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Understanding geographical variations in health system performance: a population-based study on preventable childhood hospitalisations

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ABSTRACT

Objective To investigate interdistrict variations in childhood ambulatory sensitive hospitalisation (ASH) over the years.

Design Observational population-based study over 2008–2018 using the Primary Health Organisation Enrolment Collection (PHO) and the National Minimum Dataset hospital events databases.

Setting New Zealand primary and secondary care.

Participants All children aged 0–4 years enrolled in the PHO Enrolment Collection from 2008 to 2018.

Main outcome measure ASH.

Results Only 1.4% of the variability in the risk of having childhood ASH (intracluster correlation coefficient=0.014) is explained at the level of District Health Board (DHB), with the median OR of 1.23. No consistent time trend was observed for the adjusted childhood ASH at the national level, but the DHBs demonstrated different trajectories over the years. Ethnicity (being a Pacific child) followed by deprivation demonstrated stronger relationships with childhood ASH than the geography and the health system input variables.

Conclusion The variation in childhood ASH is explained only minimal at the DHB level. The sociodemographic variables also only partly explained the variations. Unlike the general ASH measure, the childhood ASH used in this analysis provides insights into the acute conditions sensitive to primary care services. However, further information would be required to conclude this as the DHB-level performance variations.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ It is a population-based study.
⇒ A new and robust measure of the socioeconomic deprivation, the Index of Multiple Deprivation, is used.
⇒ Macrolevel health system input variables are included besides the major socioeconomic, demographic and geographical measures.
⇒ Specific access barriers like transport could not be included.
⇒ The denominator population is retrieved from the source that includes only those who have had at least one contact with primary care service providers.

INTRODUCTION

Ambulatory sensitive hospitalisation (ASH) refers to the hospital (hospitalisation) events related to the health conditions potentially preventable in the ambulatory care setting through prophylactic or therapeutic interventions.[1–3] Ambulatory care sensitive conditions are often defined within specific country contexts given their scope of healthcare services and the purpose for which the indicator is used.[3]

In Aotearoa New Zealand (NZ), the Ministry of Health (MOH) has defined a list of ASH conditions. These conditions are intended to be used as proxy markers of access and quality of the primary care services and diagnostic measures for District Health Boards (DHBs) to identify and address disparities across different population groups.[2] NZ currently comprises 20 DHBs, which are the subnational administrative units responsible for planning, delivering and funding of health services in NZ.

NZ's healthcare delivery system is highly decentralised, although the core administration functions linked to the overall public sector management, for example, national service frameworks and the national-level contracts for some services, are centralised. The Ministry of Health is responsible for providing advice (stewardship role) on health services policy issues to the government, and 20 DHBs have been responsible for planning and funding of overall services for the last 20 years (from 2000 to 2021).[4]

Existing evidence shows the variations in ASH rates among different ethnic groups,[5] across socioeconomic gradients,[6 7] and on other general social determinants of health including health literacy.[2] Health system factors such as hospital admission policies,[2] available hospital beds and local supply of

general practitioners[8] also contribute to the overall ASH rates. Access to primary care is considered as one of the most important predictors of ASH.[9 10] Rurality and remoteness, including transport unavailability, are other common factors that affect access to care and may subsequently cause higher ASH rates.[11–13]

Within-country geographical variation is one aspect of unwarranted variation that has attracted considerable attention, and focused on the paediatric (<18 years),[11] adult[14–16] or general (all age)[8 12 17] population. For example, recent research has been about hospital districts in Finland,[12] counties in USA,[11] French regions,[8] metropolitan areas versus rural areas in Victoria, Australia,[17] South Korean districts,[14] hospitals in New South Wales, Australia,[15] Spanish health districts[16] and counties within the New York state, USA.[18] The studies generally confirm that ASH rates vary by geographical units. However, the Modifiable Area Unit Problem acknowledges that the strength of the association between ASH and demographic factors is heavily influenced by the size of geographical units used.[19]

More recently ASH has been used as an indicator of overall health system performance although the evidence relating to the effectiveness in measuring performance is reported to be mixed.[15] The ASH rate for children aged 0–4 (hereafter referred to as childhood ASH) is one of the six headline measures in the NZ System Level Measures framework since 2016.

Reducing childhood ASH is a policy priority in NZ. The routinely collected data illustrates that the childhood ASH rate vary across the DHBs.[2] However, there is no information about the extent to which the variation comes from the differences in sociodemographic and economic characteristics of the population between DHBs. In this paper, we investigate interdistrict variations in childhood ASH over the years, adjusting for the effects of the key sociodemographic, economic, geographical and health system characteristics across the DHBs. Answering this question is helpful in determining the suitability of childhood ASH as an indicator of health system performance at the district level.

METHODS

Data sources

We obtained anonymised, individual-level datasets from the National Collections division of the NZ Ministry of Health. The National Minimum Dataset hospital events provided childhood ASH data. The dataset provides national collection of public and private hospital discharge information that contains clinical and individual demographic data in NZ.[20] Additional sociodemographic data (age, sex and self-reported ethnicity) for the study population were provided from the Primary Health Organisation Enrolment Collection (PHO), a nationwide collection of patient enrolment with primary care providers reported quarterly and available since 2005.[21]

The NZ Index of Deprivation, NZDep, provides a small area ordinal scale (deciles) of relative deprivation status, with each decile representing 10% of areas, and updated after every census.[22] We also accessed the more recent Index of Multiple Deprivation (IMD), which used 28 indicators grouped into 7 domains (income, employment, crime, housing, health, education and access), thus allowing us to consider overall deprivation and its drivers (ie, domains) separately.[23]

Rurality of the study population's Domicile was mapped against the Area Unit 2013 as reflected in the Geographic Concordance file, a publicly available customised dataset of Stats NZ,[24] and the Census domicile code table. Area Unit represents a non-administrative single geographical entity with a unique name formed by aggregating adjacent census Mesh blocks (the smallest geographical area unit) with coterminous boundaries. It is then regrouped into urban and non-urban categories based on the urban–rural description 2018.[24] Similarly, NZ Health Workforce Survey reports and the Health Workforce Information Programme[25] provided human resource data, number of general practice (GP) full time equivalents per 100 000 population and DHB staffed total health workforce full time equivalents respectively, aggregated by the DHBs and study years. The financial data (Annual Health Expenditure per Capita) was obtained from the MOH through the Official Information Act requests.

Patient and public involvement

The ethics approval covers the privacy and confidentiality aspect of using the secondary data. We declare no direct involvements of patients or the public in the research process.

Measurements

Childhood ASH is defined as the acute or arranged hospitalisation events related to the ambulatory sensitive conditions among children aged 0–4 years. The clinical conditions included are as per the MOH 2018 lists of the International Classification of Diseases-10 Australia Modifications diagnosis codes[26] (online supplemental appendix 1). We included only the acute conditions for the primary diagnosis events except for dental conditions, where elective cases were also included. 'Acute' is defined as having one of the following admission type codes: AA (Arranged Admission), AC (Acute admission) or RL (Psychiatric patient returned from leave); and 'Elective', having one of the following admission type codes: AP (Private hospital elective admission) or WN (Admitted from waiting list—normal). The non-case mix events, those aged less than 29 days at admission, and events with an overseas or unknown DHB of Domicile were excluded. We followed the childhood ASH analysis methodology as recommended by the NZ Child and Youth Epidemiology service.[27]

Data analysis

We screened the eligible childhood ASH events for the calendar years 2008 to 2018 separately and identified

each patient's number of events for the respective years. The coverage of the denominator population before 2008 were less than 90% of the total estimated resident population, and therefore, excluded from the analysis. At the time of request, 2018 was latest year for which the data was available. The childhood ASH records were then merged with a population dataset for all the registered population aged 0–4 years for the respective calendar year.

We merged the numerator dataset with the denominator population by six variables: Year (2008–2018), Domicile-codes, sex (male and female), age groups (0–1 year, 1–2 years and 2–4 years) and ethnicity (non-Māori non-Pacific—NMNP, Māori and Pacific Peoples; prioritised ethnicity groups as defined in the respective datasets. NZ Census allows individuals to identify with multiple ethnic groups. Then, it is presented in three aggregated forms—total response, prioritised and sole/combination. Prioritised ethnicity, the most common form in the health and disability sector, allocates individuals to only one of the groups that they identified with in the priority order of: Māori, Pacific, Asian, European/other. For example, a person identified as Chinese and Māori is labelled as Māori. Consistent with previous ASH research in NZ,[28] the cases with 'no data' for the childhood ASH variable in the merged file were assumed to have had no ASH events in the respective year and thus coded accordingly.

When predictor variables representing the same aspect (eg, area deprivation) were colinear, only one predictor was retained based on the relevancy. For example, since NZDep, and IMD were strongly correlated in this analysis (R=0.83, p<0.001) and both measured a relative area-level socioeconomic deprivation, IMD demonstrating a stronger relationship to the outcome variable was chosen for further analysis. The final dataset allowed us to conduct population-based cross-sectional analyses.

The dataset structure was hierarchical, with the outcome variable and demographic variables measured at the individual level, socioeconomic status (deprivation) and rurality measured at domicile level, and finance and human resource variables measured at DHB level. We followed the 2010 definition of DHBs when Otago DHB and Southland DHB were amalgamated to form the new Southern DHB. It reduces the total number of DHBs from 21 to 20.

Understanding DHB-level geographical variations in childhood ASH was the primary objective of this research. Therefore, we undertook analyses using a mixed effects logistic regression model (a hierarchical random intercept model) with DHB as a random effect variable and the rest of the predictors as (stepwise) fixed effect variables. A 'lme4' package in R was used.[29] The proportion of the variation in childhood ASH attributable to the DHB is estimated by calculating intracluster correlation (ICC). ICC is a measure of the effects of the cluster itself on subject outcomes for hierarchical structure data and estimates between and withincluster variance. ICC values range from 0 to 1, with 0 indicating no effect and 1 as 100% (completely explained).[30]

The variance estimates of the random effect variable were transformed into median OR (MOR) using the MOR function in R.[31] MOR is considered to be a more meaningful and interpretable scale in multilevel logistic regression analysis because this can be compared with the OR of the fixed effect variables.[30]

The number of clusters/groups in this analysis (n=20) is less than that recommended for a multilevel model (eg, 50/50 rules).[32 33] Similarly, the distributions of the total number of individuals (and the outcomes) within each of the clusters/groups are highly variable. Some literature suggests that when the number of clusters is small and ICC is minimal, single-level fixed effect regression results are similar to the mixed effect model with minimal computations required.[34] Other literature suggests comparing the results from both single and multilevel models.[35]

Therefore, we performed both multilevel logistic regression (mixed effect random intercept model, labelled as 'model 1'), and single-level multiple logistic regression (fixed-effect model labelled as 'model 2'). The estimates for the fixed-effect variables were compared and found to be consistent (as shown in online supplemental appendix 2).

In model 2, we entered childhood ASH (yes/no) as outcome variable and DHB, age (age groups), sex, ethnicity (three categories), year (grouped into four categories), deprivation (IMD deciles, three categories), rurality (two groups) and human resource or finance (continuous) variables entered as fixed factors. The R software's 'glm' function with the logit link (RStudio V.1.2.5019) was used for the analysis. The numerical covariates (finance or human resource) were rescaled between 0 and 1 using the 'scales' library.[36] The variable having higher effects in the unadjusted (bivariate) analysis was prioritised first.[37]

We also examined the trajectories of the DHBs over the years by including DHB and year (grouped—3 years windows) interaction term. The model did not converge in the random-effect structure but worked well in the fixed-effect one. This is the third model in this analysis labelled as 'model 3'.

Multicollinearity of the predictor variables in the models were checked using the R package 'car' (V.3.0–7).[38] The decision criteria were based on the variance inflation factor[39] with a cut-off of <3 for main effects and <20 for interaction effects.[40] Because of the high correlation of the workforce and finance variable, we generated the estimates with only finance variable except in the model with GP (General Practice Full Time Equivalent per 100,000 population) variable.

We undertook a separate analysis for the dataset having GP variable (human resource input) that has information for only up to 2016. This analysis was done in the fixed-effect structure, equivalent to the models 2 and 3 as above but GP variable replacing the finance variable. Table 1 summarises the three primary models analysed:

Table 1 Details of the models

Models	Structure	Variables	Note
Model 1	Multilevel random intercept model (logistic regression)	Random effect variable: DHB Fixed effect variables: age, ethnicity, sex, deprivation, rurality, finance and year-window (stepwise)	All model terms had Pr(> χ^2) value <0.001
Model 2	Fixed effect multiple logistic regression model	Age, DHB, ethnicity, sex, deprivation, rurality, year-window and finance (orderly)	As above
Model 3	Fixed effect multiple logistic regression model with interaction	Model 2 variables plus DHB-year interaction term	all model terms had Pr(>χ^2) value <0.001, and all VIFs including that for the interaction terms were less than five except for finance variable (VIF=5.06)

DHB, District Health Board; VIF, Variance Inflation Factor.

The R prediction function estimated the childhood ASH events for the focal variables (DHB and year) by keeping all other covariates constant, defined at the mean for the numerical variable and the reference category for each of the categorical variables.[41] Auckland DHB that features a good mix of the population characteristics is taken as a reference category for the geographical variation analyses.

We also conducted sensitivity analysis for the DHB-wide variation to test the effects of hospital admission and coding practices that varies across the DHBs[2 42] by excluding the patients discharged in an emergency department specialty after a length of stay of <2 days from the dataset based on the fixed-effect model (model 2).

RESULTS

The composition of the study population in the DHBs varied by ethnicity, rurality and area-level deprivation. For example, the proportion of the indigenous Māori children (0–4) in our dataset range from 28% in (Auckland DHB) to 46% in (Tairawhiti DHB) and the proportion of Pacific children ranging from 29% to four percent across the DHBs. In case of deprivation, Northland (61%) has the highest proportion of children (0–4) living in the deciles 7–10 in contrast to that in South Canterbury (4%).

The average childhood ASH admissions range from 46.2 per 1000 PHO enrolled population in South Canterbury to 98.9 per 1000 population in Whanganui for the study period. Similarly, the distributions of the causes or conditions of the childhood hospitalisations also vary, with Asthma, gastroenteritis and upper respiratory tract infection representing more than half of the total causes (table 2). Details of district-wide variation of the observed childhood ASH events over the years is in online supplemental appendix 3.

The hierarchical logistic regression model with the DHBs added as a random effect variable (model 1) found that only 1.4% of the variability in the risk of childhood ASH (intracluster correlation coefficient, ICC=0.014) is explained at the level of DHB. When adjusted for the effects of the predictor variables, the ICC of DHB as a cluster variable is reduced to less than 1.0% (ICC=0.006). The MOR estimates show that a typical pair of randomly chosen DHB will differ in odds of having childhood ASH by a factor of 1.23, which reduces to 1.14 when adjusted for the available predictor variables as shown in the table 3.

The odds of childhood ASH vary across the districts (DHB as an independent predictor variable in the fixed-effect model—model 2); with the lowest among those living in South Canterbury DHB (OR=0.86, 95% CI 0.81 to 0.92) and highest in Southern DHB (OR=1.39, 95% CI 1.33 to 1.46) compared with that in Auckland. Six DHBs demonstrated no significantly different odds of childhood ASH from the reference DHB (figure 1).

Table 4 details the relationship of predictor variables and the likelihood of childhood ASH (parameters from the fixed-effect model (model 2)). The adjusted odds of overall childhood ASH declined by 2% (OR=0.98, 95% CI 0.96 to 0.99) in 2010–2012 compared with that in 2008–2009. Then, it increased in the successive years (OR=0.96, 95% CI 0.94 to 0.98) in 2013–2015 and (OR=0.96, 95% CI 0.94 to 0.99) in 2016–2018.

The likelihood of childhood ASH varies across ethnic categories (table 4). Overall, Māori children have 75% (OR=1.75, 95% CI 1.73 to 1.77) and Pacific children have more than twofold (OR=2.05, 95% CI 2.03 to 2.08) higher odds of being hospitalised than that among NMNP children. In the case of those living in urban areas, the odd of childhood ASH is 25.1% higher than that in non-urban, and 46.6% and 21.6% higher among those living in deciles 7–10 and deciles 5–6, respectively, compared with those in deciles 1–4.

The relationship of the distributions of DHB-level annual health expenditure per capita with the risk of children (0–4 years) being hospitalised for ambulatory sensitive conditions is positive. The distributions of GP per 100 000 population demonstrate a significant relationship only when DHB and year interaction effect was allowed in the adjusted model (see table 4 notes).

Table 2 Childhood ASH conditions by major cause categories

	2008		2018	
Causes	Frequency	%	Frequency	%
Asthma	3595	18.51	5087	23.05
Lower respiratory tract infections	899	4.63	1607	7.28
Cellulitis	1533	7.89	1513	6.86
Constipation	314	1.62	426	1.93
Dermatitis	488	2.51	446	2.02
Dental	2581	13.29	2744	12.43
Gastroenteritis	3646	18.78	3021	13.69
Gastro-oesophageal reflux diseases (GORD)	278	1.43	200	0.91
Nutrition	30	0.15	77	0.35
Rheumatic fever	2	0.01	2	0.01
Upper respiratory tract infection	3696	19.03	5162	23.39
Vaccine preventable diseases	32	0.16	37	0.17
Acute pneumonia	2324	11.97	1745	7.91
Total	19418	100.00	22067	100.00

The childhood ASH events are as per the hospitalisation register (not the merged population dataset used for further analysis); standard exclusion criteria applied, for example, only primary diagnosis, only acute conditions except for the dental conditions, aged 29 days to 4 years at admission, casemix events only, excluded unknown or overseas DHB domicile.
ASH, ambulatory sensitive hospitalisation; DHB, District Health Board.

The time-trend varies across the districts, although there is no obvious pattern (estimates based on the model with DHB-year interaction term (model 3) in figure 2). For example, Tairawhiti DHB demonstrated a gradual decline in the likelihood of childhood ASH events over the years, estimated events (reference: aged 0–1 year, female, deprivation (deciles 1–4), non-urban and mean expenditure) among NMNP declined from approximately 50 to <30 per 1000 PHO registered population in 2008–2009 and 2016–2018, respectively. In four other districts (Counties Manukau, Nelson Marlborough, Whanganui and Lakes) the estimated number of events declined significantly in 2010–2012 but remained unchanged after that.

DISCUSSION

Ethnicity, deprivation and rurality are the factors most strongly associated with childhood ASH. The result largely confirms the conclusion drawn by another NZ study that reported overall ASH for the years 2001–2009,[28] although we noticed further different trajectories at the district level. The ethnicity-wise variation is significant in terms of health system performance in NZ as it indicates a failure to uphold Māori rights under the Treaty of Waitangi (the founding constitutional document in NZ between Māori and the British Crown) to good governance, self-determination and equity.[43 44]

Literature from other high-income countries generally reports a higher likelihood of ASH in rural areas,[17 45] but we found it higher in the urban areas. It may be because of the healthcare-seeking practices (eg, overcrowding at emergency department in the urban areas)[46] or that related to the age group of the study population; children aged 0–4 in our case vs all age (general population)[17 45] or those aged under 15 years.[11] Furthermore, in our analysis,

Table 3 Details of the mixed-effect model (model 1)

Covariates	Variance	SD	ICC	MOR
A.DHB only	0.046	0.216	0.014	1.23
B.Adjusted (individual level variables)—age, sex, ethnicity	0.026	0.161	0.008	1.17
C.Adjusted (individual and area level variables)—age, sex, ethnicity, deprivation and rurality	0.02	0.141	0.006	1.14
D.Adjusted (individual, area and DHB level variables)—age, sex, ethnicity, deprivation, rurality and finance	0.018	0.135	0.005	1.14
E.Adjusted (individual, area and DHB level variables)—age, sex, ethnicity, deprivation, rurality, finance and year	0.018	0.135	0.005	1.14

DHB, District Health Board; ICC, intracluster correlation coefficient; MOR, median OR.

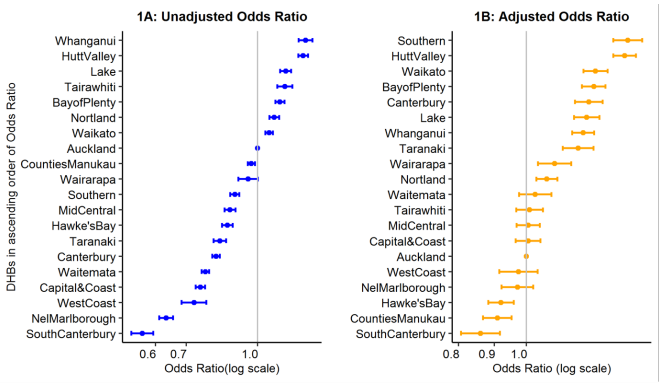

Figure 1 Fixed effect OR of childhood ambulatory sensitive hospitalisation (0–4 years) by District Health Boards (DHBs). Notes: model p<0.001, model covariates: 1A=DHB only, 1B (model 2)=age, DHBs, ethnicity, gender, deprivation, rurality, year-window and finance; deprivation: Index of Multiple Deprivation (IMD1=decile 1–4, IMD2=decile 5–6, IMD3=decile 7–10; finance (AHE-PP): annual health expenditure per capita rescaled (0–1).

the definition of urban includes a wide range of urban-type areas, for example, small urban areas as well as the major urban areas.[24] Further investigation into it may be helpful given that both sociodemographic[47] and health service characteristics (eg, availability of GP) tend to vary within the specific urban categories as well as between the urban and non-urban settings.[45] We could not go into depth as we concentrated more on the DHB level analysis. Some of the DHBs (eg, Auckland and Capital and Coast) have less than 5% of the study population from the non-urban areas.

The distribution of GPs plays important roles not only as gatekeepers of the NZ medical care system but also in delivering core medical and preventive care through an integrated approach.[48] Along with the studies in France and Australia that reported an inverse association between GP supply and general ASH rates,[8 15] we also found that a higher number of GP is associated with a lower likelihood of childhood ASH. Given that the number of GP varies across the DHBs, this could be an important factor making the DHBs different.

Hospital admission criteria are another important health system factors reported to affect ASH rates.[2] According to the Ministry of Health, DHBs had different admission practices from 1999 to 2012, and the differences in data reporting are likely to vary by the causes of the hospitalisations.[42] We did not find any changes in the patterns of the variations except that in Auckland DHB (the reference group) having a dedicated Starship Children's Hospital, which manages the majority of the cases in an emergency department setting, thereby resulting in the lowest odds of childhood ASH, compared with that by all other DHBs (online supplemental appendix 4).

This analysis also features a few limitations.

First, the denominator population comes from the PHO enrolment dataset. The total number of children aged 0–4 years included in the dataset for the overall study period was 3 003 340 that range from 276 961 in 2008 to 281 125 in 2018. The proportion of the estimated resident population covered in the data was 91.0% in 2008 and 98.7% in 2018. The inherent limitations that apply to the PHO enrolment system, particularly around the differential likelihood of the groups being enrolled depending on the population characteristics,[49 50] and that related to the dataset itself—accurate and up to date address data (eg, Domicile Code)[51]—apply to our results as well. Nevertheless, the distribution of the numerator population (childhood ASH events from the hospitalisation dataset) and the denominator population (PHO enrolled) with a complete set of information available across the study variables were broadly consistent, with an average of 95.2% and 95.7% coverage of the original datasets respectively. Similarly, the share of the total population by the DHBs in our dataset (2008–2018) compares well with that in the estimated resident population for the same period. For example, the highest difference is of only two percentage points (higher in our dataset) in Auckland, Southern and Waitemata DHBs, and close to zero in all other DHBs.

The variations we reported for the DHB-level geographical administrative units could have been influenced by the sociodemographic factors within the DHBs.[19] However, we could not go into the further details because of the smaller population size of some of the DHBs. The finance variable used is a macrolevel overall DHB-level health system input variable, not specific to the childhood ASH interventions. Variables related to the socioeconomic status and access are also proxy, area-level measures.

Furthermore, we could not include the specific Access variable available in the IMD dataset[23] that measures geographical access to essential services at the 'data zone' level, which is different to the Domicile. Lack of transport is one of the important factors affecting access to health services in society.[13] The New Zealand Health Survey 2020/2021[52] reports that 1% of the children aged 0–14 years had unmet need for GP services due to lack of transport, which is higher among Māori and Pacific children and those living in the most deprived areas. We could not include a transport variable in the analysis as no individualised DHB-level information was available for the study population over the study years. The overall IMD classification, however, incorporates access effects within it (in contrast to the NZDep13).[23] Our results are not directly comparable to previous research in NZ that used either individual socioeconomic position or NZDep as their measures of social position.

Another minor limitation, particularly around the geographical analysis based on the cross-sectional dataset, is that we could not capture the potential inter-DHB movements of the population within the study period. The DHB of domicile, rurality and deprivation of the study population represent the place as reflected in the PHO dataset for the particular year. Therefore, longitudinal studies following a specific population cohort may provide robust estimates of the individuals' risk across the

Table 4 Fixed effect estimates of OR of childhood ambulatory sensitive hospitalisation (0–4 years) by other covariates

	Unadjusted OR		Adjusted OR	
Variables	**OR**	95% **CI**	**OR**	95% **CI**
Year windows				
2008–2009	Ref		Ref	
2010–2012	1.0176	1.0041 to 1.0313	0.9783	0.9623 to 0.9946
2013–2015	1.0209	1.0074 to 1.0347	0.9595	0.9398 to 0.9795
2016–2018	1.0513	1.0374 to 1.0654	0.9653	0.9404 to 0.9909
Age—group				
0–1 year	Ref		Ref	
1–2 years	0.8274	0.8178 to 0.8371	0.8250	0.8153 to 0.8347
2–4 years	0.7666	0.7591 to 0.7741	0.7668	0.7593 to 0.7744
Gender				
Female	Ref		Ref	
Male	1.1984	1.1880 to 1.2089	1.1977	1.1873 to 1.2083
Ethnicity (prioritised)				
NMNP	Ref		Ref	
Māori	1.9669	1.9476 to 1.9864	1.7465	1.7277 to 1.7655
Pacific	2.2482	2.2209 to 2.2758	2.0556	2.0274 to 2.0843
Deprivation (IMD)—three categories				
IMD 1 (deciles 1–4)	Ref		Ref	
IMD 2 (deciles 5–6)	1.3949	1.3785 to 1.4114	1.2158	1.2007 to 1.2311
IMD 3 (deciles 7–10)	1.9852	1.9641 to 2.0066	1.4664	1.4476 to 1.4854
Urban-rural locality				
Non-urban	Ref		Ref	
Urban	1.3754	1.3580 to 1.3930	1.2506	1.2335
Finance (Annual Health Expenditure per Capita, rescaled)				
AHE_PP	1.4547	1.4233 to 1.4869	1.4250	1.3085
Human Resource (GP FTE per 100,000 population, rescaled)				
GP_FTE*	1.0224	1.0032 to 1.0418	0.9851*	0.9231 to 1.0512*

Model covariates (model 2): age, DHBs, ethnicity, gender, deprivation, rurality, years and finance (orderly).
*GP FTEs rescaled (0–1), analysed in a separate dataset (2008–2016), the adjusted OR values are based on the fixed-effect model without interaction terms (equivalent to the model 2). The corresponding OR value when DHB*year interaction term was included (equivalent to model 3) is 0.8685 (0.7873, 0.9579). Finance variable not included in the equivalent models with GP_FTE variable as these two variables were correlated strongly, VIF of all but GP FTE terms <5 reported in this equivalent model 3, with 5.15 for the GP_FTE term.
.AHE_PP, Annual Health Expenditure Per Capita, rescaled; DHB, District Health Board; GP, General Practice; GP_FTE, General Practice Full Time Equivalent; IMD, Index of Multiple Deprivation; NMNP, non-Māori non-Pacific; VIF, Variance Inflation Factor.

DHBs. Further investigations by the cause of deaths were not possible because of too few cases in some DHBs. Separate studies at the aggregated level may help understand the dynamics within each of the major cause-categories with large number of events like asthma, gastroenteritis and upper respiratory tract infection.

Childhood ASH as an indicator of health system performance is relatively unique to NZ. In one of the recent performance frameworks, the system level measures framework, childhood ASH was expected to indicate the contributions of the primary care sector and the secondary and community care to overall health system performance and measure and manage the performance of the DHBs. Given that almost one-third of childhood hospital discharges for the acute and arranged medical and surgical cases fall under ASH,[53] prioritising interventions around reducing childhood ASH may have helped DHBs improve their overall health outcomes.

The roles played by health sector organisations' initiatives within the districts over the years potentially explain the residual variation in childhood ASH. The DHBs may have responded to the issue differently, with some having more specific targeted interventions than their other counterparts and it is yet to be reflected at the national level performance results.[54] Still, attributing the unexplained variations solely to the DHB-level health

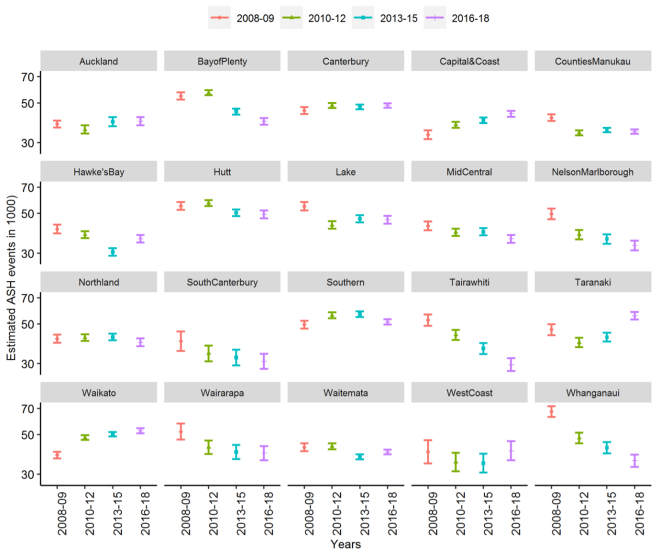

Figure 2 Estimated childhood ambulatory sensitive hospitalisation (ASH) events by District Health Boards (DHBs) based on model 3 (with DHB-year interaction term included) reference group: female children aged 0–1 year, living in non-urban deciles 1–4 (Index of Multiple Deprivations), with an average (mean) DHB level per capita expenditure.

system-specific performance should be done cautiously, mainly because of the minimal proportion of the overall variation explained at the level of DHBs. Some of the strong determinants of childhood ASH that tend to vary within the categories and between the DHBs (eg, ethnicity and deprivation) require interventions from the sectors beyond health.

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Appendix 1: List of Ambulatory Sensitive Hospitalization (ASH) conditions, Ministry of Health, New Zealand, 2018

ASH Chapter	ASH Condition	Diagnosis Code	Diagnosis Description	Applicable Ages	Includes Elective Events
Cardiovascular	**Rheumatic fever/heart disease**	I00	Rheumatic fever without mention of heart involvement	All	No
		I01	Rheumatic fever with heart involvement	All	No
		I02	Rheumatic chorea	All	No
		I05	Rheumatic mitral valve diseases	All	No
		I06	Rheumatic aortic valve diseases	All	No
		I07	Rheumatic tricuspid valve diseases	All	No
		I08	Multiple valve diseases	All	No
		I09	Other rheumatic heart diseases	All	No
Dental	**Dental conditions**	K02	Dental caries	All	Yes
		K04	Diseases of pulp and periapical tissues	All	Yes
		K05	Gingivitis and periodontal diseases	All	Yes
Dermatological	**Cellulitis**	L01	Impetigo	All	No
		L02	Cutaneous abscess, furuncle and carbuncle	All	No
		L03	Cellulitis	All	No
		L04	Acute lymphadenitis	All	No
		L08	Other local infections of skin and subcutaneous tissue	All	No
		H000	Hordeolum and other deep inflammation of eyelid	All	No
		H010	Blepharitis	All	No
		J340	Abscess, furuncle and carbuncle of nose	All	No
		L980	Pyogenic granuloma	All	No
	Dermatitis and eczema	L20	Atopic dermatitis	All	No
		L21	Seborrhoeic dermatitis	All	No
		L22	Diaper [napkin] dermatitis	All	No
		L23	Allergic contact dermatitis	All	No
		L24	Irritant contact dermatitis	All	No
		L25	Unspecified contact dermatitis	All	No
		L26	Exfoliative dermatitis	All	No
		L27	Dermatitis due to substances taken internally	All	No
		L28	Lichen simplex chronicus and prurigo	All	No
		L29	Pruritus	All	No
		L30	Other dermatitis	All	No
Gastrointestinal	**Constipation**	K590	Constipation	All	No
	Gastroenteritis/dehydration	A02	Other salmonella infections	All	No
		A03	Shigellosis	All	No
		A04	Other bacterial intestinal infections	All	No
		A05	Other bacterial food-borne intoxications, not elsewhere classified	All	No
		A06	Amoebiasis	All	No
		A07	Other protozoal intestinal diseases	All	No
		A08	Viral and other specified intestinal infections	All	No
		A09	Other gastroenteritis and colitis of infectious and unspecified origin	All	No
		R11	Nausea and vomiting	All	No
		K529	Noninfective gastroenteritis and colitis, unspecified	All	No
	GORD (Gastro-oesphageal	K21	Gastro-oesophageal reflux disease	All	No

	reflux disease)				
	Nutrition defiency and anaemia	D50	Iron deficiency anaemia	All	No
		D51	Vitamin B12 deficiency anaemia	All	No
		D52	Folate deficiency anaemia	All	No
		D53	Other nutritional anaemias	All	No
		E40	Kwashiorkor	All	No
		E41	Nutritional marasmus	All	No
		E42	Marasmic kwashiorkor	All	No
		E43	Unspecified severe protein-energy malnutrition	All	No
		E44	Protein-energy malnutrition of moderate and mild degree	All	No
		E45	Retarded development following protein-energy malnutrition	All	No
		E46	Unspecified protein-energy malnutrition	All	No
		E50	Vitamin A deficiency	All	No
		E51	Thiamine deficiency	All	No
		E52	Niacin deficiency [pellagra]	All	No
		E53	Deficiency of other B group vitamins	All	No
		E54	Ascorbic acid deficiency	All	No
		E55	Vitamin D deficiency	All	No
		E56	Other vitamin deficiencies	All	No
		E58	Dietary calcium deficiency	All	No
		E59	Dietary selenium deficiency	All	No
		E60	Dietary zinc deficiency	All	No
		E61	Deficiency of other nutrient elements	All	No
		E63	Other nutritional deficiencies	All	No
Respiratory	**Asthma**	J45	Asthma	All	No
		J46	Status asthmaticus	All	No
		R062	Wheeze	0 to 4 years	No
	Lower respiratory infections	J22	Unspecified acute lower respiratory infection	0 to 4 years	No
	Pneumonia	J13	Pneumonia due to Streptococcus pneumoniae	All	No
		J14	Pneumonia due to Haemophilus influenzae	All	No
		J15	Bacterial pneumonia, not elsewhere classified	All	No
		J16	Pneumonia due to other infectious organisms, not elsewhere classified	All	No
		J18	Pneumonia, organism unspecified	All	No
	Upper and ENT respiratory infections	J00	Acute nasopharyngitis [common cold]	All	No
		J01	Acute sinusitis	All	No
		J02	Acute pharyngitis	All	No
		J03	Acute tonsillitis	All	No
		J04	Acute laryngitis and tracheitis	All	No
		J06	Acute upper respiratory infections of multiple and unspecified sites	All	No
		H65	Nonsuppurative otitis media	All	No
		H66	Suppurative and unspecified otitis media	All	No
		H67	Otitis media in diseases classified elsewhere	All	No
Vaccine preventable disease	**Vaccine preventable MMR**	B05	Measles	15 months to 14 years	No
		B06	Rubella [German measles]	15 months to 14 years	No
		B26	Mumps	15 months to 14 years	No

		P350	Congenital rubella syndrome	15 months to 14 years	No
	Other vaccine preventable disease	A33	Tetanus neonatorum	6 months to 14 years	No
		A34	Obstetrical tetanus	6 months to 14 years	No
		A35	Other tetanus	6 months to 14 years	No
		A36	Diphtheria	6 months to 14 years	No
		A37	Whooping cough	6 months to 14 years	No
		A80	Acute poliomyelitis	6 months to 14 years	No
		B16	Acute hepatitis B	6 months to 14 years	No
		B18	Chronic viral hepatitis	6 months to 14 years	No
		A403	Sepsis due to Streptococcus pneumoniae	6 months to 14 years	No

Appendix 2: Comparative results illustrating the estimates of the fixed effect variables based on the fixed effect and mixed effect logistic regression models

Variables	Unadjusted - Odds Ratio			Adjusted - Odds Ratio (Multivariate LR, model 2)			Adjusted - Odds Ratio (Multilevel LR, model 1)		
	OR	95% CI		OR	95% CI		OR	95% CI	
Year windows									
2008-09		Ref			Ref			Ref	
2010-12	1.0176	1.0041	1.0313	**0.9783**	0.9623	0.9946	**0.9788**	0.9629	0.9949
2013-15	1.0209	1.0074	1.0347	**0.9595**	0.9398	0.9795	**0.9602**	0.9408	0.9800
2016-18	1.0513	1.0374	1.0654	**0.9653**	0.9404	0.9909	**0.9664**	0.9418	0.9916
Age - group									
0-1 Year		Ref			Ref			Ref	
1-2 Years	0.8274	0.8178	0.8371	**0.8250**	0.8153	0.8347	**0.8250**	0.8153	0.8347
2-4 Years	0.7666	0.7591	0.7741	**0.7668**	0.7593	0.7744	**0.7668**	0.7593	0.7744
Gender									
Female		Ref			Ref			Ref	
Male	1.1984	1.1880	1.2089	**1.1977**	1.1873	1.2083	**1.1977**	1.1873	1.2083
Ethnicity (Prioritized)									
NMNP		Ref			Ref			Ref	
Maori	1.9669	1.9476	1.9864	**1.7465**	1.7277	1.7655	**1.7466**	1.7278	1.7656
Pacific	2.2482	2.2209	2.2758	**2.0556**	2.0274	2.0843	**2.0553**	2.0270	2.0839
Deprivation (Index of Multiple Deprivation) - 3 categories									
IMD 1 (deciles 1-4)		Ref			Ref			Ref	
IMD 2 (deciles 5-6)	1.3949	1.3785	1.4114	**1.2158**	1.2007	1.2311	**1.2158**	1.2007	1.2311
IMD 3 (deciles 7-10)	1.9852	1.9641	2.0066	**1.4664**	1.4476	1.4854	**1.4664**	1.4477	1.4855
Urban-Rural locality									
Non-Urban		Ref			Ref			Ref	
Urban	1.3754	1.3580	1.3930	**1.2506**	1.2335	1.2680	**1.2506**	1.2335	1.2679
Finance (Annual Health Expe per Capita, rescaled)									
AHE_PP*	1.4547	1.4233	1.4869	**1.4250**	1.3085	1.5519	**1.4190**	1.3056	1.5422

Notes: *Model p < 0.001, Model co-variates: model 1(multilevel logistics regression) = age, ethnicity, gender, deprivation, rurality, year-window, and finance; model 2 (multivariate logistics regression) = age, DHBs, ethnicity, gender, deprivation, rurality, year-window, and finance. CI = Confidence Interval; LR = Logistics Regression; Deprivation: Index of Multiple Deprivation (IMD1 = decile 1-4, IMD2 = decile 5-6, IMD3 = decile 7-10; finance (AHE-PP): Annual Health Expenditure Per Capita rescaled (0-1)*

Appendix 3: Distribution of observed (un-adjusted) Childhood Ambulatory Sensitive Hospitalization (0-4 yrs.) events by District Health Boards and Years

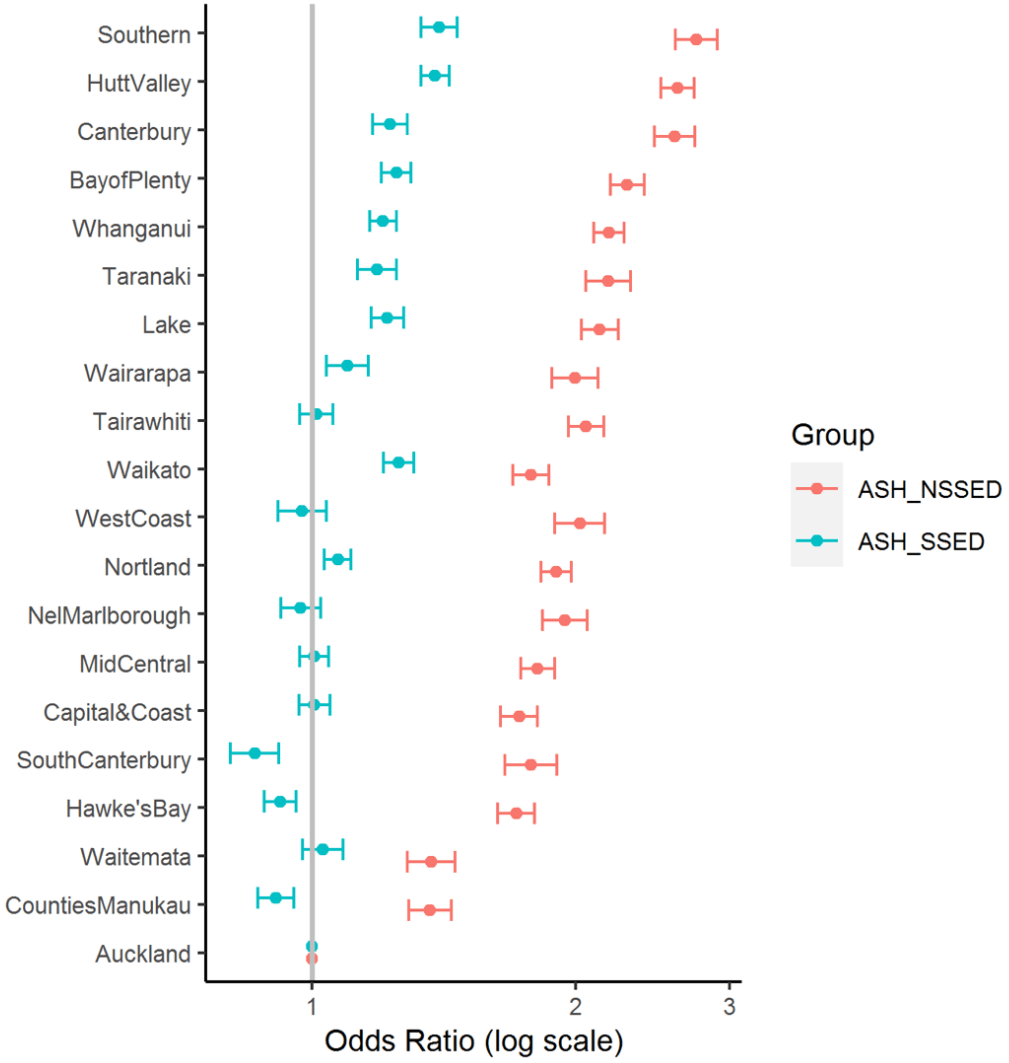
DHBs	2008		2009		2010		2011		2012		2013		2014		2015		2016		2017		2018		Total	
	N	Rate	N	Rate	N	Rate	N	Rate	N	Rate	N	Rate	N	Rate	N	Rate	N	Rate	N	Rate	N	Rate	N	Rate
Auckland	1977	78.77	1935	72.95	1989	72.46	2092	74.84	2198	78.52	2158	77.22	2445	87.74	2453	87.95	2260	83.78	2057	78.02	2075	80.64	23639	79.40
Bay of Plenty	1036	86.02	1262	99.28	1385	106.37	1375	102.40	1280	96.52	1085	82.71	1029	78.32	1154	87.87	1084	80.12	1031	75.28	1061	75.13	12782	88.00
Canterbury	1528	56.31	1743	62.27	1887	65.01	1739	59.85	1947	70.73	1914	69.41	1917	68.21	1702	59.64	2063	71.76	1976	67.44	2098	70.25	20514	65.60
Capital and Coast	811	47.34	834	48.13	1034	58.30	1084	61.02	964	54.73	1006	58.21	1139	66.25	1104	65.36	1179	70.59	1094	65.83	1229	75.65	11478	60.90
Counties Manukau	2902	83.40	3047	85.88	2637	71.99	2793	74.76	2831	75.85	2777	73.79	3116	81.33	2993	77.31	3049	78.27	2853	73.41	2889	73.69	31887	77.20
Hawke's Bay	656	70.42	737	74.18	729	70.55	792	76.29	686	65.70	583	57.30	636	63.58	592	58.78	645	64.39	673	67.95	900	90.75	7629	69.00
Hutt	909	97.23	902	93.95	1020	104.24	1041	105.44	960	98.18	871	90.89	954	102.51	812	89.15	868	100.75	893	96.60	897	96.63	10127	97.80
Lakes	682	91.72	783	105.10	603	79.07	563	75.73	639	88.30	537	75.56	640	92.02	711	103.34	647	94.41	629	90.48	689	100.20	7123	90.40
Mid Central	571	62.42	736	80.86	640	67.45	652	66.69	733	74.21	651	67.39	701	71.90	756	77.72	702	72.65	644	66.39	620	61.80	7406	69.90
Nelson Marlborough	426	66.50	428	59.25	373	49.75	362	47.44	410	53.88	372	49.93	392	53.68	329	46.05	330	46.63	349	50.05	340	48.21	4111	51.80
Northland	721	81.12	780	77.08	859	80.24	941	86.43	930	86.91	864	82.53	943	90.79	969	91.87	956	90.63	913	85.55	968	89.41	9844	85.80
South Canterbury	117	52.26	129	51.60	137	50.15	114	41.79	123	45.44	126	45.10	124	42.63	138	46.95	149	49.73	122	40.68	132	44.40	1411	46.20
Southern	863	59.02	1030	68.33	1119	70.28	1185	72.95	1248	74.62	1313	78.93	1292	79.61	1100	67.92	1060	69.70	1134	70.32	1191	73.46	12535	71.60
Tairawhiti	354	105.01	389	114.24	348	101.19	349	99.86	313	89.81	276	80.99	331	97.15	256	76.10	257	75.37	269	79.35	242	70.70	3384	90.00
Taranaki	334	52.61	499	76.66	406	60.04	362	53.29	391	56.99	350	51.40	459	65.63	467	65.81	554	78.16	575	82.20	627	88.66	5024	66.70
Waikato	1176	52.78	1661	72.90	1752	74.41	1875	78.18	2165	89.66	2064	85.88	2161	88.52	2104	85.22	2061	84.98	2319	91.87	2861	112.77	22199	83.90
Wairarapa	191	90.87	167	85.60	151	67.71	190	83.08	185	76.13	137	57.95	176	74.39	189	81.12	173	74.41	190	80.03	170	69.25	1919	76.10
Waitemata	1907	60.78	2058	63.65	2275	66.88	2269	65.40	2264	64.23	2168	61.31	2172	60.35	1981	54.61	2283	64.46	2216	60.83	2309	63.19	23902	62.30
West Coast	75	53.30	100	63.01	107	59.41	97	53.98	83	44.65	98	52.77	98	57.58	102	60.07	92	56.37	103	66.07	135	87.10	1090	59.10
Whanganui	434	124.93	523	139.88	495	128.30	349	90.60	316	82.55	325	84.22	379	99.32	368	95.86	282	71.45	354	89.19	341	86.90	4166	98.90
Total	**17670**	**69.60**	**19743**	**75.00**	**19946**	**72.90**	**20224**	**72.90**	**20666**	**74.70**	**19675**	**71.50**	**21104**	**76.40**	**20280**	**73.20**	**20694**	**75.50**	**20394**	**73.50**	**21774**	**78.10**	**222170**	**73.97**

Note:

N = Total number of childhood ASH hospitalization events with complete information for age, sex, ethnicity, deprivation, and Domicile (DHB)

Rate = Rate per 1000 PHO enrolled population (darker the colour of the shades, the larger the value for the respective year

Appendix 4: Fixed effect odds ratio of childhood ambulatory sensitive hospitalization (0-4 years) by hospital admission types



Notes: *Model p < 0.001, Model co-variates (model 2): age, DHBs, ethnicity, gender, deprivation, rurality, year-window, and finance; Deprivation: Index of Multiple Deprivation (IMD1 = decile 1-4, IMD2 = decile 5-6, IMD3 = decile 7-10; finance (AHE-PP): Annual Health Expenditure Per Capita rescaled (0-1). ASH_SED = Short Stay Emergency Department admission cases included ASH_NSSED = Short Stay Emergency Department admission cases excluded*