Spatial distribution, determinants and trends of full vaccination coverage in children aged 12–59 months in Peru: A subanalysis of the Peruvian Demographic and Health Survey

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ABSTRACT

Objective To assess the spatial distribution, trends and determinants of crude full vaccination coverage (FVC) in children aged 12–59 months between 2010 and 2019 in Peru.

Design, setting and analysis A cross-sectional study based on the secondary data analysis of the 2010 and 2019 Peruvian Demographic and Health Surveys (DHSs) was conducted. Logit based multivariate decomposition analysis was employed to identify factors contributing to differences in FVC between 2010 and 2019. The spatial distribution of FVC in 2019 was evaluated through spatial autocorrelation (Global Moran’s I), ordinary kriging interpolation (Gaussian process regression) and Bernoulli-based purely spatial scan statistic.

Outcome measure FVC, as crude coverage, was defined as having completely received BCG; three doses of diphtheria, pertussis, and tetanus, and polio vaccines; and measles vaccine by 12 months of age.

Participants A total of 5 751 and 14 144 children aged 12–59 months from 2010 and 2019 DHSs, respectively, were included.

Results FVC increased from 53.62% (95% CI 51.75% to 55.49%) in 2010 to 75.86% (95% CI 74.84% to 76.85%) in 2019. Most of the increase (70.39%) was attributable to differences in coefficients effects. The trend of FVC was non-linear and increased by 2.22% annually between 2010 and 2019. FVC distribution was heterogeneous at intradepartmental and interdepartmental level. Seven high-risk clusters of incomplete coverage were identified.

Conclusions Although FVC has increased in Peru, it still remains below the recommended threshold. The increase of FVC was mainly attributed to the change in the effects of the characteristics of the population. There was high heterogeneity across Peruvian regions with the presence of high-risk clusters. Interventions must be redirected to reduce these geographical disparities.

INTRODUCTION

Vaccines are one of the most cost-effective public health measures worldwide, since they prevent more than 25 diseases. Thus, the incidence of all immune-preventable diseases has markedly decreased and some of them have even been eradicated or eliminated, such as smallpox. In addition to conferring individual immunity on those vaccinated, they provide herd immunity.

Globally, according to the WHO and UNICEF, 86% of children completed the basic vaccination schedule in 2019. Although full vaccination coverage (FVC) has increased in Latin American and Caribbean regions, it remains low (69.9%) with wide differences due to economic inequalities within each country. Furthermore, one of the major threats of childhood vaccination is the rejection of its application due to fear and/or mistrust, fostered mainly by antivaccine groups, which have increased during the last decade. Other obstacles to vaccination acceptance are religious beliefs and cultural patterns.

The available literature about the factors associated with FVC varies between countries. Antenatal care (ANC) follow-up, institutional delivery, having employed parents,
higher maternal educational status, access to the media, among others, increased the probability of FVC.12–17 Other important factors which decrease the probability of FVC include rural residence, female household head and having a large family size.12–14 18 Some of these associations can be explained by the key role that socioeconomic level plays in the acceptance and access to vaccination.19 To reduce these gaps, it is necessary to implement locally designed multicomponent strategies.

The Peruvian vaccination schedule, in addition to being administered free of charge, is one of the most comprehensive in Latin America. However, broad spectrum coverage, does not imply equal coverage. And unlike other countries, the recent implementation of insurance policies has made vaccination a universal right.20 In Peru, vaccination coverage has increased by 10.2% between 2013 and 2018,21 and in the last decade, two new vaccines have been implemented in the national childhood vaccination schedule. Nevertheless, coverage remains low in lower socioeconomic strata.9 22 Similar to Peru, an upward trend in immunisation coverage has been reported in recent decades worldwide, but this trend differs between regions. Although there was an overall increase in FVC in Latin America, some countries showed a lower increase than others, and there are even countries that reduced their FVC.21 23 24

Currently, mass vaccination campaigns against COVID-19 are being carried out in Peru. In addition, outbreaks of vaccine-preventable diseases have been recently reported in our country.25 26 Therefore, it is necessary to determine where gains in vaccination coverage remain low despite Peru’s overall increase in vaccine coverage.21 Likewise, we aimed to evaluate what factors influenced the increase in FVC and its trend, which could support the redirection of public health policies and the efficient distribution of health resources.

MATERIALS AND METHODS
Study design and data sources
A secondary data analysis was conducted using information from the 2010 and 2019 Demographic and Health Surveys (DHSs) in Peru. Peru is an upper-middle-income country located in South America and inhabited by approximately 32 million people. The DHS is conducted annually by the National Institute of Statistics and Informatics (INEI, from Spanish Acronym), and it is representative at departmental level and area of residence. Peru has been the first country to conduct the DHS in a yearly frequency (since more than a decade), instead a standard frequency approach that is typically in a 5-year interval.27 The DHS design was probabilistic, two-stage, stratified, independent and self-weighted. However, since 2015, the survey design turned balanced (also known as the cube method) to provide better estimations and to improve the population coverage. A total of 27576 households were included in 2010 and 36760 households in 2019. The data were collected and processed through tablets, which were used by previously trained interviewers, whose procedures were evaluated by a local supervisor. Despite the Peruvian DHS collects information at the household level, it is mapped at the sampling cluster level. We included a map showing all sampling clusters of the 2019 DHS (online supplemental file 1). Further details on the data collection, processing and quality of the information is available in the main DHS report.28 29

Selection criteria
We included children from 12 to 59 months with complete data for the variables of interest recorded by DHS in 2010 and 2019. This age range was chosen because the vaccines that constitute our definition of FVC are scheduled to be administered during the first year of life, in accordance with the immunisation schedule established by the Ministry of Health (MINSA, from Spanish acronym) and the WHO.

Definition of variables
The outcome variable (children’s vaccination status) was defined according to the WHO definition of crude coverage. It was categorised into FVC and incomplete vaccination coverage.30 31 The children’s vaccination status was categorised as FVC if they had fully received the eight recommended vaccines: one dose of Bacillus of Calmette-Guerin (BCG); three doses of diphtheria, pertussis, and tetanus vaccine (DPT); three doses of polio vaccine; and one dose of measles vaccine. Incomplete vaccination coverage (partially/unvaccinated status) was defined as not having received at least one of the vaccines mentioned above. In Peru, the measles vaccine is administered with the mumps and rubella vaccine (MMR); while DPT vaccine is administered with hepatitis B and Haemophilus influenzae type b vaccine (pentavalent vaccine).32 Information on vaccination status was collected from the children’s vaccination record card and, in its absence, from the mother’s verbal report. Unfortunately, Peruvian DHS lacks data of vaccination dates, even when the vaccination record card is the source of information. This dummy variable was coded as ‘FVC=1’ or ‘incomplete vaccination coverage=0’.

The age of the child was categorised into four groups: 12–23 months, 24–35 months, 36–47 months and 48–59 months. ANC follow-up was categorised into ≤6and >6 visits, while family size was divided into ≤4 and >4 members. Moreover, we included other sociodemographic variables such as child sex, residence area, wealth index (poorest, poor, middle, rich and richest), place of delivery (home or health facility), mother’s education (no education or primary, secondary and higher), mother’s age at first delivery (<20 or ≥20 years), mother’s employment status (employed or unemployed), visit of health workers in the last 12 months, and sex of the household head.

Patient and public involvement
There was no public and patient involvement in the design, planning, reporting and dissemination plans of
our study, as it was based on a secondary data analysis of a database of public domain.

Procedures
We used the DHS databases of the Household Questionnaire, the Individual Questionnaire for Women and the Health Questionnaire, which are publicly available in the ‘Microdatos’ webpage of INEI.33 These databases were imported into STATA V.16.0 (Stata Corporation, College Station, TX, USA) and were merged, according to the variables of interest for each year. For the decomposition analysis, the 2010 and 2019 DHSs databases were appended. For trend analysis, the DHSs databases comprised within the period from 2010 to 2019 were merged. Finally, for the spatial analysis we only included data from 2019 DHS.

STATISTICAL ANALYSIS
To quantify group differences contributions and to compare the data of 2010 and 2019 over time, multivariate decomposition and trend analysis were performed with STATA V.16.0 (Stata Corporation, College Station, TX, USA). The estimates were made considering the complex design of the survey through the `svy` command. By adjusting the stratum, clusters and primary sampling units, the sampling errors were corrected. The spatial analysis was performed with ArcGIS V.10.8 (ESRI, Redlands, CA, USA) and SaTScan V.9.6. Values of p<0.05 were considered significant and confidence intervals were computed to 95% CI.

Decomposition analysis
In order to determine the factors that contributed to the increase in FVC, a multivariate decomposition for non-linear response models with the logit-based approach was used. For logistic regression, the logit or log-odd of the FVC over time is given by:

$$\text{logit}(\text{A}) = \text{logit}(\text{B}) - [\text{R}(\text{A}) + \text{R}(\text{B}) - \text{R}(\text{A}) \cdot \text{R}(\text{B})]$$

This uses the result of the logistic regression model to divide the increase in FVC over time into two components (overall decomposition). An E component attributable to differences in endowments or characteristics (characteristics effects), and a C component attributable to differences in coefficients or effects (coefficients effects). Likewise, to estimate the contribution of each factor for each component, E and C were separated into portions (detailed decomposition). This analysis was performed by using the `mdecomp` command.34

Time trend analysis
The FVC was yearly estimated from 2010 to 2019. Subsequently, the trend pattern of those years was analysed with

Table 1  Sociodemographic characteristics of children aged 12–59 months in Peru, 2010 and 2019

| Characteristics | Children aged 12 to 59 months | DHS 2010 | DHS 2019 |
|-----------------|-------------------------------|----------|----------|
|                 | n=5 751                       | n=14 144 |
| Child age (months) |                              | (%)      | (%)      |
| 1–23            | 28.04                         | 26.51    |
| 24–35           | 24.38                         | 24.55    |
| 36–47           | 24.09                         | 25.29    |
| 48–59           | 23.5                          | 23.65    |
| Sex             |                               |          |          |
| Male            | 50.32                         | 50.35    |
| Female          | 49.68                         | 49.65    |
| Residence area  |                               |          |          |
| Urban           | 64.43                         | 74.54    |
| Rural           | 35.57                         | 25.44    |
| Place of delivery |                             |          |          |
| Home            | 18.08                         | 6.23     |
| Health facility | 81.92                         | 93.77    |
| Mother’s age at first delivery (years) | |          |          |
| <20             | 47.04                         | 41.86    |
| ≥20             | 52.96                         | 58.14    |
| ANC follow-up (visits) |                       |          |          |
| ≤6              | 28.29                         | 16.73    |
| >6              | 71.71                         | 83.27    |
| Mother’s education |                             |          |          |
| No education or primary | 36.38                  | 19.82    |
| Secondary       | 42.38                         | 45.62    |
| Higher          | 21.24                         | 34.56    |
| Wealth Index    |                               |          |          |
| Poorest         | 24.91                         | 23.95    |
| Poor            | 23.09                         | 24.32    |
| Middle          | 21.44                         | 20.02    |
| Rich            | 17.6                          | 16.96    |
| Richest         | 12.96                         | 14.75    |
| Mother’s employment status | |          |          |
| Employed        | 61.6                          | 59.21    |
| Unemployed      | 38.4                          | 40.79    |
| Visit of health workers in the last 12 months | |          |          |
| Yes             | 42.27                         | 45.48    |
| No              | 57.73                         | 54.52    |
| Sex of the household head |                       |          |          |
| Male            | 83.33                         | 77.5     |
| Female          | 16.67                         | 22.5     |
| Family size (members) |                             |          |          |
| ≤4              | 34.95                         | 44.77    |
| >4              | 65.05                         | 55.23    |
| Source of vaccination data | |          |          |
| Record card     | 69.11                         | 81.93    |
| Verbal report   | 30.89                         | 18.07    |

ANC, antenatal care; DHS, Demographic and Health Survey.
Cochran-Armitage trend test; whose null hypothesis establishes the linearity of the trend. It calculates a Pearson $\chi^2$ statistic for trend in binary proportions across levels of a single factor.

**Spatial analysis**

FVC was estimated at the departmental level and plotted on a choropleth map. Spatial autocorrelation was evaluated using the Global Moran’s I statistic. This has a range of values from −1 to +1, where −1 indicates a disperse pattern, 0 indicates a random pattern and 1 indicates a clustered pattern. To evaluate its significance, the $z$-score and $p$ value were estimated. To estimate the FVC with better geographical accuracy, an ordinary kriging spatial interpolation (Gaussian process regression) was conducted, which estimates the coverage of the unsampled/unmeasured areas, based on the sampled areas. These analyses were performed in ArcGIS V.10.8.

In the presence of positive Global Moran’s I (clustered pattern), we performed the Kulldorff’s purely spatial scan statistical analysis to identify high-risk clusters of incomplete vaccination coverage in SaTScan V.9.6. This software uses a circular scanning window, which moves systematically around the study area in search of clusters. Bernoulli based model was employed, in which infants with incomplete coverage were defined as cases and infants with FVC as controls. The maximum size of the clusters was set at 50% of the population, which allows identifying small and large clusters. For each potential cluster, a log-likelihood ratio (LLR) was calculated, based on 999 Monte Carlo replications. A cluster was considered statistically significant when its LLR is greater than the Monte Carlo standard critical value for a significance level of 0.05. The clusters identified were ranked according to their LLR. The primary cluster was defined as the one with the highest LLR and the others as secondary clusters.35

**RESULTS**

**Characteristics of the study population**

In this study, a total sample of 5,751 and 14,144 children aged between 12 and 59 months from 2010 to 2019 DHSs were included, respectively (online supplemental file 2).

The average age of the participants was 35.39 (SD: 14.02) months in 2010 and 35.78 (SD: 13.89) months in 2019. The population living in urban areas increased from 64.43% in 2010 to 74.54% in 2019. Likewise, the proportion of deliveries in healthcare facilities increased from 81.92% in 2010 to 93.77% in 2019. In 2010, 21.24% of mothers had a higher educational level, this figure increased to 34.56% in 2019. Families with more than four members decreased from 65.05% to 55.23%, between 2010 and 2019, respectively. In addition, the proportion of infants who had more than 6 ANC visits increased from 71.71% to 83.27%. Moreover, 69.11% of the vaccination data was obtained from record cards in 2010, while 81.93% in 2019. Except for the distribution of sex, age and socioeconomic level; all other variables showed significant changes in the composition of infants between the surveys (table 1).

**Vaccination coverage**

FVC increased from 53.62% (95% CI 51.75% to 55.49%) in 2010 to 75.86% (95% CI 74.84% to 76.85%) in 2019. Only the polio 1 vaccine achieved a coverage greater than 95% in 2010; while in 2019, the BCG, polio 1, polio 2 and DPT1 vaccine reached this threshold. The dropout rate between the polio 1 and polio 3 vaccines decreased from 17.12% in 2010 to 8.93% in 2019. Moreover, the dropout rate between the DPT 1 and DPT 3 vaccines decreased from 11.55% in 2010 to 9.02% in 2019 (figure 1).

FVC has increased between 2010 and 2019 by 22.24%. Children aged 48–59 months were the age range with the greatest increase (26.77%) in FVC in this period. The group of children whose mothers had a higher education level and mothers without education or primary education
## Table 2  Full vaccination coverage distribution among children 12–59 months in Peru in 2010 and 2019

| Characteristics                      | FVC in children aged 12 to 59 months | DHS 2010 | By vaccination record card | By verbal report | DHS 2019 | By vaccination record card | By verbal report | Percent change 2010–2019 (%) |
|--------------------------------------|--------------------------------------|----------|----------------------------|------------------|----------|----------------------------|------------------|-------------------------------|
|                                      | All data sources*                    | (%)      | (%)                        | (%)              | All data sources* | (%)                  | (%)              | (%)                           |
| Child age (months)                   |                                      |          |                           |                  |          |                           |                  |                               |
| 12–23                                | 52.06                                | 62.68    | 14.29                     | 74.16            | 79.67    | 31.23                     | 22.1             |                               |
| 24–35                                | 59.81                                | 75.37    | 17.29                     | 78.2             | 86.32    | 34.32                     | 18.39            |                               |
| 36–47                                | 53.87                                | 78       | 10.67                     | 75.61            | 85.61    | 38                        | 21.74            |                               |
| 48–59                                | 48.85                                | 77.13    | 7.66                      | 75.62            | 87.57    | 39.72                     | 26.77            |                               |
| Sex                                  |                                      |          |                           |                  |          |                           |                  |                               |
| Male                                 | 51.91                                | 70.98    | 11.24                     | 75.23            | 84.59    | 34.89                     | 23.32            |                               |
| Female                               | 55.37                                | 73.59    | 12.54                     | 76.5             | 84.43    | 38.6                      | 21.13            |                               |
| Residence area                       |                                      |          |                           |                  |          |                           |                  |                               |
| Urban                                | 54.08                                | 73.18    | 13.75                     | 75.89            | 85.22    | 37.15                     | 21.81            |                               |
| Rural                                | 52.82                                | 70.77    | 8.03                      | 75.8             | 82.56    | 34.66                     | 22.98            |                               |
| Place of delivery                    |                                      |          |                           |                  |          |                           |                  |                               |
| Home                                 | 42.78                                | 60.24    | 5.79                      | 61.13            | 70.5     | 21.76                     | 18.35            |                               |
| Health facility                      | 56.28                                | 75.27    | 13.36                     | 77.14            | 85.76    | 37.79                     | 20.86            |                               |
| Mother’s age at first delivery (years)|                                      |          |                           |                  |          |                           |                  |                               |
| <20                                  | 48.28                                | 66.51    | 8.32                      | 71.71            | 81.54    | 31.69                     | 23.43            |                               |
| ≥20                                  | 58.38                                | 77.37    | 15.09                     | 78.85            | 86.57    | 40.83                     | 20.47            |                               |
| ANC follow-up (visits)               |                                      |          |                           |                  |          |                           |                  |                               |
| ≤6                                   | 46.28                                | 63.86    | 10.84                     | 66.99            | 78.93    | 26.53                     | 20.71            |                               |
| >6                                   | 57.83                                | 76.77    | 13.42                     | 78.49            | 86.12    | 39.62                     | 20.66            |                               |
| Mother’s education                   |                                      |          |                           |                  |          |                           |                  |                               |
| No education or primary              | 50.33                                | 67.74    | 7.26                      | 73.21            | 80.82    | 31.59                     | 22.88            |                               |
| Secondary                            | 54.77                                | 74.17    | 12.08                     | 73.93            | 83.9     | 30.98                     | 19.16            |                               |
| Higher                               | 57                                  | 76.82    | 18.17                     | 79.94            | 87.5     | 46.7                      | 22.94            |                               |
| Wealth Index                         |                                      |          |                           |                  |          |                           |                  |                               |
| Poorest                              | 50.88                                | 67.12    | 6.87                      | 74.12            | 81.1     | 33.6                      | 23.24            |                               |
| Poor                                 | 53.57                                | 73.16    | 7.1                       | 74.59            | 84.28    | 31.75                     | 21.02            |                               |
| Middle                               | 53.9                                 | 72.77    | 13.64                     | 77.17            | 86.2     | 36.89                     | 23.27            |                               |
| Rich                                 | 55.96                                | 75.73    | 16.31                     | 78.75            | 88.47    | 38.3                      | 22.79            |                               |
| Richest                              | 55.42                                | 76.22    | 17.91                     | 75.72            | 83.88    | 45.16                     | 20.3             |                               |
| Mother’s employment status           |                                      |          |                           |                  |          |                           |                  |                               |
| Employed                             | 52.72                                | 71.88    | 13.99                     | 75.19            | 84.8     | 36.95                     | 22.47            |                               |
| Unemployed                           | 55.07                                | 72.9     | 7.79                      | 76.83            | 84.12    | 36.08                     | 21.76            |                               |
| Visit of health workers in the last 12 months |          |          |                           |                  |          |                           |                  |                               |
| Yes                                  | 58.55                                | 75.19    | 15.95                     | 79.16            | 86.97    | 40.11                     | 20.61            |                               |
| No                                   | 50.02                                | 70.03    | 9.31                      | 73.12            | 82.39    | 34.15                     | 23.1             |                               |
| Sex of the household head            |                                      |          |                           |                  |          |                           |                  |                               |
| Male                                 | 54.29                                | 72.23    | 12.23                     | 76.68            | 84.84    | 37                        | 22.39            |                               |
| Female                               | 50.33                                | 72.66    | 10.32                     | 73.07            | 83.31    | 35.72                     | 22.74            |                               |
| Family size (members)                |                                      |          |                           |                  |          |                           |                  |                               |
| ≤4                                   | 53.99                                | 75.05    | 1001                      | 79.88            | 87.2     | 40.3                      | 25.89            |                               |
| >4                                   | 53.44                                | 70.87    | 1293                      | 72.61            | 82.21    | 34.35                     | 19.17            |                               |

*The denominator includes all children, and the numerator includes all children with FVC.
†The denominator includes all children whose source of vaccination data was the record card, and the numerator includes those children with FVC from the same source.
‡The denominator includes all children whose source of vaccination data was the verbal report, and the numerator includes those children with FVC from the same source.

ANC, antenatal care; DHS, Demographic and Health Survey; FVC, full vaccination coverage.
increased their coverage by 22.94% and 22.88%, respectively. In addition, FVC showed an increase of 25.89%, 23.43% and 23.24% in households with four or fewer members, mother’s aged less than 20 years at first delivery, and the lowest wealth status, respectively. Similarly, the group of children with employed mothers increased its FVC by 22.47%, while the increase was 22.74% in those having a female-headed household, and 21.81% in those who live in urban areas (table 2).

**Decomposition analysis**

The overall decomposition analysis revealed that about 70% of the increase in FVC was attributable to the difference in coefficients (C component), while the remaining 30% was attributed to the difference in characteristics or endowments (E component) (table 3).

In the detailed decomposition analysis, with regard to the effect of characteristics, many factors that contributed to the change in FVC were identified. The findings of the study indicated that an estimated increase of 14.74% was due to delivery at health facilities (B=0.038, 95% CI 0.027, 0.049). In addition, having more than 6 ANC visits contributed with 11.82% (B=0.030, 95% CI 0.023 to 0.038); while a family size of 4 or fewer members with 5.03% (B=0.013, 95% CI 0.008 to 0.018). Living in a rural setting was negatively associated with the change (−2.79%, B=−0.007, 95% CI −0.011 to −0.003). Other factors identified were having a male-headed household (0.03% B=0.001, 95% CI 0.001 to 0.001), having received a health worker visit in the last 12 months (2.34%, B=0.006, CI 95% 0.004 to 0.008) and having a mother over 20 years old at her first delivery (3.78%, B=0.009, 95% CI 0.006 to 0.013). On the other hand, regarding effects of coefficients, 10.87% and 5.39% of the increase in FVC was due to smaller families (B=0.028, 95% CI 0.14 to 0.042), and being rich (B=0.014, 95% CI 0.001 to 0.027), respectively (table 4).

**Time trend analysis**

FVC increased by 22.24% between 2010 and 2019. The annual growth rate was 2.22%. The highest increase (10.39%) was between 2010 and 2011. The trend was non-linear (P trend test p<0.0001) (figure 2).

**Spatial analysis**

The departments with the lowest coverage in 2019 were Puno (65.26%), Madre de Dios (68.92%) and Loreto (69.57%); meanwhile the departments with the highest coverage were Tumbes (87.62%), Huánuco (87.25%) and Tacna (84.22%) (figure 3A). The spatial autocorrelation analysis revealed a clustered pattern of FVC (Global Moran’s I=0.01, p<0.0001) (online supplemental file 3).

Kulldorff’s spatial scan statistic identified seven statistically significant high-risk cluster areas with incomplete vaccination coverage in 2019. It means that the prevalence of incomplete vaccination coverage is higher inside the circular window than outside the circular window. The most likely primary cluster (cluster 1) was located between Loreto and Amazonas (LLR 41.07, p<0.0001). The second most likely cluster (cluster 2) comprised the regions of Madre de Dios, Puno and Cusco (LLR 26.20, p<0.0001). The third most likely cluster (cluster 3) was detected in Lima, Ica and Huancavelica regions (LLR 21.51, p<0.0001). The fourth most likely cluster (cluster 4) comprised regions of Ancash, Trujillo, Cajamarca and San Martín (LLR 16.14, p<0.0003). The fifth most likely cluster (cluster 5) was detected between the north of Lima and the south of Ancash (LLR 12.27, p 0.014). Likewise, the sixth (cluster 6) and seventh (cluster 7) most likely clusters were detected between Junin and Pasco regions (LLR 10.97, p 0.041) and Piura region (LLR 10.88, p 0.043), respectively (figure 3C and online supplemental file 4).

**DISCUSSION**

We performed a secondary data analysis from 2010 to 2019 Peruvian DHS, which are representative at national level. There have been many improvements in certain sociodemographic and health indicators in the last decade, such as urbanisation, childbirth institutionalisation, education, among others, which have positively impacted on child health, and have reduced infant mortality, anaemia and malnutrition. In the same way, FVC has increased in recent years. We found an increase from 53.62% to 75.86% between 2010 and 2019, respectively. Nevertheless, our country still remains below the threshold recommended by the WHO and the global vaccination coverage. The low FVC found in 2019 implies the eventual failure of our country to achieve the goals established in the Global Vaccine Action Plan 2011–2020, implemented by WHO, which seeks to achieve ≥90% coverage in all vaccines for

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**Table 3** Overall decomposition analysis of the increase in full vaccination coverage among children aged 12–59 months in Peru, 2010–2019

| FVC | Coefficient | 95% CI | Percentage | P value |
|-----|-------------|--------|------------|---------|
| E   | 0.07593     | 0.06912 to 0.08274 | 29.61 | <0.001 |
| C   | 0.18056     | 0.16160 to 0.19951 | 70.39 | <0.001 |
| R   | 0.25649     | 0.23840 to 0.27458 |          | <0.001 |

C, coefficient; E, endowment; FVC, full vaccination coverage; R, residual.

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Furthermore, strict social, economic and health measures implemented by the government to mitigate the effects of the COVID-19 pandemic have hindered the access to vaccination, which could lead to a decrease in FVC. This implies a situation of vulnerability to outbreaks and an increase in public expenditure on the treatment of immune-preventable diseases.

This study did not find a significant gap in FVC between urban and rural areas, unlike other studies. This is mainly due to the increase in availability of vaccines in the lowest socioeconomic level, which was previously much lower compared with other wealth quintiles. In addition, MINSA has made great efforts to promote vaccinations through the support of social programmes in recent years. This has led Peru to be considered one of the four Latin American countries that have achieved the greatest progress in improving coverage among the lowest quintiles. However, large differences in FVC are still observed on December 5, 2022 by guest. Protected by copyright.

### Table 4: Detailed decomposition analysis of the change in full vaccination coverage (FVC) among children aged 12–59 months in Peru, 2010–2019

| FVC                              | Endowments (E) | Pct  | Coefficients (C) | Pct  |
|----------------------------------|----------------|------|------------------|------|
|                                  | Coef (95% CI)  |      | Coef (95% CI)    |      |
| Residence area                   |                |      |                  |      |
| Rural                            | -0.007 (-0.01089 to 0.00339)* | -2.79 | 0.01261 (-0.00334 to 0.02856) | 4.92 |
| Urban                            | Ref            | Ref  | Ref              | Ref  |
| Wealth Index                     |                |      |                  |      |
| Poorest                          | Ref            | Ref  | Ref              | Ref  |
| Poor                             | -0.00125 (-0.00336 to 0.00086) | -0.48 | -0.00304 (-0.01448 to 0.0084) | -1.19 |
| Middle                           | -0.00041 (-0.00133 to 0.00049) | -0.16 | 0.01194 (-0.00225 to 0.02615) | 4.66 |
| Rich                             | 0.00017 (-0.00007 to 0.00043) | 0.06 | 0.01384 (0.00037 to 0.02731)* | 5.39 |
| Richest                          | -0.00153 (-0.00331 to 0.00025) | -0.59 | 0.00685 (-0.00506 to 0.01878) | 2.67 |
| Sex of the household head        |                |      |                  |      |
| Male                             | 0.00008 (0.00003 to 0.00012)* | 0.03 | 0.02364 (-0.01498 to 0.06227) | 9.22 |
| Female                           | Ref            | Ref  | Ref              | Ref  |
| Family size (members)            |                |      |                  |      |
| ≤4                               | 0.01289 (0.00804 to 0.01776)* | 5.03 | 0.02789 (0.01371 to 0.04206)* | 10.87 |
| >4                               | Ref            | Ref  | Ref              | Ref  |
| Visit of health workers in the last 12 months |                |      |                  |      |
| No                               | Ref            | Ref  | Ref              | Ref  |
| Yes                              | 0.00599 (0.00362 to 0.00836)* | 2.34 | -0.00459 (-0.01982 to 0.01062) | -1.79 |
| Mother’s employment status        |                |      |                  |      |
| Unemployed                       | 0.01841 (-0.00003 to 0.00371) | 0.72 | 0.00195 (-0.01152 to 0.01543) | 0.76 |
| Employed                         | Ref            | Ref  | Ref              | Ref  |
| Mother’s education               |                |      |                  |      |
| No education or primary           | Ref            | Ref  | Ref              | Ref  |
| Secondary                        | -0.00263 (-0.00561 to 0.00033) | -1.03 | -0.01686 (-0.036 to 0.00227) | -6.57 |
| Higher                           | 0.00386 (-0.00569 to 0.01342) | 1.51 | 0.00188 (-0.0125 to 0.01627) | 0.73 |
| ANC follow-up (visits)           |                |      |                  |      |
| ≤6                               | Ref            | Ref  | Ref              | Ref  |
| >6                               | 0.03031 (0.02291 to 0.03772)* | 11.82 | 0.01189 (-0.01660 to 0.04039) | 4.64 |
| Mother’s age at first delivery (years) |                |      |                  |      |
| <20                              | Ref            | Ref  | Ref              | Ref  |
| ≥20                              | 0.00969 (0.00587 to 0.01350)* | 3.78 | -0.01008 (-0.03068 to 0.01051) | -3.93 |
| Place of delivery                |                |      |                  |      |
| Home                             | Ref            | Ref  | Ref              | Ref  |
| Health facility                  | 0.03779 (0.0265 to 0.04909)* | 14.74 | 0.03058 (-0.01502 to 0.07618) | 11.92 |
| Constant                         | 0.07203 (-0.00983 to 0.1539) | 28.08 |

*Significance at p<0.05.
ANC, antenatal care.
according to the child’s place of delivery, mother’s educational status, mother’s age at first delivery, number of ANC visits, family size and visit of health workers in the last 12 months.

Although the coverage of each vaccine has increased between 2010 and 2019, half of them did not reach the recommended 95% coverage, which is necessary to guarantee the prevention of these diseases. Regarding the BCG vaccine, given the endemic nature of tuberculosis in Peru, its high coverage in 2019 (95.45%) is favourable since it provides protection against severe clinical presentations in infants. On the other hand, DPT and polio vaccine dropout rate have been greater than the 5% recommended by the Pan American Health Organization, both in 2010 and 2019. Recently, an epidemic alert declared the first case of diphtheria in 20 years in Peru, which reflects the consequences of a suboptimal vaccination coverage. Otherwise, polio vaccination has led to eradicate polio in the Americas; therefore, full doses administration are necessary for proper immunity development. It should be noted that MINSA introduced a new polio vaccine schedule since 2013, in which the first and second doses from oral polio vaccine to inactivated polio vaccine were changed, according to post eradication recommendations. In addition, the inadequate coverage of measles vaccine and the recent massive migration of Venezuelans with the absence of the respective public health policies, contributed to the emergence of measles outbreaks since 2018. In 2018, 42 indigenous cases were reported, 85.7% of which were located in regions found within our high-risk clusters. Meanwhile, in 2019, three imported cases were reported. In order to control the increase in cases, the government ordered a vaccination campaign at a national level in 2019. Thereafter, no cases were reported.

Figure 2  Time trend of full vaccination coverage in children aged 12–59 months in Peru, 2010–2019. P trend p<0.0001.

Figure 3  (A) Choropleth map at the departmental level of the full vaccination coverage in children aged 12–59 months in Peru, 2019 (B). Kriging interpolation of full vaccination coverage in children aged 12–59 months in Peru, 2019 (C). Spatial clustering of areas with incomplete vaccination coverage in children aged 12–59 months in Peru, 2019.
Routine administrative data on vaccination coverage could be used to monitor trends by geographical area in Peru. Indeed, the COVID-19 pandemic has highlighted the necessity of vaccination records, as it has helped to implement public health policies. Nevertheless, in the context of a fragmented and segmented health system, it is challenging. There is an electronic immunisation registry, but it has certain limitations such as the information gaps in certain areas. Although the vaccines are administered by the MINSA, the records are made from all the actors in the system, which predisposes to lag. The main difficulties facing the implementation and sustainability of an electronic registry system are financing, strong governance structures and reluctance among healthcare staff. This registry may overestimate coverage compared with the DHS, although it has been improving in recent years. Cross-sectional coverage platforms are needed, seeking greater interactivity between records.

The overall decomposition analysis showed that most of the increase in FVC between 2010 and 2019 was due to the difference in coefficients (C component). This finding is in line with a recent study conducted in Ethiopia among children aged 12–23 months. Regarding the detailed decomposition, the increase due to the effect of smaller family size is probably explained by a lower children caregiving workload that could imply bringing more time for each one of their children, compared with larger families. In contrast, another study indicated that this change was mainly attributable to the difference in the effect of mother’s education status. Otherwise, this study identified that the increase attributed to differences in characteristics (E component) was due to deliveries at health facilities, having more than six ANC visits, smaller family size, male-headed households, visit of health workers in the previous 12 months and mother’s age at first delivery. Our results coincide with other studies in which delivery at health facilities, having more ANC visits and mother’s education status contributed together to FVC raise. These findings highlight the role of maternal education, ANC follow-up and institutional delivery as essential factors to achieve an adequate immunisation coverage, being established as targets of public health policies.

FVC among children aged 12–59 months showed an upward trend between 2010 and 2019. We highlight the large increase observed between 2010 and 2011, which was probably due to the influenza AH1N1-2009 pandemic since multiple public health interventions were promoted, including the strengthening of vaccination plans. Otherwise, Peru was distinguished as the first country in Latin America in restarting immunisation campaigns among children, since its access was restricted because of the pandemic. In order to continue with this trend, a systematic review revealed that health education, providing information on immunisation, home visits, among others, may increase childhood immunisation coverage.

Recently, spatial analysis techniques application has gained importance for exploring geographical distribution of immunisation coverage. In Peru, FVC had a heterogeneous distribution at the intradepartmental and interdepartmental level. Nevertheless, a clustered pattern was found, which is consistent with other studies on vaccines. This suggests that similar coverages are aggregated in nearby geographical areas. SaTScan found the presence of seven statistically significant high-risk clusters of incomplete vaccination coverage located in different regions across the country. We hypothesise that the presence of these clusters could be due to: (1) geographical areas with low vaccine availability; (2) limited number of healthcare facilities for the assigned population; (3) remote location of health facilities; (4) presence of anti-vaccine groups and (5) poor adherence to immunisations.

The highest risk clusters mainly encompass vulnerable rural population centres amid the Amazon rainforest and the highlands. A report from the USA described that the exemptions for non-vaccination were highly clustered at different geographical scales, and the reasons for clustering could be miscellaneous, such as similar immunisation policies and the propensity of shared beliefs among neighbours. Those areas are particularly more vulnerable to future immune-preventable disease outbreaks. Precisely, the recent diphtheria case was identified in one of the clusters found by this study (cluster-3). Based on this, it is important to redirect and prioritise strategies to these geographical areas. In addition, it is essential to have an interdisciplinary group able to address the possible causes of these high-risk areas. Further studies should be conducted to evaluate the determinants of spatial clustering of low vaccination coverage in Peruvian children, and they should also address its spatio-temporal pattern over the latest years.

**Strengths and limitations**

This study has several strengths. First, to the best of our knowledge, this is the first study assessing the factors contributing to the change in FVC and its spatial pattern in a Latin American country. Second, the databases used (Peruvian DHSs) are representative at national level and have a large sample size. It has quality control methods (careful design and numerous tests of the questionnaire, intense training of interviewers, arduous and permanent supervision in field work, review of questionnaires in the field by supervisors with immediate feedback to interviewers, appropriate supervision at the processing stage of the data and careful cleaning of the file from the quality control charts) to reduce information bias. In addition, sampling weights were considered to compensate for unequal probabilities of selection and non-response. Third, multivariate decomposition analysis allowed us to estimate which factors contributed positively or negatively to the increase of FVC, being useful to propose new interventions. Similarly, spatial analysis identified specific geographical areas with incomplete vaccination coverage; hence, it facilitates an appropriate approach for future
vaccination campaigns. Fourth, despite the fact that our outcome variable (FVC) definition includes only 8 of the 15 vaccines that are currently in the Peruvian childhood immunisation schedule, which is provided by MINSA, its use allows comparisons with studies from other countries since immunisation schedules vary between them. On the other hand, this study has some limitations. The sample design of the DHS changed in 2015, which may affect inferences but not associations. As well, our results should be reevaluated in the current context. Some mothers, accounting 30.89% in 2010 DHS and 18.07% in 2019 DHS, self-reported the vaccination status as they did not have the vaccination record card at the time of the survey. This could arise information bias, and social desirability bias. In addition, due to the cross-sectional design of the study, causality cannot be determined. The vaccines administered by the MINSA schedule before 5 years and not included in our outcome definition are: rotavirus, pneumococcal, influenza, chickenpox, yellow fever, second dose of MMR and boosters of DPT and polio.

CONCLUSIONS

Although FVC has increased over the latest years, it remains below the recommended threshold. The increase of FVC was mainly attributed to the change in the effects of the characteristics of the population. Our results suggest that size of the household, visits of health workers in the previous 12 months, ANC visits and institutionalised delivery have contributed to the increase in FVC in the last decade. The spatial distribution of FVC is heterogeneous, with the presence of high-risk clusters of incomplete vaccination coverage in some regions. Based on this, interventions should be strengthened and redirected to reduce these geographical disparities. It is important to use geographical information systems for prioritising areas and an efficient allocation of resources.

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