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Childhood Immunization Inequalities in the Horn of Africa: Long-Term Trends, Vaccine- Specific Gaps and Country-Level Disparities, 1980–2025

Fatima Abdijabbar Ibrahim

fatimaabdijabbaribrahim@gmail.com

Somali National University

Nasra Salad Ahmed

Somali National University

Nur Dahir Warsame

Faculty of Technology and Engineering, Salaam University, Mogadishu, Somalia

Omar Aweis Ali Ali

Universidade Estadual de Mato Grosso do Sul

Yasir Mohamed Abdinur

Asia Pacific University of Technology and Innovation (APU/APIIT), Kuala Lumpur, Federal Territory of Kuala Lumpur, Malaysia

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Childhood Immunization Inequalities in the Horn of Africa: Long-Term Trends, Vaccine-Specific Gaps and Country-Level Disparities, 1980–2025

Fatima Abdijabbar Ibrahim[1,2]
Email: fatimaabdijabbaribrahim@gmail.com
ORCID: https://orcid.org/0009-0008-5284-5589

Nasra Salad Ahmed[1,2]
Email: nasrasaladahmed@gmail.com
ORCID: https://orcid.org/0009-0006-6639-6724

Nur Dahir Warsame[3]

Email: fet@salaam.edu.so

Omar Aweis Ali[2,4*]
Email: Omarfaaruuq@dhu.edu.so
Yasir Mohamed Abdinur[2,5]
Email: yasirmhaji@gmail.com

Affiliations

[1] Faculty of Health Sciences and Tropical Medicine, Somali National University, Mogadishu, Somalia

[2] Climate and Environmental Research Institute (CERI), Mogadishu, Somalia

[3] Faculty of Technology and Engineering, Salaam University, Mogadishu, Somalia

[4] Center for Natural Resources, PGRN, Universidade Estadual do Mato Grosso do Sul (UEMS), Dourados, Brazil

[5] Asia Pacific University of Technology and Innovation (APU/APIIT), Kuala Lumpur, Federal Territory of Kuala Lumpur, Malaysia

Corresponding Author

Fatima Abdijabbar Ibrahim[1,2]
Email: fatimaabdijabbaribrahim@gmail.com
ORCID: https://orcid.org/0009-0008-5284-5589

Abstract

Childhood vaccination coverage has improved throughout the Horn of Africa, but long-term differences in first-dose and multi-dose completion are poorly described. This study investigates trends and inequalities in immunisation in Somalia, Ethiopia, Djibouti and Eritrea from 1980 to 2025. We analysed 1,006 country–year–vaccine observations for 14 antigens/dose indicators from the 2025 revision of the WHO/UNICEF Estimates of National Immunisation Coverage. Outcomes included DTP1, DTP3, MCV1, MCV2, DTP1-derived zero-dose surrogates and DTP dropout. We

used descriptive trends, Mann-Kendall tests, Sen slopes, absolute measures of cross-country inequality, country-specific segmented regressions and an exploratory repeated-measures generalised estimating equations model. Comparison of observation periods was facilitated by not imputing missing MCV2 histories or projecting indicators backward to 1980, and respecting the windows of availability of specific vaccines. The coverage of Somalia (DTP1, DTP3, MCV1 and MCV2) was 77%, 72%, 61% and 31% in 2025, respectively, and that of Eritrea was 98%, 96%, 93% and 89%. The between-country ranges were 21, 24, 32 and 58 percentage points respectively. Somalia's DTP3 rose from 2% in 1981 to 72% in 2025 (Kendall τ=0.853; $p<0.001$; Sen slope=1.31 percentage points/year). Its proxy for zero-dose coverage was 23% in 2025; the DTP1–DTP3 gap was 5 percentage points. Only four-country MCV2 comparisons were available for 2021-2025. Significant gains have been made over time, but inequities persist, especially for the second dose of measles vaccination and first-dose access in Somalia. National estimates support prioritising previously unreached children and dose continuity, while subnational data are needed to localise gaps.

Childhood immunisation; Horn of Africa; Somalia; DTP3; Measles-containing vaccine; Zero-dose; Vaccination inequality; WUENIC

BACKGROUND AND RATIONALE:

1. Introduction .

Routine childhood immunisation remains a key intervention to reduce morbidity and mortality from vaccine-preventable diseases. International strategies are increasingly focusing not only on greater national coverage but also on equal access to timely vaccination and completion of scheduled doses. The Immunisation Agenda 2030 explicitly emphasises reaching systematically missed populations, recognising that national averages can hide exclusion of remote, mobile and underserved groups (World Health Organization [WHO], 2020; O'Brien et al., 2024). However, global analyses suggest that despite decades of progress, there remain large differences in the level and speed of vaccination progress between and within countries (GBD 2023 Vaccine Coverage Collaborators, 2025; UNICEF, 2026).

First and third doses of diphtheria–tetanus–pertussis-containing vaccine (DTP1 and DTP3) offer complementary programmatic perspectives. DTP1 is a proxy for first contact with infant routine immunisation; children who have not received it are often used as a proxy for monitoring the "zero-dose" population. DTP3 is indicative of the receipt of a multidose infant series and therefore relies on both access and continuity. An important pair of indicators is the first and second doses of measles-containing vaccine (MCV1 and MCV2), the latter often requiring a later vaccination contact. However, the difference between two annual national estimates of coverage is not the same as observed dropout from the same children, as doses may involve different ages and denominators

(WHO, 2026).

International studies on inequality also show that the effects of vaccination are stratifying according to social, geographic and health system factors. A multi-country spatial analysis identified persistent socioeconomic gradients in essential childhood immunisation, while a systematic review of barriers in sub-Saharan Africa highlighted challenges in service access and utilisation (Dimitrova et al., 2023; Bangura et al., 2020). Long-term comparative studies have observed heterogenous coverage trajectories over several decades, instead of smooth and unbroken progress (Lanza-León et al., 2024; GBD 2023 Vaccine Coverage Collaborators, 2025). This evidence suggests to simultaneously evaluate the magnitude of the trend, volatility and inequality.

This latter approach is particularly relevant for the Horn of Africa. Somalia, Ethiopia, Djibouti and Eritrea vary in population size, health-service infrastructure, vaccination delivery histories and availability of supporting data, so simple comparisons of endpoint percentages are inadequate. WHO country profiles document country-specific coverage records and sources, while the WHO/UNICEF Estimates of National Immunisation Coverage (WUENIC) combine official administrative submissions, surveys and technical review into annual series that are more suitable for longitudinal benchmarking (World Health Organization, 2024a, b, c, d, 2026). But these series are estimates, and are revised; they do not directly measure the vaccination history of each child.

Research from Somalia provides particularly strong support for prioritising access to the first dose. A high proportion of children without the study defined basic routine vaccines was reported in the analysis of the 2020 Somali Health and Demographic Survey and associations with rural or nomadic residence and maternal health care contacts were identified (Mohamoud et al., 2024). Additional analyses examined vaccination status and correlates among Somali children and described regional differences in zero-dose immunisation, and research among internally displaced persons in Mogadishu demonstrated the significance of education and inequalities due to displacement (Hassan & Hossain, 2024; Hassan et al., 2025; Halane et al., 2025; Abdi et al., 2025). The survey-based definitions of zero-dose, age groups, and denominators need to be distinguished from the national DTP1-derived proxy used in this study.

The wider regional literature suggests complementary mechanisms and analytical priorities. Studies from Ethiopia identified gains in full basic immunisation from repeated household surveys with continuing inequalities by maternal education, wealth and residence (Yibeltal et al., 2022). Studies of underserved populations have identified marked disparities in zero-dose status including spatial clustering and socioeconomic gradients (Biks et al., 2024a, 2024b; Shiferie et al., 2024; Agimas et al., 2024; Endehabtu et al., 2025). Other studies looked at uptake of measles at the second dose in Jigjiga and inequalities in poliovirus immunisation showing that programme-specific results may differ from national DTP indicators (Ibrahim et al., 2024; Fekadu et al., 2024). Findings from the

Somali Region, Ethiopia, should not be confused with those from the sovereign state of Somalia (Elmi et al., 2026).

Evidence from Eritrea also suggests the importance of demographic and program factors: maternal education was associated with childhood full immunisation and historical measles surveillance showed progress toward measles elimination (Kibreab et al., 2020; Yehdego et al., 2020). Country profiles for Djibouti illustrate national vaccine patterns, but offer limited grounds for a harmonised four-country vaccine-specific longitudinal inequality study (World Health Organization, 2024a). Similarly, a recent post-campaign coverage study in Somalia also shows the need for programme-sensitive evidence beyond national routine vaccination summary statistics (Salad et al., 2026). These studies provide useful country level insights; however, much of the evidence is limited to one vaccine, one survey round, one national setting or household level predictors. A different descriptive research question can be addressed by a similar longitudinal description of DTP1, DTP3, MCV1 and MCV2 alongside first dose access, dropout indicators, absolute cross-country inequality and persistent coverage gaps. It is also important to avoid overstatement of inference: fixed country characteristics, World Bank classifications, and fragile/conflict-affected labels cannot credibly explain annual coverage variation with a sample of only four national units (Dires et al., 2025). This study therefore aimed to examine trends and inequalities in childhood immunisation in Somalia, Ethiopia, Djibouti and Eritrea during 1980–2025 with special emphasis on Somalia. Specifically, we examined trends in historical coverage, measured disparities in four key vaccine indicators, evaluated DTP1 nonreceipt and DTP-series dropout, compared routine program performance, and identified country–period combinations with sustained undercoverage. The contribution is a harmonised comparative description and not a causal test of country policies or household determinants, using the 2025 WUENIC revision (World Health Organization, 2026).

2. Material and Methodology

2.1 Study design and data source

We performed a retrospective ecological repeated cross-sectional time-series study using the annual national WHO/UNICEF Estimates of National Immunisation Coverage (WUENIC), 2025 revision, released in July 2026. Source: Excel workbook provided by the study. Four countries of the core Horn of Africa—Somalia, Ethiopia, Djibouti and Eritrea—were selected a priori. The analytical window was 1980–2025 and we retained observations with existing estimates rather than imputing earlier program years. The data extraction yielded 1,006 country–year–vaccine observations for 14 antigens/dose indicators. Analyses on child-identifiable data were not performed.

2.2 Definition of outcomes and data completeness

The main outcome variable was estimated national coverage (percent) for DTP1, DTP3, MCV1 and MCV2. We defined an access-oriented zero-dose proxy as 100 - DTP1; an absolute DTP1-DTP3

gap as DTP1-DTP3 (percentage points); and a relative DTP dropout percentage as 100 x (DTP1-DTP3)/DTP1 where DTP1>0. The zero-dose proxy is a proxy for estimated nonreceipt of DTP1, not receipt of no vaccine at all, and cannot be converted to an absolute number without age-appropriate population denominators. Linked vaccination records for individual children do not also follow the difference between DTP1 and DTP3.

The country-specific observation periods for the four primary vaccination indicators are presented in Table 1.

Table 1. Observation windows for four primary vaccination indicators

Vaccine	Somalia	Ethiopia	Djibouti	Eritrea
DTP1	1981–2025 (45)	1981–2025 (45)	1982–2025 (44)	1993–2025 (33)
DTP3	1981–2025 (45)	1981–2025 (45)	1982–2025 (44)	1993–2025 (33)
MCV1	1980–2025 (46)	1980–2025 (46)	1982–2025 (44)	1993–2025 (33)
MCV2	2021–2025 (5)	2019–2025 (7)	2012–2025 (14)	2015–2025 (11)

Values in parentheses denote the number of available annual estimates. Four-country comparisons for MCV2 are limited to 2021–2025.

The independent variables were year, country and vaccine. We used the World Bank economic classifications and WHO fragile/conflict/vulnerable (FCV) labels for contextual description only: four fixed country-level observations do not allow for meaningful multivariable estimation of their effects. For the descriptive threshold analysis, undercoverage was operationally defined as coverage <80%. This threshold is not introduced as a general program target.

2.3 Análisis descriptivo y desigualdades

Annual series were plotted by country and antigen, and coverage by endpoint was tabulated, without extrapolation before the first available observation. Absolute cross-country inequalities were calculated annually only when data from all four countries were available: the maximum-minimum, the population standard deviation across countries and the mean absolute difference across the six country pairs. Thus, complete comparison windows were 1993-2025 for DTP1, DTP3 and MCV1 and 2021-2025 for MCV2. The four countries were weighted equally. These are measures of inequality across countries, not population-weighted regional coverage

2.4 Analysis of trends over time

We assessed monotonic trends in country–vaccine annual coverage by using two-sided Mann–Kendall tests and Kendall's τ . Sen's slope was calculated as the median pairwise annual percentage-

point change with conventional 95% slope intervals . For the set of coverage tests, nominal p values were provided with Benjamini–Hochberg false-discovery-rate adjusted q values in the supplemental workbook. These estimates are considered exploratory, because the standard tests are not adjusted for the temporal autocorrelation of WUENIC annual estimates and the coverage series are model-informed national estimates, not independent samples.

2.5 Piecewise regression

Continuous one-breakpoint linear models with a hinge term were used to summarise country-specific DTP3 trends. Candidate breakpoints were evaluated based on corrected Akaike information criterion (AICc) and slopes before and after the selected breakpoint are reported in percentage points per year. Inference can underestimate uncertainty of a breakpoint chosen by the data . Estimated knots reflect changes in the shape of the descriptive trend and cannot be used to define causal effects for policy or conflict .

Repeated measures model 2.6

We fitted an exploratory Gaussian generalised estimating equations (GEE) model for coverage with terms for country, vaccine, centred year (2021 = 0) and country-by-year interactions, for the fully comparable 2021–2025 period. The working correlation was assumed exchangeable for each country-vaccine panel. Sandwich-based standard errors were employed. Which resulted in 80 observations in 16 panels. Djibouti and DTP1 were reference categories. The very small number of independent panels limits formal inference, as does aggregation to national estimates and model assumptions. Coefficients are reported to describe adjusted mean coverage contrasts and recent slopes, not causal effects.

2.7 Spatial representation, analytical rigour and ethics

Four national choropleth maps display 2025 DTP3, MCV1, MCV2 and the DTP1-inverse zero-dose proxy. Map polygons for the underlying Natural Earth layer “Somalia” and “Somaliland” are shaded identically to depict the national WUENIC Somalia estimate consistently. There is no separate estimate for the northwest and the map is not evidence of district- or region-level coverage. Values, axes, units and year ranges checked against source workbook The analysis used secondary country-level public-health estimates, with no personal data; institutional ethics procedures should be confirmed against the requirements of the submitting institution.

2.8.1 Reproducibility and reporting

All tables, tests and graphs are taken from the supplied 2025-revision WUENIC file. The companion analysis files include annual series, derived indicators, trend tests, country-specific segmented models, and GEE coefficients. Years were not imputed and the assumption of comparability of historical periods was never made for MCV2 unless all four countries had observations. Throughout we distinguish descriptive differences from causal claims.

3. Results

3.1 Coverage levels in 2025

Somalia had the lowest national coverage in each of the four priority indicators in 2025; Eritrea recorded the highest. Ethiopia and Djibouti had intermediate DTP1 and DTP3 levels. The between-indicator contrasts were greatest for the measles second dose: MCV2 coverage was 31% in Somalia compared with 89% in Eritrea (Table 2; Figure 1).

Table 2. National routine vaccination coverage and derived access measures, 2025

Country	DTP1	DTP3	MCV1	MCV2	Zero-dose proxy	DTP gap
Somalia	77%	72%	61%	31%	23%	5 pp
Ethiopia	84%	81%	77%	72%	16%	3 pp
Djibouti	86%	83%	75%	58%	14%	3 pp
Eritrea	98%	96%	93%	89%	2%	2 pp

Zero-dose proxy = 100 − DTP1; DTP gap = DTP1 − DTP3. pp, percentage points. All figures are national WUENIC estimates, not subnational or individual-level observations.

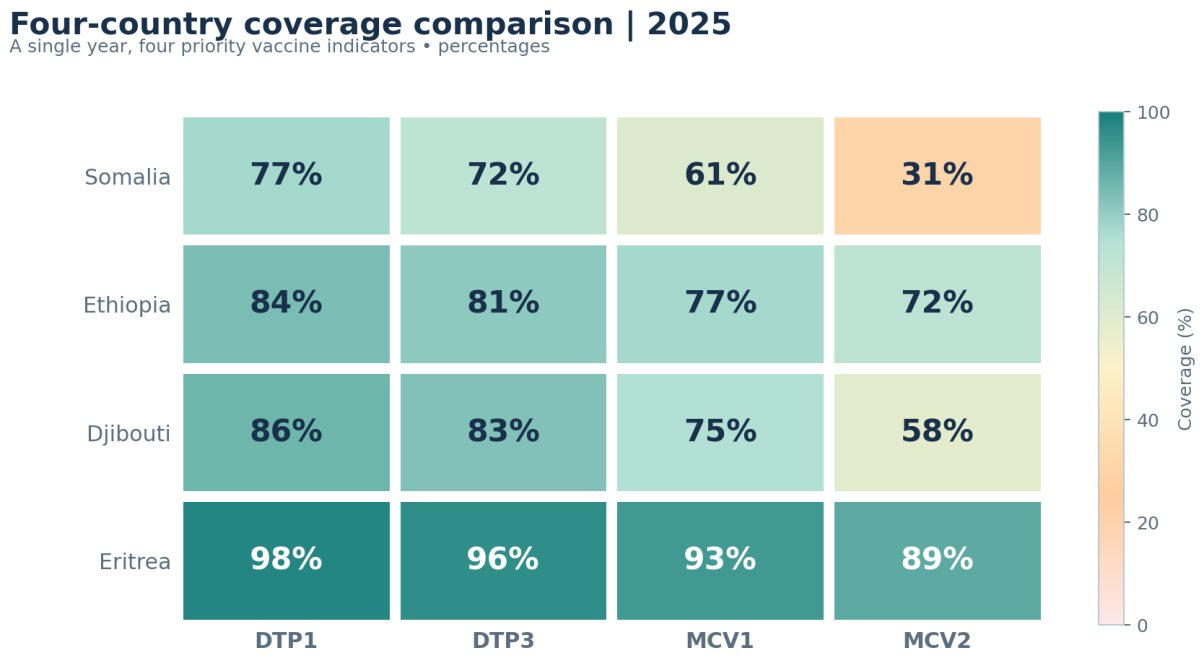


Figure 1. National 2025 coverage of four priority vaccine-dose indicators. Source: Analysis of WHO/UNICEF WUENIC, 2025 revision.

The MCV1–MCV2 difference was 30 percentage points in Somalia, 5 in Ethiopia, 17 in Djibouti and 4 in Eritrea. This comparison characterizes differences between dose-specific national indicators rather than measured measles dropout in an individual cohort.

3.2 Long-term trends in DTP and measles coverage

Coverage trajectories improved over much of the study period, with substantial differences in slope and stability between countries (Figure 2). Somalia's DTP3 rose from 2% in 1981 to 72% in 2025. Eritrea increased from 32% in 1993 to 96% in 2025. Djibouti showed pronounced oscillations, including DTP3 coverage of 85% in 2019, 59% in 2021 and 83% in 2025. These are national time-series estimates rather than direct annual cohort follow-up.

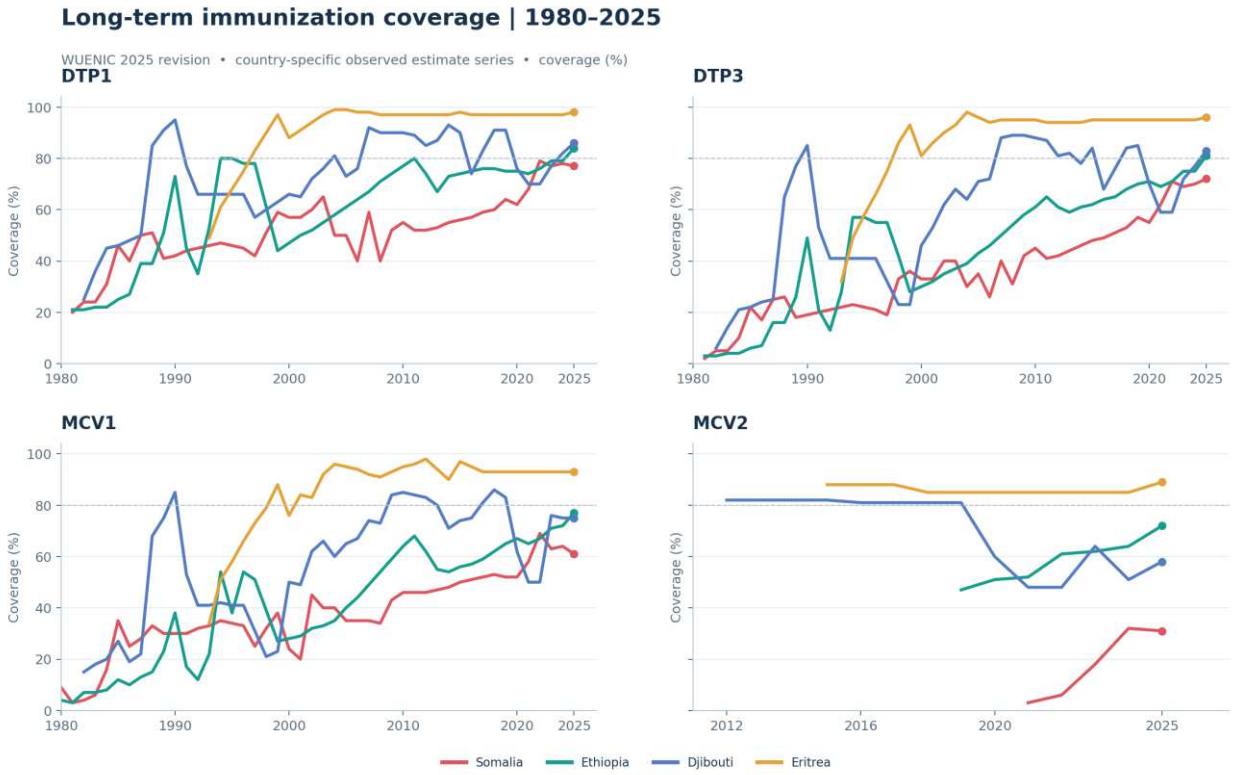


Figure 2. Annual observed WUENIC coverage for DTP1, DTP3, MCV1 and MCV2, by country; non-available years are not interpolated. Source: Analysis of WHO/UNICEF WUENIC, 2025 revision.

Mann–Kendall tests were positive for all four DTP3 series (nominal $p<0.001$). Somalia had Kendall's $\tau=0.853$ and a Sen slope of +1.31 percentage points/year (95% slope interval: +1.17 to +1.45). Ethiopia recorded the greatest estimated annual DTP3 gain (+1.74 pp/year). Results for MCV2 require a distinct interpretation because the available histories differ sharply by country and only five observations are available for Somalia.

3.3 Trend-test estimates

The country-specific Mann–Kendall tests and Sen slope estimates for DTP3 and MCV1 are summarised in Table 3.

Table 3. Mann–Kendall tests and Sen slopes for DTP3 and MCV1

Vaccine	Country	n	Kendall τ	p	Sen slope (pp/y)
DTP3	Somalia	45	+0.853	<0.001	+1.31
DTP3	Ethiopia	45	+0.831	<0.001	+1.74
DTP3	Djibouti	44	+0.481	<0.001	+1.40
DTP3	Eritrea	33	+0.643	<0.001	+0.26
MCV1	Somalia	46	+0.794	<0.001	+1.00
MCV1	Ethiopia	46	+0.817	<0.001	+1.57
MCV1	Djibouti	44	+0.498	<0.001	+1.39
MCV1	Eritrea	33	+0.464	<0.001	+0.56

Standard two-sided tests on estimated annual series. Standard errors/p-values are not corrected for possible serial dependence; 16 vaccine-specific trend tests and FDR-adjusted q values are retained in the companion statistical workbook.

The MCV2 coverage in Somalia increased from 3% in 2021 to 31% in 2025. The five-point Mann–Kendall test was not significant at the conventional 5% level (τ=0.800, p=0.083). Conversely, the observed MCV2 trend for Ethiopia was positive for 2019-2025, while Djibouti had a declining longer-run MCV2 series. When comparing these slopes it is important to note the very uneven availability windows and low number of measurements for newer vaccine indicators.

3.4 Absolute inequality across countries

In 2025, maximum–minimum differences were 21 percentage points for DTP1, 24 for DTP3, 32 for MCV1 and 58 for MCV2. The same ordering was apparent for between-country standard deviations and mean pairwise differences (Table 4).

Table 4. Four-country absolute coverage disparities, 2025

Indicator	Range (pp)	Between-country SD (pp)	Mean pairwise gap (pp)
DTP1	21	7.6	10.8
DTP3	24	8.6	12.3

MCV1	32	11.3	16.3
MCV2	58	21.2	31.3

All countries weighted equally. Cross-country standard deviation is calculated across the four national coverage values; no population weights are applied.

The annual variation in the absolute cross-country coverage range is illustrated in Fig. 3.

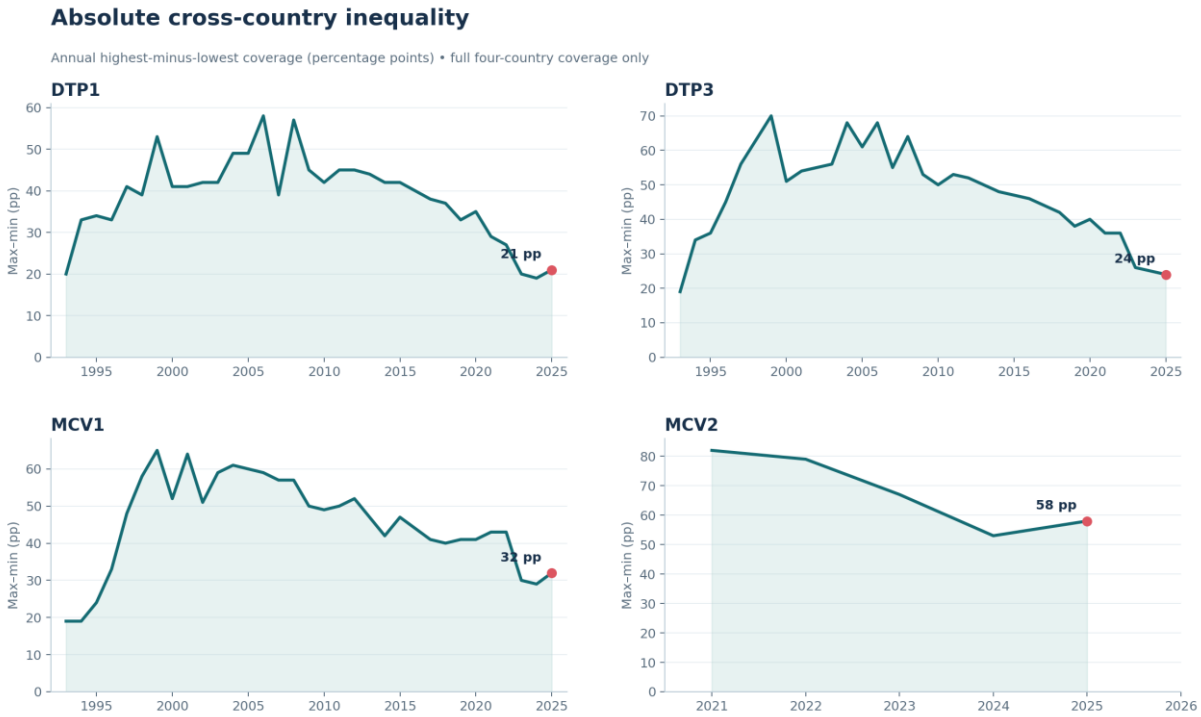


Figure 3. Annual absolute range across four countries, with series restricted to years when all four estimates exist. Source: Analysis of WHO/UNICEF WUENIC, 2025 revision.

Across 1993–2025 the DTP3 cross-country range had a negative Sen slope (−1.00 pp/year; nominal $p<0.001$), but the endpoint gap was larger in 2025 (24 pp) than in 1993 (19 pp), reflecting a nonlinear and non-monotonic path. For MCV2, the range narrowed from 82 pp in 2021 to 58 pp in 2025; five annual comparisons are insufficient to establish a persistent historical convergence trend.

3.5 Zero-dose proxies and DTP-series dropout

The DTP1-derived zero-dose proxy in 2025 was 23% in Somalia, 16% in Ethiopia, 14% in Djibouti and 2% in Eritrea. DTP1–DTP3 coverage gaps were 5, 3, 3 and 2 percentage points, corresponding to approximate relative dropout measures of 6.5%, 3.6%, 3.5% and 2.0%, respectively. Historical zero-dose proxies and dropout gaps generally declined, yet Somalia retained the highest nonreceipt proxy (Figures 4–5; Table 5).

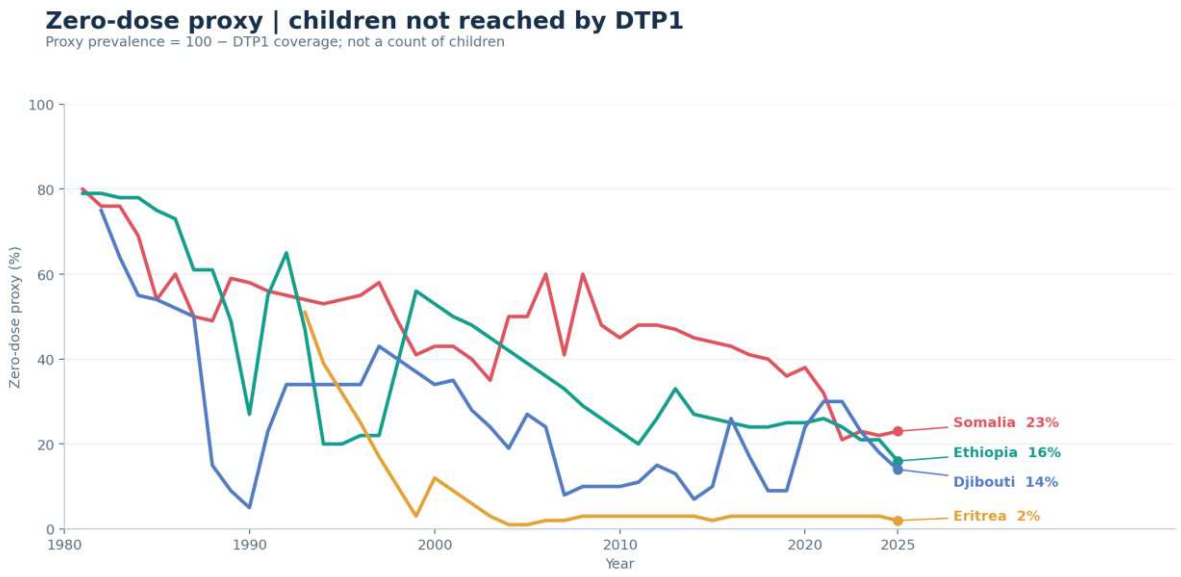


Figure 4. DTP1 nonreceipt proxy (100 − DTP1) over available annual observations. Source: Analysis of WHO/UNICEF WUENIC, 2025 revision.

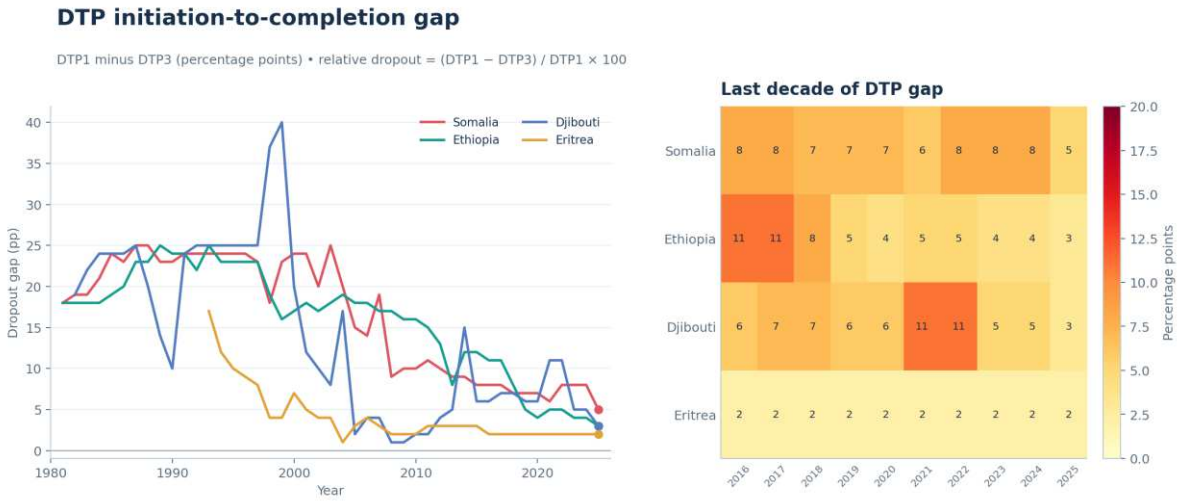


Figure 5. Absolute DTP1–DTP3 coverage gap, percentage points, by country. Source: Analysis of WHO/UNICEF WUENIC, 2025 revision.

Table 5. DTP access and dropout trends

Country	2025 zero-dose	2025 DTP gap	Dropout (%)	Sen slope: proxy	Sen slope: gap
Somalia	23%	5 pp	6.5%	−0.84	−0.45
Ethiopia	16%	3 pp	3.6%	−1.30	−0.46
Djibouti	14%	3 pp	3.5%	−0.87	−0.48
Eritrea	2%	2 pp	2.0%	−0.15	−0.14

Sen slopes are percentage points/year. Negative slopes signify declines in the proxy or gap. All conventional Mann–Kendall p values for these eight series were <0.001; tests are descriptive and unadjusted for serial correlation.

The degree of improvement was not uniform. The zero-dose proxy of Somalia declined at a Sen slope of −0.84 pp/year, while its DTP coverage gap declined at −0.45 pp/year. These data suggest improved access and continuation of series over time, but do not distinguish between missed vaccines due to supply, demand, household vulnerability or measurement variation. Most importantly, the relatively small gap in the DTP-series among starters does not exclude low DTP1 coverage: estimated first-dose nonreceipt remains substantial.

3.6 Comparison ofRoutine Immunisation Programs

In 2025, the second dose measles coverage was the lowest program indicator among the eight routine indicators in all countries (Figure 6). BCG coverage was 74% in Somalia, DTP3, HepB3 and Hib3 coverage was 72% each, IPV1 was 70%, MCV1 was 61%, and MCV2 was 31%. When antigens are administered during the same visit for vaccination, correlations are expected between DTP3, hepatitis B and Hib indicators. The date of vaccine introduction varies by country, so not all countries can be compared for the same length of time on each indicator.

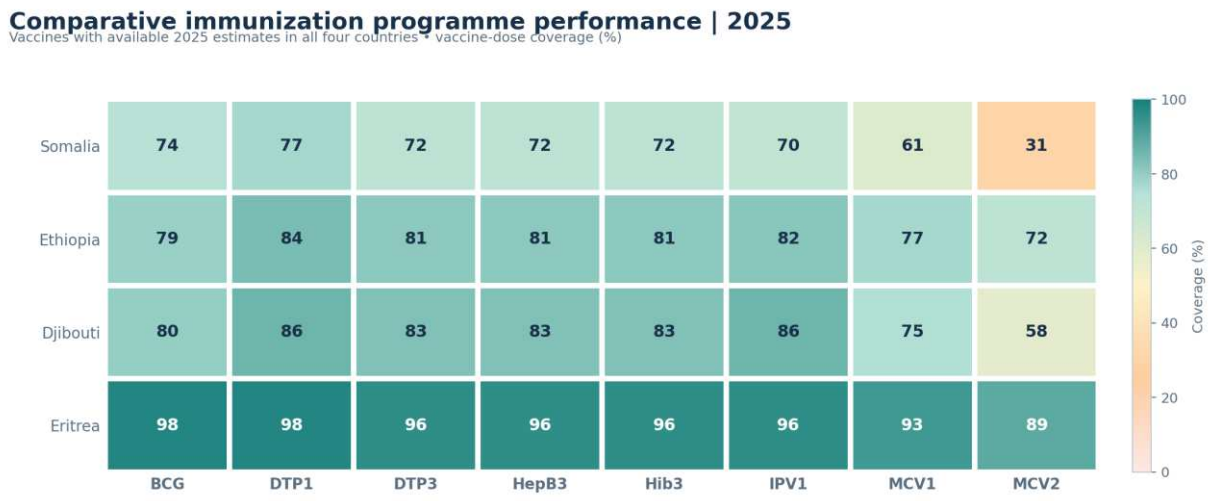


Figure 6. Comparison of eight childhood vaccination indicators in 2025, showing differences in the later measles-dose indicator. Source: Analysis of WHO/UNICEF WUENIC, 2025 revision.

3.7 Persistent periods of undercoverage

Using coverage below 80% as a descriptive threshold, Somalia had DTP3 coverage below 80% in all 45 available years (1981–2025) and MCV1 coverage below 80% in all 46 years (1980–2025). Ethiopia also remained below 80% for MCV1 throughout its 46-year observation period. The 2016–2025 comparison illustrates the continued contrast with Eritrea (Table 6; Figure 7).

Table 6. Years with estimated coverage <80% during 2016–2025

Country	DTP3	MCV1	MCV2
Somalia	10/10	10/10	5/5
Ethiopia	9/10	10/10	7/7
Djibouti	7/10	7/10	6/10
Eritrea	0/10	0/10	0/10

Numerator is number of observed years below 80%; denominator is number of observed years in 2016–2025. MCV2 denominators vary with reporting availability; 80% is a descriptive analytic threshold, not a universal recommended target.

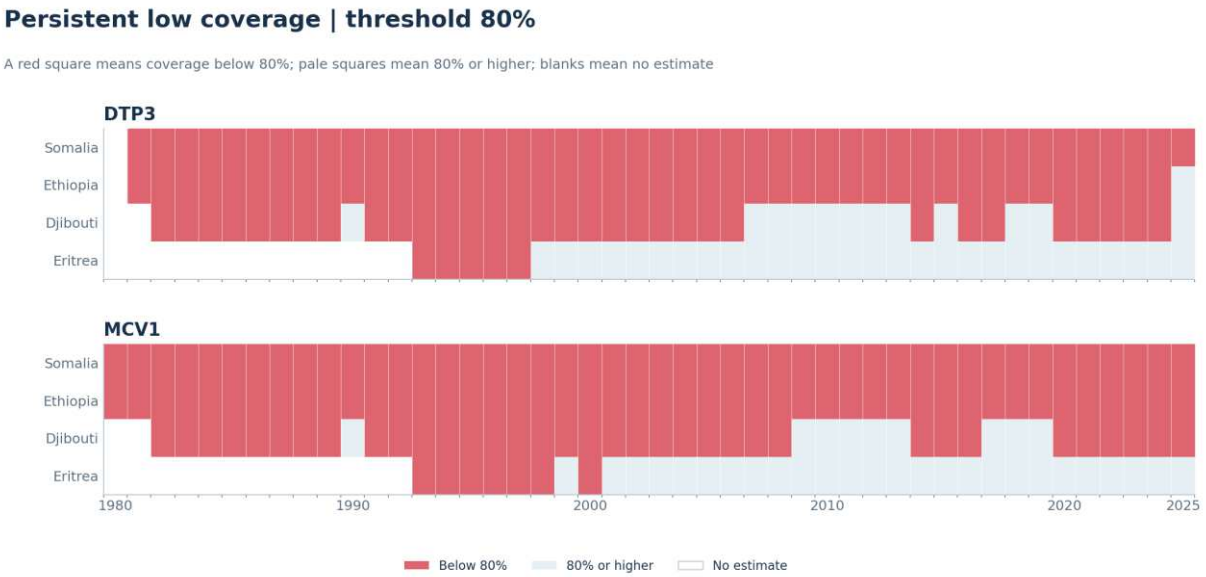


Figure 7. Counts of years with national coverage below 80% during the latest decade; observed-year denominators vary for MCV2. Source: Analysis of WHO/UNICEF WUENIC, 2025 revision.

3.8 Segmented DTP3 regression

Exploratory single-hinge regressions summarized differences in the apparent timing and pace of DTP3 change across countries. The AICc-selected knot was 2016 in Somalia, with a fitted slope of +1.10 pp/year before and +2.87 pp/year after the break. Ethiopia's selected 1994 knot was associated with subsequent slowing; Djibouti's selected 2011 knot with a negative post-break linear slope; and Eritrea's selected 2000 knot with a nearly flat post-break trajectory (Table 7; Figure 8).

Table 7. Country-specific one-breakpoint DTP3 models

Country	Selected year	Before (pp/y)	After (pp/y)	ΔAICc
Somalia	2016	+1.10	+2.87	14.9
Ethiopia	1994	+2.91	+1.25	6.6
Djibouti	2011	+2.11	−0.84	8.1
Eritrea	2000	+7.50	+0.09	68.7

Continuous one-knot piecewise linear regressions fitted separately by country; candidate knots selected by corrected Akaike information criterion (AICc). ΔAICc is improvement over the unsegmented model. These are descriptive model selections, not causal intervention tests.



Figure 8. Observed national DTP3 annual series and selected single-breakpoint linear fits by country. Source: Analysis of WHO/UNICEF WUENIC, 2025 revision.

3.9 Recent repeated-measures analysis

The 2021–2025 GEE analysis comprised 80 national country–vaccine–year observations across 16 series. Relative to Djibouti in the DTP1 reference category at 2021, Eritrea had a positive baseline country coefficient (+36.10 pp; 95% CI, +27.76 to +44.44; p<0.001), whereas the Somalia coefficient (−5.65 pp; 95% CI, −24.91 to +13.61; p=0.565) was imprecisely estimated. Across countries, MCV2 was associated with coverage 27.15 pp below DTP1 (95% CI, −40.72 to −13.58; p<0.001). These are coefficients conditional on the model specification, not raw 2025 between-country differences.

Selected coefficients from the 2021–2025 repeated-measures GEE analysis are presented in Table 8.

Table 8. Selected Gaussian GEE repeated-measures coefficients, 2021–2025

Model term	Estimate (pp)	95% CI	p
Eritrea vs Djibouti	+36.10	+27.76 to +44.44	<0.001
Ethiopia vs Djibouti	+9.05	+1.97 to +16.13	0.012
Somalia vs Djibouti	−5.65	−24.91 to +13.61	0.565
MCV2 vs DTP1	−27.15	−40.72 to −13.58	<0.001
Year (Djibouti)	+5.20	+3.22 to +7.18	<0.001
Year × Somalia	−2.23	−5.85 to +1.40	0.229

Gaussian GEE, exchangeable working correlation within 16 country–vaccine series; 80 observations; year centered on 2021. Country coefficients refer to baseline year; small-cluster sandwich inference is exploratory.

The recent 2021–2025 country-level trajectories for all four priority indicators are shown in Fig. 9.

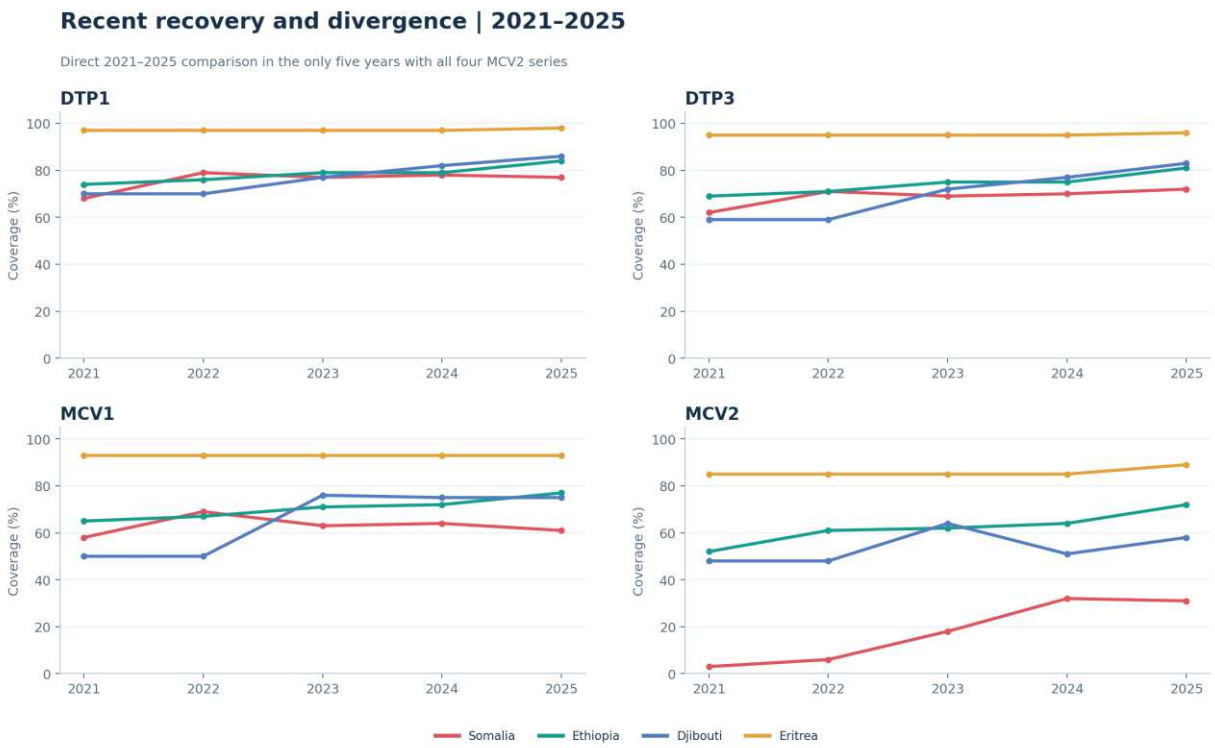


Figure 9. Recent observed trajectories used for common-window cross-country comparisons. Source: Analysis of WHO/UNICEF WUENIC, 2025 revision.

3.10 National cartographic presentation

The 2025 national maps reiterate Somalia's lower DTP3, MCV1 and MCV2 coverage, alongside its higher DTP1 nonreceipt proxy, compared with the other three countries (Figure 10). The north-western portion of Somalia is fully displayed and assigned the same WUENIC national value as the remainder of the country; these maps contain no subnational vaccination estimates.

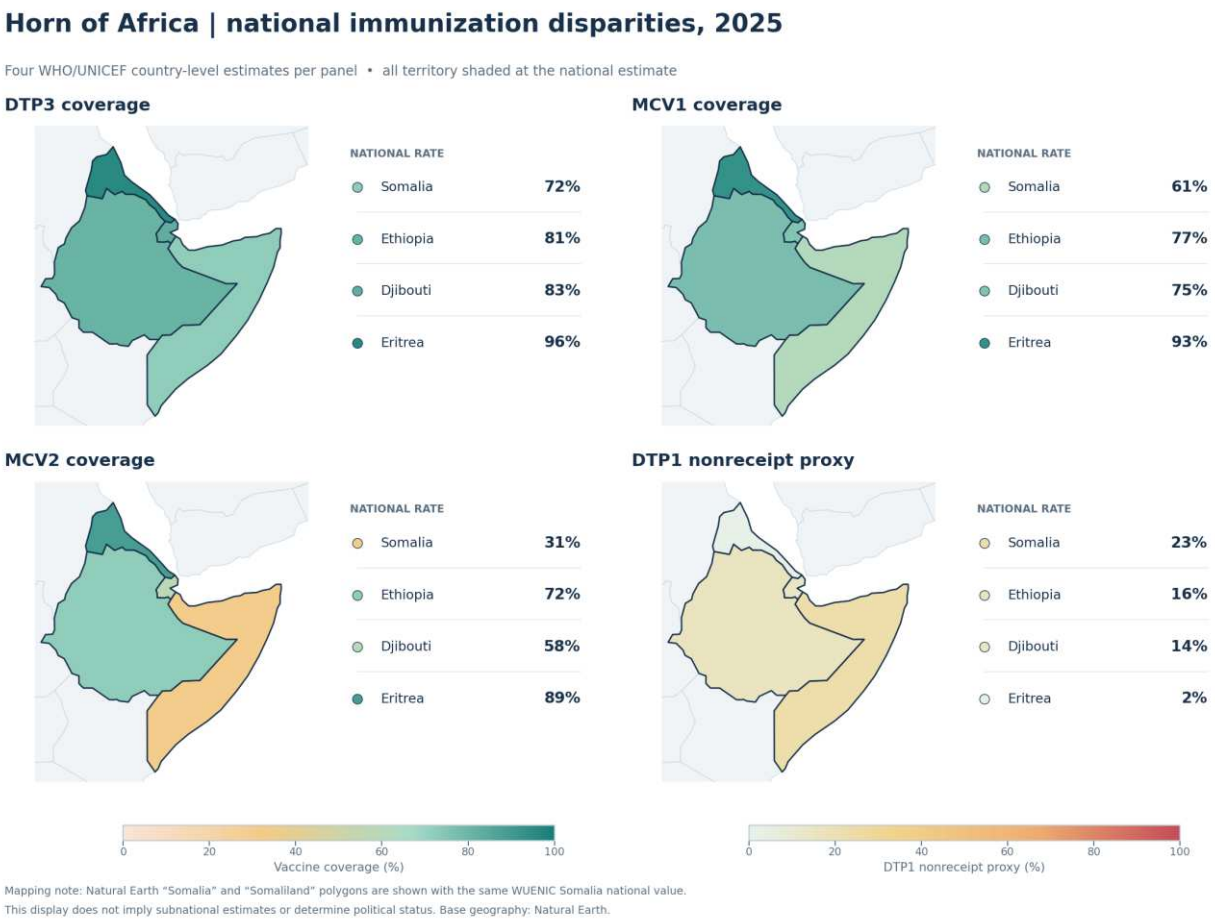


Figure 10. Four national choropleth maps for DTP3, MCV1, MCV2 and the DTP1 nonreceipt proxy. The Natural Earth polygons labelled Somalia and Somaliland are uniformly mapped to the WUENIC Somalia national estimate; no north-western subnational results are inferred. Boundaries: Natural Earth (public domain). Source: Analysis of WHO/UNICEF WUENIC, 2025 revision.

Country map patterns communicate between-country rather than within-country inequalities. The sizeable MCV2 deficit in Somalia (31% in 2025) and the comparatively high Eritrea coverage (89%) contribute most visibly to the geographic contrast.

4. Discussion

4.1 Main contribution and results

Tracking this over time shows two trends running in parallel: historic gains in vaccination coverage and persistent gaps among four Horn of Africa countries. All four had shown positive DTP3 trends, but the 2025 end-point comparison revealed Somalia to be the furthest behind in DTP1, DTP3, MCV1 and MCV2. The largest gap between countries was for MCV2 (58 percentage points), 34 percentage points larger than the DTP3 gap. This is consistent with the global literature showing that improvements in aggregate vaccination coverage can co-occur with large inequities in access and completion (GBD 2023 Vaccine Coverage Collaborators, 2025; Dimitrova et al., 2023; Lanza-León et al., 2024). This reinforces the case for concurrent surveillance of early access, multidose-series development and later childhood vaccination contacts.

The results expand upon previous country-specific literature by considering four vaccine-dose indicators in a common comparative framework, and by tracking disparities over time instead of at a single survey. Ethiopia's positive slope for DTP3 is consistent with the general direction of progress observed in successive household surveys; however, DTP3 coverage from WUENIC is not the same as full basic immunisation coverage from a child-level survey. Ethiopian full-immunization gains coexisted with wealth, educational and rural–urban inequalities (Yibeltal et al., 2022). National vaccination patterns here raise similar questions about who is left behind, but individual-level gradients are not measurable in the current data (Yibeltal et al., 2022; Dires et al., 2025).

4.2 Somalia: first dose coverage and measles second dose

Somalia is an outlier, with a significant increase in national DTP3 coverage but with the first-dose nonreceipt proxy estimated at 23% in 2025. The small DTP1–DTP3 gap (5 percentage points) between the two aggregate indicators should not be taken as an indication that all age-eligible children are enrolled in the immunisation system. Rather, the low DTP1 value suggests initial reach as a key challenge of the program. Plausible populations for further investigation are indicated by evidence from the 2020 Health and Demographic Survey in Somalia that links zero-dose vulnerability to rural and nomadic residence, and lower contact with maternal care services (Mohamoud et al., 2024). Other studies from Somalia have explored determinants of child vaccination and disparities in zero-dose prevalence (Hassan & Hossain, 2024; Hassan et al., 2025; Halane et al., 2025).

Crucially, the zero-dose prevalence from SHDS reported by Mohamoud et al. (2024) is based on survey respondents, a specific child age range, and its study-specific definition of basic routine vaccination. It cannot be compared numerically to the national DTP1 inverse in 2025 as it is not the same estimand. Differences may be due to variations in the definition of vaccination, timing of the survey, age eligibility, data sources, and estimation procedures. These measures are, in our view,

complementary rather than interchangeable, and the current national monitoring signal can motivate a more granular investigation of missed vaccination opportunities.

DISCUSSION / continued:

A second distinct challenge is the large MCV1–MCV2 difference in Somalia (30 percentage points). Measles second-dose delivery often requires a later recommended contact than DTP or MCV1, thus lower coverage could reflect incomplete access to age-specific services, schedule delivery, reporting or other program differences. The national data do not provide the causal explanation. However, recent data on the disparities of vaccination and service contexts among Somali populations support prioritising research on continuity of immunisation in vulnerable families, including displaced and mobile populations (Abdi et al., 2025; Salad et al., 2026). For Somalia, the MCV2 trajectory has only five observed annual values, and so the positive change from 3% to 31% during 2021–2025 should not be interpreted as a statistically established long-run trend.

4.3 country comparisons

Ethiopia had large long-term increases in DTP3 and MCV1 but MCV1 stayed below 80% for the whole historical series. Household surveys of zero-dose populations have shown significant variation across underserved settings and geographical locations, highlighting the need to account for inequality within the national aggregate (Biks et al., 2024a, 2024b; Shiferie et al., 2024; Agimas et al., 2024; Endehabtu et al., 2025). Evidence from Jigjiga regarding measles second-dose coverage indicates that the timing of dose delivery needs to be evaluated independently of the program, however, evidence from the Somali Region of Ethiopia cannot be used to infer the situation in Somalia (Ibrahim et al., 2024; Elmi et al., 2026). Analysis of polio vaccination disparities also demonstrates that different antigens can reveal nonidentical patterns of access (Fekadu et al., 2024). The Djibouti DTP3 fluctuation pattern is a reminder to look at administrative denominators, survey observations and technical revisions in national immunisation estimates. The 2025 MCV2 estimate was much lower than DTP3 and MCV1 which makes dose-specific monitoring relevant even where DTP coverage has recovered. The WHO country material provides a relevant context for interpreting the source estimates but it does not specify which determinant is responsible for the changes (World Health Organization, 2024a, 2026).

Eritrea had the highest estimated coverage for each primary vaccine indicator in 2025, illustrating the difference between ongoing national high coverage and continuing gaps elsewhere. The authors have linked full immunisation to maternal education and have described the efforts toward measles elimination (Kibreab et al., 2020; Yehdego et al., 2020). However, a high national estimate does not rule out local service gaps, variation in data quality, or pockets of susceptible children, and the present maps cannot be used to infer subnational homogeneity (World Health Organization, 2024b).

4.4 Statistical interpretation and dynamics of inequality

The trend analysis suggested a generally negative Sen slope for the four-country DTP3 inequality range but with a larger gap at 2025 than at 1993 endpoints. This pattern is not inconsistent: a monotonic rank based summary of a nonmonotonic historical series may be different than an endpoint comparison. Any assertion that inequalities have been steadily shrinking, therefore, would be a stretch of the evidence. The shorter comparable MCV2 series provide an even tighter constraint: only 2021–2025 can be evaluated simultaneously across all four countries, implying that the observed narrowing of the cross-country range is more descriptive than reliable evidence of durable convergence.

Exploratory segmented regressions identify breaks in the fitted DTP3 trajectories, but cannot identify underlying interventions. The 2016 Somalia breakpoint is one possible way of describing changing average growth, not evidence of a particular policy impact. The GEE model also distinguishes country, vaccine and recent-year contrasts under a common specification, but it only has 16 correlated country-vaccine panels and five years. Confidence intervals based on a small number of independent clusters may be unstable. The reported estimates are best read alongside descriptive plots not as confirmatory tests.

4.5 Implications for public health interpretation

The results are in favour of a differentiated understanding of the programme's performance. DTP1 remains an access-oriented indicator, DTP3 a marker of infant series progression and MCV2 an indicator requiring attention to later childhood contacts. They indicate that relatively small dropout gaps do not make up for sizeable first-dose nonreceipt, while MCV2 may lag even where DTP-series coverage is comparatively higher. The equity focus of Immunisation Agenda 2030 and broader evidence on barriers to childhood immunisation support monitoring these distinct pathways rather than relying on a single national summary indicator (World Health Organization, 2020; O'Brien et al., 2024; Bangura et al., 2020).

Country level comparison is useful for setting research priorities, but is not sufficient, on its own, to allocate local resources. Before districts are selected, before socioeconomic groups are compared, and before shortfalls are attributed to fragile/conflict-affected status, vaccination outcomes must be linked to appropriately sampled household data, small-area administrative datasets, denominator quality assessments and uncertainty estimates. Somalia's specific requirement to identify children missed by DTP1 implies that routine administrative microplanning could be supplemented by independently validated population and survey information. All interventions should be tailored to the local service context, rather than extrapolated from national choropleths alone.

4.6 Strengths and weaknesses

The primary strengths are a consistent four-country source, a study window up to 2025, explicit discussion of vaccine-specific observation windows, a unified access/series completion framework,

a number of complementary absolute inequality measures, and fully documented figures and derived indicators. These design features permit a more complex interpretation than a simple end-point ranking.

There are a number of limitations to note. Second, the ecological design cannot identify individual determinants, causal program effects or within-country inequalities; maps only present national values. Secondly, WUENIC estimates may vary based on updated administrative data, surveys, age denominators and expert judgement. Third, the years of available observations differ, with Eritrea starting in 1993 and all-country MCV2 comparisons only beginning in 2021. Fourth, standard Mann–Kendall p values and selected segmented model knots do not fully address serial correlation or breakpoint uncertainty. Fifth, the GEE analysis for short and small cluster is exploratory. 6. The zero-dose proxy and the DTP gap are based on estimated coverage, not linked-cohort or true no-vaccine counts. Finally, World Bank or FCV labels at the country level are not valid explanatory regressors in a four-country historical ecological sample. These restrictions should inform interpretation and further data collection (WHO, 2026).

5. Conclusions

The 2025 revision of national WHO/UNICEF coverage estimates was used to assess long-term childhood immunisation coverage and inequalities across Somalia, Ethiopia, Djibouti and Eritrea within a maximum study window of 1980-2025. The results indicate a region of substantial progress but uneven accomplishment. All four countries had positive DTP3 trajectories over the periods for which data were available, supporting that routine immunisation coverage increased substantially. But the improvements were neither simultaneous nor sufficient to eliminate the absolute differences in program performance. In 2025 the difference in coverage between the highest and lowest coverage country was 21 percentage points for DTP1, 24 for DTP3, 32 for MCV1 and 58 for MCV2. The largest difference was therefore observed for the second dose of measles-containing vaccine. This indicator is therefore of particular priority for comparative program monitoring.

Of the four countries, Somalia was most consistently the least advantaged in terms of national vaccination coverage. The country has never achieved 80% DTP3 coverage for any year for which data are available, increasing from 2% DTP3 in 1981 to 72% in 2025. Somalia also had the lowest 2025 MCV1 (61%) and MCV2 (31%) values and the highest DTP1 nonreceipt proxy (23%). Critically, the national DTP1–DTP3 gap was much smaller than the difference in initial DTP1 access, highlighting the need to look at series completion as well as first dose reach. The difference in MCV1 and MCV2 also indicates that success in infant services does not necessarily translate to similar uptake of subsequent age-eligible vaccination contacts.

Ethiopia and Djibouti had intermediate performance with different vulnerabilities: Ethiopia had large increases in DTP3 over the long term but retained measles first-dose undercoverage, while

Djibouti had large temporal instability and a large 2025 MCV2 gap. In 2025, Eritrea had the highest national coverage among the four countries. Taken together, these cross-country differences imply that a single headline vaccination percentage can mask the programme-specific and temporal dimensions of inequality.

The methodological contribution of this analysis is the integrated comparison of trends, vaccine-specific gaps, failure to receive the first dose, DTP-series continuation, between-country inequalities, and periods of persistent low coverage. At the same time, careful inference is needed due to the short full MCV2 series, estimated nature of data, serial dependence and national ecological scale. Yet, these national trends alone cannot explain causality of a country's relative performance and the country-level maps do not identify underserved districts. Future work should incorporate subnational coverage, child-level survey data, population denominators and uncertainty assessments to identify which populations account for the observed national inequities.

Overall, the findings support a shift away from measuring program success based solely on national average coverage, toward measuring who is reached first, who receives all scheduled vaccines and whether opportunities for later doses are equitable. Central priorities include improving access for children missed by DTP1, strengthening MCV1 and MCV2 delivery, and improving the geographic resolution of monitoring, especially in Somalia. Sustainable progress in the Horn of Africa will require not only raising average coverage, but also closing vaccine-specific and country level gaps in routine childhood immunisation.

6. Suggestions

1. Somalia: Target children not reached by DTP1 Disaggregated health facility catchment reviews, outreach micro-planning and validated local denominator estimates should be used to identify communities with low access to the first dose. Target nomadic, displaced, rural and other underserved populations where there is localised evidence to support the need.

2. Reinforce continuity of measles vaccination. Monitor MCV1 and MCV2 separately. Assess age-eligible contact opportunities, availability of sessions and defaulter tracing. Do not treat the MCV1–MCV2 gap as an individual series dropout unless child-level follow-up data are available.

3. Investigate the constraints that impede the implementation of country programs. Assess ongoing gaps in MCV1 and in-country inequities in Ethiopia. • Time-series volatility analysis of measles delivery (second dose) in Djibouti. Eritrea: Ensure high national coverage, but conduct an independent assessment of data quality and heterogeneity of subnational coverage.

4. Create vaccine-specific equity dashboards. Publish annually trends for DTP1, DTP3, MCV1 and MCV2 in addition to the DTP1 inverse proxy, absolute dropout gap and well defined cross-country inequality range. Add annotations for data availability and mark changes in vaccine schedule or estimates

5. Enhance quality and transparency of national estimates. Triangulate administrative reports, household surveys, birth-cohort denominators and outreach registers; document uncertainty and changes between annual WUENIC revisions. An estimated gap in an indicator does not necessarily imply a failure in an individual follow-up.
6. Expand population-based and subnational research. Household wealth, displacement, geographic access, and health service continuity link local coverage and zero-dose indicators. Don't confuse DTP1 nonreceipt with zero-dose as defined by study-specific surveys.
7. Use stronger longitudinal inference when supported by data. Use appropriate small cluster methods. Expand multi-country datasets. Use methods that are robust to serial correlation and breakpoint uncertainty. Interpret results for MCV2 over 2021–2025 as short-run observations, not long-run trends.

Authors' Contributions

Fatima Abdijabbar Ibrahim: Conceptualization, study design, methodology, data analysis, interpretation of findings, and writing of the original manuscript draft.

Nasra Salad Ahmed: Conceptualization, literature review, data collection, data validation, interpretation of results, and manuscript drafting.

Nur Dahir Warsame: Data processing, software support, statistical analysis, data visualization, and critical review and editing of the manuscript.

Omar Aweis Ali: Methodological guidance, supervision, validation of analytical approaches, interpretation of findings, and critical revision of the manuscript.

Yasir Mohamed Abdinur: Data analysis, statistical validation, visualization, interpretation of findings, and manuscript review and editing.

All authors contributed to the intellectual development of the study, reviewed and approved the final version of the manuscript, and agreed to be accountable for their respective contributions to the work.

Declarations

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Conflict of interest

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

Data Availability Statement

The data used in this study are publicly available from the UNICEF Data website. Immunization coverage datasets can be accessed and downloaded from the official UNICEF immunization data portal: https://data.unicef.org/resources/immunization/. The datasets are available under the Creative Commons Attribution 3.0 IGO license. The data source should be appropriately acknowledged in any publication.

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