019
AGE5BRUSH	Total number of individual educations in brushing technique delivered to age 5 children in public clinics and hospitals	Numeric	2012-2019
AGE6BRUSH	Total number of individual educations in brushing technique delivered to age 6 children in public clinics and hospitals	Numeric	2008-2019
AGE0EXO	Total number of dental extractions delivered to age 0 children in public clinics and hospitals	Numeric	2017-2019
AGE1EXO	Total number of dental extractions delivered to age 1 children in public clinics and hospitals	Numeric	2017-2019
AGE2EXO	Total number of dental extractions delivered to age 2 children in public clinics and hospitals	Numeric	2008-2019
AGE3EXO	Total number of dental extractions delivered to age 3 children in public clinics and hospitals	Numeric	2012-2019
AGE4EXO	Total number of dental extractions delivered to age 4 children in public clinics and hospitals	Numeric	2008-2019
AGE5EXO	Total number of dental extractions delivered to age 5 children in public clinics and hospitals	Numeric	2012-2019
AGE6EXO	Total number of dental extractions delivered to age 6 children in public clinics and hospitals	Numeric	2008-2019
AGE0FLUO	Total number of fluoride varnish applications delivered to age 0 children in public clinics and hospitals	Numeric	2017-2019

AGE1FLUO	Total number of fluoride varnish applications delivered to age 1 children in public clinics and hospitals	Numeric	2017-2019
AGE2FLUO	Total number of fluoride varnish applications delivered to age 2 children in public clinics and hospitals	Numeric	2008-2019
AGE3FLUO	Total number of fluoride varnish applications delivered to age 3 children in public clinics and hospitals	Numeric	2012-2019
AGE4FLUO	Total number of fluoride varnish applications delivered to age 4 children in public clinics and hospitals	Numeric	2008-2019
AGE5FLUO	Total number of fluoride varnish applications delivered to age 5 children in public clinics and hospitals	Numeric	2012-2019
AGE6FLUO	Total number of fluoride varnish applications delivered to age 6 children in public clinics and hospitals	Numeric	2008-2019
AGE0GROU	Total number of group educations in brushing technique delivered to age 0 children in public clinics and hospitals	Numeric	2017-2019
AGE1GROU	Total number of group educations in brushing technique delivered to age 1 children in public clinics and hospitals	Numeric	2017-2019
AGE2GROU	Total number of group educations in brushing technique delivered to age 2 children in public clinics and hospitals	Numeric	2011-2019
AGE3GROU	Total number of group educations in brushing technique delivered to age 3 children in public clinics and hospitals	Numeric	2012-2019
AGE4GROU	Total number of group educations in brushing technique delivered to age 4 children in public clinics and hospitals	Numeric	2011-2019
AGE5GROU	Total number of group educations in brushing technique delivered to age 5 children in public clinics and hospitals	Numeric	2012-2019
AGE6GROU	Total number of group educations in brushing technique delivered to age 6 children in public clinics and hospitals	Numeric	2011-2019
AGE0IONO	Total number of glass ionomer restorations performed in age 0 children in public clinics and hospitals	Numeric	2017-2019
AGE1IONO	Total number of glass ionomer restorations performed in age 1 children in public clinics and hospitals	Numeric	2017-2019
AGE2IONO	Total number of glass ionomer restorations delivered to age 2 children in public clinics and hospitals	Numeric	2008-2019
AGE3IONO	Total number of glass ionomer restorations performed in age 3 children in public clinics and hospitals	Numeric	2012-2019

AGE4IONO	Total number of glass ionomer restorations performed in age 4 children in public clinics and hospitals	Numeric	2008-2019
AGE5IONO	Total number of glass ionomer restorations performed in age 5 children in public clinics and hospitals	Numeric	2012-2019
AGE6IONO	Total number of glass ionomer restorations performed in age 6 children in public clinics and hospitals	Numeric	2008-2019
AGE0POLI	Total number of coronary polishes delivered to age 0 children in public clinics and hospitals	Numeric	2017-2019
AGE1POLI	Total number of coronary polishes delivered to age 1 children in public clinics and hospitals	Numeric	2017-2019
AGE2POLI	Total number of coronary polishes delivered to age 2 children in public clinics and hospitals	Numeric	2008-2019
AGE3POLI	Total number of coronary polishes delivered to age 3 children in public clinics and hospitals	Numeric	2012-2019
AGE4POLI	Total number of coronary polishes delivered to age 4 children in public clinics and hospitals	Numeric	2008-2019
AGE5POLI	Total number of coronary polishes delivered to age 5 children in public clinics and hospitals	Numeric	2012-2019
AGE6POLI	Total number of coronary polishes delivered to age 6 children in public clinics and hospitals	Numeric	2008-2019
AGE0PULP	Total number of pulpotomies carried out on age 0 children in public clinics and hospitals	Numeric	2017-2019
AGE1PULP	Total number of pulpotomies carried out on age 1 children in public clinics and hospitals	Numeric	2017-2019
AGE2PULP	Total number of pulpotomies carried out on age 2 children in public clinics and hospitals	Numeric	2008-2019
AGE3PULP	Total number of pulpotomies carried out on age 3 children in public clinics and hospitals	Numeric	2012-2019
AGE4PULP	Total number of pulpotomies carried out on age 4 children in public clinics and hospitals	Numeric	2008-2019
AGE5PULP	Total number of pulpotomies carried out on age 5 children in public clinics and hospitals	Numeric	2012-2019
AGE6PULP	Total number of pulpotomies carried out on age 6 children in public clinics and hospitals	Numeric	2008-2019
AGE0RESI	Total number of composite resin restorations delivered to age 0 children in public clinics and hospitals	Numeric	2017-2019
AGE1RESI	Total number of composite resin restorations delivered to age 1 children in public clinics and hospitals	Numeric	2017-2019

AGE2RESI	Total number of composite resin restorations delivered to age 2 children in public clinics and hospitals	Numeric	2008-2019
AGE3RESI	Total number of composite resin restorations delivered to age 3 children in public clinics and hospitals	Numeric	2012-2019
AGE4RESI	Total number of composite resin restorations delivered to age 4 children in public clinics and hospitals	Numeric	2008-2019
AGE5RESI	Total number of composite resin restorations delivered to age 5 children in public clinics and hospitals	Numeric	2012-2019
AGE6RESI	Total number of composite resin restorations delivered to age 6 children in public clinics and hospitals	Numeric	2008-2019
AGE0SEAL	Total number of pits and fissure sealants delivered to age 0 children in public clinics and hospitals	Numeric	2017-2019
AGE1SEAL	Total number of pits and fissure sealants delivered to age 1 children in public clinics and hospitals	Numeric	2017-2019
AGE2SEAL	Total number of pits and fissure sealants delivered to age 2 children in public clinics and hospitals	Numeric	2008-2019
AGE3SEAL	Total number of pits and fissure sealants delivered to age 3 children in public clinics and hospitals	Numeric	2012-2019
AGE4SEAL	Total number of pits and fissure sealants delivered to age 4 children in public clinics and hospitals	Numeric	2008-2019
AGE5SEAL	Total number of pits and fissure sealants delivered to age 5 children in public clinics and hospitals	Numeric	2012-2019
AGE6SEAL	Total number of pits and fissure sealants delivered to age 6 children in public clinics and hospitals	Numeric	2008-2019
AGE2KITS	Total number of dental hygiene kits (4 soft toothbrushes and 1 1,000 ppm fluoride paste) delivered by the Sembrando Sonrisas programme to children age 2	Numeric	2015-2019
AGE3KITS	Total number of dental hygiene kits (4 soft toothbrushes and 1 1,000 ppm fluoride paste) delivered by the Sembrando Sonrisas programme to children age 3	Numeric	2015-2019
AGE4KITS	Total number of dental hygiene kits (4 soft toothbrushes and 1 1,000 ppm fluoride paste) delivered by the Sembrando Sonrisas programme to children age 4	Numeric	2015-2019
AGE5KITS	Total number of dental hygiene kits (4 soft toothbrushes and 1 1,000 ppm fluoride paste) delivered by the Sembrando Sonrisas programme to children age 5	Numeric	2015-2019
AGE2SSDM	Total children aged 2 with a dental examination for Sembrando Sonrisas programme in nurseries and schools	Numeric	2015-2019

AGE3SSDM	Total children aged 3 with a dental examination for Sembrando Sonrisas programme in nurseries and schools	Numeric	2015-2019
AGE4SSDM	Total children aged 4 with a dental examination for Sembrando Sonrisas programme in nurseries and schools	Numeric	2015-2019
AGE5SSDM	Total children aged 5 with a dental examination for Sembrando Sonrisas programme in nurseries and schools	Numeric	2015-2019
AGE2SSFL	Total number of fluoride varnish applications delivered to children aged 2 in the Sembrando Sonrisas programme	Numeric	2015-2019
AGE3SSFL	Total number of fluoride varnish applications delivered to children aged 3 in the Sembrando Sonrisas programme	Numeric	2015-2019
AGE4SSFL	Total number of fluoride varnish applications delivered to children aged 4 in the Sembrando Sonrisas programme	Numeric	2015-2019
AGE5SSFL	Total number of fluoride varnish applications delivered to children aged 5 in the Sembrando Sonrisas programme	Numeric	2015-2019
AGE0EGRESS	Total number of children aged 0 discharged from the CERO programme	Numeric	2017-2019
AGE1EGRESS	Total number of children aged 1 discharged from the CERO programme	Numeric	2017-2019
AGE2EGRESS	Total number of children aged 2 discharged from the CERO programme	Numeric	2017-2019
AGE3EGRESS	Total number of children aged 3 discharged from the CERO programme	Numeric	2017-2019
AGE4EGRESS	Total number of children aged 4 discharged from the CERO programme	Numeric	2017-2019
AGE5EGRESS	Total number of children aged 5 discharged from the CERO programme	Numeric	2017-2019
AGE6EGRESS	Total number of children aged 6 discharged from the CERO programme	Numeric	2017-2019
AGE0HIGHRI	Total number of children aged 0 diagnosed with a high risk of caries according to the survey applied by a dentist for the CERO programme	Numeric	2017-2019
AGE1HIGHRI	Total number of children aged 1 diagnosed with a high risk of caries according to the survey applied by a dentist for the CERO programme	Numeric	2017-2019
AGE2HIGHRI	Total number of children aged 2 diagnosed with a high risk of caries according to the survey applied by a dentist for the CERO programme	Numeric	2017-2019
AGE3HIGHRI	Total number of children aged 3 diagnosed with a high risk of caries according to the survey applied by a dentist for the CERO programme	Numeric	2017-2019

AGE4HIGHRI	Total number of children aged 4 diagnosed with a high risk of caries according to the survey applied by a dentist for the CERO programme	Numeric	2017-2019
AGE5HIGHRI	Total number of children aged 5 diagnosed with a high risk of caries according to the survey applied by a dentist for the CERO programme	Numeric	2017-2019
AGE6HIGHRI	Total number of children aged 6 diagnosed with a high risk of caries according to the survey applied by a dentist for the CERO programme	Numeric	2017-2019
AGE0LOWRIK	Total number of children aged 0 diagnosed with a low risk of caries according to the survey applied by a dentist for the CERO programme	Numeric	2017-2019
AGE1LOWRIK	Total number of children aged 1 diagnosed with a low risk of caries according to the survey applied by a dentist for the CERO programme	Numeric	2017-2019
AGE2LOWRIK	Total number of children aged 2 diagnosed with a low risk of caries according to the survey applied by a dentist for the CERO programme	Numeric	2017-2019
AGE3LOWRIK	Total number of children aged 3 diagnosed with a low risk of caries according to the survey applied by a dentist for the CERO programme	Numeric	2017-2019
AGE4LOWRIK	Total number of children aged 4 diagnosed with a low risk of caries according to the survey applied by a dentist for the CERO programme	Numeric	2017-2019
AGE5LOWRIK	Total number of children aged 5 diagnosed with a low risk of caries according to the survey applied by a dentist for the CERO programme	Numeric	2017-2019
AGE6LOWRIK	Total number of children aged 6 diagnosed with a low risk of caries according to the survey applied by a dentist for the CERO programme	Numeric	2017-2019
AGE0NEWREG	Total number of children aged 0 enrolled in the CERO programme	Numeric	2017-2019
AGE1NEWREG	Total number of children aged 1 enrolled in the CERO programme	Numeric	2017-2019
AGE2NEWREG	Total number of children aged 2 enrolled in the CERO programme	Numeric	2017-2019
AGE3NEWREG	Total number of children aged 3 enrolled in the CERO programme	Numeric	2017-2019
AGE4NEWREG	Total number of children aged 4 enrolled in the CERO programme	Numeric	2017-2019
AGE5NEWREG	Total number of children aged 5 enrolled in the CERO programme	Numeric	2017-2019
AGE6NEWREG	Total number of children aged 6 enrolled in the CERO programme	Numeric	2017-2019