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Patterns of basic pneumococcal conjugated vaccine coverage in Ethiopia from 2015 to 2018; further analysis of Ethiopian DHS (2016–2019)

Mulugeta Gamachu [a], Ibsa Mussa [b,*], Alemayehu Deressa [b], Moti Tolera [b], Abdi Birhanu [a], Tamirat Getachew [c], Abraham Negash [c], Usmael Jibro [c], Dureti Abdurahman [b], Aboma Motuma [c], Fethia Mohammed [d], Bikila Balis [c], Lemma Demissie Regassa [b]

[a] School of Medicine, College of Health and Medical Sciences, Haramaya University, Harar, Ethiopia
[b] School of Public Health, College of Health and Medical Sciences, Haramaya University, Harar, Ethiopia
[c] School of Nursing and Midwifery, College of Health and Medical Sciences, Haramaya University, Harar, Ethiopia
[d] Department of Psychiatry, School of Nursing and Midwifery, College of Health and Medical Sciences, Haramaya University, Harar, Ethiopia

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ABSTRACT

Background: Geographic variation is crucial in spotting performance gaps in immunization programs, including the Pneumococcal Conjugated Vaccine (PCV). This will help speed up targeted vaccination and disease elimination programs in resource-limited countries. Thus, this study aimed to investigate the geographic variation and determinants of PCV vaccination coverage among children aged under five years old in Ethiopia.

Methods: This analysis was carried out based on the 2016 and 2019 nationally representative Ethiopia Demographic and Health Survey (EDHS). We included two surveys of 10,640 children aged 12–23 months. The spatial analysis also covered 645 and 305 clusters with geographical information for both 2016 and 2019, respectively. We explored the spatial distribution, global spatial autocorrelation, spatial interpolation, and Stats Can windows of children with PCV-3 vaccination. P-values were generated using 999 Monte Carlo simulations to identify statistically significant clusters. To understand the coverage of PCV-3 in all areas of the country, we employed the ordinary Kriging interpolation method to estimate the coverage in unsampled areas. We also used hierarchical multivariate logistic regression to identify the factors associated with the utilization of the PCV vaccine (full vaccination).

Results: Except for Addis Ababa, children in all regions have lower odds of receiving all three PCV vaccines compared to the Tigray region. Residence, sex of a child, mother's literacy status, household wealth index, and place of delivery were significant factors associated with receiving the third dose of PCV. Spatial analysis also showed the Somali and Afar regions had the lowest coverage, while the Addis Ababa and Tigray regions had higher coverage in both surveys.

Conclusion: Even though the coverage of the full PCV vaccine improved from 2016 to 2019, variation was observed among regions and between rural and urban areas. The wealth index and educational status of mothers were the most important determinants of PCV vaccine utilization. Hence, the mass campaign might boost coverage in nomadic and semi-nomadic regions and rural areas. Similarly, programs that narrow the gap due to low socioeconomic differences should be formulated and implemented to increase uptake and general coverage.

Introduction

Immunization is a crucial component of primary healthcare and human rights used for preventing and controlling infectious disease outbreaks, which saves millions of lives annually. Vaccines can protect against diseases by enhancing the immune system's natural defenses [1,2]. Vaccines prevent over 25 life-threatening diseases, preventing 3.5–5 million deaths annually and promoting healthier lives [1–3]. This has resulted in a significant decline in the prevalence of all immune-preventable diseases, and some of them, like smallpox, have even

Abbreviations: **PCV**, **Pneumococcal Conjugate Vaccine**; **SSA**, Sub-Sahara Africa; **SNNPR**, **Southern Nation Nationalities and Peoples Region**; **UNICEF**, **United Nations International Children's Emergency Fund**; **WHO**, **World Health Organization**.

* Corresponding author.
E-mail address: ibsamussa93@gmail.com (I. Mussa).

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been eliminated [4,5]. Vaccines provide herd immunity and individual immunity to those who receive vaccinations [6].

Pneumococcal infections were thought to be the cause of 294,000 of the estimated 5.83 million deaths of children under the age of five that occurred worldwide in 2015; more than 90 % of these deaths took place in developing countries [7,8]. Before the pneumococcal vaccine was introduced, pneumonia accounted for 28 % of all under-five deaths in the country [9,10]. In November of 2011, the Ethiopian Ministry of Health, with support from the Global Alliance for Vaccines and Immunization (GAVI), began vaccinating children against *Streptococcus pneumoniae* with the 13-valent pneumococcal conjugate vaccine (PCV-13), which protects against 13 strains of *pneumococcal* bacteria, as part of the Ethiopian national infant immunization program [10].

Based on the World Health Organization (WHO) and United Nations International Children's Emergency Fund (UNICEF) reports, about 86 % of children completed the basic vaccination schedule in 2019 globally [11]. As a result, the global under-five mortality rate dropped from 93 per 1000 live births in 1990 to 38 per 1000 in 2019, while it was reduced from 178 per 1000 in 1990 to 78 per 1000 in 2019 in sub-Saharan Africa (SSA) [12,13]. The full basic immunization coverage rate in Ethiopia has improved substantially, from 14.3 % in 2000 to 44.1 % in 2019 [14].

The consistent increases in immunization coverage over the past few decades, pro-urban, pro-rich, and pro-educated disparities in coverage have been noted in SSA countries [15]. Low levels of education, a low wealth index, the location of residency, a weak health service delivery system, a high rate of dropouts, vaccine stock-outs, breaks in the cold chain, and a lack of an immunization culture are all factors contributing to low vaccination coverage in low-resource nations [15,16]. However, there has not been much research done on the correlation between these variables and the likelihood of receiving a full course of vaccination in the country.

Despite significant efforts by the WHO and the Ethiopian Ministry of Health to raise the national target of comprehensive basic immunization coverage to 75 %, the achievement still falls short of 53.6 % immunization of the population by 2025 [17]. Since the Sustainable Development Goal of the United Nations is to eliminate preventable infant and under-five mortality by 2030 and lower under-five mortality to 25 per 1000 live births, vaccination coverage is a crucial indicator of how well the goal is being achieved [18]. As a result, it is helpful to recognize spatial heterogeneity and understand geographic variation to spot performance gaps in PCV immunization programs. This will help speed up targeted vaccination and disease elimination programs in the country. Thus, the purpose of this study was to investigate the geographic distribution and determinants of PCV rates among children under the age of five in Ethiopia.

Methods and materials

Study setting and design

This analysis was carried out based on the 2016 and 2019 nationally representative Ethiopia Demographic and Health Survey (EDHS). Ethiopia is located between 30 and 150 north latitudes and 330 and 480 east longitudes. It has over 80 ethnic groups and is administratively split into nine regional states and two city administrations. Those regions and administrative states are Amhara, Oromia, Tigray, Benishangul-Gumuz, Somali, Afar, Harari, Southern Nations Nationalities and Peoples (SNNP), and Gambela, as well as two city administrations (Addis Ababa and Dire Dawa) [19,20]. According to the 2007 population and housing census, Ethiopia has a total population of more than 96 million people, with around 13 million children under the age of five [21]. The Ethiopian Demographic and Health Survey is regarded as the country's primary data source since it was created to provide demographic and health indicators at the national and regional levels. It is a nationally representative sample and provides estimates at the national and regional levels for rural and urban areas.

Population

We included data on children aged one year to two years (12–23 months) who expected to be fully vaccinated for the PCV. Children with basic vaccines, which are included in the expanded immunization program (EPI) were included in this study.

Sampling procedures

The EDHS used a two-stage cluster sampling design with both rural and urban regions as strata. In the first stage, enumeration areas (EA) were selected with a probability proportional to EA size, with independent selection in each sampling stratum. In the second stage, an appropriate number of households per cluster were selected with an equal probability of systematic selection. This study used a total sample of 4,852 children eligible for the PCV and their mothers from the 2016 survey and 5,752 from the 2019 survey, respectively. Moreover, we included 645 and 305 clusters with geographical information for both 2016 and 2019, respectively.

Data collection methods

Data sets were downloaded from the MEASURE DHS website. (https://www.dhsprogram.com/data/dataset_admin) after forms were filled out and requests were made to download data. The data were collected using five components of questionnaires: the Fieldworker's Questionnaire, the Household Questionnaire, the Women's Questionnaire, the Anthropometry Questionnaire, and the Health Facility Questionnaire. Additional details on the procedures for gathering data and selecting participants for both surveys are available in the EDHS 2016 [22] and 2019 reports [23].

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Study variables and measurements

The outcome variable was PCV vaccination among under-two-year-old children. In Ethiopia, PCV 13 is provided at the 6th, 10th, and 14th weeks after birth, and we computed the proportion of these three doses for each year. Socio-demographic factors, including maternal age, marital status, education level, and household wealth index, were classified into five quintiles; child-related factors, including age, sex, birth order, and being twins, and maternal health utilization factors, including antenatal care and place of delivery, were considered independent variables.

Spatial analysis

ArcGIS v.10.8.1 (ESRI, Redlands, CA, USA) and Sat Scan v.9.6 statistical software was used for exploring the spatial distribution, global spatial autocorrelation, spatial interpolation, and for identifying significant hotspot areas of children's PCV-3 vaccination. The weighted prevalence of PCV was computed for all 645 clusters in EDHS-2016 and 305 clusters in EDHS-2019 in Stata v.18. Then, the proportions were imported and linked to the existing variables in the geospatial location data (Ethiopian shapefile). The shapefile with regional and zonal boundaries for Ethiopia was accessed and obtained from the DHS along with other vaccine-related data in Stata format. The DHS provides global positioning system (GPS) coordinates for clusters, and the coordinates are displaced up to 2 km in urban areas and 5 km in rural areas, with up to 1 % of points displaced up to 10 km in rural areas [24]. The steps followed to produce maps have been described and documented elsewhere [25,26].

Autocorrelation

Global Moran's I statistic was used to measure the overall spatial autocorrelation of basic pneumococcal vaccine coverage in Ethiopia based on the locations and attribute values of the data. The value of the calculated Moran's I ranges between −1 (perfect dispersion) and + 1 (perfect correlation), with its interpretation based on its sign and magnitude. Positive autocorrelation and significance ($p < 0.05$) show evidence of similar values (high or low) that are clustered. In contrast, the existence of negative (negative autocorrelation) and significant statistics indicates dispersion (closely associated points are more dissimilar). A zero value of Moran's I statistics indicates a random spatial pattern [27].

Cluster and outlier analysis

Since the global Moran's I index can't indicate areas within the map where the different clusters (or outliers) are, we used the local Moran's I index to identify local clusters and examine their variation in spatial autocorrelation across each of the study regions. This helps to examine the relationships between each observation and its surroundings, as well as the regions or clusters that contribute more to the global spatial autocorrelation. The local Moran's index, I, whose value also ranges between −1 and + 1 [28]. In this approach, different clusters were identified, namely clusters of high values (high-high), areas of low values (low-low), and outliers. High-high areas are those with a high value of cases and are also surrounded by areas with high values, while low-low areas refer to those with a low value of cases and are also surrounded by areas with low values of the outcome. Such areas were defined as having positive spatial autocorrelation. On the contrary, all areas of low-value cases surrounded by those with high values (low–high) or vice versa (high-low) were considered outliers and therefore exhibited negative autocorrelation. A p-value < 0.05 at the 95 % confidence interval was used as a significant level for this analysis.

Hotspot analysis (Getis-Ord Gi statistic)*

We then conducted a hotspot analysis using Getis-Ord Gi* statistics to show the variation as well as identify cluster locations that have a greater proportion of children vaccinated with PCV-3. This analysis generates z-scores and p-values that help to separate clusters of high-value or high-risk areas (hotspots) from those of low-value or low-risk areas (coldspots). The statistical significance of this autocorrelation was determined by z-scores and $p < 0.05$ with a 90 % CI, 95 % CI, and 99 % CI.

Spatial scan statistics analysis

The Bernoulli-based model spatial scan statistical analysis was conducted to identify the most likely (primary) and secondary spatial clusters of immunized children using Kulldorff's SaTScan version 9.6 software. All children who took PCV-3 were taken as cases, while those who had no PCV-3 were considered controls to fit the Bernoulli model. The SaTScan uses a circular scanning window that goes across the entire region of the study. For each window at any given position, the relative risk of PCV-3 among children inside was compared to that outside the window using the likelihood ratio test. P-values were generated using 999 Monte Carlo simulations to identify statistically significant clusters. This method has been widely adopted and described elsewhere [29,30].

Spatial interpolation

To understand the coverage of PCV-3 in all areas of the country, we employed the ordinary Kriging interpolation method to estimate the coverage in unsampled areas. This technique uses data in the sampled areas to predict the prevalence in the unsampled areas since it incorporates spatial autocorrelation and optimizes the weight statistically [31].

Statistical analysis

Data analysis started with a summary of the socio-demographic characteristics, and other important factors were presented using frequency distribution analysis. The data were analyzed using STATA version 18 statistical software. The data were weighted using sampling weight, primary sampling unit, and strata before any statistical analysis to ensure the representativeness of the survey and to consider the sampling design when calculating standard errors to get reliable statistical estimates. Assuming children were born within the five years preceding the survey year, each PCV dose coverage was calculated as follows:

$$\text{Pcvi}(\%) = \left((\text{number of infants and children receiving PCVi dose})/(\text{number of infants and children born in the same year})\right) \times 100$$

where i stand for dose (1st or 2nd or 3rd).

We calculated coverage for each year separately, and the final year's (2019) data was used to model predictors. We also calculated the completeness rate as described elsewhere [32].

$$\text{PCV completeness} = \left((\text{no.of infants and children receiving full immunization})/(\text{number of infants and children receiving 1st dose}) \times 100\right)$$

To determine the relationship between PCV vaccination and predictors, logistic regression assumptions (chi-square and multicollinearity) were tested. Because members of a cluster shared a trait, the assumptions of independence of observations and equal variance across clusters were broken. To ensure the accuracy of the standard error and an unbiased estimate, it is important to overcome the violated independence assumption and take into account the variability between clusters in multi-level advanced statistical modelling. The mixed-effect model with the lowest AIC and BIC (information criteria) was chosen. Important variables were selected based on stepwise and backward elimination criteria, with a p-value of 0.2 as the cutoff point to retain variables in the model. Factors were interpreted as significant predictors of PCV vaccination if their p-value was less than 0.05. The odds ratio was used to measure how strong the link was, with a 95 % confidence interval. The estimation of the association between the PCV vaccination and explanatory variables was performed using the fixed effects model. The intra-cluster correlation coefficient (ICC) with standard deviation was employed to measure cluster variance. A null model (a model without independent variables), a model considering only individual-level factors, a model taking into account community-level variables, and a fourth model taking into account both individual and community-level variables were also fitted. The comparison of the multilevel-

Table 1
Socio-demographic and socioeconomics characteristics of the study participants.

Variables	Categories	Frequency	Percentage
Sex of household head	Male	8,411	79.3
	Female	2,193	20.7
Sex of child	Male	5,390	50.8
	Female	5,214	49.2
Educational Level of household head	No Education	5,767	54.4
	Primary	3,324	31.4
	Secondary	960	9.1
	Higher	553	5.2
Age groups mother	15–19	707	6.7
	20–24	2,360	22.3
	25–29	3,289	31.0
	30–34	2,203	20.8
	35–39	1,362	12.8
	40–44	550	5.2
	45–49	133	1.3
Place of residence	Urban	2,435	23.0
	Rural	8,169	77.0
Region	Tigray	1,040	9.8
	Afar	1,060	10.0
	Amhara	1,050	9.9
	Oromia	1,428	13.5
	Somali	1,046	9.9
	Benishangul	929	8.8
	SNNPR	1,254	11.8
	Gambela	812	7.7
	Harari	709	6.7
	Addis Adaba	594	5.6
	Dire Dawa	682	6.4
Wealth index combined	Poorest	3,460	32.6
	Poorer	1,783	16.8
	Middle	1,510	14.2
	Richer	1,346	12.7
	Richest	2,505	23.6
Child is twin	Single birth	904	97.2
	Multiple	26	2.8
Birth order	First	2,284	21.5
	Two to four	4,787	45.1
	Fifth or above	3,533	33.3

ordered logistic regression models was checked using the MOR and PCV. The best-fitting model among the fitted models was ultimately chosen using the Akaike and Bayesian Information Criteria (AIC and BIC).

Results

Participants characteristics

A total weighted sample of 10,604 children was included in the analysis. The majority, 8,411 (79.3 %) of household heads were males, and 5,390 (50.8 %) of children were males. Out of 3,289 (31.0 %), mothers were aged 25–29. More than half, 5,767 (54.4 %) of household heads, had no formal education. The majority, 8,169 (77.0 %), of respondents were rural dwellers. Regarding the region of participants, 1,428 (13.5 %), 1,254 (11.8 %), and 1,060 (10.0 %) were from Oromia, Southern Nation Nationalities and Peoples Region (SNNPR), and Afar regions, respectively. The majority, 3,460 (32.6 %), were from the poorest household wealth index status. The mean (+SD) of respondents ages at first birth was 19.0 (+4.0) **(**Table 1**)**.

Table 2
PCV Vaccination status by year and place of residency among children of Ethiopia (2016 and 2019).

PCV	Year	Urban	Rural	Total	Chi-sqr (p-value)
1st	2016	850(83.3 %)	2,088(54.5 %)	2,938(60.6 %)	2.2 (0.138)
	2019	1,150(81.3 %)	2,414(55.7 %)	3,564(62.0 %)	
2nd	2016	772(75.6 %)	1,735 (45.3 %)	2,507(51.7 %)	12.0 (0.001)
	2019	1,062(75.1 %)	2,104(48.5 %)	3,166 (55.0 %)	
3rd	2016	678(66.4 %)	1,369(35.7 %)	2,047(42.2 %)	8.4 (0.004)
	2019	950(67.2 %)	1,638(37.8 %)	2,588(45.0 %)	

PCV vaccination coverage by place of residence

Among the 10,604 participants in the study, 6,502 (61.3 %) were vaccinated for PCV-1, while the remaining 4,102 were unvaccinated. Out of 2,938 (60.6 %) children eight hundred fifty (83.3 %) who received the PCV-1 vaccination in 2016 were in urban areas, while 2,088 (54.5 %) were in rural areas. PCV-1, PCV-2, and PCV-3 each had a coverage percentage of 60.6 %, 51.7 %, and 42.2 % of these in 2016, respectively. In a similar vein, 3,564 (62.0 %) children received PCV-1 vaccinations in 2019. Of them, 2,414 (55.7 %) were rural residents and 1,150 (81.3 %) were urban dwellers. Among them, 3,166 (55.0 %) of the children received the PCV-3 shot (Table 2). The 2019 PCV coverage rose by less than 5 % from the 2016 survey. The higher coverage for PCV-2 and PCV-3 was significant, according to the chi-square test.

The coverage of PCV vaccination had a regional variation. In 2016, the highest coverage of PCV-1 (91.3 %), PCV-2 (87.8 %), and PCV-3 (80.3 %) was observed in Addis Ababa, and the lowest coverage of PCV-1 (27.7 %), PCV-2 (17.3 %), and PCV-3 (12.2 %) was reported in the Afar region. Similarly, in 2019, the highest coverage of PCV-1 (93.5 %), PCV-2 (92.4 %), and PCV-3 (87.7 %) was seen in Addis Ababa, and the coverage of PCV-1 (31.5 %), PCV-2 (24.7 %), and PCV-3 (15.9 %) was reported in the Afar region. Fig. 1 shows the PCV-3 coverage for both EDHS 2016 and Mini-EDHS 2019 (Fig. 1).

Spatial analysis

Results from both spatial and statistical analysis of both surveys showed that the variation in PCV-3 among children is heterogeneous at the regional level. The intra-cluster correlation coefficient in the final model (Table 3) indicates that 16 % of the total variability of coverage is due to communities within regions. Results from Moran's index also confirm that PCV-3 among children was generally clustered (Fig. 2).

Fig. 3 maps the hot spots and cold spots of PCV-3 (for both surveys) among regions and zones in Ethiopia. In the results, Northern Tigray, Addis Ababa, Dire Dawa, Harari, and Central Benishangul Gumuz areas had higher coverage (hotspots), while Somali, Afar, and SNNPs regions had low coverage (cold spots). Conversely, in the 2019 Mini-EDHS data, Addis Ababa is the only region with high coverage. However, SNNPs in the Afar and Somali regions remained with low coverage (Fig. 3). Additionally, the outlier analysis also strengthens the evidence from the hotspot analysis (**S1**).

Based on the Kriging interpolation technique, EDHS-2016 data showed most of the Somali region and Afar region had lower predicted coverage, while Addis Ababa, Tigray, and Dire Dawa had higher predicted coverage. On the other hand, Mini EDHS 2019 showed central and western Oromia, Addis Ababa, Dire Dawa, Harar, and northern and western Tigray; Benishangul Gumuz (Southwest) predicted higher coverage. However, Southeastern Somalia had a lower predicted coverage of PCV-3 **(S2)**.

Sat Scan Statistics Window

In 2016 data, a total of four high spots were statistically significant (one primary/most likely and the other secondary) and were identified in the spatial scan analysis as significant ($p < 0.05$). The primary cluster spatial window with a total sampled population of 1716 (llr = 111.14), covered Benishangul Gumuz, followed by Addis Ababa, Eastern Hararghe, Dire Dawa, and Gambela. The primary cluster showed that

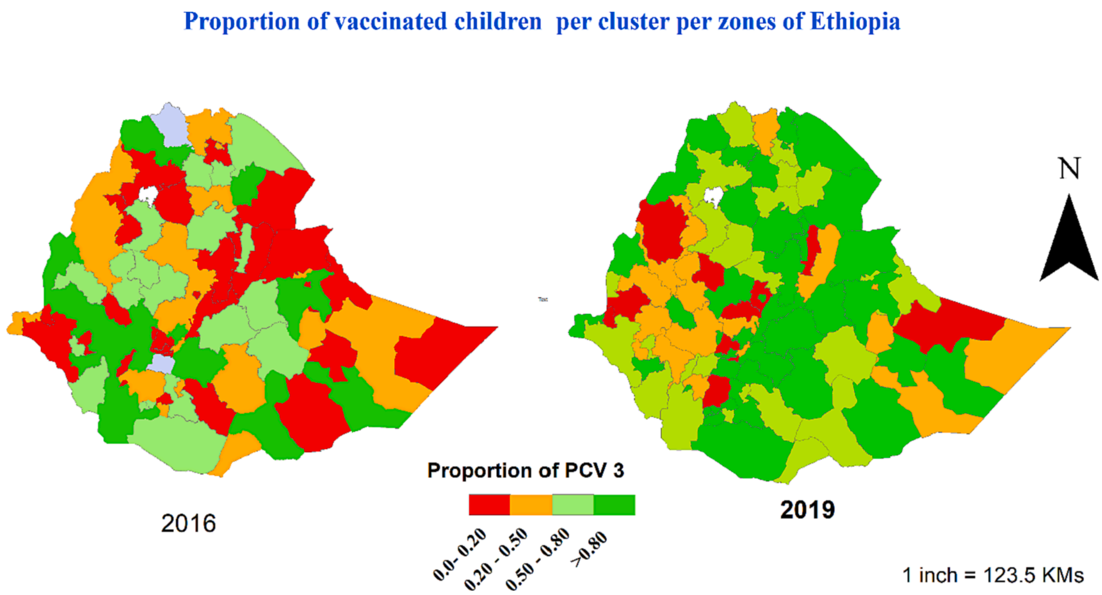

Fig. 1. Regional distribution of 3rd dose of PCV Vaccination in Ethiopia from 2015 to 2018.

Table 3
Multilevel logistic regression of factors associated with pcv-3 using edhs 2019.

Variables	Categories	AOR [95 % CI]	P>|z|
Region			
	Tigray	1.00	
	Afar	0.10 (0.06, 0.17)	0.000
	Amhara	0.63 (0.44, 0.91)	0.013
	Oromia	0.27 (0.19, 0.40)	0.000
	Somali	0.16 (0.10, 0.26)	0.000
	Benishangul	0.62 (0.41, 0.95)	0.029
	SNNPs	0.30 (0.21, 0.44)	0.000
	Gambela	0.28 (0.18, 0.44)	0.000
	Harari	0.25 (0.17, 0.38)	0.000
	Addis Ababa	0.94 (0.59, 1.51)	0.809
	Dire Dawa	0.50 (0.32, 0.76)	0.001
Residence			
	Urban	1.00	
	Rural	0.60 (0.45, 0.80)	0.001
Sex of child			
	Male	1.00	
	Female	0.88 (0.78, 0.99)	0.032
Sex of household head			
	Male	1.00	
	Female	1.06 (0.90, 1.24)	0.479
Age of mother		0.99 (0.98, 1.01)	0.379
Literacy			
	Cannot read at all	1.00	
	Able to read	1.33 (1.11, 1.60)	0.002
Household wealth index			
	Poorest	1.00	
	Poorer	1.53 (1.25, 1.88)	0.000
	Middle	1.74 (1.41, 2.14)	0.000
	Richer	1.88 (1.47, 2.40)	0.000
	Richest	2.39 (1.81, 3.16)	0.000
Twin birth			
	Single Birth	1.00	
	Multiple	0.84 (0.44, 1.60)	0.596
Delivery			
	Home	1.00	
	Health Facilities	1.90 (1.62, 2.23)	0.000
Cluster			
	var(_cons)	0.61 (0.48, 0.78)	
ICC		**15.68 % (12.72, 19.16)**	

clusters within this window were 1.64 times more likely to have higher coverage compared to children outside the area. Further, in the 2019 data, a total of three high spots that were statistically significant (one primary or most likely and the other secondary) were identified in the spatial scan analysis as significant ($p < 0.05$). The primary cluster spatial window, with a total sampled population of 2074 (llr = 156.6), covered the Benishangul Gumuz Assosa zone, followed by Addis Ababa and the Eastern Hararghe Zone, respectively. The primary cluster showed that clusters within this window were 1.43 times more likely to have higher coverage compared to children outside the area. A list of primary and secondary districts in each of the sub-regions has been presented in the **(S3 Table).**

Determinants of receiving the 3rd dose of PCV

Using stepwise selection methods, we included nine variables in the final model. Among these nine variables, residence, sex of the child, mother's literacy status, household wealth index, and place of delivery were significant factors associated with receiving the third dose of PCV. Except for Addis Ababa, children in all regions have lower odds of receiving all three PCV vaccines compared to the Tigray region. The likelihood of children from the Afar, Somali, and Harari regions receiving the third dosage of PCV was the lowest among these regions, at 90 %, 84 %, and 75 %, respectively. The odds of receiving all three doses of PCV decreased by 40 % (AOR = 0.60; 95 % CI: 0.45, 0.80) among children in rural areas compared to urban residents. The probability of female children receiving a full PCV was lower by more than 10 % (AOR = 0.88; 95 % CI: 0.78, 0.99) compared to male children. Those children whose mothers can read and write have a 33 % (AOR = 1.33; 95 % CI: 1.11, 1.60) higher chance of receiving a full dose of the PCV compared to children whose mothers cannot read. The chance of receiving all doses of the PCV increased with the household wealth index; children from the middle and rich wealth index quintiles were 1.7 and 1.9 times more likely to receive all doses of the PCV compared to children from the poorest households, respectively. Similarly, the chance was 2.4 times higher for children from the richest households compared to the poorest households. Finally, children born at health facilities (AOR = 1.90; 95 % CI: 1.62, 2.23) are more likely to have a full PCV compared to children born at home.

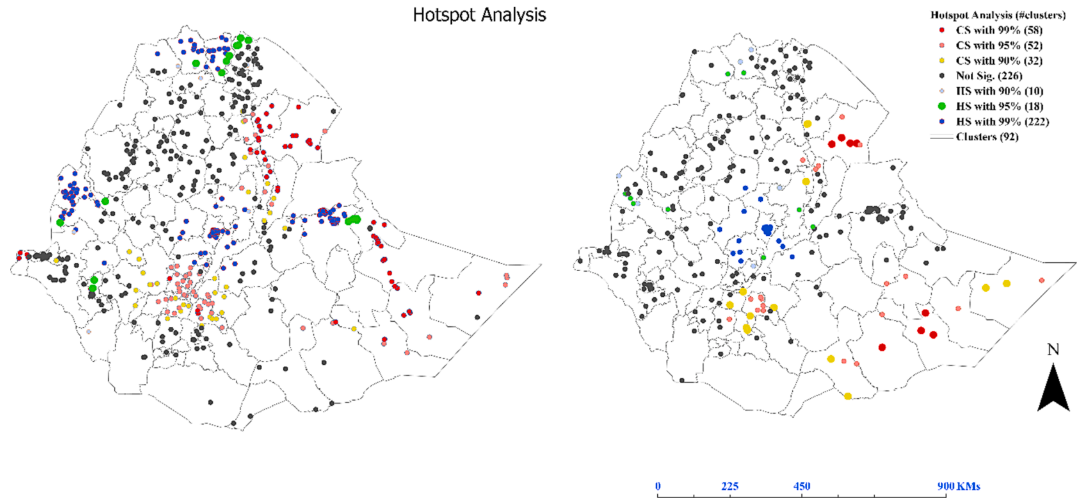

Fig. 2. Spatial variation of PCV vaccination in Ethiopia.

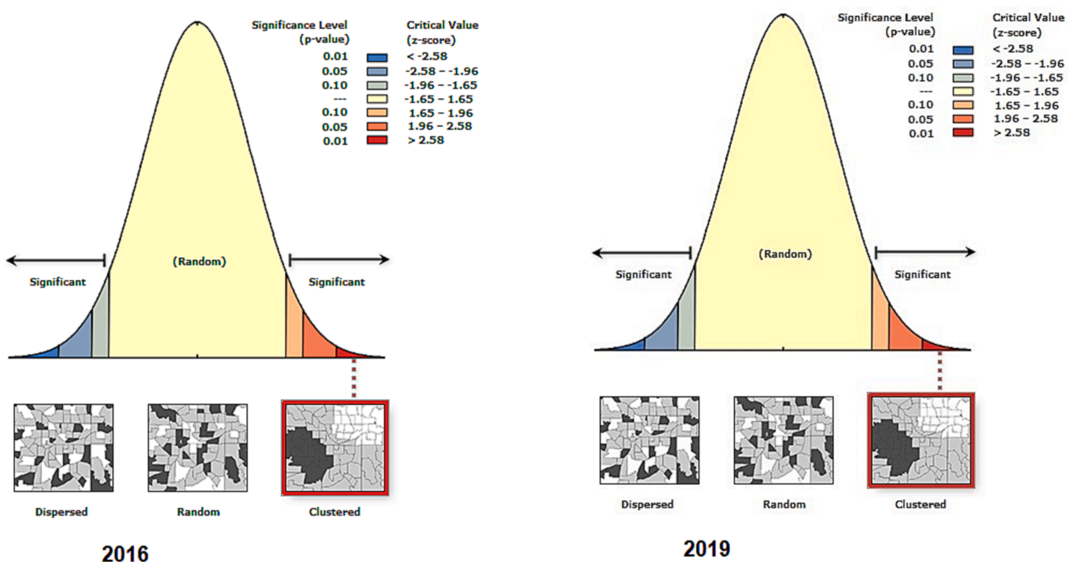

Fig. 3. Cluster variation of regions in PCV vaccination.

Discussion

This study evaluated the spatial variation and associated factors of PCV-3 vaccination in Ethiopia. A total of 2,938 (60.6 %) eligible children received PCV-1 vaccinations in 2016, and 3,564 (62.0 %) did so in 2019. Children in rural areas, female children, mother's literacy status, household wealth index, and place of delivery were factors significantly associated with PCV-3 vaccination. The recent (2019) overall coverage of PCV-1, PCV-2, and PCV-3 was 62.0 %, 55.0 %, and 45.0 %, respectively. A significant difference was observed in PCV-2 and PCV-3 vaccination coverage, with a slight increment from 2016 to 2019. There was also a regional variation in overall PCV-3 vaccination coverage, in which higher coverage was observed in Tigray, Addis Ababa, Benishangul Gumuz, Dire Dawa, Harar, and central Oromia regions, while Somalia, Afar, and SNNPs are regions with lower coverage of PCV3 vaccination.

This study showed that the likelihood of PCV vaccination was lower among children from all regions except Addis Ababa compared to those from the Tigray region. A spatial analysis of this study also reported a regional difference in overall PCV vaccination coverage. This finding is supported by studies conducted in Ethiopia that showed childhood vaccination coverage varied across different regions of the country [33–35], in which lower levels of complete basic childhood were reported in similar regions to the current study. This might be due to disparities in the health care systems, poor infrastructure such as transportation and electricity, and geographic access to mother and child health information. Additionally, two-thirds of Ethiopia's landmass is made up of pastoral and semi-pastoral regions, with the Somali region in the east and southeast, the Afar region in the northeast, and the Borena zone in the south being the most significant in terms of population and area occupied. People in pastoral villages frequently have semi-nomadic lifestyles, and many of them are rudimentary and easily mobile [36].

The study found that the odds of receiving all three doses of PCV decreased by 40 % among children in rural areas compared to urban residents, which is supported by the study conducted in Ethiopia, which reported that fifty percent of children from rural areas were not vaccinated for measles [36]. This finding is also supported by the studies done in Northwest Ethiopia [37], Ghana [38], and Afghanistan [39]. This could be a result of disparities in the availability and accessibility of immunization services in rural and urban areas due to several health-related factors. It was claimed that the distance to health facilities in pastoralist and semi-pastoralist regions has been noted as a difficulty for routine immunization services, which could explain the geographical variances [40].

The child's sex was significantly associated with PCV vaccination. The probability of female children receiving a full PCV-3 was lower by 12 % compared to male children. This finding is in line with the studies done in northwest Ethiopia [41], Amhara Regional State, Ethiopia [42], Bangladesh [43], and Pakistan [44] that found gender-based sex disparities in access to health services. This might be explained by the fact that, in the Ethiopian context, families and/or caregivers favor taking males to healthcare facilities, especially those located in rural areas. This may be the result of a lack of understanding of gender equality and inadequate education.

The study also depicted that children whose mothers can read and write have a 1.3 times higher chance of PCV-3 compared to children whose mothers cannot read and write. This study is consistent with other research showing a relationship between a mother's educational attainment and the likelihood of completing the recommended dose of vaccine among children [45–47]. Another study's findings found that children of mothers with at least a secondary level of education have a higher chance of completing the recommended dose of the immunization series than children of mothers with no formal education [48,49]. One possible explanation could be that mothers are more likely to comprehend written vaccine-related health messages and obtain knowledge about the benefits of vaccinating their children through various media as their educational attainment increases, which directly relates to getting their children vaccinated, including PCV. There are a variety of potential explanations for why educated mothers vaccinate their children more frequently than uneducated mothers. Educated mothers have greater access to healthcare services, sources of information that support vaccination, and knowledge of the advantages and risks of vaccine-preventable diseases. They may also be influenced by peer-based education interventions that use conversation and trust to encourage vaccination [50,51].

The study revealed that a child whose household had a wealth index of poorer, middle, richer, and richest was 1.5, 1.7, 1.9, and 2.4 times more likely to be fully PCV vaccinated compared to children with a wealth index of poorest. This finding is in line with similar studies that found that as the household wealth index quintile rises, children are more likely to be fully vaccinated [46,52,53]. This is explicitly related to the fact that as the wealth index rises, households may have TV, radio, and mobile devices, which may directly relate to having the chance of getting key vaccinations transmitted [54,55]. On another occasion, even though they are far from the vaccination-giving health care center, the mothers may easily pay and use public transportation or their private transportation for the three cumulative doses of pneumococcal conjugate vaccines [56,57].

Finally, the study revealed that children born at health facilities are two times more likely to have a full PCV3 compared to children born at home. This finding is in line with similar studies that found the place of delivery and completed the recommended dose of vaccine [46,58]. This is explicitly explained: mothers who gave birth in health facilities are more likely to vaccinate their children because they have the opportunity to learn more about immunizations, and the chance to develop a greater level of trust in the health professionals who provide them with a vaccine and the chance to receive more education and counseling about the value and advantages of vaccination [59–62].

Conclusion

The Global Moran I statistics of the spatial variation of PCV vaccination among children in Ethiopia showed that there is a spatial dependency with clustering (p-value = 0.01). The spatial analysis identified that PCV has significant spatial variation across the country. Tigray, Addis Ababa, Benishangul Gumuz, Dire Dawa, Harari, and central Oromia were regions that showed the highest cluster coverage of PCV vaccination, while Somalia, Afar, and SNNPs were identified as having low coverage. Children in rural areas, female children, mothers' literacy status, household wealth index, and place of delivery were factors significantly associated with PCV vaccination. Thus, to increase PCV vaccination coverage in Ethiopia, public health services should develop focused interventions like immunization campaigns in recognized cold spots with lower coverage and associated determinants. The promotionof ideal institutional delivery and support for women's education should be a priority for health programmers.

Strengths and limitations of this study

- This study used nationally representative data, which were collected with standardized and validated data collection tools.
- This study used an advanced model that accounts for the correlated nature of the Ethiopian Demographic and Health Survey (EDHS) data in the determination of estimates.
- The cross-sectional nature of the survey does not show the temporal or causal relationship between independent variables and the outcome variable.
- In addition, due to the use of secondary data, essential factors such as attitudes and knowledge about pneumococcal conjugated vaccination techniques and PCV training for healthcare workers were not accessible in the EDHS and were thus excluded from our analysis.

Consent to the publication

Not applicable.

Authors' contributions

All authors devised the project, the main conceptual ideas and the proof outline. LDR and IM designed the model and the computational framework and analysed the data. MG and ADW wrote the draft with IM and LDR. All authors discussed the results and contributed to the final manuscript. IM supervised the overall study process. All authors reviewed and approved the manuscript for the publication.

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CRediT authorship contribution statement

Mulugeta Gamachu: Data curation, Conceptualization. **Ibsa Mussa:** . **Alemayehu Deressa:** Writing – review & editing. **Moti Tolera:** Data curation. **Abdi Birhanu:** Conceptualization. **Tamirat Getachew:** Data curation, Conceptualization. **Abraham Negash:** Writing – review & editing, Conceptualization. **Usmael Jibro:** Data curation, Conceptualization. **Dureti Abdurahman:** Writing – review & editing, Data curation, Conceptualization. **Aboma Motuma:** Data curation, Conceptualization. **Fethia Mohammed:** Data curation. **Bikila Balis:** Conceptualization. **Lemma Demissie Regassa:** .

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data for this study were sourced from Ethiopian Demographic and

Health Surveys (EDHS) and are available at: https://www.dhsprogram.com/data/dataset_admin.

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