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Spatial distribution of effective coverage of child immunisation in Ethiopia

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ABSTRACT

Introduction Child immunisation is a cost-effective strategy to reduce vaccine-preventable diseases. While effective coverage is key to ensuring quality immunisation, little is known about its geographical distribution in Ethiopia. This study aims to assess the spatial distribution of effective coverage of child immunisation and identify areas with low coverage to inform targeted interventions.
Methods We used the 2019 Ethiopia Mini Demographic and Health Survey and Ethiopia Service Provision Assessment datasets. After calculating the effective coverage of immunisation, Bayesian model-based geostatistics were employed to assess the spatial distribution of effective immunisation coverage in Ethiopia, using relevant covariates to estimate coverage rates across regions.
Results The national effective coverage of immunisation was 34% (95% CI: 31.9% to 36.5%), with significant regional variation. Addis Ababa, western Benishangul-Gumuz, Dire Dawa city administrative, the northern part of South West Ethiopia and the northwest part of Amhara had hotspots for high level of effective coverage of child immunisation. On the other hand, central Amhara, northern Gambela, central Oromia, Sidama, northern Southern Nations, Nationalities and Peoples regions (SNNPR) and Somali had low effective coverage of child immunisation. Travel time to the nearest city (−0.292: 95% CI:−0.533 to −0.052) was found to be negative predictor of spatial distribution.
Conclusion There were significant geographical variations in the effective coverage of immunisation services in Ethiopia. Travel time to nearest city was a significant predictor of spatial distribution. Policymakers are advised to prioritise underserved areas and improve spatial predictors to have a safe, effective and life-saving vaccination program in Ethiopia.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Immunisation is a proven strategy to prevent childhood diseases, yet many low-income and middle-income countries, including Ethiopia, face challenges in achieving high and equitable coverage. Prior research has primarily focused on crude coverage rates, with limited attention to effective coverage and its spatial variation across regions.

WHAT THIS STUDY ADDS

⇒ This study provides new insights into the spatial distribution of effective coverage of immunisation coverage in Ethiopia, highlighting regional disparities and identifying factors that influence vaccine uptake.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The findings provide actionable insights for health planners and policymakers to prioritise underserved areas and address inequities in both access and quality of immunisation services. This evidence supports more targeted and equitable immunisation strategies, improving child health outcomes at the national and subnational levels.

INTRODUCTION

Child immunisation is one of the most cost-effective public health initiatives, significantly reducing morbidity and mortality rates from vaccine-preventable diseases.[1] It is a vital component in the global effort to achieve Sustainable Development Goal 3, which aims to ensure healthy lives and promote well-being for all ages.[1]

As of 2023, approximately 84% of infants worldwide received the third dose of the diphtheria-tetanus-pertussis (DTP3) vaccine, a critical indicator of immunisation coverage.[1] However, around 14.5 million children missed any vaccination, commonly referred to as ‘zero-dose’ children.[2] The coverage rates for other vaccines, such as measles, have also declined, with 22.2 million children missing their first dose in 2023, a significant increase from previous years.[3] The disparities in immunisation coverage are stark when comparing high-income and low-income countries.[4] For instance, while Europe boasts coverage rates near 96%, Africa struggles with rates as low as 75% for DTP3.[5]

The 2019 Ethiopia Mini Demographic and Health Survey (EMDHS) reported that only 43% of children aged 12–23 months had received all basic vaccinations.[6] This figure is considerably lower than the global target of 90% coverage, highlighting significant gaps in immunisation services and uptake.[1] In Ethiopia, the Expanded Programme on Immunisation was launched in 1980 to provide routine immunisations to all children.[7] Despite this long-standing initiative, Ethiopia continues to face substantial challenges in achieving high and equitable immunisation coverage.[1]

Effective coverage refers to the proportion of the target population that receives vaccines according to the recommended schedule, while the quality of immunisation encompasses aspects such as the reliability of vaccine storage, administration practices and monitoring of adverse effects.[8] The concept of effective immunisation coverage is essential because it provides a more accurate assessment of the public health impact of vaccination programmes, reflecting not just access, but also the quality and effectiveness of the vaccination process.[8 9]

Geographical disparities in immunisation coverage are pronounced in Ethiopia.[10] Remote and rural areas are particularly affected due to logistical barriers such as difficult terrain, inadequate infrastructure and limited access to healthcare facilities, making it harder to reach children with vaccination service facilities.[11 12] Also, cultural and religious beliefs significantly influence immunisation uptake.[13] For instance, in the Afar region, traditional practices often prioritise livestock health over human immunisation, while in the Somali region, misconceptions about vaccine safety contribute to hesitancy or refusal to vaccinate children.[14 15] These challenges result in lower immunisation rates and increased vulnerability to vaccine-preventable diseases in these regions.[11] Therefore, the spatial distribution of immunisation services requires careful analysis to identify the areas with the greatest need and develop tailored interventions accordingly.[16 17]

Effective coverage and high-quality immunisation services are fundamental to the success of vaccination programmes.[18 19] Yet, the absence of spatial analysis on effective coverage limits the ability to identify and address regional disparities in immunisation coverage. This research aims to fill these gaps by systematically investigating the spatial distribution of effective coverage of child immunisation in Ethiopia. The findings will equip policymakers with precise, location-specific data needed to design and implement targeted interventions. By identifying underserved areas, the study supports more equitable resource allocation, ultimately strengthening immunisation programmes and improving child health outcomes.

METHODS

Study area

This study was conducted in Ethiopia, a landlocked country located in the Horn of Africa. Ethiopia operates under a federal system and is administratively divided into nine regional states and two city administrations, namely Addis Ababa and Dire Dawa. Each region is further subdivided into zones, woredas (districts) and kebeles (the smallest administrative units). The country's healthcare system has seen improvements over recent years, yet challenges remain, particularly in rural and underserved areas, where disparities in health service coverage and outcomes persist. This diverse administrative and sociodemographic structure makes Ethiopia a unique setting for public health research aimed at addressing inequalities in health and healthcare access.

Study design and data source

A cross-sectional study design was used, drawing data from the 2019 EMDHS. In this study, a secondary data analysis was conducted using the 2019 EMDHS data which was designed to provide estimates of key indicators for the country as a whole, for urban and rural areas separately, and each of the nine regions and the two administrative cities. The other dataset used was Service Provision Assessment (SPA), which is part of the DHS programme and SPA 2020–2021 is the second facility survey which collects data on quality of care and service availability. The Ethiopian Demographic and Health Survey (EDHS) holds data that are publicly available via the DHS website.[20]

Sample size

To determine crude coverage, a total of 5753 children across 305 clusters were initially included. However, due to the absence of data from the Tigray region in the Ethiopia SPA (ESPA) dataset, the region was excluded for consistency, resulting in a sample of 5299 children from 280 clusters. Subsequently, children who were not alive were excluded, reducing the sample to 4974 children across the same number of clusters. Further filtering was done by excluding children older than 23 months of age, resulting in 1932 children from 279 clusters. After removing children younger than 12 months of age, the final sample comprised 915 children aged 12–23 months, drawn from 262 clusters using the Kids Record file of the EDHS.

For assessing service quality, the ESPA dataset initially included 1158 health facilities. From these, 774 facilities that provided vaccination services were selected for the study based on the availability of relevant health facility records (figure 1).

Measure of variable

Crude coverage

Full child immunisation history was recoded using the information from the mother's report and the child's immunisation card; if the card was available or the mother gave confirmation, the child was fully vaccinated.[21] A child

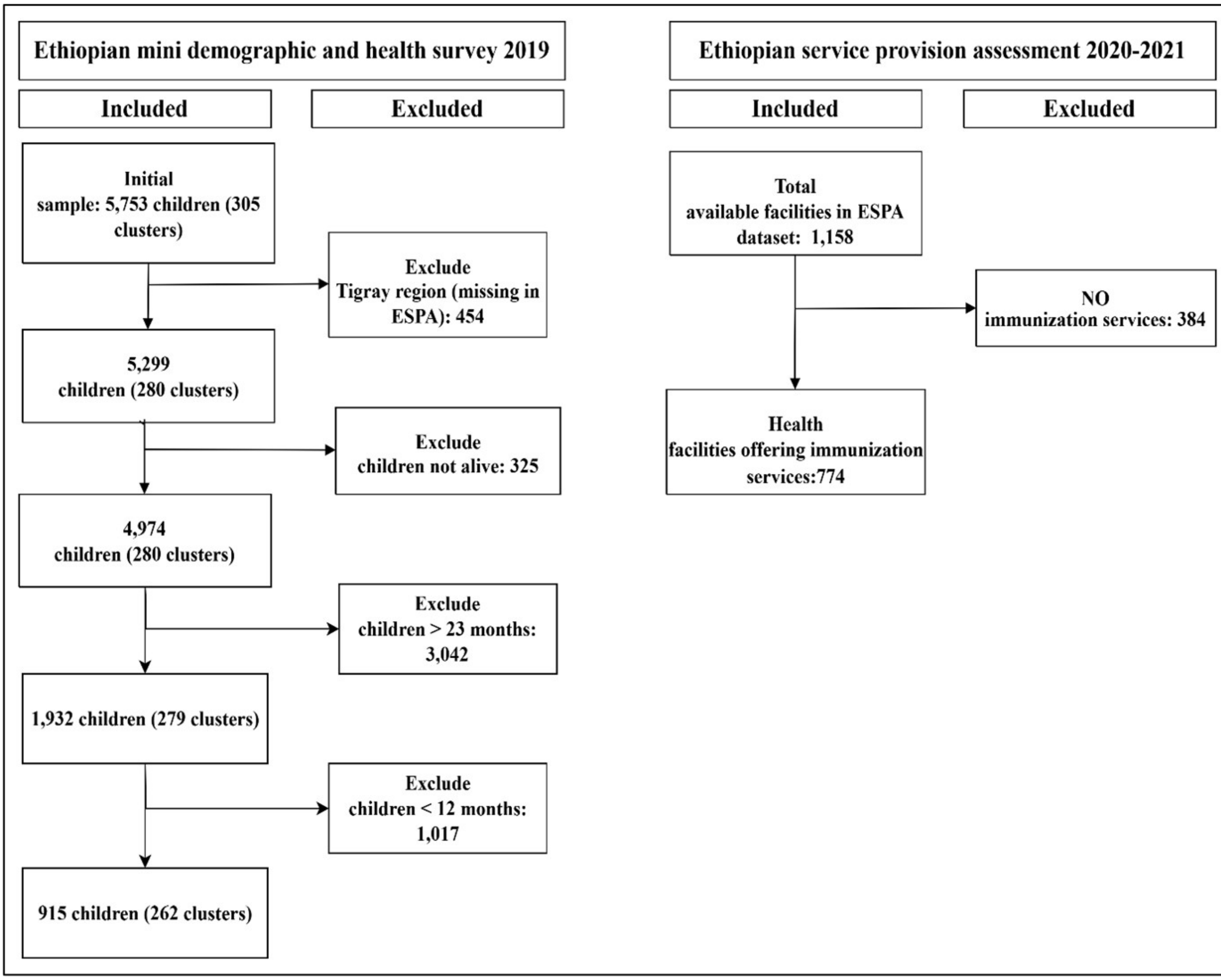

Figure 1 Schematic illustration of respondents included in the study, EMDHS 2019 and health facilities included in the study, ESPA 2020–2021. EMDHS, Ethiopia Mini Demographic and Health Survey; ESPA, Ethiopia Service Provision Assessment.

is considered fully immunised if they have gotten three doses of the pentavalent vaccination (DPT-HepB-Hib), three doses of the polio vaccine, one dose of the measles vaccine and one dose of the BCG vaccine for tuberculosis between the ages of 12 and 23 months.[22]

Quality

Three dimensions (structure, procedure and outcome) are used to assess the calibre of services.[23] The quality of the child immunisation service is evaluated using its structural component, which pertains to the facility's preparedness to provide immunisation services, including the presence of medical supplies, qualified people, equipment and commodities.[24] We used 14 indicators to generate the quality of health facilities (online supplemental table 1).

Staff and guidelines variable staff were recoded as 'yes' if the staff were trained and 'no' if they did not receive any training. Guidelines are recorded as 'yes' if observed and 'no' if none is available and reported (not observed). Equipment variables are coded as 'yes' if they are observed and valid and else recoded as 'no'. Medicines and commodities variables are recoded as 'yes' if they are observed and at least one valid and else recoded as 'no'.[25]

Data management and analysis

We used Stata V.17 for analysis. The data was cleaned, and missing values were managed using a guide to DHS statistics. The data were weighted using sampling weights to restore the representativeness of the survey.

The readiness scores for child immunisation services were determined by calculating averages following WHO guidelines.[26] The three areas of vaccine preparedness are personnel and guidelines, equipment and medications and commodities. The readiness for each area is calculated by summing the averages for its items, dividing that sum by the total number of items in the domain, and then multiplying the outcome by 100.[26]

The readiness score was calculated using the following formula:

$$Readiness = \frac{Total\ number\ of\ \text{"yes"}\ responses\ in\ each\ item}{Total\ number\ of\ parameter} \times 100\%$$

The Euclidean distance method, which uses Global Positioning System (GPS) coordinates to match records spatially, was used to link the EMDHS and the health facility record from the ESPA.[27] Using health facilities as a base, each health institution was linked to the closest EMDHS survey cluster within a 15 km radius using the 'geonear' command in Stata.[28] The facility was connected to the nearest cluster, regardless of distance, if no cluster could be found within this range. Finally, 246 DHS clusters and 774 health facilities were successfully linked. To acknowledge the difference when using the EMDHS cluster as a base, we included a supplementary file (online supplemental file 1).

The effective coverage of immunisation was calculated by multiplying the quality of the health facility (readiness) with the immunisation coverage. Effective coverage goes beyond crude coverage by accounting not only for service utilisation but also for the quality of service delivery needed to achieve protective health outcomes.[9] Effective immunisation coverage was defined as the proportion of children aged 12–23 months who received all recommended vaccines at the appropriate ages, and whose immunisation services met essential quality criteria.[29] The formula was adopted from the WHO effective coverage framework.[25 29]

Effective coverage = quality of the health service (readiness) × crude coverage

Spatial analysis

After calculating the effective coverage of immunisation for each health facility, we merged the coordinates of the health facilities. We analysed the spatial distribution using R V.4.4.3 and ArcGIS V.10.7 software. EMDHS cluster coordinates were used for the analysis based on cluster averages and were provided as supplementary data (online supplemental file 1).

Geospatial analysis

We employed a Bayesian model-based geostatistics to estimate the effective coverage of child immunisation across regions of Ethiopia, treating it as a continuous proportion bounded between 0 and 1. Key covariates included travel time to the nearest city and health facility, wealth, income, literacy and population density.[30 31] To reduce noise and avoid instability from sparsely populated areas, grid cells with fewer than five people per km^2 were excluded.[32] These gridded population estimates also served as weights in generating population-adjusted coverage estimates.[33]

The proportion of effective immunisation coverage was linked to a linear predictor via a logit link function suitable for continuous proportions. We performed inference using R-INLA in combination with the Stochastic Partial Differential Equations approach for computational efficiency.[34] Non-informative priors were used for the intercept and covariates, while default priors were assigned to the spatial parameters. The outputs included 1 km^2 resolution maps and posterior summaries (mean, SD and 95% credible intervals) of effective immunisation coverage.

Spatial autocorrelation

The spatial distribution of effective immunisation coverage in Ethiopia was evaluated using the Global Moran's I statistic, a measure of spatial autocorrelation. This method helps assess whether the distribution of immunisation coverage across regions is random or exhibits a spatial pattern. Results from the analysis indicated a positive Global Moran's I value, suggesting that immunisation coverage in Ethiopia is not randomly distributed but rather clustered in specific regions, with certain areas demonstrating higher or lower coverage than expected by chance.[35]

Hotspot analysis

The Getis-Ord Gi* statistic was employed to conduct a hot spot analysis, effectively identifying significant clusters of high (hot spots) and low (cold spots) immunisation coverage. This spatial statistical tool is commonly used to detect patterns in geographical data, allowing for the identification of areas where immunisation efforts are particularly successful or where gaps in coverage are pronounced.[36]

Patient and public involvement

No patient involved.

RESULTS

A total of 951 mothers who had a live child aged 12–23 months were included in the study. The majority of the respondents were aged 25–35 years (56.81%), followed by those aged 15–24 years (30.47%) and 36–49 years (12.72%). Most of the mothers were married (96.06%) and lived in rural areas (69.52%) (table 1).

Health facility characteristics

A total of 774 health facilities which give immunisation services were included. The majority of the facilities were from rural areas (58.4%). Most of the facilities were governmental facilities (96%) (table 2).

Effective coverage of child immunisation

The national effective coverage of immunisation was 34% (95% CI: 31.9% to 36.5%) with a large variation in different regions, ranging from 16.6% in Afar to 87.6% in Addis Ababa (table 3).

Spatial distribution of effective coverage of child immunisation

Effective child immunisation coverage showed a significant positive spatial autocorrelation in Ethiopia with the Global Moran's index value of 0.87 with ($p<0.001$) (online supplemental figure 1). The spatial distribution analysis showed that facilities found in Benishangul-Gumuz, Dire Dawa city administrative, Western Amhara, Western Gambela and the Northern part of SNNPR had higher effective coverage (online supplemental figure 2).

Table 1 Socioeconomic and demographic characteristics of participants EMDHS 2019 (n=951)

Variables	Categories	Frequency	Percentage
Mother's age	15–24	290	30.47
	25–35	540	56.81
	36–49	121	12.72
Marital status	Unmarried	37	3.94
	Married	913	96.06
Residence	Urban	290	30.48
	Rural	661	69.52
Religion	Orthodox	309	32.46
	Muslim	348	36.57
	Protestant	265	27.9
	Others	29	3.07
Region	Afar	15	1.58
	Amhara	218	22.91
	Oromia	405	42.62
	Somali	56	5.88
	Benshangule	11	1.12
	SNNPR	199	20.96
	Gambela	4	0.44
	Harari	3	0.27
	Addis Abeba	34	3.60
	Dire Dawa	6	0.63
Mother's education	No education	433	45.51
	Primary education	395	41.59
	Secondary education	73	7.65
	Higher	50	5.25
Wealth status	Poorest	214	22.5
	Poorer	169	17.74
	Middle	221	23.23
	Richer	168	17.7
	Richest	179	18.84

EMDHS, Ethiopia Mini Demographic and Health Survey; SNNPR, Southern Nations, Nationalities and Peoples Region.

Hotspot analysis of effective coverage of child immunisation

There were hot and cold spot areas for effective coverage of child immunisation in Ethiopia. Addis Ababa, western Benishangul-Gumuz, Dire Dawa city administrative, the northern part of South West Ethiopia and the northwest part of Amhara had hotspots for effective coverage of child immunisation. On the other hand, central Amhara, northern Gambela, central Oromia, Sidama, northern SNNPR, Afar and Somali had cold spots for effective coverage of child immunisation (online supplemental figure 3).

Table 2 Health facilities characteristics Ethiopian SPA 2020–2021 (n=774)

Variable	Categories	Frequency	Percentage
Facility type	Hospital	274	35.40
	Health centre	253	32.69
	Health post	242	31.27
	Clinic	5	0.65
Area	Urban	322	41.60
	Rural	452	58.40
Managing authority	Government	743	95.99
	Private	20	2.58
	NGO	11	1.42

NGO, non-governmental and non-profit organisations.

Spatial prediction of effective coverage of child immunisation

The spatial prediction of effective coverage of child immunisation showed a high coverage mainly in Addis Ababa, northern and western part of Benishangul-Gumuz, Western Amhara, western part of Oromia, central Gambela, Harari and Dire Dawa. There was low effective coverage of child immunisation in Somali, southern Oromia, Afar and the eastern and southern parts of Amhara. The predicted low effective coverage of child immunisation was shown in red colour (figure 2).

Factors associated with spatial distribution of effective coverage of child immunisation

We estimated the effective coverage of child immunisation across Ethiopia while accounting for spatial dependencies and key covariates. Among the predictors, travel time to the nearest city was significantly associated with effective immunisation coverage, showing a negative effect (−0.292: 95% CI: −0.533 to −0.052) (online supplemental table 2). The results based on cluster averages were presented (online supplemental file 1).

DISCUSSION

This study has revealed the spatial distribution of effective coverage of child immunisation in Ethiopia. The effective coverage of child immunisation is 38%. The result was lower than the crude coverage of child immunisation at 44%.[22] This suggests that while a significant number of children receive vaccines, various factors may undermine the actual protective impact of these immunisations. This study was consistent with a study conducted in Mexico and Nicaragua that found lower effective coverage.[19] The possible reason for this might be the lower quality of child immunisation services resulting from inadequate healthcare infrastructure, insufficient training of healthcare workers and poor supply chain management leading to vaccine shortages.[37] Additionally, lower immunisation uptake resulted from limited community awareness and engagement, along with cultural or religious resistance, which in turn affects the effective coverage.[11 38 39]

Table 3 Effective coverage of immunisation across regions of Ethiopia

Region	CC (95% CI)	Quality (95% CI)	EC (95% CI)	CC – EC
Afar	22.8 (13.7 to 32.0)	77.3 (67.9 to 86.7)	16.6 (10.1 to 23.1)	6.2
Amhara	39.3 (32.5 to 46.1)	85.4 (81.9 to 88.9)	33.1 (27.2 to 39.0)	6.2
Oromia	44.1 (38.0 to 50.2)	81.8 (78.4 to 85.2)	36.1 (30.8 to 41.4)	8
Somali	23.2 (16.8 to 29.7)	82.5 (77.0 to 88.1)	19.6 (13.7 to 25.5)	3.6
Benishangul	59.1 (46.4 to 71.7)	91.3 (85.8 to 96.7)	53.4 (41.7 to 65.0)	5.7
SNNPR	29.2 (24.2 to 34.2)	74.6 (71.4 to 77.8)	22.3 (18.3 to 26.3)	6.9
Gambella	39.0 (26.1 to 51.9)	84.4 (77.8 to 91.0)	34.1 (23.1 to 45.1)	4.9
Harari	63.2 (47.5 to 78.9)	90.6 (86.2 to 95.1)	46.6 (40.6 to 52.6)	16.6
Addis Ababa	91.9 (86.6 to 97.1)	95.5 (92.5 to 98.5)	87.6 (84.8 to 90.4)	4.3
Dire Dawa	59.8 (48.7 to 71.0)	82.0 (75.3 to 88.6)	46.8 (40.3 to 53.3)	13
National level	41.3 (38.6 to 44.1)	82.0 (80.4 to 83.5)	34.2 (31.9 to 36.5)	7.1

CC, crude coverage; EC, effective coverage; SNNPR, Southern Nations, Nationalities and Peoples Region.

The study revealed significant spatial clustering of effective coverage of immunisation in Ethiopia, which highlights the disparities in healthcare access and infrastructure within Ethiopia. Previous studies found that child immunisation coverage was different across regions[16 40] as well as the quality of immunisation service.[41 42] The possible reason for this might be the unequal distribution of healthcare resources, including trained health personnel, cold chain systems and access to health facilities, particularly in remote and rural areas.[43 44] Another possible explanation might be regional differences in maternal education and exposure to mass media, which further exacerbate these challenges by limiting awareness and understanding of the benefits of immunisation.[45]

Travel time found to be associated with regional disparities in immunisation. This result was consistent with a study conducted in Ethiopia.[17] The possible reason might be that families residing far from health centres may face challenges such as high transportation costs, poor road infrastructure and time constraints, which can reduce their likelihood of completing vaccination schedules.[46]

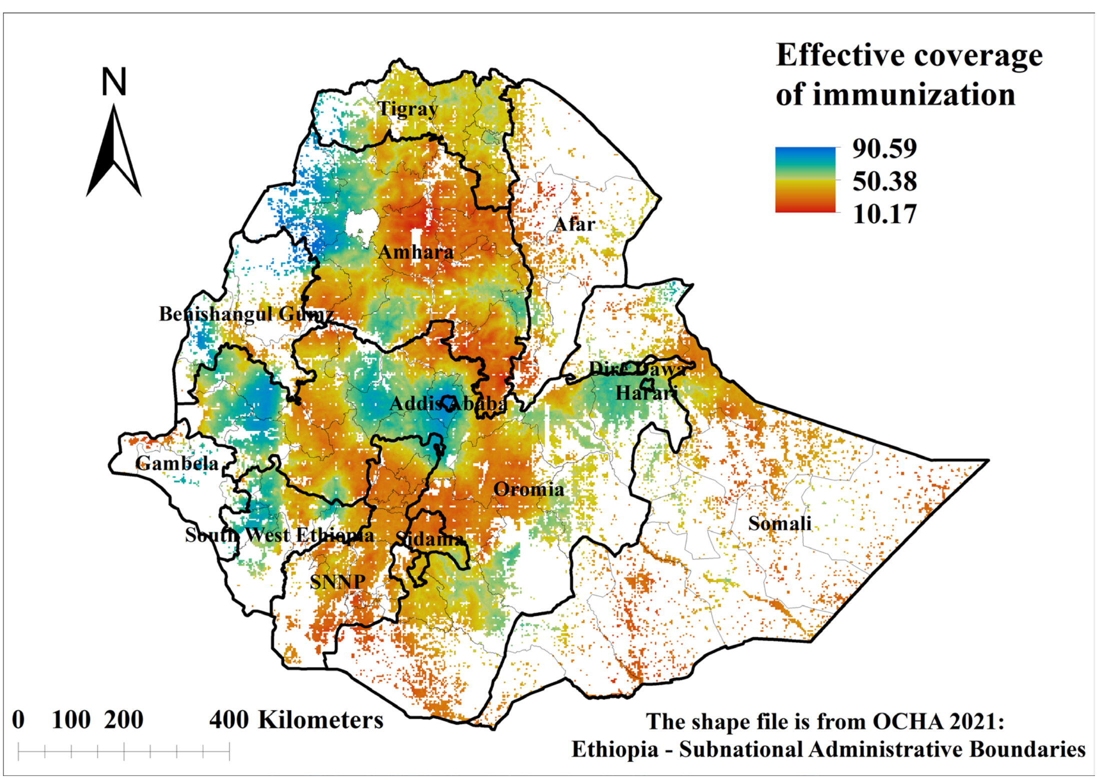

Figure 2 Spatial prediction of effective coverage of immunisation in Ethiopia. OCHA, United Nations Office for the Coordination of Humanitarian Affairs; SNNP, Southern Nations, Nationalities and Peoples.

The study identified Addis Ababa, western Benishangul-Gumuz, Dire Dawa city administrative, northern part of South West Ethiopia and the northwest part of Amhara as significant hotspots for the effective coverage of child immunisation. These regions demonstrated higher immunisation rates compared with other areas, suggesting a stronger implementation of vaccination programmes and better accessibility to healthcare services. These results were consistent with a study conducted in Ethiopia.[47] The possible reason for this might be because these regions are more urbanised, with improved healthcare infrastructure and easier access to medical services.[12] Additionally, higher education levels in these regions likely contribute to greater understanding of the benefits of vaccination, adherence to immunisation schedules and active engagement with healthcare services, which in turn lead to higher effective immunisation coverage.[48] Another possible reason might be regional differences in the proportion of low-income families and those engaged in informal or daily labour, who may face financial and time-related barriers to accessing immunisation services, contributing to disparities in immunisation coverage.[49 50]

On the other hand, central Amhara, northern Gambela, central Oromia, Sidama, northern SNNPR, Afar and Somali regions had cold spots for effective coverage of child immunisation. These results were consistent with a study conducted in Ethiopia.[47] The possible reason for this might be that remote and rural areas face challenges like limited healthcare facilities, lower literacy rates among mothers which may lead to limited understanding of the benefits of immunisation and difficulties in navigating health services.[17 51] Another possible explanation might be pastoralist communities in Afar and Somali regions, where mobility patterns make consistent healthcare access difficult, and traditional norms may deprioritise routine immunisation.[14]

Moreover, other possible reasons may help explain the observed spatial clustering. These include vaccine hesitancy, often driven by misinformation, fear of side effects or mistrust in healthcare systems, particularly in regions with lower educational attainment such as parts of Oromia and SNNPR.[52–54] High birth rates and large family sizes, especially in SNNPR, Afar and Somali,[55] can make it logistically difficult for caregivers to adhere to immunisation schedules for all children.[56 57] Challenges within the healthcare system, such as poor supply chain management, can lead to suboptimal service delivery, including missed or delayed vaccine doses, ultimately reducing the effectiveness of immunisation programmes.[58] These contextual factors highlight the need for deeper exploration in future studies.

Implications

These findings highlight the need for regionally tailored interventions to address specific barriers in low-coverage areas. By closing these gaps and improving both the quality and accessibility of immunisation services, Ethiopia can bridge the divide between crude and effective coverage. This, in turn, will enhance the real-world impact of its immunisation programmes and support progress towards achieving universal health coverage.

Strength and limitation

One of the major strengths of this study is the use of a nationally representative dataset (EMDHS), which enhances the generalisability of the findings across Ethiopia. The application of Bayesian model-based geostatistical analysis allowed for the estimation of spatial variations with improved precision, accounting for both observed and unobserved spatial heterogeneity.

However, the study has some limitations. The study used data from a mini DHS, which included only half of the clusters typically covered in the full demographic survey in Ethiopia. Furthermore, the Tigray region was excluded because the SPA lacks records for facilities in that area. A limitation of our matching methods is that they ignore geographical barriers like mountains or lack of roads. Using Euclidean distance assumes straight-line travel, which may not reflect actual accessibility, potentially misrepresenting location closeness and affecting study outcomes.

CONCLUSION

There were significant geographical variations in the effective coverage of immunisation services across Ethiopia. Central Amhara, northern Gambela, central Oromia, Sidama, northern SNNPR and Somali had low effective coverage of child immunisation. These disparities highlight the urgent need for region-specific strategies that address both supply and demand side barriers. Policymakers should prioritise underserved regions by strengthening rural healthcare systems, investing in cold chain logistics, enhancing training for healthcare workers and implementing targeted health education campaigns to raise awareness about the benefits of immunisation. Furthermore, mobile outreach services and community engagement strategies are essential, particularly in remote and pastoralist communities, where consistent access to healthcare is limited.

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Patient consent for publication Not applicable.

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Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data may be obtained from a third party and are not publicly available. The dataset is available on the DHS website: https://dhsprogram.com/

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