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# Risk factors associated with zero-dose and under-immunized children, and the number of vaccination doses received by children in Ethiopia: a negative binomial regression analysis

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## Abstract

**Introduction** Despite the proven effectiveness of vaccination in improving child health and well-being, millions of children remain unvaccinated globally. Ethiopia has increased child vaccination coverage by threefold in the last decades. However, it is one of the top contributors to zero-dose and unimmunized children in Africa. Thus, we examined risk factors associated with zero-dose, under-immunization, and the number of vaccination doses received by children in Ethiopia.

**Methods** A cross-sectional household survey was conducted as part of the formative assessment for the Strengthening Service Delivery (SSD) project from July to August 2024. A stratified two-stage sampling was employed to recruit 1,368 mothers of children aged 12–23 months from agrarian and pastoral regions of Ethiopia. A multilevel negative binomial model was then fitted to estimate associations between individual- and community-level independent variables and the number of vaccine doses received. Adjusted incidence rate ratios (AIRR) with 95% CI were reported to declare the associations.

**Results** About 14% of children did not receive any vaccinations, and 62% were under-immunized, with significant regional disparities: 9% of children in agrarian regions versus 69% in the pastoral areas received no vaccinations, while 60% of children in agrarian regions were under-immunized compared to 92% in the pastoral areas. Mothers attended higher education (AIRR = 1.20; 95% CI [1.01–1.42]), household wealth status of rich (AIRR = 1.39; 95% CI: [1.16–1.67]) and middle class (AIRR = 1.32; 95% CI: [1.09–1.61]), previous history of facility delivery (AIRR = 1.57; 95% CI: [1.35–1.83]) and home visit by community health workers (CHW) during pregnancy (AIRR = 1.32; 95% CI: [1.15–1.52]) and having

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any under 5 children with vaccination card (AIRR = 2.45; 95% CI: [2.08–2.90]) increased the likelihood of receiving vaccinations. However, children from the pastoral region (AIRR = 0.40; 95% CI: [0.29–0.54]) were less likely to receive higher vaccination doses.

**Conclusion** Our study highlighted individual and community-level factors associated with the number of vaccination doses children received in Ethiopia. To address zero-dose and under-immunized children in Ethiopia, contextualized intervention focusing on the pastoral and vulnerable population is needed. Moreover, strengthening the health system and expanding healthcare access in the underserved population could help improve child vaccination.

**Keywords** Children, Ethiopia, Vaccination, Zero-dose, Under-immunization

## Background

Routine childhood vaccination has been a cost-effective and proven strategy for the prevention and control of deadly infectious diseases [1, 2]. It also can significantly improve the future school enrolment and cognitive development of adolescents, and the overall well-being of the communities [2, 3]. The World Health Organization (WHO) estimates that immunization saves 3.5–5 million lives every year [4]. Furthermore, immunization reduces healthcare expenditures, by preventing the overload of the healthcare system, averting productivity losses, and diminishing health inequalities among the population [2, 4].

Decreasing child mortality has been a global public health priority and a cornerstone of the Sustainable Development Goals [5]. The World Health Assembly set an ambitious target of reducing the number of zero-dose children by 50% through the Immunization Agenda 2030 [6]. Despite the commitment, millions of children remain unvaccinated and under-immunized. Globally, 14.5 million children are zero-dose, where they did not receive the first dose of diphtheria, tetanus, and pertussis (DPT)-containing vaccine [7]. Among these, Ethiopia ranks as the second most burdened country, with significant disparities in vaccine coverage, where the pastoral and hard-to-reach areas are highly affected [8, 9].

Multiple factors were identified that affect the zero-dose and under-immunized children. These include socio-demographic and economic factors such as mothers' age and educational status, antenatal (ANC) and postnatal care (PNC) follow-up, distance to the health facility, and household wealth status [8, 10–15] Moreover, cultural practices and access to health facilities were also found to be associated with children's vaccination status [12, 16].

Ethiopia achieved significant gains in increasing immunization coverage, which increased from 14 to 44% between 2000 and 2019 [17]. Despite the significant progress, the country fell short of the 90% target for 2025. Moreover, regional disparities in vaccination coverage remain a challenge, where pastoral and hard-to-reach have low vaccination coverage [8, 17]. The country has been making strides to address inequities in coverage by expanding access and strengthening the health system and supply chain [18]. To inform the national goal and design strategies for reaching zero-dose children, it is crucial to identify the factors influencing zero-dose and under-immunized children through a comprehensive analysis of data from diverse settings.

With funding from the Gates Foundation, JSI in collaboration with its consortium partners has been implementing the *"Strengthening Service Delivery in Ethiopia (SSD)"* project since November 2023. The project aims to improve the identification and vaccination of zero-dose and under-immunized children through enhancing the capacity of healthcare providers, service integration and quality, and last-mile commodities including vaccines.

As part of the project establishing baseline and benchmarks for project monitoring, we conducted a formative assessment from July to August 2024 in seven regions of Ethiopia. Based on this data, this study aims to identify risk factors associated with zero doses, under-immunization, and the number of vaccination doses received by children in Ethiopia to inform quality programming.

## Methods

### Setting

Ethiopia's healthcare system is structured into three tiers of care: primary, secondary, and tertiary. The primary ideally consists of one primary hospital, 4–5 health centers, and 20–25 health posts, serving a population of approximately 100,000 people. It mainly provides preventive and curative services, while primary hospitals provide emergency surgical services and blood transfusions. Family planning, ANC, and immunization are among the packages of health services that Health Extension Workers (HEWs) are delivering at the kebele level, the lowest administrative unit. These services are also provided through outreach programs with the support of community volunteers, including Village Health Leaders and Women Development Unions.

We included 20 project-targeted woredas (i.e., districts) —16 agrarian and 4 pastorals—across the seven Ethiopian regions of Afar, Amhara, Oromia, Sidama, Central, Somali, and Southwest Ethiopia. The project covered 5 primary hospitals, 112 health centers (103 in agrarian and 10 in pastoral areas), and 496 health posts or kebeles (446 in agrarian and 50 in pastoral areas). In the Somali and Afar regions, pastoral groups are renowned for their mobility and small population size, but inadequate infrastructure makes it difficult to access many areas. Relatively, the agrarian woredas have better infrastructure and access to health services compared to the pastoral woredas.

### Design
This study is part of a larger baseline community-based cross-sectional study designed to monitor household reproductive, maternal, newborn, and child health (RMNCH) behaviors and practices, including a vaccination coverage survey, to evaluate the effectiveness of innovations aimed at reaching zero-dose children. The study was conducted from July–August 2024.

### Sampling strategy
A two-stage stratified cluster sampling technique was employed for household selection. This approach is stratified by agrarian and pastoral regions and program domains, to recruit three groups of women: women of reproductive ages 15–49 years, women with infants ages 0–11 months, and women with children ages 12–23 months. The survey collected data on child immunization from women with children ages 12–23 months and estimated vaccination coverage. The list of kebeles and their corresponding catchment populations was obtained from the intervention woredas. In the first stage of the original study, 91 kebeles were randomly selected in agrarian regions—30 from each of the three program domains—while all 50 kebeles were included in the pastoral regions as primary sampling units, stratified by program domain. For this vaccination coverage survey, 91 kebeles were selected as primary sampling units—57 from agrarian regions and 34 from pastoral regions. Sample sizes within each kebele were proportionally allocated after getting each selected kebeles 12–23 months child population size.

An updated list of households with women having children aged 12–23 months, along with their unique household identifiers, was retrieved from the family folders of the Community Health Information System or the digital electronic community health information System(eCHIS) in most agrarian woredas, maintained at the respective kebele health posts. In cases where household registration was incomplete, a fresh household listing was conducted in consultation with HEWs, community volunteers, and kebele managers. This list served as the sampling frame for data collectors. In the second stage, a systematic random sample of households with 12–23 months of age children was drawn from this frame, proportional to the kebele clusters.

### Sample size
The required sample size to monitor the program's effectiveness was calculated using StatCalc Epi Info software, based on a comparative cross-sectional household study design. A double population proportion formula was applied to evaluate the large-scale implementation of the SSD investment on household maternal and child health care behaviors and practices. The assumptions were: a 95% confidence level ($Z\alpha/2 = 1.96$), a 5% margin of error, a design effect of 1.5, 80% power, and a two-sided alpha error of 0.05. The study aimed to detect a 15-percentage-point increase in the uptake of basic vaccinations, from 27% to 54% at baseline in agrarian and pastoral settings, respectively [19], by the end of the project. Consequently, a sample of 1,367 mothers of children aged 12–23 months was recruited, including 568 from agrarian regions and 799 from pastoral regions.

### Data collection tool, procedures and quality assurance
Mothers or caregivers were interviewed using a pre-tested questionnaire (Supplementary file.1) prepared in local languages which included Amharic, Afaan Oromo, and Af-Somali. The data was collected by 53 experienced data collectors and supervisors with backgrounds in health professions. They underwent six days of training, followed by a one-day field test in Addis Ababa from July 1–6, 2024.

The data was collected from July-August, 2024 using a web-based mHealth platform (SurveyCTO) via tablets and smartphones, which also enabled the collection of geographic positioning system (GPS) data. Each data collector was allowed to collect data from no more than six mothers/caregivers per day. To validate the quality of the data, survey supervisors and coordinators supervised the fieldwork to ensure data quality, which included randomly revisiting selected households to validate responses. The project research team also closely monitored the data entered into SurveyCTO and established real-time communication of necessary adjustments to the entire data collection team.

### Measurements
The outcome variable for this study was the number of vaccine doses received by children aged 12–23 months. Independent variables included individual and household characteristics such as religion, maternal age, education, child's sex, household wealth index, household health insurance coverage, parity, and distance to the nearest health facility. Health system and obstetric-related factors, including women's autonomy, previous history of facility delivery, community health worker home visits

during the last pregnancy, model family status, possession of a family health card, and whether any child under the age of 5 years had an immunization card, were also considered. Administrative region and area of residence (clusters/kebeles) were included as community-level random components.

A wealth index score was constructed for each household using Principal Component Analysis (PCA) based on the household's possessions (such as bank account, electricity, watch, radio, television, mobile phone, telephone, refrigerator, bed, electric stove, bicycle, motorcycle, and three-wheeler bajaj), assets (including number of goats, milk cows or bulls, sheep, horses, donkeys, mules, camels, and chickens), and characteristics (such as type of latrine, water source, floor, and wall material). Households were then ranked according to their wealth scores and divided into three wealth categories: poor, middle, and rich. Women's autonomy was assessed based on the mother's involvement in the decision-making about spending money, healthcare for her and her child, major household purchases, and acceptance of spousal violence [20, 21].

**Zero-dose children** Children who have not received any routine vaccine [8, 22].

**Under-immunized children** those children missing the third dose of diphtheria, tetanus, and pertussis (DTP)-containing vaccine (DTP3) [8].

**Fully immunized children** defined as the proportion of children aged 12–23 months who received BCG, three doses of polio and pentavalent vaccines, and first dose of measles vaccine (MCV1) [23, 24].

### Analysis

Data were analyzed using Stata version 15.1. Descriptive statistics were used to summarize the respondents' characteristics. Differences between respondent characteristics were examined using Pearson's chi-square test, adjusted for the cluster survey design. Post-stratification sampling weights were applied to account for non-proportional sample allocation across regions, ensuring the representativeness of survey estimates through weighted analysis.

A multilevel negative binomial regression model, offsetting child age, was fitted to account for clustering and overdispersion in the data (observed variance: 9.7, is greater than mean: 6.6; median rate ratio: 1.41). No excess zeros were detected, as the observed zero-dose was 13.5%, compared to an expected 0.1% under a Poisson distribution. The log-transformed child age was used as an offset to adjust for differing exposure or opportunities for children to receive vaccinations, ensuring that variations in age were appropriately accounted for.

The null model (Model 1) is fitted without the explanatory variable. A random-intercept negative binomial model (Model 2) was then fitted to estimate associations between individual- and community-level independent variables and the number of vaccine doses received, using the '*menbreg*' command in Stata. Additionally, the model (Model 3) adjusted for both individual- and community-level variables, incorporating a cross-level interaction between region and distance to health facilities to assess any evidence of effect modification in the association between distance to health facilities and the number of vaccine doses received by region.

It is modeled as follows;

$$\log(\mu_{ij}) = \beta_0 + \sum_{k=1}^{n} \beta_k X_{kij} + \mathrm{uj} + \log(child\ age_{ij})$$

Where,

$\mu_{ij}$ =Expected count outcome (number of vaccine doses received) for individual *i* in cluster *j*.

$\beta_0$= Intercept (fixed effect).

$X_{kij}$= Covariates (individual and community-level independent variables).

$\beta_k$ = Fixed-effect coefficients for covariates

uj=$\sim N(0,\sigma^2)$ = Cluster-level random effect, accounting for between-cluster variability.

$\log(child\ age_{ij})$ = Offset term, adjusting for different exposures to vaccination.

Theoretical and iterative statistical methods, including forward selection and backward elimination, were used to identify explanatory variables. As a result, the following variables were retained in the model: religion, maternal education, household wealth index, distance to the nearest health facility, previous exposure to facility delivery, community health worker home visits during the last pregnancy, whether any child under the age of 5 years had an immunization card and administrative region. Model goodness-of-fit was evaluated using global Wald statistics, likelihood ratio tests for cluster-level random effects, and sensitivity of the quadrature approximation. The Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) were applied to assess model suitability and fit. We checked for overdispersion, excess zeros, and multicollinearity. Model fit was further evaluated through AIC and BIC comparisons, while the Intraclass Correlation Coefficient (ICC) measured clustering effects.

## Results

### Background characteristics of respondents

Most of the women in agrarian settings were aged 20–34 (84%) while a significant portion in pastoral settings were

**Table 1** Percentage distribution of characteristics of women with children ages 12–23 months by region type, July–August 2024

| Variable | Agrarian | Pastoral | Total |
|---|---|---|---|
| **Mean age (SD)** | **28.0 (5.1)** | **32.4 (6.2)** | **28.3 (5.3)** |
| **Age group** | | | |
| < 20 | 1.4 | 1.7 | 1.5* |
| 20–25 | 20.9 | 9.3 | 20.1 |
| 25–34 | 62.8 | 47.2 | 61.6 |
| 35–49 | 14.9 | 41.8 | 16.8 |
| **Married or in a union** | | | |
| Yes | 97.8 | 96.5 | 97.7 |
| **Number of children** | | | |
| ≤ 3 | 69.7 | 58.0 | 68.9** |
| 4+ | 30.3 | 42.0 | 31.1 |
| **Religion** | | | |
| Christian | 67.2 | 0.1 | 62.3* |
| Muslim | 32.8 | 99.9 | 37.7 |
| **Educational status** | | | |
| Can't read and write | 30.8 | 87.4 | 34.9* |
| Primary education | 26.7 | 7.8 | 25.3 |
| Secondary education or higher | 42.5 | 4.8 | 39.8 |
| **Walking time to the nearest health facility** | | | |
| < 30 min | 31.2 | 84.7 | 35.1* |
| 30–60 min | 40.5 | 8.9 | 38.2 |
| > 60 min | 28.3 | 6.4 | 26.7 |
| **Number of women** | **569** | **799** | **1,368** |

* $p < 0.01$; ** $p < 0.05$ with chi-square test

aged 25–49 (89%). Additionally, most women in pastoral areas did not have formal education and resided within 30 min of walking distance from the nearest health facility (hospital, health center, or health post). The sociodemographic characteristics of women with children ages 12–23 months significantly varied across regions (Table 1).

### Vaccination coverage

A little higher than one-third (38%) of mothers from agrarian settings possessed immunization cards at the time of the survey, though only 9% of women in pastoral settings had a card. More than 80% of children received BCG, first doses of Pentavalent, and measles. However, less than three-quarters continued to receive the third dose of the Pentavalent vaccine, and only about 60% completed the full vaccination schedule. As shown in Table 2, reported child vaccination rates were higher in agrarian settings, with 89% of children in these areas receiving BCG, 89% receiving Penta 1, and 86% receiving first dose measles vaccine (MCV 1). In contrast, in pastoral settings, only 22% received BCG and 25% received MCV 1. Vaccination coverage also varied significantly across maternal education and household wealth, with poorer and less educated women having the lowest coverage. It also differed based on walking time to the nearest health facilities, with communities farther from health facilities experiencing lower vaccination coverage (Table 2).

**Table 2** Child vaccination coverage of children ages 12–23 months at any time before the survey by region type, July–August 2024

| Variable | BCG | Penta 1 | Penta 3 | MCV 1 | All vaccinations |
|---|---|---|---|---|---|
| **Educational status** | | | | | |
| Can't read and write | 70.5* | 70.1* | 60.7* | 68.6* | 54.9 |
| Primary education | 85.4 | 88.4 | 74.4 | 84.0 | 56.8 |
| Secondary education or higher | 95.4 | 94.1 | 83.1 | 92.0 | 65.3 |
| **Religion** | | | | | |
| Christian | 89.3* | 89.7* | 78.7* | 86.6** | 60.8 |
| Muslim | 75.7 | 75.2 | 63.6 | 74.1 | 57.7 |
| **Walking time to the nearest facility** | | | | | |
| < 30 min | 77.1** | 75.7* | 64.2** | 74.3** | 54.9 |
| 30–60 min | 87.1 | 87.1 | 78.1 | 83.2 | 63.1 |
| > 60 min | 89.3 | 91.6 | 77.4 | 89.7 | 60.5 |
| **Wealth** | | | | | |
| Poor | 60.3* | 62.6* | 49.1* | 57.5* | 35.0* |
| Middle | 81.1 | 81.2 | 68.7 | 77.0 | 56.0 |
| Rich | 92.2 | 91.8 | 81.8 | 91.0 | 67.6 |
| Region | | | | | |
| Agrarian | 89.1* | 89.3* | 77.9* | 86.3* | 63.4* |
| Pastoral | 22.3 | 19.9 | 11.1 | 24.7 | 9.9 |
| **Total** | **84.2** | **84.3** | **73.1** | **81.8** | **59.5** |

* $p < 0.01$; ** $p < 0.05$ with chi-square test

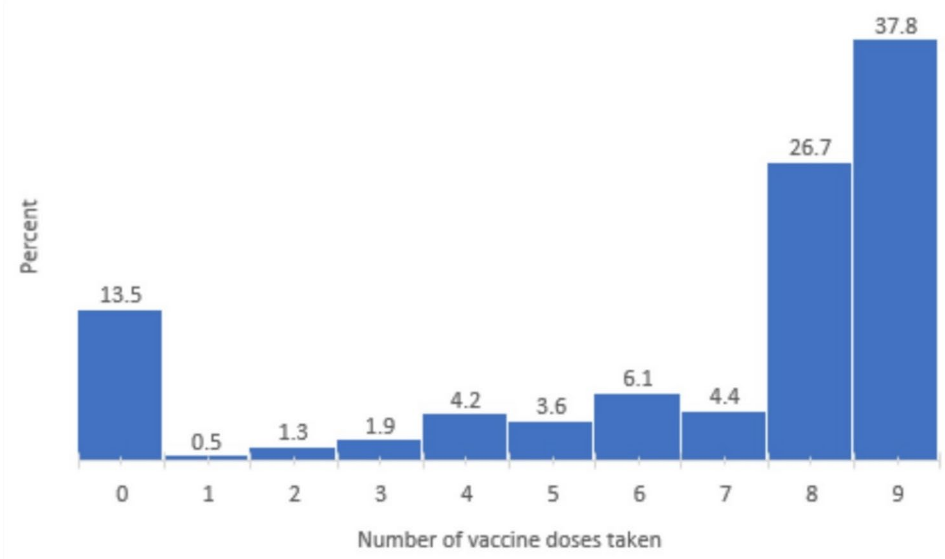


**Fig. 1** Number of vaccine doses taken by 12–23 months old children at any time before the survey, July-August 2024

**Table 3** Number of vaccine doses children ages 12–23 months took at any time before the survey, July–August 2024

| Variable | 0 (zero-dose) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 (all doses) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Educational status** | | | | | | | | | | |
| Can't read and write | 26.0* | 1.4** | 2.3 | 1.9 | 2.7** | 3.5 | 2.9 | 1.6 | 24.8 | 33.0 |
| Primary | 11.5 | 0.04 | 0.6 | 1.9 | 7.8 | 2.7 | 7.5 | 5.4 | 23.7 | 39.0 |
| Secondary education or higher | 3.8 | 0.0 | 0.9 | 1.9 | 3.2 | 4.3 | 8.0 | 6.4 | 30.3 | 41.1 |
| **Religion** | | | | | | | | | | |
| Christian | 9.2** | 0.0** | 0.8 | 0.0* | 3.8 | 5.4* | 8.0* | 6.4** | 27.8 | 38.7 |
| Muslim | 20.6 | 1.3 | 2.1 | 5.1 | 4.9 | 0.7 | 2.5 | 1.3 | 25.1 | 36.5 |
| **Walking time to the nearest facility** | | | | | | | | | | |
| < 30 min | 20.0** | 1.3* | 2.3 | 3.2 | 3.4 | 1.3* | 5.3 | 2.4 | 23.5 | 37.4 |
| 30–60 min | 11.1 | 0.07 | 0.9 | 1.6 | 2.5 | 7.1 | 3.8 | 4.6 | 30.6 | 37.8 |
| 1 + hrs. | 8.4 | 0.02 | 0.6 | 0.6 | 7.6 | 1.8 | 10.5 | 6.9 | 25.4 | 38.3 |
| **Wealth quintile** | | | | | | | | | | |
| Poor | 34.3* | 2.0* | 0.6 | 2.5 | 6.0 | 4.3 | 6.6 | 4.4 | 20.6 | 18.9** |
| Middle | 17.1 | 0.2 | 1.1 | 1.4 | 4.1 | 3.5 | 6.6 | 5.1 | 23.8 | 37.1 |
| Rich | 5.8 | 0.3 | 1.6 | 2.1 | 3.9 | 3.6 | 5.8 | 4.1 | 30.4 | 42.4 |
| **Region** | | | | | | | | | | |
| Agrarian | 9.1* | 0.3** | 1.0* | 1.6* | 4.2 | 3.8* | 6.5* | 4.8* | 28.6* | 40.1* |
| Pastoral | 69.2 | 2.6 | 4.7 | 5.5 | 4.8 | 1.5 | 0.6 | 0.3 | 3.1 | 7.9 |

** $p < 0.01$; * $p < 0.05$ with chi-square test

## Zero-dose children

Only 38% of children received full doses of vaccination, while 27% received eight doses. Notably, 14% of children were zero-doses, meaning they did not receive any doses of vaccination (Fig. 1). Further, 22% of children received vaccination doses ranging from 1 to 7.

## Vaccination dose variation

About 14% of children did not receive any vaccinations, and 62% were under-immunized, with significant regional disparities: 9% of children in agrarian regions versus 69% in pastoral regions received no vaccinations, while 60% of children in agrarian regions were under-immunized compared to 92% in pastoral regions. The prevalence of zero-dose children also varied significantly across educational status, religion, and wealth quintile. Conversely, communities living closer to health facilities had a higher zero-dose vaccination rate than those farther away (Table 3).

Household wealth status is another crucial determinant, with children from rich households having the highest full-dose coverage (42%) and the lowest zero-dose rate (6%). In contrast, children from poor households are the most disadvantaged, with a high zero-dose rate (34%) and the lowest full-dose coverage (19%).

### Reasons for no vaccination

For mothers whose children were not vaccinated at all or not fully vaccinated ($n=760$; 166 in agrarian regions and 594 in pastoral regions), we asked what the reasons were. These included lack of awareness (46%), inconvenient vaccination times and places (25%), absence of vaccine or vaccinator (21%), fear of side effects (15%), mother's workload (14%), and lack of faith in immunization (7%). Inconvenient vaccination times and locations were more common in pastoral settings, while lack of faith in immunization was more prevalent in agrarian settings (Fig. 2).

### Factors associated with the number of vaccination doses children received

As shown in Table 4, children from mothers with secondary and above education level (AIRR = 1.20; 95% CI [1.01–1.42]), families with wealth category of rich (AIRR = 1.32 (95% CI: 1.09–1.61)) and middle (AIRR = 1.39; 95% CI: [1.16–1.67]) were more likely to receive more vaccinations compared to children from poor families. Similarly, the frequency of receiving more doses of vaccination was 1.52 (AIRR = 1.52; 95% CI: [1.35–1.83]) and 1.32 (AIRR = 1.32; 95% CI: [1.15–1.52]) times higher for children of mothers who had previous history of facility delivery and visited by community health workers during pregnancy, respectively.

Children from families with under 5 years child who had a vaccination card were two times (AIRR = 2.45; 95% CI: [2.08–2.88]) more likely to receive more doses of vaccination compared to children from families without vaccination cards. Moreover, children from pastoral areas had a 60% (AIRR = 0.40; 95% CI: [0.29–0.54]) lower rate of receiving the number of vaccination doses compared to children from agrarian areas.

The cross-level interaction model, Model 3, revealed that there was evidence of effect modification of the association between distance to the nearest health facility and vaccination doses by region. Within the community effect of the region, as well as the community effect of the distance to the nearest health facility disappears. In pastoral regions, children who resided for less than 30 min (AIRR = 3.20; 95% CI: [1.83–5.57]) and 30–60 min (AIRR = 3.65; 95% CI: [2.09–6.37]) to the nearest health facility had higher rates of receiving more doses of vaccination in comparison to children from agrarian regions who resided further away from the health facilities (Table 4).

## Discussion

This study highlights a substantial proportion of children who either miss vaccinations entirely or remain under-immunized, with disadvantaged pastoral communities

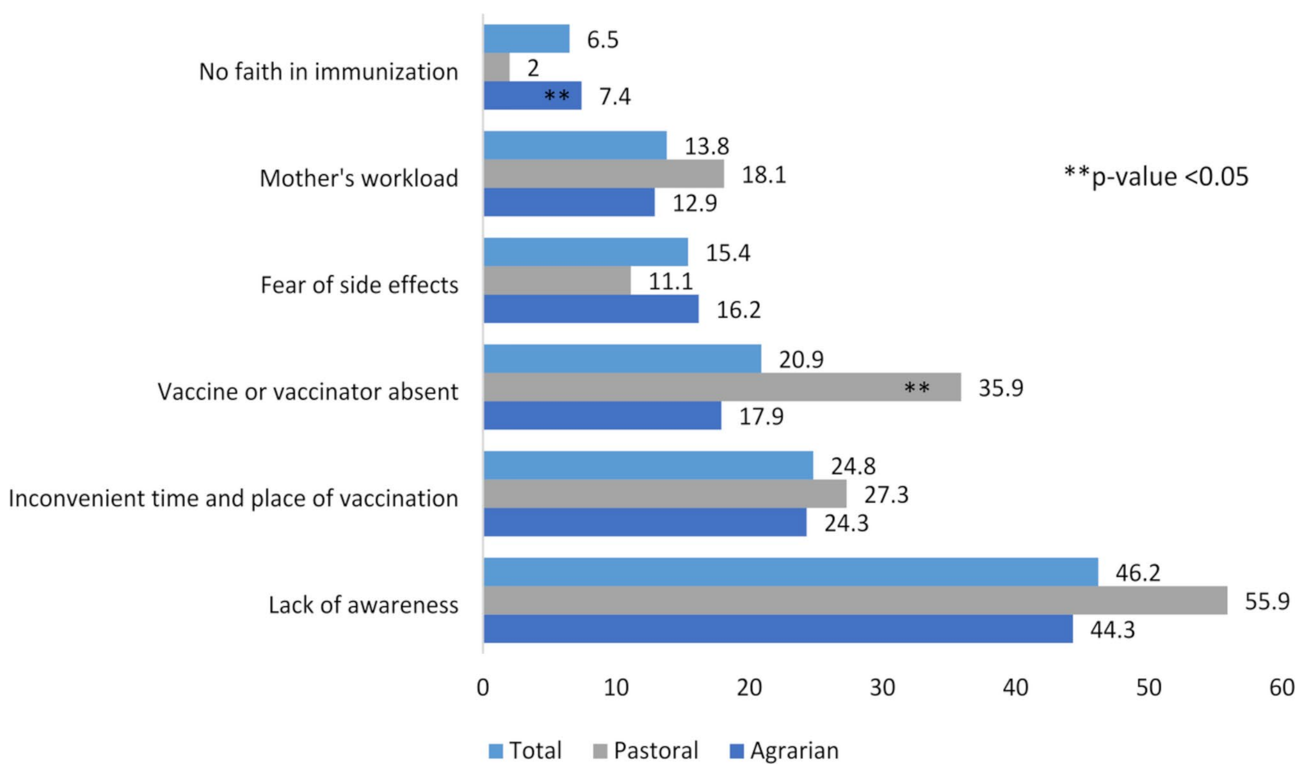


**Fig. 2** Reasons for the child not being immunized or not being fully immunized by region type, July–August 2024

**Table 4** Multilevel negative binomial regression showing factors associated with the number of vaccination doses children received, July–August 2024

| | **Model 1: Null model** | **Model 2: Intercept** | | | **Model 3: Interaction effets** |
|---|---|---|---|---|---|
| | **IRR (95% CI)** | **IRR (95% CI)** | ***p*-value** | **IRR (95% CI)** | ***p*-value** |
| Maternal education (Ref: Can't read and write) | | | | | |
| Primary education | | 1.12 (0.94–1.33) | 0.213 | 1.09 (0.92–1.29) | 0.329 |
| Secondary education or higher | | **1.20 (1.01–1.42)** | **0.036** | **1.20 (1.01–1.41)** | **0.033** |
| Religion (Christian vs. Muslim) | | 1.02 (0.80–1.29) | 0.894 | 1.02 (0.80–1.30) | 0.895 |
| Walking time to nearest health facility (hospital, health center, or health post) (Ref: > 60 min) | | | | | |
| < 30 min | | 1.10 (0.90–1.34) | 0.360 | 0.93 (0.74–1.16) | 0.499 |
| 30–60 min | | **1.28 (1.06–1.56)** | **0.01** | 1.06 (0.86–1.30) | 0.586 |
| Wealth quintile (Ref.: poor) | | | | | |
| Middle | | **1.39 (1.16–1.67)** | **< 0.001** | **1.39 (1.16–1.68)** | **< 0.001** |
| Rich | | **1.32 (1.09–1.61)** | **0.006** | **1.31 (1.08–1.60)** | **0.006** |
| Previous history of facility delivery (yes vs. no) | | **1.56 (1.35–1.83)** | **< 0.001** | **1.54 (1.32–1.79)** | **< 0.001** |
| CHW home visit during pregnancy (yes vs. no) | | **1.32 (1.15–1.52)** | **< 0.001** | **1.29 (1.13–1.48)** | **< 0.001** |
| Any child under the age of 5 years had an immunization card (yes vs. no) | | **2.45 (2.08–2.88)** | **< 0.001** | **2.32 (1.97–2.73)** | **< 0.001** |
| Region (agrarian vs. pastoral) | | **0.40 (0.29–0.54)** | **< 0.001** | **0.13 (0.07–0.23)** | **< 0.001** |
| Walking time to nearest health facility Agrarian* Region | | | | | |
| < 30 min*Pastoral | | | | **3.20 (1.83–5.57)** | **< 0.001** |
| 30–60 min*Pastoral | | | | **3.65 (2.09–6.37)** | **< 0.001** |
| **Model fit statistics** | | | | | |
| ICC | **0.205** | **0.044** | | **0.050** | |
| AIC/BIC | **6,3829.88/ 6,398.54** | **5,513.41/5,585.032** | | **5,494.65/5,576.50** | |

bearing the greatest burden. Distance to the nearest health facility, maternal educational level, household wealth status, previous history of facility delivery, community health worker home visits during pregnancy, possession of vaccination cards for under-five children, and region of residence were factors associated with number of vaccination doses children received.

In this study, vaccination coverage was negatively associated with shorter walking time to the nearest health facility. This may be due to the service delivery modality, as most health facilities provide services through outreach rather than at static sites. As a result, those living closer to the facility may have fewer opportunities to access facility-based immunization services. Cross-level interaction analysis also showed that the region modified the association between distance to a health facility and the number of vaccination doses children received. In pastoral regions, children living near health facilities received a higher number of vaccination doses compared to those living farther away. Mothers in pastoral communities had better access to health posts, as documented in this study, which may have motivated them to adhere to vaccination schedules [25–27].

Regional disparities in childhood immunization have been highlighted in different studies conducted in Ethiopia [8, 10, 28]. Our study showed children from pastoral regions were less likely to receive a higher number of vaccination doses compared to those from agrarian regions. This could be due to limited access to health facilities for dispersed populations and sub-optimal health-seeking behavior in pastoral communities [8]. These regions struggle with poor road networks and limited healthcare infrastructure, making it difficult to access vaccination services. Moreover, the nomadic lifestyle of the pastoral community further makes the immunization service difficult, as families frequently move in search of water and grazing lands [12]. This finding calls for tailored interventions including strengthening mobile health and outreach vaccination programs with strengthening community engagement activities. Furthermore, increased investment for the implementation of the expansion of healthcare infrastructure through HEP optimization is needed.

We found a significant association between household wealth status and number of vaccination doses of children. Thus, children from the middle and rich wealth categories had higher rates of receiving more vaccination doses when compared to children from poor households. Similarly, maternal education had a positive association with a higher number of vaccination doses children received, which is consistent with similar other studies [24, 29]. Socio-economic inequality including educational status poses a significant challenge to healthcare access and service utilization in developing countries [8, 29, 30]. Program implementers need to design strategies to reach zero-dose children from families with poor socio-economic conditions including women's literacy.

Children of mothers who had a previous history of facility delivery were more likely to receive higher doses of vaccination compared to those delivered at home. This finding could be explained by facility delivery enhancing the chance of receiving birth dose vaccination, counseling, and vaccination schedule. The finding is consistent with studies conducted in Cameroon and Ethiopia [31, 32]. Hence, children delivered at home need to be reached through context-informed approaches such as outreach, and home-to-home vaccination through Community Health Workers including Village Health Leaders and Women Development Unions.

Community Health Workers' home visits during pregnancy significantly increased the likelihood of receiving higher doses of child vaccination. Mothers who received visits during pregnancy could get counseling and information about child vaccination, which increases the likelihood of these mothers vaccinating their children. Previous studies documented that CHW played a significant role in promoting vaccination, dispelling misinformation, counseling mothers for vaccination of their expectant baby, identifying defaulters, and linking with the health system [33–35].

This study also identified, that having any under 5 children with vaccination cards positively correlated with the likelihood of receiving more doses of vaccination. This might be explained by mothers have already have a positive attitude and experience of vaccinating their child, which further motivates them to vaccinate other children in the family. This finding is in agreement with studies conducted in Ethiopia [36, 37] and Georgia [38], where those mothers who had an experience of vaccinating their child were more likely to vaccinate other children too.

Previous studies conducted in Ethiopia and elsewhere reported the association between religion with child vaccination [24, 29, 39]. On the contrary, religion did not significantly predict the number of vaccine doses children received in this study. Indeed, some studies reported no significant association between religion with child vaccination [11, 23]. The possible explanation for this variation could be due to the study population and the changing societal attitudes towards vaccination.

This study has several strengths including using advanced multilevel negative binomial analysis accounting for individual and community-level factors, and representative samples from the majority of the country's region. Though we tried to minimize bias by using prompts, non-judgmental interviews, and vaccination cards the study could suffer from recall and social desirability biases. In addition, the lack of sero-surveys, and reliance on mothers' reports in the absence of documented vaccination records could bias the observed vaccination prevalence.

## Conclusion

Multiple risk factors were associated with the number of vaccination doses children received including distance to the nearest health facility, maternal education level, household wealth status, mother delivered at the health facility, being visited by CHW during pregnancy, having any under 5 children with vaccination card, and region of residence. Contextualized intervention including improving the access and outreach vaccination program for the pastoral and vulnerable population is needed to address zero-dose children in Ethiopia. Moreover, strengthening the health system capacity and community health workers' involvement in underserved populations could help in improving child vaccination.

### Abbreviations

AIC Akaike Information Criterion
ANC Antenatal care
BCG Bacillus Calmette-Guérin vaccine
BIC Bayesian Information Criterion
ICC Intra-class correlation coefficient
DTP Diphtheria-tetanus-pertussis-containing vaccine
MCV Measles-containing vaccine
SSD Strengthening Service Delivery in Ethiopia project

## Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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### Author contributions

BB, GTT, DE, BM, NF, and TS conceptualized the paper. GT, BB, NB, TS, BM, HT, HM and TY designed the survey and coordinated fieldwork. BB and GTT analyzed the data and drafted the manuscript. All authors did interpretation, critical review, and approved the final manuscript.

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**Data availability**
Data is provided within the manuscript or supplementary information files.

## Declarations

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare no competing interests.

**Ethical approval and consent to participate**
The study received ethical approval from the Ethiopian Public Health Association's Research Ethics Review Committee (Ref. #: EPHA/OG/382/24, June 28, 2024). Support letters and written permission to conduct the study were also sought from the regional health bureaus, zonal health departments, and relevant institutions. Verbal informed consent was acquired, and the study was conducted with voluntary participation guaranteed. The goal, advantages, and potential risks of the study were explained to each participant, along with their ability to refuse participation or to refuse to answer any questions. The interviewer recorded consent by marking the questionnaire and providing a digital signature beneath the consent statement once a responder had read the consent material and decided to participate. To protect participants' privacy and preserve the study's integrity, the researchers made sure that all information they collected from them was kept private and secret. We confirmed that the study was conducted in accordance with the Declaration of Helsinki.

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