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Multilevel and geographically weighted regression analysis of factors associated with full immunization among children aged 12–23 months in Ethiopia

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Immunization is the process of building immunity or resistance to an infectious disease, typically through administering a vaccine. It is one of the most effective strategies for lowering child morbidity and death. It protects against more than 20 potentially fatal diseases, increasing longevity and health. Despite progress, Ethiopia failed to meet its vaccination coverage target. The magnitude of full immunization is different across areas. Therefore, conducting geographically weighted regression to identify the local factors and multilevel analysis to investigate and identify factors associated with full immunization coverage among children aged 12–23 months is necessary. The study was conducted using the 2019 Ethiopian Mini Demographic Health Survey dataset. A sample of 1028 weighted children aged 12–23 months were included in the analysis. Descriptive statistics were used to describe variables. For the spatial analysis, Arc-GIS version 10.8 statistical software was used. Spatial regression (geographically weighted regression) was done to identify factors associated with the proportion of full immunization, and model comparison was based on adjusted R2 and Akaike Information Criteria (AICc). Multilevel mixed-effect binary logistic regression models were fitted to identify factors associated with full immunization. The fitted models were compared based on log-likelihood, deviance, median odds ratio, and Proportional Change in Variance. Finally, statistically significant factors were reported using an adjusted odd ratio (AOR) with a 95% Confidence Interval for fixed effect. All variables with a p-value less than 0.05 in the final model were considered statistically significant factors. In Ethiopia, the overall full immunization coverage among children aged 12–23 months was 40.58%, with spatial variation across regions in Ethiopia. The significant spatial distribution of full immunization coverage among children aged 12–23 months was detected in northern Tigray, Addis Ababa, central Oromia, and southeastern Amhara regions. The proportion of rural residents,the proportion of women aged 35–44 years, the proportion of women who had ANC 4 and above andthe proportion of women who had PNC were local factors associated with the proportion of full immunization among children aged 12–23 months. Rural residence [AOR 0.27 (95% CI 0.10, 0.70)], family size 4 and above[AOR 0.41 (95% CI 0.17, 0.96)], never breastfeed [AOR 0.026(95% CI 0.003, 0.21)], 1–3 times ANC visit [AOR 0.45 (95% CI 0.23, 0.86)], being from Oromia region [AOR 0.23 (95% CI 0.05, 0.97)], Eastern pastoralist region [AOR 0.09 (95% CI 0.023, 0.35)], age 35–44 years [(AOR 6 (95% CI 1.57, 22.9)], and PNC [AOR 2.40 (95% CI 1.24, 4.8)] were significant factors associated with fully immunization in multilevel mixed effect analysis. Full immunization coverage in Ethiopia is below the global target with significant geographical variation. The high proportion of rural residents, the high proportion of women who had ANC 4 and above, mothers who had a high proportion of PNC, and the high proportion women age 35-44 years were local geographical factors for the proportion of full immunization among children age 12–23 months in Ethiopia. Women who had PNC, ANC visits four or more times, and increased maternal age were positively associated, whereas larger family size, no breastfeeding, rural residence, and being from Oromia and eastern pastoralist region were negatively associated with full immunization. Strengthening maternal and child health services, focusing on rural areas and low-coverage regions, is essential to increase immunization coverage in Ethiopia.

Keywords Fully immunization, Children aged 12–23 months, Ethiopian demographic health survey, Geographically weighted regression

Abbreviations

AOR	Adjusted odds ratio
BCG	Bacilli Calamite Guerin
CI	Confidence interval
DPT	Diphtheria, pertussis and tetanus
EA	Enumeration area
EDHS	Ethiopia demographic and health survey
EPI	Expanded program of Immunization
FMoH	Federal Ministry of Health
HEWs	Health extension workers
GWR	Geographically weighted regression
HSDPs	Health sector development programs
HSTP	Health sector transformation plan
ICC	Intra-class correlation coefficient
MOR	Media odd ratio
MEDHS	Mini Ethiopia demographic and health survey
OPV	Oral polio vaccine
OR	Odds ratio
OLS	Ordinary list square
PCV	Pneumococcal conjugate vaccine
PHC	Population and housing census
VPD	Vaccine preventable disease
VIF	Variance inflation factor

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Immunization is developing immunity or resistance to an infectious disease, usually by administering a vaccine. It is one of the most successful interventions for reducing child morbidity and mortality. Vaccination protects not only the individual but also community members who cannot be immunized[1–3].

The World Health Organization (WHO) launched the Expanded Programme for Immunization (EPI) in 1974 to provide vaccines to all children worldwide. Immunization is necessary for primary health care, a fundamental human right, and the most cost-effective health investment in controlling and preventing infectious disease outbreaks[2–6].

Immunizations are estimated to have contributed to preventing more than 17 million future deaths globally[7]. Every year, 4.4 million children in Sub-Saharan Africa die from infectious diseases that immunization could have prevented. The occurrence of vaccine-preventable diseases in Sub-Saharan African countries is linked to low immunization coverage, challenges, and inadequate infrastructure[8].

The universal immunization of children against the six preventable diseases is crucial in reducing child and infant mortality, a good indicator of the population's health. It is one of the most cost-effective health intervention strategies to improve child health and survival. Basic child immunization services are part of the country's essential health services and are free of charge at all public health institutions[8,9].

In Ethiopia, since its inception in 1980, it has been a key priority in previous Health Sector Development Programs (HSDPs) and the current Health Sector Transformation Plan (HSTP) FMOH 2015. In 2011, improved district planning and management were implemented in all districts. The three major platforms providing vaccination services are static, outreach, and mobile. Furthermore, several campaigns provide children with polio, measles, and other antigens[10].

Ethiopia follows WHO immunization schedules and provides the following vaccines as part of those schedules: At birth, one dose of Bacillus Calmette-Guerin (BCG) and the first dose of oral polio vaccine (OPV0) were administered; three doses of each Pentavalent (DPTHEPB-HIB), OPV, and Pneumococcal Conjugate Vaccine (PCV) were administered; two doses of Rotavirus vaccine were administered at the sixth and tenth weeks; and measles vaccine was administered at nine months. Other childhood vaccines in Ethiopia protect against hepatitis B and homophile influenza type B (Hib). Safe and effective vaccines are widely available, and routine immunization services are frequently provided at no cost to families[4,11]. Immunization is a part of the Ethiopian health sector transformation plan and has never reached the target figures and planned goals (90%). It directly or indirectly affects the sustainable development goals that Ethiopia signed Children under the age of 12 months are the target group for vaccination in Ethiopia. So, children aged 12–23 months are appropriate for assessing full immunization and its associated factors. Also, it is crucial for further intervention to increase coverage.

Even though different studies were conducted separately after the 2016 EDHS, it does not show the overall local and global factors of full immunization status. The previous studies did not consider local factors. Therefore, using the 2019 MEDHS, this study fills the gaps by identifying the potential local factors, as well as other factors associated with full immunization among Ethiopian children aged 12–23 months.

Methods

Study design

The nationwide cross-sectional survey was conducted.

Study area and periods

Ethiopia is the Federal Democratic Republic with 9 geographical regions and two city administrations. Regional states are divided into zones, then zones are subdivided into woreda/district and woreda/districts into Kebeles, the lowest administrative units. In terms of its population size, Ethiopia is the second most populous nation in Africa, with more than 112 million people (56,010 000 females and 56 069 000 males) in 2019. Women of reproductive age (15–49 years) represent 21% of the population in the country (6). According to the 2020 World Population Pyramid report in Ethiopia, 14.6% of the population was under five[12]. The 2019 Mini-DHS was conducted in all the geographic areas of the country over three months, from March 21, 2019, to June 28, 2019[10].

Population

The source population included all children aged 12–23 months found in Ethiopia during the 2019 Mini-EDHS data collection period[10]. All living children aged 12–23 months who were found in selected enumeration areas were the study population. The children who stayed in the selected households the night before the interview (whether usual residents or visitors) were included in the Mini–Ethiopia Demographic and Health Survey[10]. Children aged 12–23 months reported without vaccination data were excluded.

Data source and sample selection procedures

A two-stage stratified cluster sampling technique was used to recruit study participants for the 2019 EMDHS. There are 21 sampling strata in each region, which is divided into urban and rural areas. In the first stage, 305 clusters were chosen with a sample probability proportionate to population size, out of which 212 clusters are from rural areas. Then, for each of the chosen clusters, households were listed and used as a sampling frame for selecting households. In the second stage, equal probability systematic sampling was used to select a fixed number of 30 households in each cluster, resulting in a selection of 8,794 occupied households. All women between the ages of 15 and 49 who were either permanent residents of the selected houses or guests who stayed in the household the night before the survey were eligible to participate in EMDHS[13]. As a result, 5,753 eligible children with their mothers/caretakers were selected from the KR record dataset of the 2019 mini-EDHS (http://dhsprogram.com). Among those 1068 of them are children of age between 12 and 23 months and were included in this study.

Study variables

Dependent variables

Full Immunization status was the dependent variable. Socio-demographic variables (Age, religion, sex of household head, age of household head, family size, sex of the child, and marital status), Maternal and child health-related variables (Place of delivery, birth order, birth interval, health card, number of antenatal care, postnatal care, parity, gravida, duration of breastfeeding) were the individual level variables while Region, Community-level poverty, Community literacy, Community media availability level, residence were considered a community-level variable.

Operational definitions

- The immunization status was recorded as "1" if the child had received all the recommended doses of all vaccinations and categorized as "fully immunized" or "0" if the child had missed one or more doses of vaccinations and classified as "incomplete immunization"[14].
- *Full immunization* is defined as a child that has received one dose of BCG, three doses of Pentavalent, pneumococcal conjugate vaccine (PCV), oral polio vaccines (OPV), two doses of Rotavirus and one dose of measles vaccine[14].
- *Community women's literacy level* Was categorized as low/high after aggregating the literacy level from literate proportion[15–17].

  Low: The proportion of literate below 50% of the literate level (primary, secondary, and higher education).
  High: The proportion of literate higher > = 50% of the literacy level ((primary, secondary, and higher education).

- *The community poverty level* was categorized as low/high after aggregating the poverty level from the lowest two wealth index quintiles.

  Low: The proportion of women below 50% of the lowest two quintiles (poorest and poor).
  High: The proportion of poor above the greater or equal to 50% of the lowest two quintiles (poorest and poor)[15–17].

- *Community media availability level*: Was categorized as low/ high after aggregating media availability level from either radio or television availability.

  High: The proportion of women who have media availability is 50–100%.
  Low: The proportion is below 50%. These approaches are based on previous studies[18].

Data management and analysis

The analysis was performed using STATA version 17 and ArcGIS version 10.8 for spatial statistics. MGWR version 2.2 software was also utilized to transform the data for geographically weighted regression. The data were weighted using the v005 variable (weighting variable) to ensure representativeness and obtain accurate estimates. The proportions and frequencies of variables were adjusted accordingly. This approach follows the detailed guidelines of the mini-EDHS sample weighting procedure(13). Continuous variables were classified and reclassified using data from various works of literature. Some variables (media availability, literacy status, wealth index) were aggregated to produce community-level variables. Descriptive statistics were used to describe the frequency and proportion of the variables. A multilevel mixed effect binary logistic regression model was fitted to identify the individual and community-level factors associated with full immunization. The fixed effect sizes of individual and community level factors on full immunization were expressed using the adjusted odds ratios (AOR) with a 95% confidence interval. The random effects were measured by ICC and MOR, Proportional Change in Variance ($PCV = \frac{Va-Vb}{Va}$, Where Va = variance of the initial (null) model; Vb = variance of the subsequent model), and Median Odds Ratio ($\mathrm{MOR} = \exp\left(\sqrt{2 \times V} \times 0.6745\right)$ Where V is the estimated variance of clusters)[19]. Log-likelihood ratio, deviance, and PCV were used to select the best-fitted model.

Model building and selecting the best-fitted model

To select the best-fit model, the following four models were built as below:

The null model (model I) The first model was run without predictors to test the random effect of between-cluster variation in a fully immunized child. The intercept-only model is useful because it estimates the intra-class correlation coefficient (ICC), and MOR is used to determine whether or not the data justified using a multilevel approach was possible.
Model II The second model was used to investigate the contribution of each individual-level factor to the full immunization of children. The proportional change in variance (PCV) was calculated in comparison to the null model to examine the relative contribution to explaining child full immunization. MOR is also calculated to measure cluster variability. Furthermore, ICC was estimated and compared to its value obtained in the null model.
Model III The third model used only community-level variables. This model allows us to test whether community-level explanatory variables explain the difference in cluster variation in the child's immunization. PCV was calculated using the null model to examine the relative contribution to explain the child's full immunization. Similarly, ICC was estimated. Additionally, MOR was calculated.
Final model (model IV) The fourth model was driven by simultaneously combining individual and community-level factors PCV was calculated using the null model to determine the relative contribution to explaining a child's full immunization. Similarly, ICC was estimated. MOR was also calculated.

During model construction, the best model was selected by employing post-estimation methods (log-likelihood), PCV, and deviance (-2*log-likelihood ratio). A multicollinearity test was performed using the variance inflation factor (VIF) and tolerance to rule out a significant correlation between independent variables.

Finally, in multilevel mixed effect binary logistic regression analysis, variables that showed a significant association at a p-value less than 0.05 with an adjusted odds ratio at 95% confidence intervals were reported as statistically significant factors for full immunization coverage in Ethiopia.

Spatial analysis The global spatial autocorrelation (Global Moran's I) was done to assess whether the spatial distribution of full immunization in Ethiopia was dispersed, clustered, or randomly distributed. Since Moran's I is statistically significant ($p = 0.00026$), it showed that full immunization among children aged 12–23 months is non-random. The hotspot analysis used the GetisOrdGi statistics to explore how spatial autocorrelation varies over the study location.
Spatial regression analysis The Ordinary Least Square (OLS) regression and Geographic Weighted Regression (GWR) statistical analysis explored the spatial relationship between full immunization and the independent variables.
Ordinary Least Squares (OLS) regression is a global statistical model for testing the relationship between the dependent and independent variables. The OLS can automatically check the multicollinearity between independent variables. Koenker (BP) Statistic, Koenker (BP) Statistic, and Jarque-Bera Statistic were checked. R-squared and Akaike's Information Criterion (AICc) were used for the measure of model fitness.

Geographically Weighted Regression (GWR) is a local spatial statistical method that accounts for heterogeneity in the relationship between dependent and independent variables across clusters. GWR analysis is applied when the Koenker statistic is significant (p-value < 0.05), indicating that the relationships between the dependent and independent variables vary by location. Model comparison between the OLS (global model) and GWR (local model) was based on the Akaike Information Criterion (AICc) and adjusted R-squared values. The model with the lowest AICc and highest adjusted R-squared was deemed the best fit, which, in this case, is the GWR model (Table 7).

Ethical clearance

The ethical clearance was obtained from Debre Markos University College of Health Science. The data was accessed from the Ethiopia Mini Demographic and Health Survey (DHS), the 2019 program's official database website (http://dhsprogram.com). I accepted the DHS data of all countries' data-sharing policies. The data needs to be kept confidential and not used for purposes other than the current study.

Results

Socio-demographic characteristics of the respondent

A total of 1,028 weighted children aged 12 to 23 months were included in this study. Among the respondents, 50.39% of mothers were in the age group 25–34 years, and 39.65% of their children were fully immunized. Additionally, 95.62% of the mothers were currently in a relationship. Of the participants, 37.28% were Orthodox Christians, and 28.34% of their children were fully immunized. Most participants (69.5%) lived in rural areas, with 32.65% of their children fully immunized. In the Oromia region, 39.41% of participants were from this area, and 28.34% of their children were fully immunized. Almost 86.24% of households were headed by males, and 40.26% of their children were fully immunized (Table 1).

In terms of community literacy level, six hundred fifty-two (63.41%) of the women in the community had a high literacy level; with, 44.97% of children fully immunized. Five hundred ninety-six (57.99%) of the community had low poverty levels; with 45.01% of children fully immunized (Table 1).

Maternal and child health-related characteristics

Four hundred thirty-nine (42.67%) of women had four and above ANC visits for the index child, of whom 56.01% of their children were fully immunized. The majority of women, 893(86.86%) had no PNC. Most women (82.81%) had a birth interval of two years and above for the index child, and 51.18% had 2–4 living children. On the other hand, 50.1% of women were delivered the index child at government health institutions. Of women

Variables		Weighted frequency (%)	Fully immunization	
			Yes (%)	No (%)
Maternal age	15–24 years	309 (30.05)	110 (35.69)	199 (64.3)
	25–34 years	518 (50.38)	206 (39.65)	313 (60.35)
	35–44 years	188 (18.28)	99 (53.02)	88 (46.98)
	>=45 years	13 (1.26)	2 (15.03)	11 (84.97)
Religion	Orthodox	383 (37.28)	209 (54.41)	175 (45.59)
	Muslim	350 (34.09	131 (37.50)	219 (62.50)
	Protestant	265 (25.80)	72 (27.24)	193 (72.76)
	Others	29 (2.84)	5 (17.32)	24 (82.68)
Marital status	Currently in union	983 (95.62)	402 (40.84)	582 (59.16)
	Currently not in union	45 (4.38)	16 (34.89)	29 (65.11)
Community media availability level	Low	336 (32.7)	167 (49.76)	169(50.24)
	High	692 (67.3)	250 (36.41)	441(63.89)
Age Household head	18–24 years	73 (7.12)	24 (33.42)	49 (66.58)
	25–29 years	204 (19.86)	80 (39.29)	124 (60.41)
	30–34 years	177 (17.19)	79 (44.79)	98 (55.21)
	35–39 years	216 (20.99)	88 (40.69)	128 (59.31)
	40–45 years	142 (13.84)	63 (44.47)	79 (55.53)
	>=45 years	216 (21.00)	82 (38.12)	134 (61.88)
Sex of Household head	Male	887 (86.24)	357 (40.26)	530 (59.74)
	Female	141 (13.76)	60 (42.60)	81 (57.40)
Residence	Urban	313 (30.47)	184 (58.68)	129(41.32)
	Rural	715 (69.53)	233 (32.65)	481 (67.35)
Region	Tigray	77 (7.4)	49 (63.23)	28 (36.77)
	Amhara	218 (21.19)	130.66 (59.69)	87.1825 (40.02)
	Oromia	405 (39.41)	114.85(28.34)	290.37 (71.66)
	SNNPR	199 (19.38)	71.36(35.82)	127.87 (64.18)
	Most urban*	43 (4.16)	32.459(75.93)	10.290 (24.07)
	Eastern pastoralist**	71 (6.89)	10.917(15.40)	59.96 (84.60)
	Western semi-pastoralist***	15 (1.44)	8.035(54.28)	6.766 (45.72)
Community literate level	Low	376 (36.59)	124 (32.97)	252 (67.03)
	High	652 (63.41)	293 (44.97)	359 (55.03)
Community poverty Level	Low	596 (57.99)	268 (45.01)	328 (54.99)
	High	432 (42.01)	149 (34.47)	283 (65.53)
Family size	<4 members	384 (37.36)	183 (47.56)	201 (52.44)
	>=4 members	644 (62.64)	235 (36.42)	409 (63.58)

Table 1. Socio-demographic and economic characteristics of women with children aged 12–23 months, MEDHS 2019, 2023. *Addis Ababa, Diredawa and Hareri; ** Somali and Afar; ***Gambella and Benishangul Gumuz region.

who delivered at government health institutions, 53.45% of their children were fully immunized. Seven hundred sixty-nine (74.76%) of children aged 12–23 months had health cards; 54.15% were fully immunized. About 78.1% of children were breastfed during data collection, and 45.20% were fully immunized (Table 2).

Immunization coverage in Ethiopia among children aged 12–23 months

In Ethiopia, four hundred seventy (40.58%) of children aged 12–23 months were fully immunized (Fig. 1). The coverage of BCG, Polio3, Penta3, PCV3, Rota2, and measles1 among children aged 12–23 months were 72.96%, 59.94%, 61.16%, 59.83%,66.76%, and 58.53% respectively (Table 3).

Factors associated with full immunization among children aged 12–23 months in Ethiopia

A multilevel mixed effect binary logistic regression was fitted to identify the potential factors associated with full immunization. The null model (Model I) was fitted first. The variance of the random effect in this model was 2.643, indicating that there is significant variation across clusters. Intra-cluster correlation (ICC = 44.5%) also indicated that 44.5% variability in full immunization was due to clusters, and the calculated MOR indicated that there was greater than one clustering variability in full immunization. Model II was fitted after by adding individual-level factors to the null model I (ICC = 41%). Model III was then fitted by incorporating the community-level variables into the null model. Finally, model IV was fitted by combining individual-level and community-level variables (Table 4). The final model (Model IV) was appropriate to identify the individual and Community level factors of full immunization in Ethiopia after checking the model selection criteria (log-likelihood, deviance, and proportional change in variance) (Table 5).

A multicollinearity test was performed, and all independent variables have VIF < 10 and tolerance greater than 0.1, indicating no multicollinearity.

Age of women, religion, duration of BF, place of delivery, number of ANC visits, and PNC were all significant individual-level factors in model II. Model III identified region and residence as significant community-level factors for full immunization.

Finally, after performing multilevel mixed effect binary logistic regression, the final model (model IV) result showed that the number of ANC visits, region, PNC, maternal age, residence, duration of BF, and family size were statistically significant factors associated with full immunization in Ethiopia (Table 4).

Variables	Category	Weighted frequency	Fully immunization	
			Yes (%)	No (%)
Birth interval	Less than 24 months	177 (17.19)	51 (28.66)	126 (71.34)
	>=24 months	851 (82.81)	366 (43.06)	485 (56.94)
Parity	1 Child	238 (23.17)	102 (42.96)	136 (57.04)
	2–4 Children	526 (51.18)	227 (43.09)	299 (65.9)
	>=5 Children	264 (25.65)	88 (33.42)	176 (66.58
Sex of children	Male	495 (48.17)	209 (42.30)	286 (57.70)
	Female	533 (51.83)	208 (38.98)	325 (61.02)
Place of delivery	At home	464 (45.15)	116 (24.93)	348 (75.07)
	Gov' health institution	515 (50.07)	275 (53.45)	240 (46.55)
	Privet health institution	21 (2.03)	14 (67.51)	7 (32.49)
	NGO'S	16 (1.53)	6 (39.68)	10 (60.32)
	Others	12 (1.21)	6 (54.28)	6 (45.72)
Number of ANC visits	No visit	283 (27.55)	57 (20.05)	226 (79.75)
	1–3 visit	306 (29.78)	115 (37.47)	191(62.53)
	4 and above visit	439 (42.67)	246 (56.01)	193(43.99)
PNC	No	893 (86.86)	336 (37.65)	557(62.35)
	Yes	135 (13.14)	81 (59.94)	54(40.06)
Gravida	Primigravida	227 (22.08)	99 (43.70)	128(56.30)
	Multigravida	801 (77.92)	318 (39.70)	483(60.30)
Health card	No	289 (25.24)	1 (0.40)	258(99.60)
	Yes	769 (74.76)	416 (54.15)	352(45.85)
Duration of breastfeeding	Ever BF not currently	197 (19.16)	54 (27.39)	143(72.61)
	Never BF	28 (2.76)	1 (1.60)	27(98.4)
	Still BF	803 (78.07)	363 (45.20)	440(54.80)
Birth order	1st	242 (23.53)	102 (42.26)	140(57.74)
	2nd -5th	598 (58.17)	251 (41.95)	347(58.03)
	6th and above	188 (18.31)	64 (34.08)	124(65.92)

Table 2. Maternal and child health-related characteristics women with children aged 12–23 months, MEDHS 2019, 2023.

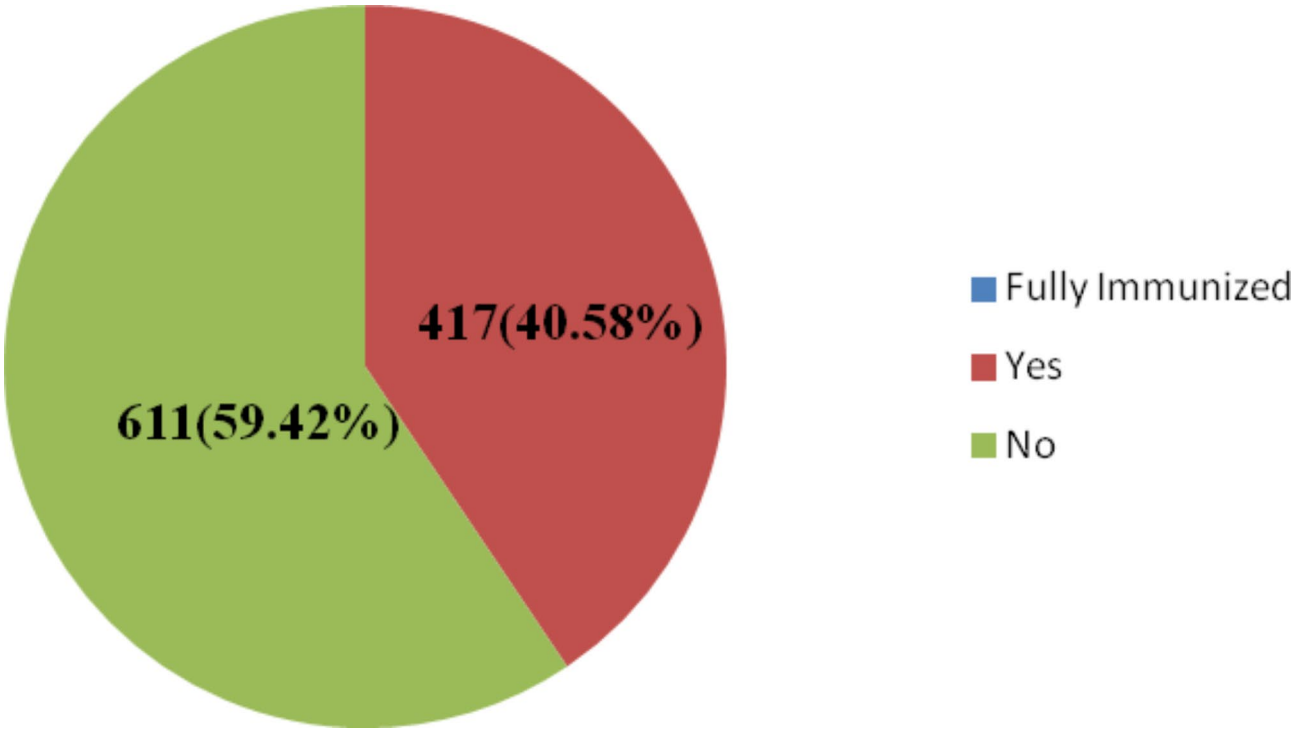

Fig. 1. Full immunization coverage among children aged 12–23 months in Ethiopia.

Variables	Category	Weighted frequency	Percentage
BCG	No	278	27.04
	Yes	750	72.96
Polio 3	No	412	40.06
	Yes	616	59.94
Penta 3	No	400	38.89
	Yes	629	61.13
PCV 3	No	413	40.17
	Yes	615	59.83
Rota 2	No	342	33.24
	Yes	686	66.76
Measles 1	No	426	41.47
	Yes	602	58.53

Table 3. Immunization coverage in Ethiopia among children aged 12–23 months from MEDHS 2019, 2023.

The findings indicated that there are factors significantly associated with full immunization among children aged 12–23 months. Children from families with more than four members had 0.41 times the odds of being fully immunized compared to children from smaller families [Adjusted Odd Ratio (AOR):0.41; 95% Confidence Interval (CI):0.17, 0.96; $P<0.05$]. Similarly, children whose mothers had 1–3 antenatal care (ANC) had 0.45 times the odds of being fully immunized compared to those with four or more ANC visits [AOR: 0.45; 95% CI 0.238, 0.860; $P<0.05$]. Maternal age is also a significant factor, with the age group of 35–44 years being six times more likely to have fully immunized children compared to the younger age group [AOR: 6; 95% CI 1.57, 22.9; $P<0.05$]. Furthermore, children who had never breastfed had 0.024 times the odds of being fully immunized compared to those currently breastfeeding [AOR: 0.024; 95% CI 0.003, 0.21; $P<0.01$]. Postnatal care (PNC) played a positive role, as women who received PNC for their children aged 12–23 months were 2.4 times more likely to have fully immunized children compared to those who did not receive PNC [AOR: 2.4; 95% CI 1.24, 4.85; $P<0.01$].

Geographical factors also had a significant impact on full immunization. Children residing in the Oromia region had 0.23 times the odds of being fully immunized compared to those in the most urban regions [AOR: 0.23; 95% CI 0.05, 0.97; $P<0.05$]. Similarly, children in Eastern Pastoralist regions had 0.09 times the odds of being fully immunized [AOR: 0.09; 95% CI 0.023, 0.35; $p<0.01$]. Furthermore, rural residences decreased the

Variables		Null Model(I)	Model II AOR[a] (95% CI)	Model III AOR (95% CI)	Model IV AOR (95% CI[a])
Age of the women	15-124years		1		1
	25–34 years		1.51(0.64–3.52)		1.49(0.62–5.36)
	35-44years		**5.92(1.61–21.75)** **		**6.0(1.5–22.9)** **
	>=44years		0.50(0.022–11.33)		0.50(0.01–14.3)
Marital status	Currently in Union		1		1
	Currently not union		0.65(0.108–3.97)		0.52(0.10–2.71)
Religion	Orthodox		1		1
	Muslim		**0.37(0.17–0.83)** *		1.09(0.40–2.99)
	Protestant		**0.36(0.157–0.86*)**		0.87(0.31–2.46)
	Others		0.27(0.042-1.80)		0.66(0.105–4.23)
Duration BF	Ever BF Not currently		1		1
	Never BF[a]		**0.020(0.002- 0.2)** ***		**0.026(0.003–0.212)** ***
	Still BF		0.98(0.42–2.26)		1.00(0.424–2.36)
Birth order	1		1		1
	2–5		1.05 (0.313–3.54)		1.45(0.40–5.22)
	6 and above		1.71(0.32–8.96)		2.54 (0.44–14.53)
Sex child	Male		1		1
	Female		0.69(0.376–1.264)		0.66(0.36–1.22)
Place of delivery	At home		1		1
	Government health institution		**2.66(1.25–5.65)***		2.13 (0.98–4.64)
	Private health institution		2.87(0.27–29.96)		1.77(0.14–21.12)
	NGOs[a]		0.57(0.040–8.10)		0.37(0.023–6.03)
	Others		0.44(0.030–6.52)		0.33(0.026–4.38)
Birth interval	Less than 24 months		1		1
	>=24 months		1.094(0.51–2.33)		1.07(0.50–2.28)
Parity	1 child		1		1
	2–4 Children		1.48(0.25–8.70)		1.68(0.29–9.49)
	>=5 children		0.53(0.065–4.37)		0.63(0.080–4.99)
Age household head	18–24 years		1		1
	25–29 years		0.99(0.24–4.02)		0.785(0.20–2.99)
	30–34 years		1.43(0.32–6.31)		1.2(0.27–5.28)
	35–39 years		1.07(0.210–5.46)		0.83(0.16–4.26)
	40–44 years		0.99(0.185–5.36)		0.82(0.15–4.37)
	>=45 years		0.76(0.153–3.798)		0.58(0.11, 2.94)
Family size	<=4 members		1		1
	> 4 members		0.43(0.185–1.014)		**0.41(0.178, 0.969)** *
Gravida	Primigravida		1		1
	Multigravida		1.21(0.31–4.72)		0.829(0.22, 3.00)
Number of ANC visits	4 and above		1		1
	1–3 visit		**0.428(0.225–0.79)** **		**0.45(0.283–0.861)** *
	No		0.47(0.161–1.41)		0.575(0.194–1.705)
PNC	No		1		1
	Yes		**2.25(1.172–4.35)** *		**2.46(1.24–4.85)** ***
Household head	Male		1		1
	Female		1.15(0.46–2.88)		1.16(0.445–3.03)
Region	Tigray			1.31(0.42–4.23)	1.40(0.33–5.87)
	Amhara			1.33(0.39–4.48)	1.45(0.34–6.13)
	Oromia			**0.26(0.08–0.88)** *	**0.23(0.058–0.974)** *
	SNNPRs[a]			0.23(0.078–0.71)	0.31(0.076–1.318)
	Most urban			1	1
	Eastern pastoralist			**0.06(0.02,0.2)** ***	**0.090(0.023,0.35)** ***
	Western semi-pastoralist			0.62(0.22–1.70)	0.759(0.23–2.48)
Residence	Urban			1	1
	Rural			**0.2(0.075,0.56)** **	**0.27(0.108–0.705)** **
Community literacy level	Low			1	1
	High			1.69(0.82–3.4)	1.48(0.744–2.95)

Continued

Variables		Null Model(I)	Model II AOR[a] (95% CI)	Model III AOR (95% CI)	Model IV AOR (95% CI[a])
Community poverty level	Low			1	1
	High			1.06(0.48–2.35	1.23(0.55–2.74)
Community Media availability level	Low			1	1
	High			1.14(0.44–2.97)	1.108(0.428–2.86)

Table 4. Individual and community level factors associated with full immunization among children aged 12–23 months in Ethiopia from MEDHS 2019, 2023. *P value less than 0.05, **p-value less than 0.01, ***p value less than 0.001. [a]BF = Breastfeeding, SNNPR = Southern Nation Nationality of People Representatives, AOR Adjusted Odds Ratio, CI: Confidence Interval, NGOs = Non-Governmental Organizations.

Parameters	Null model	Model II	Model III	Model IV
ICC	0.4455742	0.415	0.414	0.382
PCV		11.7%	11.7%	23.1%
Log-likelihood	-623.403	-506.16	-542.48	-487.54
Deviance	1247	1012	1085	975
MOR	6.8	6.01	6.0	5.24

Table 5. Variability and model comparison to select the best-fitted model, 2023.

likelihood of full immunization by 73% compared to urban residences [AOR: 0.27; 95% CI 0.10, 0.70; $P < 0.01$] (Table 4).

Random effect analysis

The ICC supported the presence of significant variations of full immunization between clusters in the empty model (null model). About 44.55% of the variation in full immunization among children aged 12–23 months was due to the variation in the cluster. The value of PCV was highest in the last model and indicates that most of the variations of full immunization were attributable to individual and community-level variables. The median odds ratio was calculated and indicated as the lowest in the final model.

Model IV had a higher log-likelihood result, making it the most appropriate model. Furthermore, the lowest value of deviance observed in the final model suggests that model IV (final model) was the best explanatory model capable of explaining the variation in full immunization between clusters (Table 5).

Spatial distribution of full immunization of children aged 12–23 months

The hotspot analysis was performed since there are significant variations of full immunization distribution across the country with a global Moran's I value of 0.164 (p-value < 0.01) (Fig. 2). The highest immunization coverage among children aged 12–23 months in Ethiopia was observed in Addis Ababa, western Tigray, central Oromia, central parts of Amhara, northwest parts of Gambella, and eastern parts of SNNPRsregions (Fig. 3). The significant hotspot areas of full immunization were identified in the west Tigray, central Oromia, Addis Ababa, and some parts of southeastern Amhara regions. On the other hand, significant cold spot areas were observed in the Afar, SNNPRs, and Somali regions (Fig. 4).

The global ordinary least square regression analysis results

The analysis used the Ordinary Least Squares (OLS) model, which explained about 37.1% (adjusted R2 = 0.371) of the variation in full immunization among children aged 12–23 months. The model showed statistical significance with substantial Joint F-statistics and Wald statistics ($p < 0.05$). The spatial distribution of residuals was normally distributed since the JarqueBera statistics were non-significant ($p = 0.31$). However, the Koenker statistics were statistically significant, indicating that the relation between the independent and dependent variables varied across the study areas. Therefore, it is advisable to use Geographically Weighted Regression (GWR).

The OLS model includes six variables. Among those, the proportion of rural residents of women who have children aged 12–23 months, the proportion of women who had ANC 4 and above for the index child, the proportion of women aged 35–44 years, the proportion of women who had PNC and the proportion of children age 12–23 months who had never been BF, were significantly associated with the proportion of fully immunized among children aged 12–23 months (Table 6).

The geographically weighted regression analysis results to identify local factors

The GWR (local model) analysis significantly improved over the OLS model. The AICc was 161.98, and the adjusted R2 was 0.3748 (37.5%), indicating the model's ability to explain the proportion of fully immunized children aged 12–23 months. The above parameters suggest that GWR slightly improved the model to explain the dependent variable (Table 7).

In the geographically weighted regression analysis, the proportion of rural residents of women who have children aged 12–23 months, the proportion of women aged 35–44 years, the proportion of women who had ANC 4 and above for the index child, the proportion of women who had PNC, the proportion of children

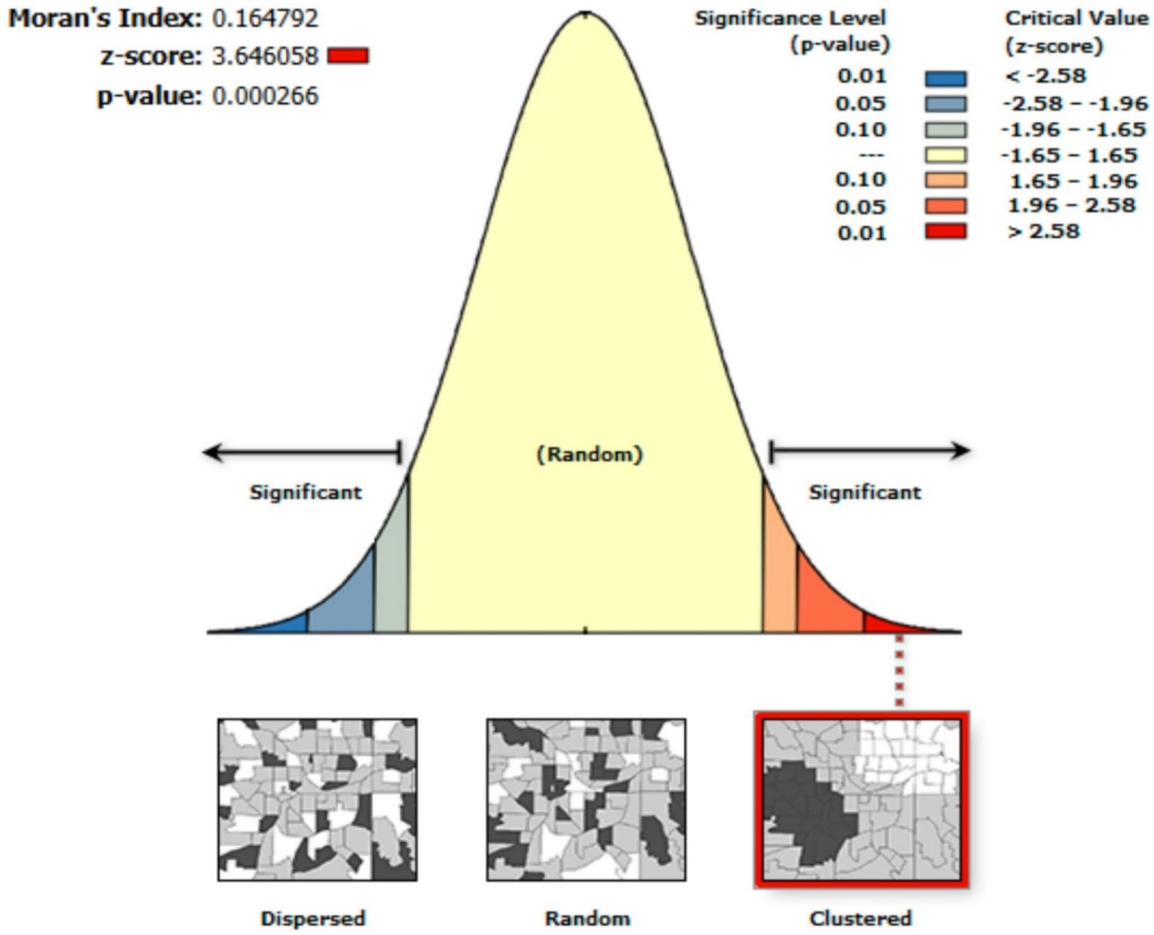

Fig. 2. The spatial autocorrelation analysis of fully immunization among children aged 12–23 months in Ethiopia, MEDHS2019.

age 12–23 months who had never been BF and the proportion of household family size four and above were considered as independent variables in the GWR model.

The proportion of children aged 12–23 months with maternal pair who live in rural areas has a negative association with full immunization in Ethiopia. As the proportion of rural residents increased, the proportion of fully immunized decreased in the southeastern part of Amhara, entire Addis Ababa, Oromia, eastern parts of SNNP regions, Harari, Dire Dewa, and southern parts of Afar. The geographic area with red colored points indicates negatively the highest coefficient of the proportion of rural residence (Fig. 5).

The proportion of women aged 35–44 years was associated with a higher proportion of fully immunized children aged 12–23 months. This had the highest effect on full immunization in the Southern Amhara area, the entire Afar region, Dire Dewa, Harari region, Benishangul-Gumuz region, western portions of Somalia, and eastern parts of the Oromia regions (Fig. 6).

The proportion of women who had ANC 4 and above was associated with a higher proportion of fully immunized children aged 12–23 months. This indicated that the highest effect on full immunization was observed in the entire Tigray, Amhara, eastern parts of Oromia, and eastern parts of Somalia region (Fig. 7). The proportion of women who had PNC was also significantly associated with the proportion of full immunization in eastern parts of Tigray, Eastern parts of Afar, and southern parts of SNNP regions with the highest coefficient (Fig. 8).

Discussion

Immunization plays a significant role in preventing communicable diseases, particularly among children, since it reduces morbidity and mortality rates. This study aims to analyze full immunization coverage, the geospatial distribution of full immunization and identify local and other factors associated with full immunization among Ethiopian children aged 12–23 months using the Mini-EDHS 2019.

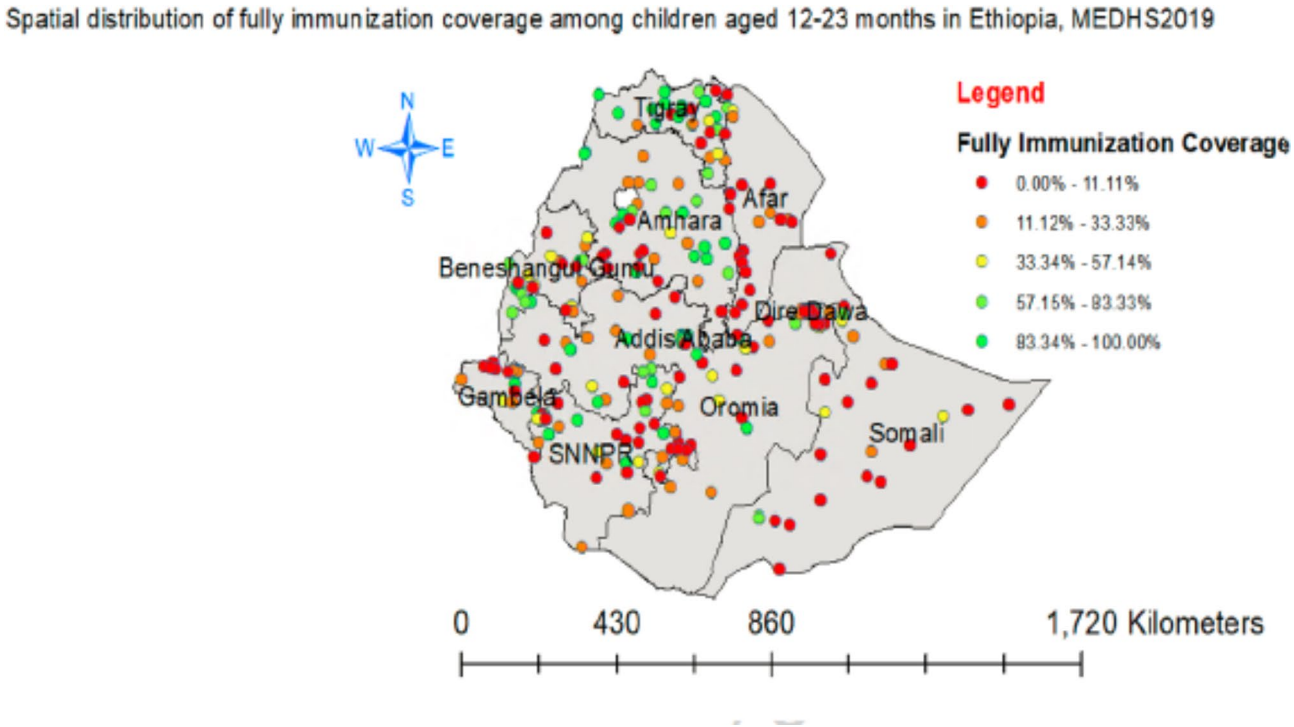

Fig. 3. The spatial distribution of full immunization among children aged 12–23 months in Ethiopia, EMDHS2019.

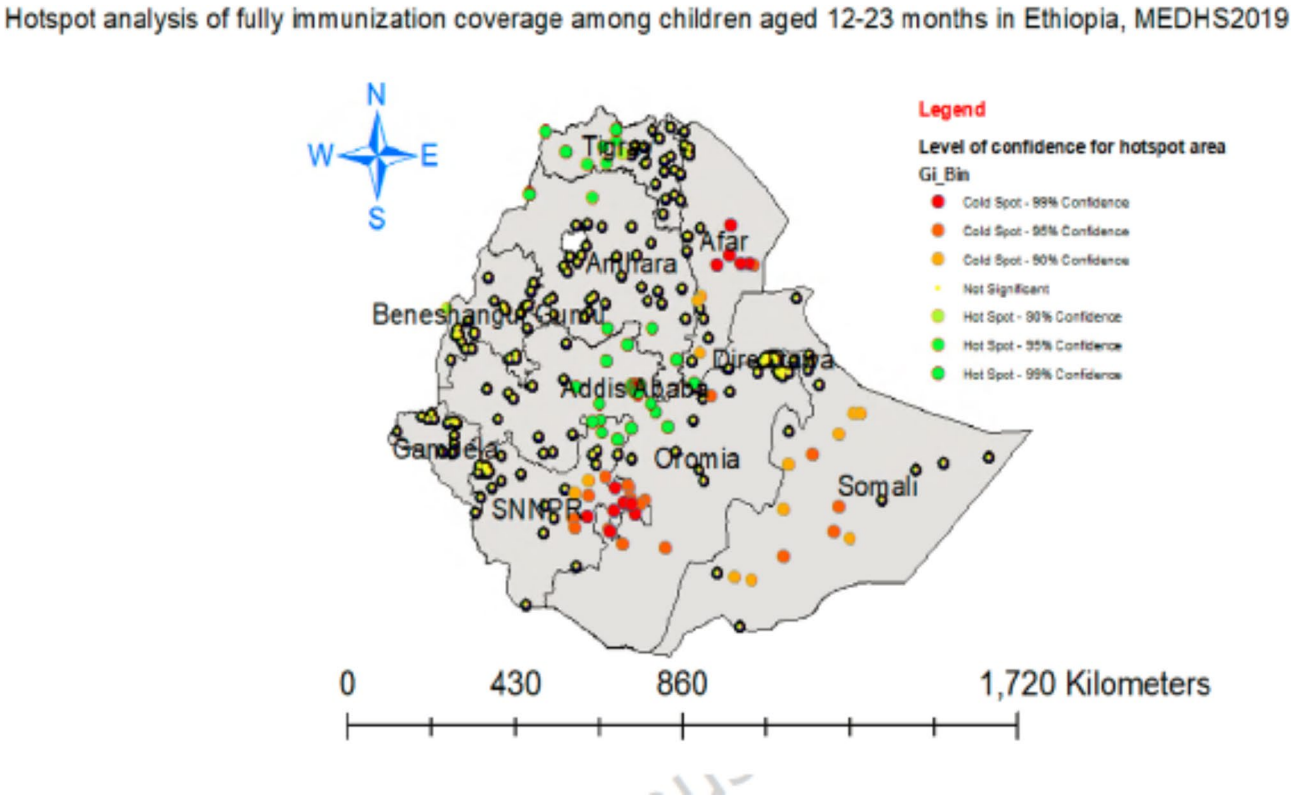

Fig. 4. The Getis Ord Gi statistical analysis of hot spots of full immunization among children aged 12–23 months in Ethiopia, MEDHS2019.

Variable	Coefficient	StdError	Robust std-error	Robust t-statistics	Robust probability	VIF
Intercept	0.228891	0.051366	0.049260	4.646634	< 0.001	-
Proportion of rural residence	-0.094757	0.044484	0.045250	-2.09407	< 0.05	1.40
Proportion women who have PNC	0.244282	0.081376	0.093570	2.610704	< 0.01	1.13
Proportion of women who have ANC_4+	0.434939	0.054125	0.061556	7.065787	< 0.001	1.36
Proportion of women age 35–44 years	0.107345	0.059306	0.067615	1.587602	> 0.05	1.14
Proportion of women who had been never BF	-0.231220	0.179619	0.095407	-2.42349	< 0.05	1.04
Proportion of family size 4 and above	-0.168511	0.058177	0.064049	-2.63098	< 0.01	1.31
Ordinary least square regression Diagnostics						
Number of observations	305	AICc	162.77			
Multiple R-Squared	0.3877	Adjusted R-Squared	0.371			
Joint F-Statistic	23.43	Prob(> F), (8,296) degrees of freedom	< 0.001			
Joint Wald Statistic	238.44	Prob(> chi-squared), (8) degrees of freedom	< 0.001			
Koenker (BP) Statistic	16.25	Prob(> chi-squared), (8) degrees of freedom	< 0.05			
Jarque-Bera Statistic	2.36	Prob(> chi-squared), (2) degrees of freedom:	0.31			

Table 6. The ordinary least square regression analysis result.

Model Comparison parameter	Ordinary list square (OLS) model	Geographically weighted regression (GMW)Model
AICc	162.77	161.98
Adjusted R-squared	0.371	0.3748

Table 7. Model comparison of OLS and GWR model.

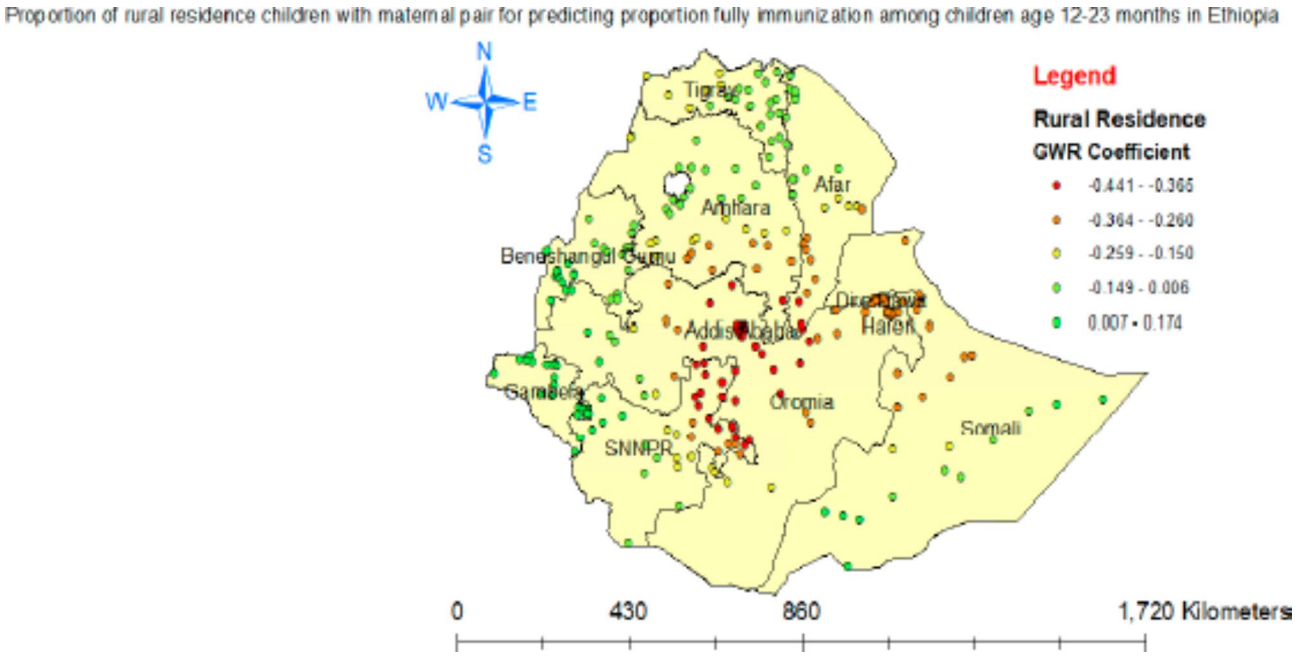

Fig. 5. Rural residence GWR coefficients for predicting full immunization among children aged 12–23 months in Ethiopia.

In Ethiopia, the overall coverage of fully immunized children aged 12–23 months was 40.58%. The result is higher than the EDHS 2011 and EDHS 2016 studies conducted in Ethiopia, which showed 22% and 38.5% respectively[14,20]. Also higher than the study conducted in Kenya 23%[21] and Nigeria 22.1%[22]. But these findings were lower than the meta-analysis study conducted in Ethiopia, 58.92% and 60%[6,23], a study in Cameroon,

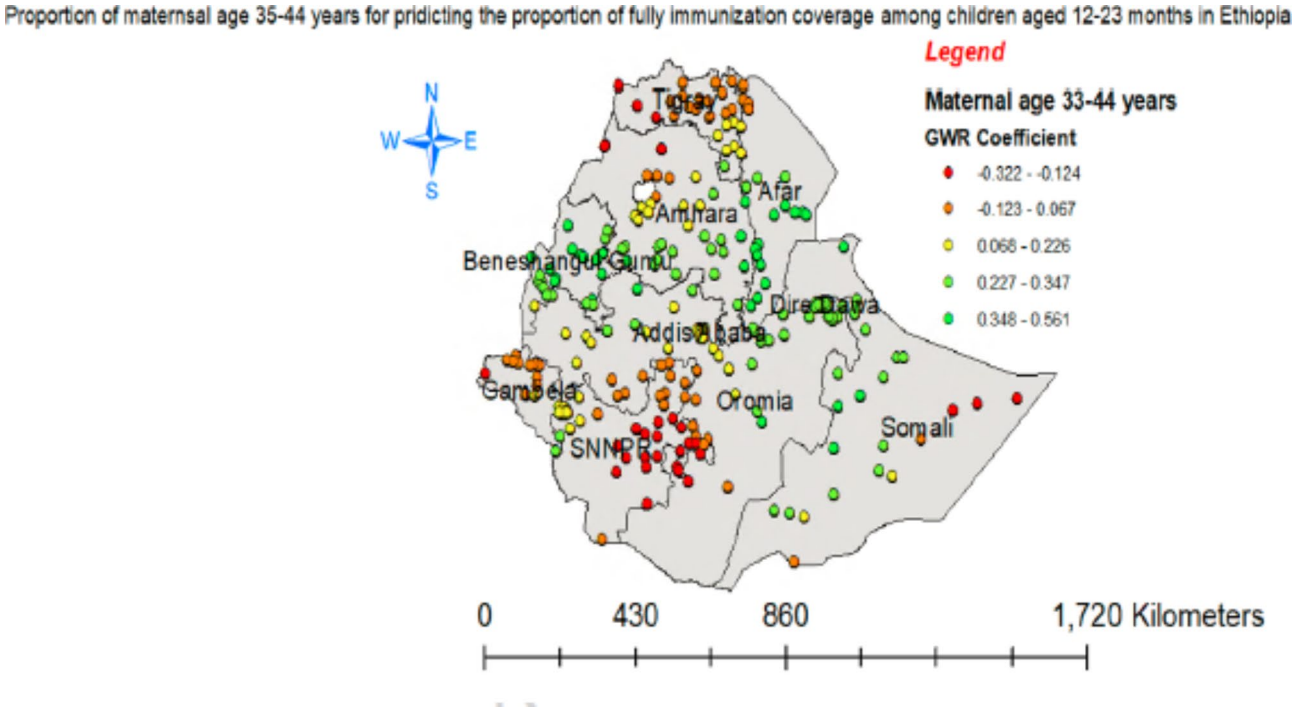

Fig. 6. Maternal age 35–44 years GWR coefficients for predicting full immunization among children aged 12–23 months in Ethiopia.

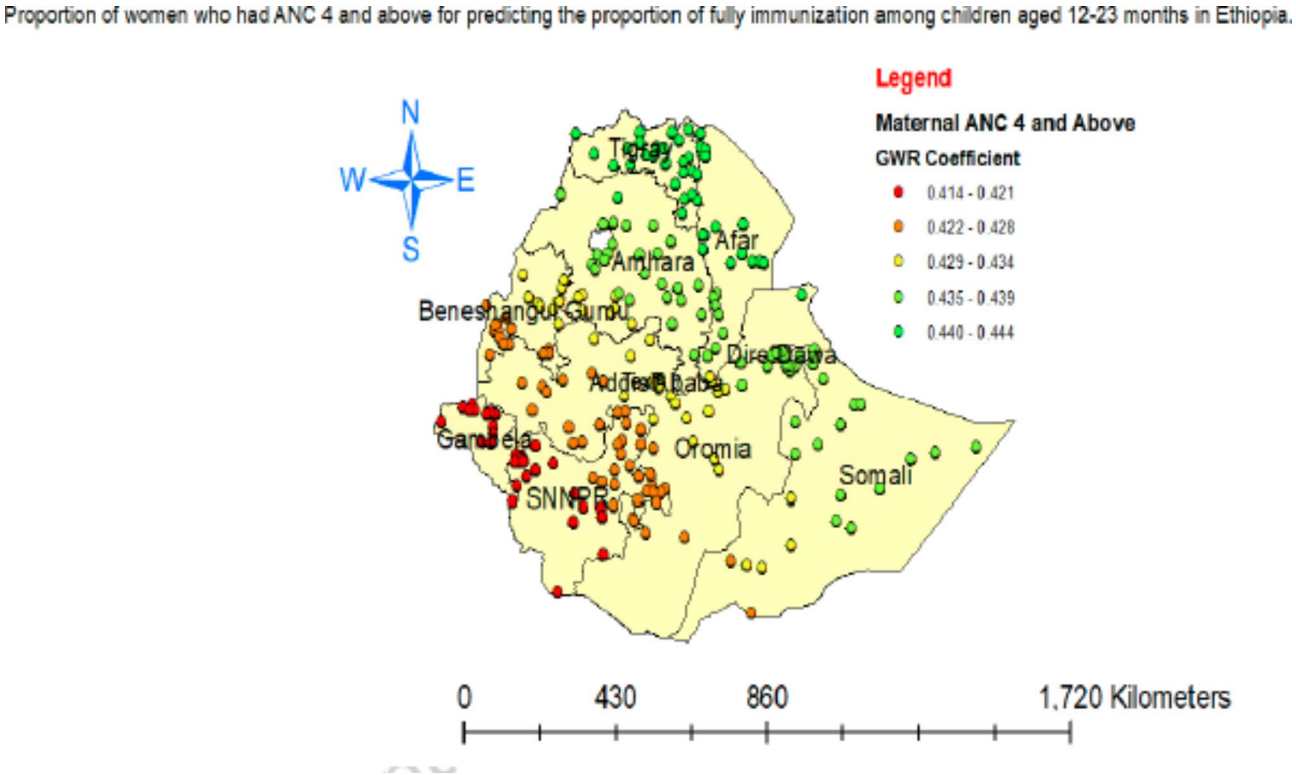

Fig. 7. Women with ANC 4 and above GWR coefficients for predicting the proportion of full immunization among children aged 12–23 months in Ethiopia.

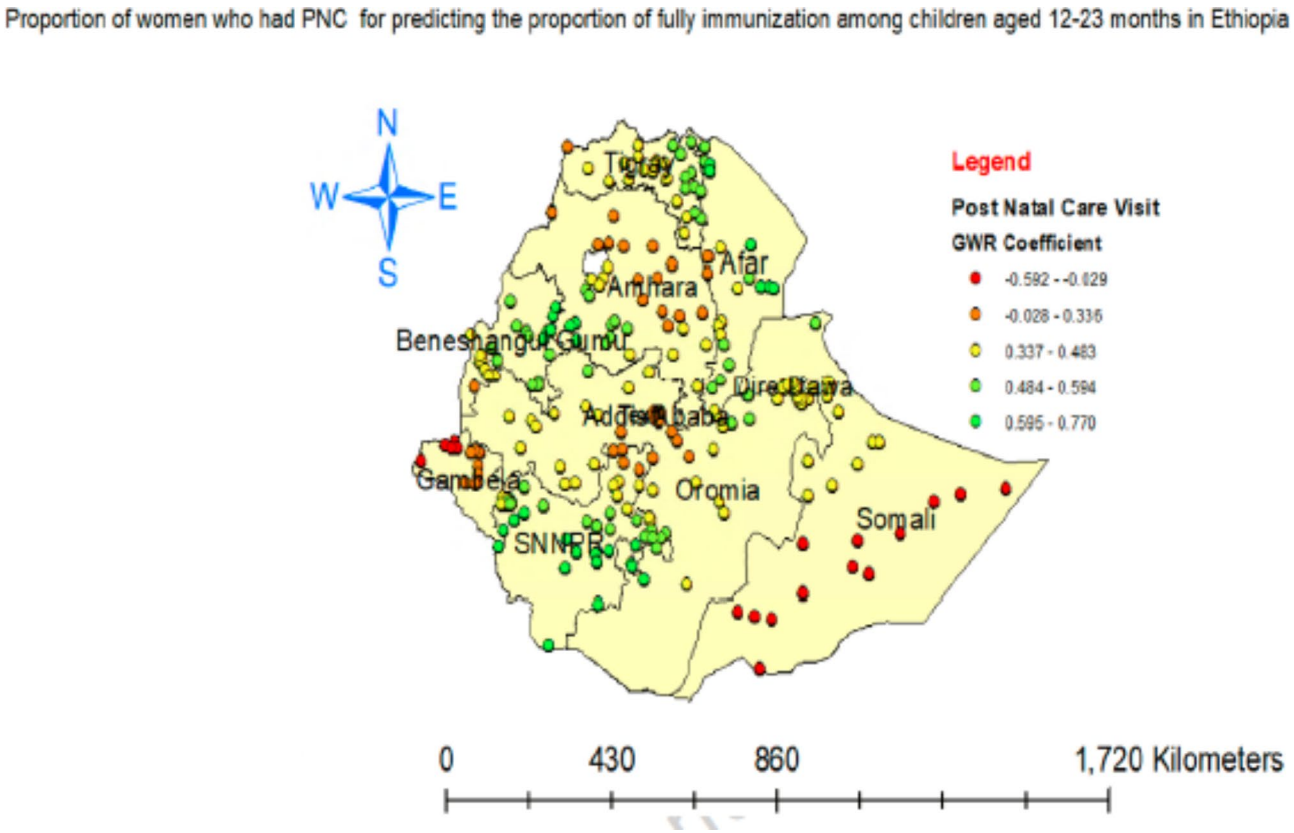

Fig. 8. Women who had PNC GWR coefficients for predicting the proportion of full immunization among children aged 12–23 months in Ethiopia.

85.9%[24], Sub-Saharan Africa, 59.40%; DHS of Senegal 62.8%[25,26], Ghana 89.5% and Sudan 82.2%[27,28], Eritrea DHS 2010 83%[29], Malaysia 2016 (NHMS) 86.4%, south africa DHS 2016 59.6%[30,31], Bangladesh 61.7%[32] and Indonesia 58.22%[33,34]. This variation occurs due to the time of studies, study area, methods of analysis, variables, and sample size. The variation in the two Ethiopian EDHS reports was that the Ethiopian government made efforts to expand primary health care services and build capacity for the prevention of childhood illnesses, which led to an increase in vaccination coverage. On the other hand, African DHS reports indicate that countries have better child health services.

On the other hand, the spatial distribution of fully immunized children aged 12–23 months in Ethiopia was clustered (non-random), with hotspot areas of fully immunized noticed in West Tigray, Central Oromia, Addis Ababa, and some parts of South Eastern Amhara region. This shows that despite numerous interventions that have been implemented to address full immunization in Ethiopia, there are spatial variations between areas. This could be due to differences in healthcare availability, infrastructure, awareness, and beliefs.

In the geographically weighted regression analysis, rural residence, maternal age 35–44 years, women with ANC 4 or more, and PNC were factors associated with hotspot areas of full immunization among children aged 12–23 months. There is a negative relationship between rural residency and the distribution of full immunization coverage in the southeast of Amhara, the entire Addis Ababa, Oromia, the eastern parts of the SNNP regions, Harari, Dire Dewa, and southern Afar. This might be due to rural areas often having limited access to healthcare facilities, including immunization services. This can make it difficult for families to access vaccines for their children, leading to lower immunization coverage compared to urban residents. Additionally, rural areas may face infrastructure challenges and awareness problems such as poor roads, lack of transportation, and limited electricity supply. These challenges can reduce the delivery and storage of vaccines, making it harder for healthcare providers to reach remote communities.

The increased proportion of maternal aged 35-44years increases the coefficient of full immunization among children aged 12–23 months in Southern Amhara, the entire Afar region, Dire Dewa, Harari region, Benishangul-Gumuz region, western portions of Somalia, and eastern parts of the Oromia regions. This could be because older mothers have had greater exposure to and experience with healthcare information, resulting in increased awareness and health-seeking behavior on the necessity of immunization.

The proportion of women who had ANC 4 and above has increased coefficient of the proportion of full immunization in the entire Tigray, Amhara, eastern parts of Oromia, and eastern parts of Somalia regions. The proportion of women who had PNC has increased the coefficient of the proportion of full immunization in eastern parts of Tigray, Eastern parts of Afar, and southern parts of SNNP regions with the highest coefficient. This might be due to women being counseled about the importance of immunization during the ANC and

PNC service, which can increase full immunization coverage. Especially during PNC visits, integrated services, including child immunizations, are provided in Ethiopia.

In multilevel mixed effect logistic regression analysis, family size, age of the mother, duration of breastfeeding, PNC, number of ANC visits, region, and place of residence were statistically significant factors associated with full immunization among children aged 12–23 months in Ethiopia. Children born from mothers who attended 1–3 times antenatal care during pregnancy were 55% less likely to be fully immunized than four and above times. This finding is supported by the study conducted in EDHS 16, Senegal DHS 2011[14,25], Pakistan[35], Indosenia[34], sub-Saharan Africa, and Bangladesh[26,32], studied in East Africa recent demographic and health surveys[36]. This might be because when women had four or more ANC services, they got counseling about child immunization. Immunization counseling is one of the services conducted during ANC visits. Children born from mothers who had PNC during the postnatal period were 2.4 times more likely to be fully immunized than their counterparts. This finding is supported by the study conducted in Ethiopia[37], sub-Saharan Africa, EDHS 2011 and Bangladesh[20,26,32], the democratic republic of Congo[33], studied in Indonesia, and East Africa recent demographic and health surveys[34,36]. The link between PNC visits and immunization could be explained by the fact that an early postnatal visit provides an opportunity to initiate BCG vaccination and polio vaccination can be administered during PNC visits, which could increase compliance with the immunization program and create an opportunity to initiate vaccination among unvaccinated children[33]. In addition, during postnatal periods, there is counseling on child immunization, which increases the maternal child's health sicking behaiver that increases child immuization. On the other hand children who had been never breastfeed were 98% times less likely to be fully immunized. This could be due to the promotion of breast feeding linked to the promotion of immunization. Therefore, mothers who does not breest feed have limited information related to immunization.

This study also revealed that four or more family members were 60% less likely to be fully immunized. This might be due to parents with large family sizes having difficulty having time to take their children to immunization appointments. This finding was supported by the study conducted in Africa systematic review[38], Angola[39] and Gambia[40], and Ethiopian study[4].

The age group of 35–44 years was six times more likely to be fully immunized than the lower age group. This is because older mothers may have more experience, a stronger sense of responsibility, and more information about childhood immunization. This finding is supported by the Ethiopian study[41] and DHS studies in East Africa, Afghanistan, and Myanmar[34,36,42]. Additionally, supported by studies in sub-Saharan Africa, Nigeria, Ghana, and Bangladesh[22,26,27,32].

In this study, children from the Oromia region and Eastern pastoralists were negatively associated with full immunization. Being from Oromia and eastern pastoralist regions, 77% and 91% times less likely to be fully immunized than most urban regions respectively. This finding supported meta-analysis in Ethiopia, EDHS 2011 and 2016[6,14,20]. Other studies outside Ethiopia indicated regions were significantly associated with full immunization coverage[29,33]. This may be due to differences in the uptake of immunization services based on cultural beliefs or differences in the quantity and/or the quality of health care services between the administrative regions. This may also be explained by vaccine supply, cold chain, or differences in other logistics issues between regions.

Additionally, children from rural residences were 73% less likely to be fully immunized than urban children. This might be due to access to health services. Rural areas typically do not have better infrastructure and no more accessible health services compared to urban areas, making it not easier for people to access immunization services. In addition, rural residents are not more educated and do not have better access to information about the importance of immunization, leading to low service uptake. This finding is supported by the study conducted in Ethiopia EDHS 2011 and 2016[14,20] and evidence from the Ethiopian 2012 national immunization coverage survey[41], Senegal DHS[25], Sub-Saharan Africa, and the Democratic Republic of Congo[26,33].

This study has both strengths and limitations. Fitting a multilevel model with community and individual-level components was the strength of this study for getting good estimates of the parameters. Also, this study identifies the local factors, which indicate the geographic variations. On the other hand, this study was prone to recall bias because the outcome variable was assessed based on the maternal report (part of the data) within the three years preceding the survey. Furthermore, some of the data was incomplete and difficult to analyze.

Conclusion

Nearly two out of every five children in Ethiopia had been fully immunized for the recommended periods and there was a significant spatial variation of full immunization among children aged 12–23 months across regions in Ethiopia. Significant hotspot areas of full immunization were identified in Tigray, Central Oromia, Addis Ababa, and some parts of South Eastern Amhara regions. The proportion of rural residents, the proportion of women aged 35–44 years, the proportion of women who had ANC 4 and above, and the proportion of women who had PNC were local factors for the proportion of full immunization in Ethiopia.

Women who had postnatal care, ANC visits four and above, and increased maternal age were positively associated factors with full immunization, whereas having a four and above family size, never breastfeeding, having a rural residence, and from Oromia and eastern pastoralist region were negatively associated with full immunization using multilevel analysis in Ethiopia.

Maternal and child health services such as ANC, PNC, and breastfeeding guidance should be strengthened to increase full vaccination coverage. Family planning also should be encouraged to restrict family size. Furthermore, the Ministry of Health and Regional Health Bureau should prioritize rural residents and reduce regional disparities. Policymakers should also focus on maximizing regional and place of residence variance and supporting existing health policies to enhance ANC and PNC care services to meet Ethiopia's goal of vaccination coverage. Researchers will also undertake large-scale studies that include additional aspects, such as service-

related factors. The family must limit the number of children and promote ANC, PNC, and breastfeeding practices.

Data availability

The datasets analyzed during the current study are available from thecorresponding author upon reasonable request.

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Author contributions

FD, HT, DB, and WG developed the proposal. FD, HT,YN and DTW involved in the design, selection of study,-data cleaning, statistical analysis, and development of the initial drafts of the manuscript. YN, DTW, FD, and HTwere involved in writing the Manuscript. HT, FD, and YN revising the prepared manuscript. FD and HT preparedthe final draft of the manuscript. All authors read and approved the final draft of the manuscript.

Declarations

Ethics approval and consent to participate

The ethical clearance was obtained from Debre Markos University College of Health Science. The data was accessed from the Ethiopia Mini Demographic and Health Survey (DHS), the 2019 program's official database website (http://dhsprogram.com). I accepted the DHS data of all countries' data-sharing policies. Participant consent is not applicable.

Competing interests

The authors declare no competing interests.

Additional information

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