

Age-appropriate Completion and Coverage of Key Childhood Vaccines in Greater Accra, Ghana, 2014–2023

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AGE-APPROPRIATE COMPLETION AND COVERAGE OF KEY CHILDHOOD VACCINES IN GREATER ACCRA, GHANA, 2014–2023

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Keywords: Vaccination, Immunisation Coverage, Vaccine-Preventable Diseases, Child Health, Ghana, Greater Accra, Public Health

Abstract

Background: Vaccination remains a critical public health intervention in reducing morbidity and mortality from vaccine-preventable diseases (VPDs). The World Health Organisation (WHO) recommends at least 90% coverage for key childhood vaccines such as Bacillus Calmette–Guérin (BCG), pentavalent vaccine (Penta3), measles–rubella (MR), and yellow fever. However, persistent gaps in vaccine coverage completeness remain in many low- and middle-income settings. In Ghana, the Expanded Programme on Immunisation (EPI) targets children under five years. Rapid urbanization and population mobility in the Greater Accra Region (GAR) present constraints to equitable service delivery. We examined EPI routine immunisation data from the District Health Information Management System 2 (DHIMS2) to assess trends in childhood vaccination coverage and completeness from 2014 to 2023.

Methods: We extracted vaccination records from DHIMS2 in GAR from 2014–2023 for children aged 0–11 and 12–23 months, including catch-up vaccinations up to 59 months. Coverage was assessed for

key vaccines (BCG, OPV1, Penta3, measles-rubella, yellow fever). Descriptive statistics, dropout rates, and geospatial mapping were employed to evaluate trends and district-level performance. Penta 1 and Penta 3 coverage were used as proxies for access and utilisation.

Results: Age-appropriate completion among children 0–11 months increased from 20.6% (37,728/183,569) in 2016 to 47.1% (95,963/203,856) in 2019, then stabilised between 38.3% and 44.0% (2020–2023). Fully immunised for 12–23 months increased from 51.9% (101,794/195,995) in 2014 to 80.5% (183,055/227,490) in 2023. Penta3 coverage improved from 67.8% (132,909/195,995) to 96.5% (219,426/227,490) between 2014 and 2023. By 2023, 45% (13/29) of districts in GAR had achieved the WHO target of 90% coverage for Measles-Rubella 2 (MR2).

The Penta 1-Penta 3 dropout rate was -16.8% in 2023. The most significant dip in vaccination coverage was in 2020.

Conclusion: Despite improvements in overall coverage in GAR, age-appropriate completion of the full immunisation schedule, particularly by 11 months remained suboptimal, with substantial district-level variation. Coverage of vaccines such as MR2 exceeded 100% in some districts, indicating notable data quality issues. Strengthening routine data quality, improving monitoring of age-appropriate vaccination, and targeting underperforming districts are essential to achieving equitable immunisation outcomes.

Keywords: Childhood immunisation; Vaccination coverage; Age-appropriate vaccination; Fully immunised child; Vaccine-preventable diseases; Expanded Programme on Immunisation; Geospatial analysis; Ghana

Background

Vaccination is a cost-effective strategy for reducing childhood morbidity and mortality from vaccine-preventable diseases worldwide [1, 2]. Globally, routine immunisation averts 4–5 million deaths each year among children under five [3]. Despite these gains, persistent gaps in vaccine completeness, coverage, timeliness, and data quality undermine progress toward universal child survival targets.

The World Health Organization (WHO) recommends achieving and sustaining at least 90% vaccination coverage nationally and 80% coverage in every district, while coverage levels of 95% or higher are required for the elimination of selected vaccine-preventable diseases such as measles and rubella [4, 5]. Although childhood vaccine coverage in sub-Saharan Africa has improved, many

57 countries still fall short due to missed opportunities, weak follow-up systems, high population mobility
58 and health system constraints [6]. These challenges were further intensified by disruptions to routine
59 immunisation services during the COVID-19 pandemic, which resulted in declines in coverage and
60 exposed underlying system vulnerabilities [7, 8].

61 In Ghana, evidence from the Demographic and Health Survey (GDHS) and the WHO-UNICEF Joint
62 Reporting Form (JRF) indicates persistent regional inequities in childhood immunisation [8, 9]. The
63 Greater Accra Region (GAR), Ghana's most densely populated and highly urbanized region, presents
64 unique challenges for immunization service delivery. Rapid urbanization, internal migration, informal
65 settlements, and socioeconomic disparities complicate vaccine delivery, population denominator
66 estimates and routine service utilisation [10, 11]. These dynamics increase the risk of delayed and
67 incomplete vaccination, particularly among children living in peri-urban and underserved
68 communities.

69 Timely and complete vaccination is crucial to the success of EPI. Children who receive vaccines later
70 than recommended remain vulnerable to VPDs for extended periods, while delays at population level
71 weaken herd immunity and increase outbreak risk [12]. Studies from urban settings in Kenya, Nigeria,
72 and Ethiopia have demonstrated associations between incomplete vaccination and factors such as low
73 maternal education, poverty, and limited access to primary healthcare services [13, 14]. Similar
74 structural and service delivery constraints have been documented in Ghana, where outreach capacity,
75 cold-chain reliability, and health worker distribution remain critical determinants of immunisation
76 performance [15, 16].

77 Despite ongoing national immunisation assessments, a key evidence gap persists. Few studies have
78 examined long-term trends in vaccination coverage and age-appropriate completion using routine
79 health information systems in highly urbanised settings such as Greater Accra. Addressing this gap is
80 essential for identifying programmatic weaknesses, improving monitoring beyond crude coverage
81 indicators, and guiding targeted interventions aligned with the WHO Immunisation Agenda 2030
82 (IA2030).

83 We analysed routine EPI data from the District Health Information Management System 2 (DHIMS2)
84 to assess trends in age-appropriate vaccination coverage and completion among children under five
85 years in the Greater Accra Region of Ghana from 2014 to 2023.

86

Methods

Study Design: This study utilized a population-based descriptive secondary data analysis of routinely collected childhood vaccination surveillance data from the Greater Accra Region, Ghana, from 2014 to 2023.

Study Setting: The Greater Accra Region (GAR) is Ghana's smallest region by land area but the second most populous, with an estimated population of approximately five million, largely driven by internal migration and rapid urbanisation. Administratively, GAR is divided into 29 metropolitan, municipal, and district assemblies. The region is predominantly urban, with approximately 93% of districts classified as urban and the remainder characterised by mixed urban–rural settings. The geographical location of the Greater Accra Region is shown in **Figure 1**.

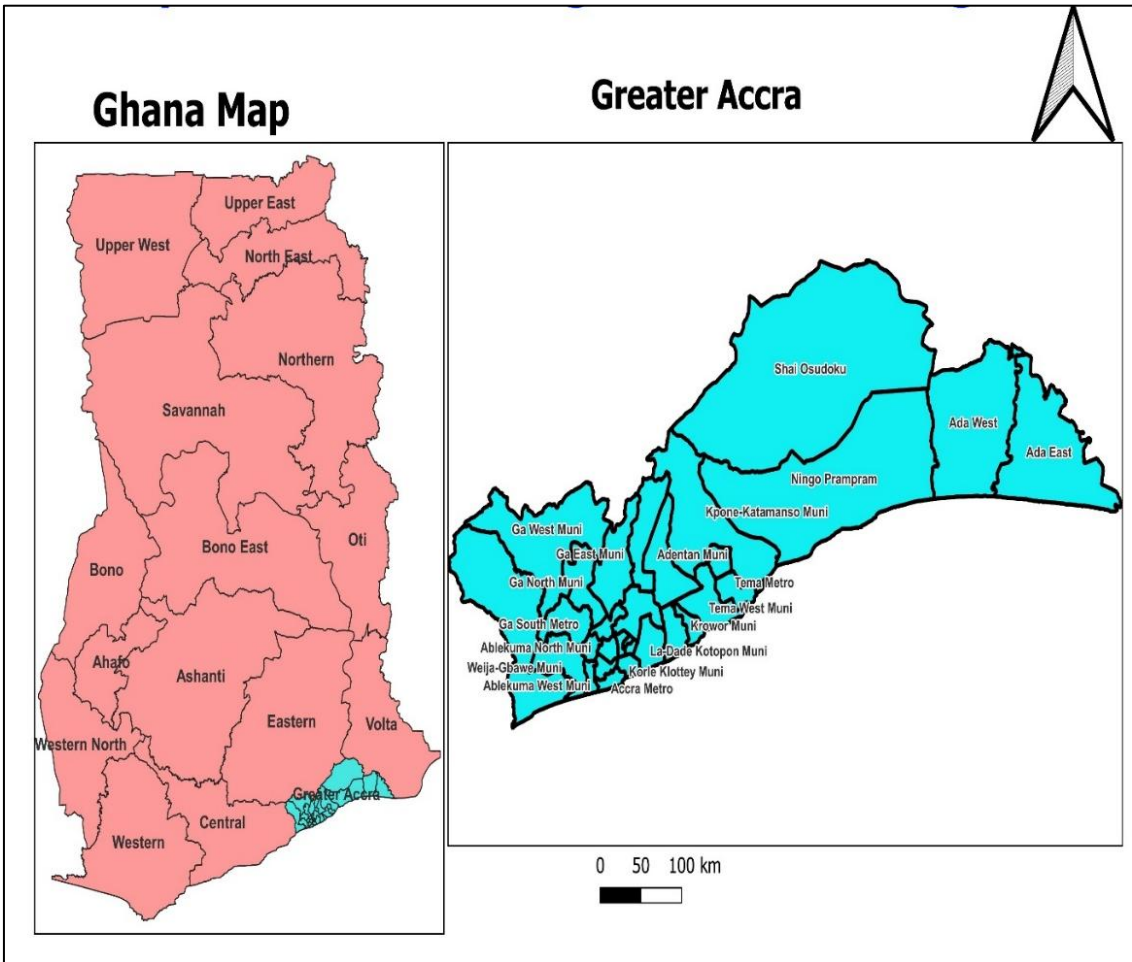


Figure 1: Map showing the Greater Accra Region

Study Population: The study population comprised children aged 0–59 months who received routine immunisation services in the Greater Accra Region during the study period. Analyses were conducted using standard EPI age cohorts: children aged 0–11 months, those aged 12–23 months, and children receiving catch-up vaccinations up to 59 months of age.

Data Source: We extracted and analysed data from the District Health Management Information System 2 (DHIMS 2), Ghana’s national health information system that compiles routinely collected immunisation data from all public and private health facilities. For this study, vaccination data were aggregated from all 29 metropolitan, municipal, and district assemblies in the Greater Accra Region.

Data Collection: The DHIMS2 aggregates routinely collected, facility-level immunisation data reported from vaccination registers and child health cards into a central electronic platform. The dataset includes records for key childhood vaccines, including Bacillus Calmette–Guérin (BCG), oral polio vaccine (OPV), pentavalent vaccine (Penta), measles–rubella (MR), and yellow fever. Vaccination data are reported by predefined child age categories, allowing assessment of immunisation coverage and completion across standard EPI cohorts.

The timing and schedule of vaccines included in Ghana's Expanded Programme on Immunisation are presented in **Table 1**.

Table 1: National Vaccination Schedule for Children in Ghana

Age Group	Vaccine	Timing/Doses	Purpose
Age 1 (0–11 months)	BCG	At birth	Protection against tuberculosis
	OPV	OPV-0 at birth, OPV1, OPV2, OPV3 at 6, 10, 14 weeks	Protection against polio
	Penta	Penta1, Penta2, Penta3 at 6, 10, 14 weeks	Protection against Diphtheria, Pertussis, Tetanus, Hepatitis B, and Haemophilus influenzae type b
	PCV	At 6, 10, and 14 weeks	Protection against pneumococcal diseases

	Rota	Rota1, Rota2, Rota3 at 6, 10, 14 weeks	Prevention of rotavirus infection
	IPV	IPV 1 at 14 weeks and IPV 2 at 7 months	Protection against polio
	YF	At 9 months	Protection against Yellow Fever,
Age 1-2 (9– 23 months)	MR	MR1 at 9 months, MR2 at 18 months	Protection against measles and rubella
	Men-A	Men A- 18 months	Protection against Meningitis A

117

118 **Data Variables:** The primary variables analysed included vaccination coverage, vaccination
119 completeness, and temporal trends for selected key childhood vaccines. Vaccines assessed were
120 Bacillus Calmette–Guérin (BCG), oral polio vaccine first dose (OPV1), pentavalent vaccine third dose
121 (Penta3), measles–rubella, and yellow fever, which represent critical milestones within Ghana’s
122 Expanded Programme on Immunisation schedule.

123 **Data Analysis:** Extracted DHIMS2 data were exported into Microsoft Excel 365 and cleaned using
124 Excel Power Query. Descriptive analyses were conducted to assess vaccination coverage, age-
125 appropriate completion, and temporal trends for the selected childhood vaccines. Coverage estimates
126 were summarised using frequencies and proportions across study years and EPI age cohorts. Vaccine
127 dropout rates were calculated to assess continuity of immunisation services. Coverage of the first dose
128 of pentavalent vaccine (Penta1) was used as a proxy indicator of access to routine immunisation
129 services, while coverage of the third dose (Penta3) was used as a proxy indicator of service utilisation
130 and continuity.

131 Geospatial analyses were performed using Geographic Information System (GIS) tools in QGIS to
132 visualise district-level variation in vaccination coverage and service utilisation across the Greater Accra
133 Region. Results were presented using tables, line graphs, and thematic maps.

134 Vaccination coverage denominators were estimated using population projections for eligible child age
135 groups obtained from the Ghana Statistical Service. In line with national EPI programmatic
136 conventions, children under five years of age were assumed to constitute approximately 4% of the total

regional population during the study period. This approach was adopted due to the absence of reliable annual live birth data and is consistent with administrative methods commonly used in routine immunisation monitoring and evaluation in similar settings.

Operational Definition:

Fully Immunised Child (FIC 1): A child aged 0–11 months who received all vaccines recommended in the primary EPI schedule by 11 months of age, including Bacillus Calmette–Guérin (BCG), oral polio vaccine (OPV), pentavalent vaccine (Penta), pneumococcal conjugate vaccine (PCV), inactivated polio vaccine (IPV), rotavirus vaccine, and the first dose of measles–rubella (MR1).

Fully Immunised Child (FIC 2): A child aged 12–23 months who received all age-appropriate vaccines by 23 months of age, including the second dose of measles–rubella (MR2), yellow fever (YF), second dose of inactivated polio vaccine (IPV2), and meningococcal A (MenA), in addition to vaccines received during infancy.

Completeness of Vaccination: The proportion of children within each EPI age cohort who received all vaccines recommended for their age group.

Coverage Category: Districts were classified per WHO standards: Green ($\geq 90\%$), Yellow (60–89%), and Red ($< 60\%$).

Trends of vaccine completion: Annual trends in age-appropriate vaccination completion assessed across the study period for each defined EPI age cohort.

Dropout Rate: The proportion of children who initiated the vaccination series with the first dose of pentavalent vaccine (Penta1) but did not complete the series by receiving the third dose (Penta3). The Penta1–Penta3 dropout rate was calculated using the formula recommended by the World Health Organization. A positive dropout rate indicates incomplete utilisation of immunisation services, whereas a negative dropout rate suggests higher uptake of later doses relative to initial doses, likely reflecting catch-up vaccination activities. The Penta1–Penta3 dropout rate was calculated using the World Health Organization–recommended formula:

$$\text{Dropout Rate (\%)} = \frac{\text{Penta 1} - \text{Penta 3}}{\text{Penta 1}} \times 100$$

Utilisation: utilisation of routine immunisation services was assessed using Penta3 coverage as a proxy, as receipt of the third dose requires repeated contact with health services over time.

Access: Access to routine immunisation services was assessed using Pental coverage as a proxy indicator of initial contact with vaccination services.

Ethical Approval: This study was conducted under the Ghana Field Epidemiology and Laboratory Training Programme (GFELTP) and the Ghana Health Service. Ethical approval for GFELTP field investigations, surveillance system evaluations, and programme evaluation activities was granted by the Ghana Health Service Ethics Review Committee (GHS-ERC Approval No. 023/05/24). The study was conducted in accordance with the ethical principles of the Declaration of Helsinki.

The study involved secondary analysis of anonymised, aggregated routine immunisation data extracted from the District Health Information Management System 2 (DHIMS2). Permission to access and analyse the data was obtained from the Ghana Health Service. No personally identifiable information was accessed, collected, or reported. As the study utilised routinely collected anonymised programme data and did not involve direct participant contact, individual informed consent was not required.

Results

Overview of Childhood Vaccination in the Greater Accra Region (2014–2023)

Between 2014 and 2023, an estimated 2,015,618 children under five years of age in the Greater Accra Region were eligible for routine immunisation, based on population projections from the Ghana Statistical Service assuming children under five constituted approximately 4% of the total population. Incomplete reporting in the DHIMS2 limited trend analyses for the years 2014 and 2015. Overall, vaccination coverage and age-appropriate completion increased over the study period, with temporal declines observed in 2020 and 2021, followed by improvements in subsequent years.

Completion of Vaccination by Age Group

Completion of Vaccination for Children Aged 0–11 Months

The proportion of fully immunised infants (FIC-1) increased from 23.9% in 2016 to 47.1% in 2019. This was followed by a decline to 38.3% in 2020. Coverage subsequently increased to 44.0% in 2022, before decreasing slightly to 39.6% in 2023. **Table 2** summarises annual estimates of the eligible

192 population of children aged 0–11 months and the proportion completing age-appropriate routine
 193 immunisation between 2014 and 2023.

194 **Table 2:** Fully Immunised Children Aged 0-11 Months, 2014–2023

Year	Estimated Eligible Population (<1 year)	Number of fully immunised children	Proportion of % Completing Vaccination (%)
2014	195995	***	***
2015	191229	***	***
2016	183008	43731	23.9
2017	183569	37728	20.6
2018	187846	70444	37.5
2019	203856	95963	47.1
2020	201586	77202	38.3
2021	218228	88734	40.7
2022	222811	98121	44.0
2023	227490	90025	39.6

195

196 **Completion of Vaccination for Children Aged 12–23 Months**

197 Among children aged 12–23 months (FIC-2), full vaccination coverage increased from 51.9% in 2014
 198 to a peak of 87.3% in 2018. Coverage subsequently declined to 71.6% in 2020, followed by a gradual
 199 increase to 80.5% in 2023. **Table 3** summarises annual estimates of the eligible population of children
 200 aged 12–23 months and the proportion fully immunised between 2014 and 2023.

201 **Table 3:** Fully Immunised Children Aged 12-23 Months, 2014–2023

Year	Population	Frequency	Proportion of children 12-23 months fully vaccinated (%)
2014	195995	101794	51.9
2015	191229	126754	66.3
2016	183008	134490	73.5
2017	183569	150601	82.0
2018	187846	163923	87.3
2019	203856	169048	82.9
2020	201586	144419	71.6
2021	218228	160953	73.8
2022	222811	173869	78.0
2023	227490	183055	80.5

202

203 **Pentavalent vaccine third dose (Penta3) coverage**

The Penta3 coverage, a key indicator of routine immunisation performance among children aged 0–11 months, increased from 67.8% in 2014 to a peak of 100.2% in 2018. Coverage declined subsequently to 92.7% in 2019 and dropped further during 2020–2021, reaching a low of 83.5% in 2020. Penta3 coverage subsequently increased, reaching 96.5% by 2023. The annual trend in Penta3 coverage between 2014 and 2023 is presented in **Figure 2**.

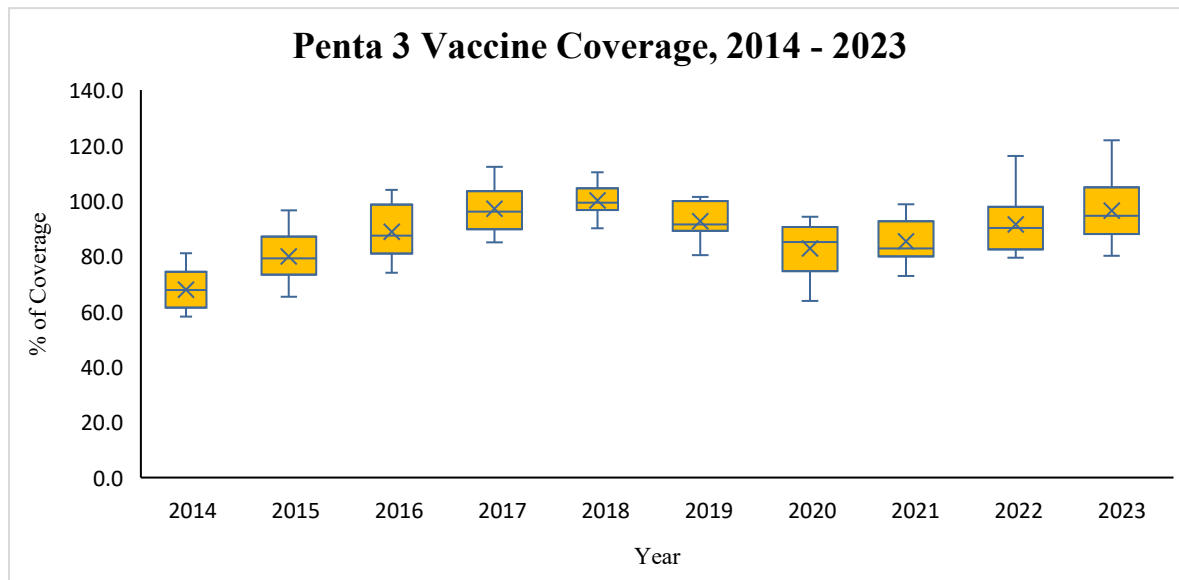


Figure 2: Trends in Penta 3 Coverage in Greater Accra Region (2014-2023), showing a decline during the pandemic period and subsequent recovery

Completion of Vaccination for Children Aged 12–23 Months (Year 2)

Measles–rubella second dose (MR2) coverage

Coverage of the measles–rubella second dose (MR2), an indicator of vaccination completion in the second year of life, declined from approximately 80% in 2019 to about 60% in 2020 and 2021. Coverage increased thereafter, returning to approximately 80% by 2023.

District-level distributions showed substantial variability across the study period. In 2019, median MR2 coverage was approximately 80%, with a wide interquartile range (IQR) and the presence of both lower and higher outliers. In 2020, the median declined to around 60%, accompanied by a wider IQR and increased dispersion. Median coverage remained near 60% in 2021, with a comparatively narrower IQR. In 2022, median coverage increased modestly, with reduced variability, while in 2023 median

coverage approached 80%, with an IQR comparable to 2019 and fewer outliers. The annual trend in MR2 coverage between 2014 and 2023 is presented in **Figure 3**.

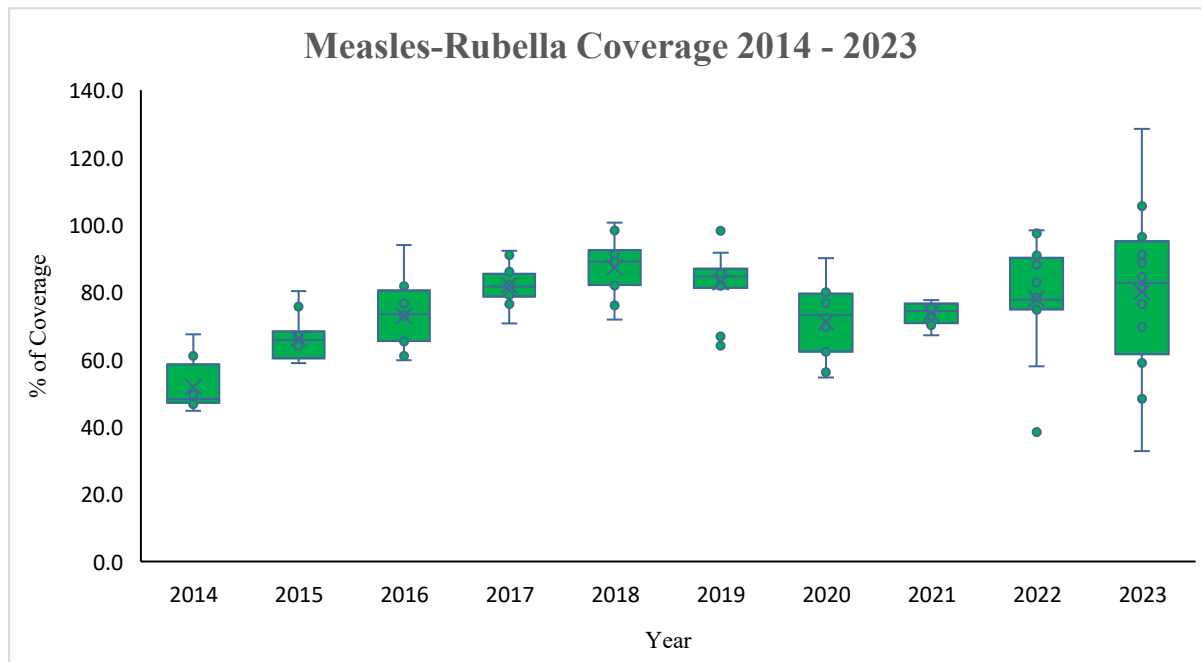


Figure 3: Trends of MR2 Coverage in Greater Accra Region, Ghana (2014–2023)

Trend of Coverage for Selected Antigens

Trends in immunisation coverage for selected antigens in the Greater Accra Region between 2014 and 2023 demonstrated distinct temporal patterns. Coverage of the third dose of pentavalent vaccine (Penta3) showed the most consistent performance over the study period, with a generally steady increase across successive years.

In contrast, yellow fever vaccine coverage exhibited greater year-to-year variability, with observable fluctuations over the study period. Coverage of the measles–rubella second dose (MR2) increased notably after 2018, following lower and more variable levels in earlier years. Meningococcal A (MenA) vaccine coverage remained relatively stable within a narrow range throughout the study

period, while inactivated polio vaccine (IPV) coverage showed greater variability across years. The trends in coverage for selected childhood vaccine antigens in the Greater Accra Region from 2014 to 2023 are presented in **Figure 4**.

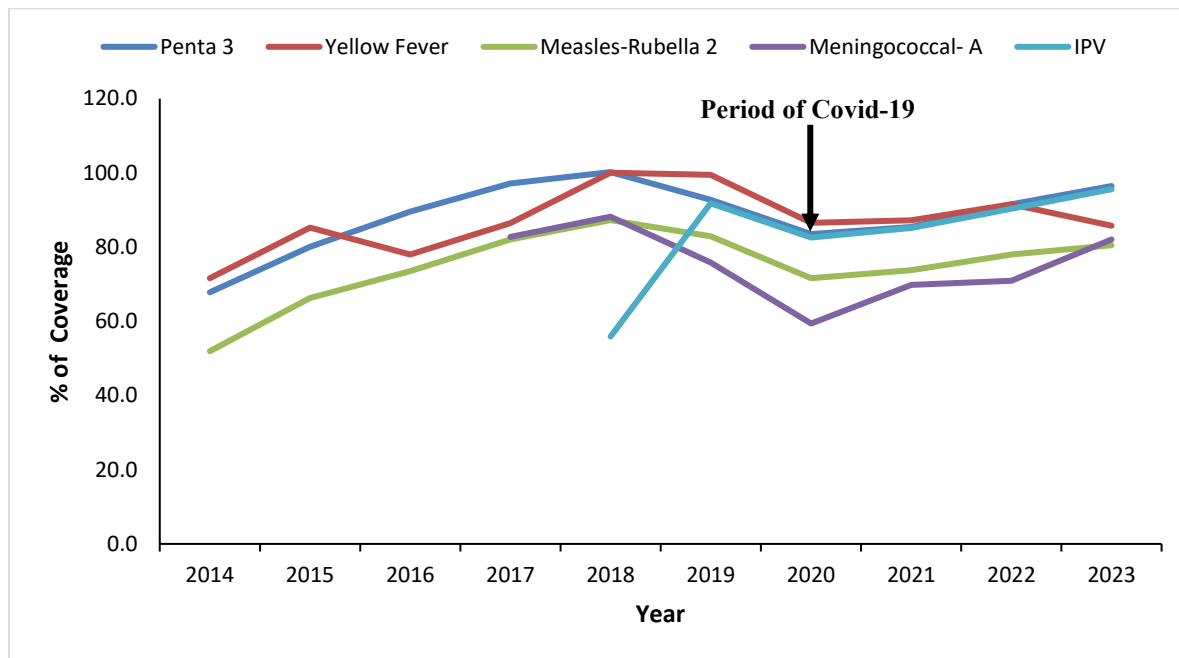


Figure 4. Trend of Coverage for Selected Antigens in the Greater Accra Region, 2014–2023

Spatial Distribution of District Level Coverage of Key Vaccines

Geospatial Analysis of Penta3 Coverage By 2023

District-level geospatial analysis of Penta3 coverage in 2023 showed substantial variation across the Greater Accra Region. Nineteen districts achieved coverage levels of at least 90%, corresponding to the WHO-defined high-performance category. These districts included major metropolitan areas such as Accra Metropolitan and Tema Metropolitan.

Nine districts recorded moderate coverage levels ranging from 60% to 89%, including Ashaiman and Ga West, while one district remained in the low-coverage category with Penta3 coverage below 60%.

Several districts classified within the high-coverage category reported coverage levels exceeding 100%, notably Accra Metropolitan (138.2%) and Ashaiman (146.4%). The spatial distribution of Penta3 coverage across districts in the Greater Accra Region in 2023 is presented in **Figure 5**.

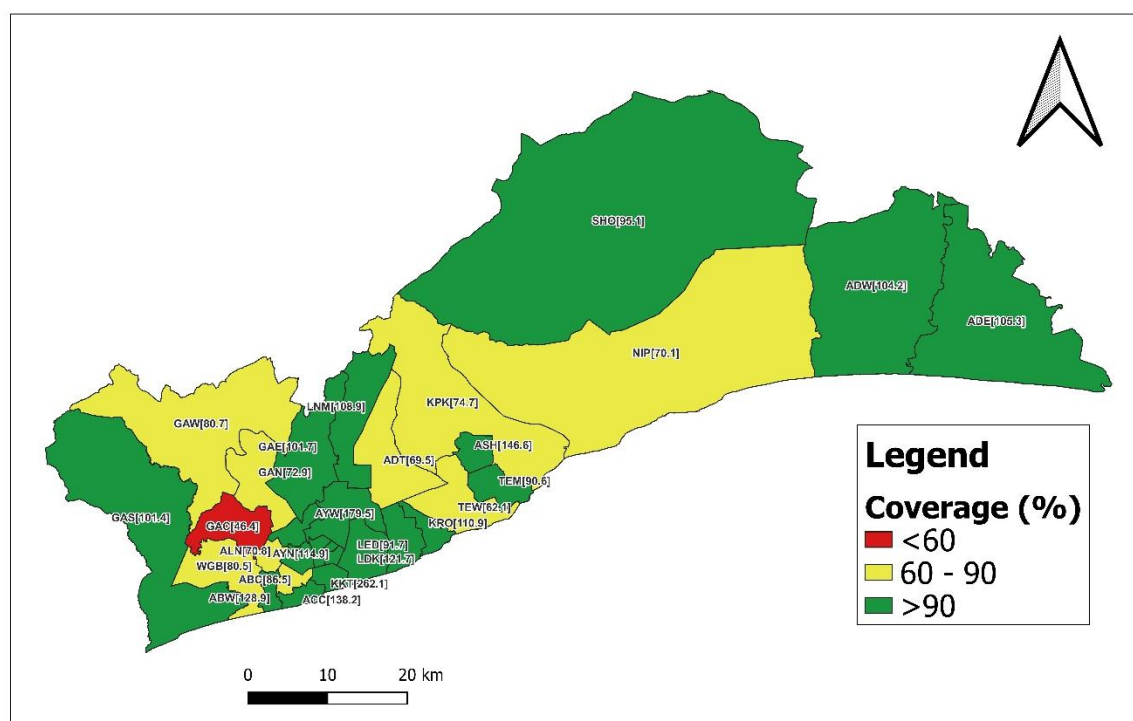


Figure 5: Spatial distribution of Penta3 coverage across districts in the Greater Accra Region, Ghana, 2023.

Geospatial Analysis of MR2 Coverage By 2023

District-level geospatial analysis of MR2 coverage in 2023 showed substantial variation across the Greater Accra Region. Four districts were classified in the low-coverage category (<60%), including Ga Central (44.9%), Kpone-Katamanso (58.7%), and Adenta (59.1%). Twelve districts recorded moderate coverage levels (60–89%), including Ningo-Prampram (60.3%) and Tema Metropolitan (77.5%), while thirteen districts achieved the WHO target of at least 90% coverage. Notably, several districts reported coverage levels exceeding 100%, including Korle Klottey Municipal (288.9%), Ayawaso Central (137.4%), and Ledzokuku Municipal (117.8%). The spatial distribution of MR2 coverage across districts in the Greater Accra Region in 2023 is presented in **Figure 6**.

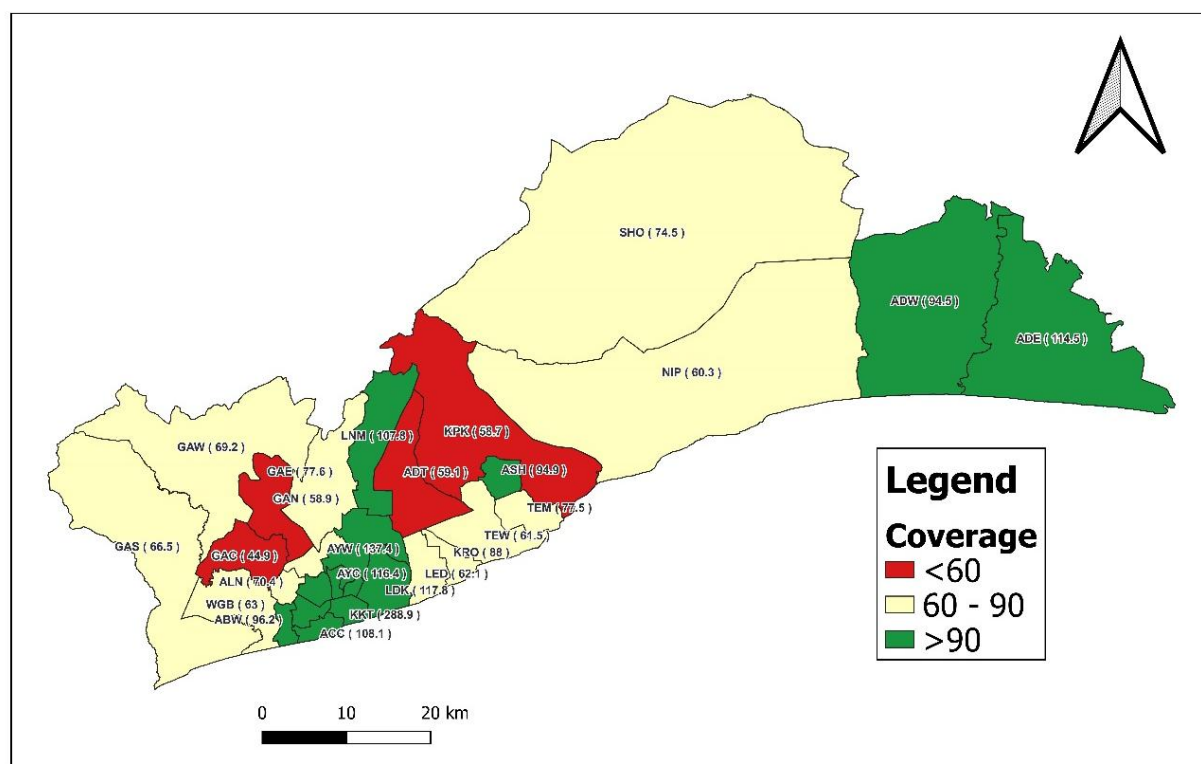


Figure 6: Spatial distribution of MR2 coverage across districts in the Greater Accra Region, Ghana, 2023.

Access and Utilisation of Vaccines

Access to and utilisation of routine immunisation services between 2014 and 2023 were assessed using coverage of the first dose of pentavalent vaccine (Penta1) as a proxy for access and the third dose (Penta3) as a proxy for utilisation. Substantial temporal variation was observed across the study period.

Median Penta1 coverage increased from approximately 70% in 2014 to above 80% in 2016 and reached around 90% in 2017 and 2018. Coverage declined between 2019 and 2021, with median values ranging from approximately 75% to 80%, before increasing again in 2022 and 2023 to between 85% and 90%. Variability in district-level coverage was greater in 2014–2015 and during 2019–2021, as indicated by wider interquartile ranges.

Penta3 coverage followed a broadly similar temporal pattern (Figure 2). Median coverage increased from approximately 68% in 2014 to above 85% in 2016, reaching around 95% in 2017 and 2018. Between 2019 and 2021, median Penta3 coverage declined to approximately 80–85%, before

increasing again in 2022 and 2023 to around 90–95%. Interquartile ranges were narrower during 2016–2018 and widened during 2019–2021, before narrowing again in 2023.

Across the study period, Penta1 coverage remained consistently higher than Penta3 coverage. The gap between access and utilisation was smallest between 2016 and 2018 and widest between 2019 and 2021. District-level variation in access to routine immunisation services, assessed using Penta1 coverage, is presented in **Figure 7**.

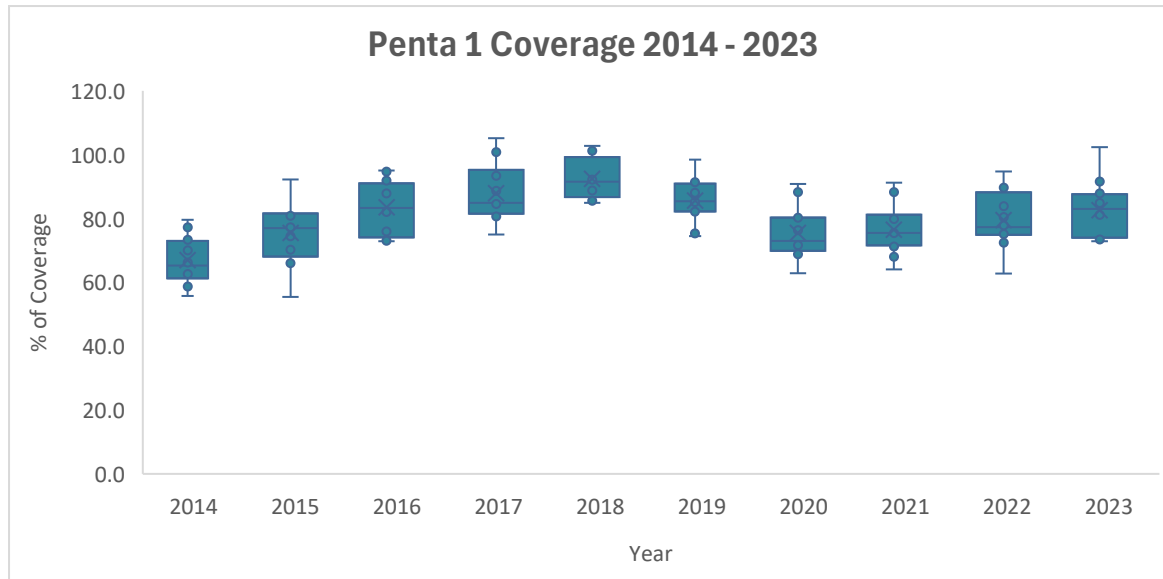


Figure 7. District-level distribution of Penta1 coverage in the Greater Accra Region, Ghana, 2014–2023.

Dropout Rate

Analysis of the Penta1–Penta3 dropout rate in the Greater Accra Region demonstrated marked changes over the study period. In 2014, a positive dropout rate of 2.9% was observed, indicating that some children who initiated the vaccination series with Penta1 did not complete it with Penta3. From 2015 onwards, the dropout rate became negative, declining from –5.8% in 2015 to –16.8% in 2023. These negative values indicate that reported Penta3 vaccinations exceeded Penta1 vaccinations during the same period, suggesting the influence of catch-up vaccination activities, population mobility, or inconsistencies in target population estimates and reporting. The annual trend in the Penta1–Penta3 dropout rate in the Greater Accra Region from 2014 to 2023 is presented in **Figure 8**.

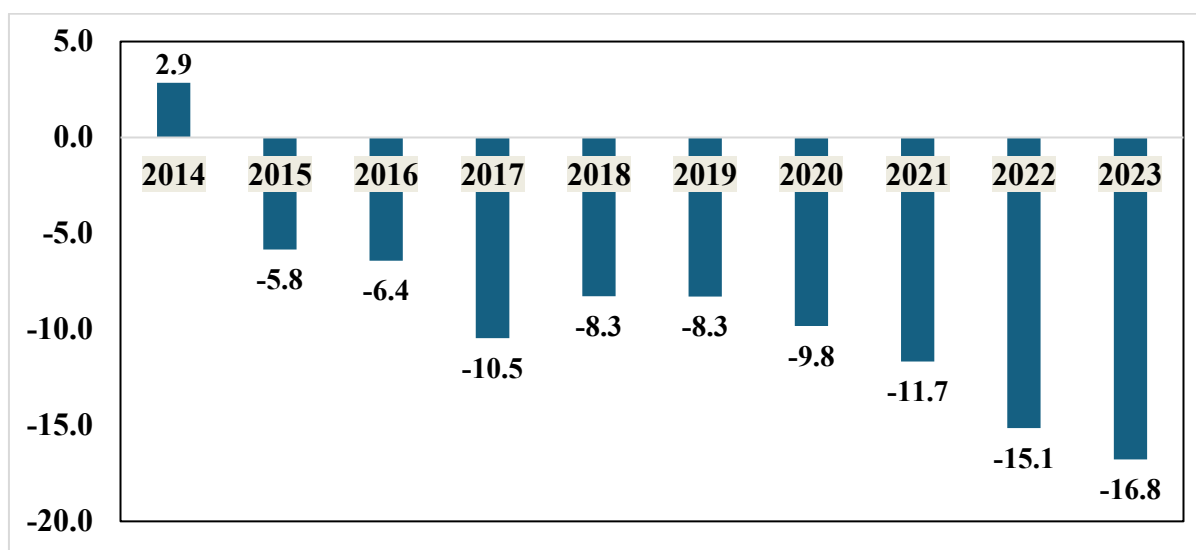


Figure 8. Trend in the Penta1–Penta3 dropout rate in the Greater Accra Region, Ghana, 2014–2023.

Discussion

This study assessed long-term trends in childhood immunisation coverage, completion, and utilisation in the Greater Accra Region (GAR) over a ten-year period using routine EPI data. Overall, the findings indicate improvements in immunisation performance, particularly in the proportion of children completing vaccination by the second year of life. These gains likely reflect the cumulative effects of sustained programme investments, periodic catch-up vaccination activities, and intensified post-pandemic recovery efforts. Our findings are consistent with recent national evidence showing improved full vaccination coverage among children aged 12–35 months, with GAR recording the highest regional performance in Ghana [17]. Nevertheless, when benchmarked against high-performing countries in the sub-region, such as Rwanda, the absolute coverage levels observed indicate that substantial gaps remain, underscoring the need for accelerated and targeted strategies [18].

Trends in Penta1 and Penta3 coverage provide important insights into access to and utilisation of routine immunisation services. The steady improvement observed between 2014 and 2018 aligns with regional evidence linking strengthened primary healthcare delivery to improved vaccine uptake across the WHO African Region [19]. In contrast, the declines recorded between 2019 and 2021 mirror patterns observed across several African countries during the COVID-19 pandemic, reflecting widespread service disruptions and constrained health system capacity [20]. The widening gap between Penta1 and Penta3 during this period suggests that while initial contact with immunisation services was relatively preserved, continuity and completion were more vulnerable to system shocks [20].

Encouragingly, the recovery observed in 2022 and 2023 reflects a resilient programme response. The narrowing gap between Penta1 and Penta3 during this period points to improved retention and completion, likely driven by intensified outreach, mop-up campaigns, and flexible service delivery approaches [21]. Similar recovery trajectories have been documented in settings that implemented targeted post-pandemic restoration plans, reinforcing the importance of adaptive strategies to rebuild routine immunisation coverage following major disruptions [30].

A notable finding was the persistence of negative Penta1–Penta3 dropout rates, reaching –16.8% by 2023. While negative dropout rates may reflect catch-up vaccination activities, such patterns are also consistent with data quality limitations and cohort definition challenges, particularly in highly urbanised and mobile settings [23]. The metropolitan nature of GAR attracts substantial in-migration of children who may initiate vaccination in other regions and complete their schedules in Accra, inflating Penta3 counts relative to Penta1 and potentially masking hidden defaulters and true programme performance [11]. Inaccurate target population estimates, delayed or incomplete reporting, and possible dose misclassification may further contribute to this anomaly [25, 11]. Similar dynamics have been described in other large urban settings in the African sub-region, such as Nairobi and Lagos, where children may initiate vaccination in one district and complete it in another [26]. These findings underscore the need to strengthen both data quality and client retention mechanisms, including reminder/recall systems, systematic defaulter tracing, inter-district reconciliation, and deliberate catch-up strategies to improve effective coverage [25, 11].

Timeliness and equity remain persistent challenges. Although Penta3 coverage approached the WHO target by the end of the study period, the proportion of children who completed the full age-appropriate immunisation schedule by 11 months remained substantially lower. This finding highlights the distinction between completion of a single vaccine series and completion of the entire infant immunisation schedule, suggesting missed opportunities for timely administration of other recommended antigens. The low and fluctuating proportion of children completing the schedule within the first year of life, alongside district-level disparities, aligns with national and regional evidence showing that socioeconomic status, maternal education, and unequal distribution of health personnel continue to shape immunisation outcomes [14, 27]. The results suggest that without targeted approaches for underserved populations, including peri-urban and vulnerable communities gains in overall coverage may obscure persistent inequities.

Consistent with regional and global evidence, the declines observed for vaccines such as OPV, Penta3, and MR2 during the COVID-19 period likely reflect broader vulnerabilities in health service continuity during public health emergencies [28, 29]. Studies in Ghana and across the continent have attributed similar declines to pandemic-related service disruptions, vaccine stockouts, and increasing hesitancy driven by misinformation and safety concerns [28, 30]. These findings reinforce the importance of strengthening risk communication, fostering community trust, and building resilient health systems capable of maintaining routine immunisation during crises.

Data quality concerns remain a critical cross-cutting issue, particularly the occurrence of reported coverage exceeding 100% in several districts. Such results point to weaknesses in denominator estimation, reporting practices, and validation processes, rather than limitations of reporting software. Recent assessments in Ghana similarly emphasise the need for sustained capacity building in data management, routine validation at facility and district levels, improved inter-district reconciliation, and strengthened use of child-level registers to minimise misclassification and ensure accurate programme monitoring [23, 31]. A major strength of this study is the use of a decade-long dataset, which enabled assessment of long-term trends in immunisation coverage, completion, and programme resilience in the Greater Accra Region. Unlike many previous studies that relied on cross-sectional survey data, this analysis utilised routine programme data to evaluate age-appropriate vaccination completion, access, utilisation, and district-level variation over time. The inclusion of geospatial analysis further provided insights into sub-regional disparities that may not be apparent from regional coverage estimates alone. These findings offer practical evidence to support programme planning, resource allocation, and performance monitoring within Ghana's Expanded Programme on Immunisation.

Overall, the immunisation programme in GAR has made substantial progress and demonstrated adaptability over the past decade but continues to face challenges related to timeliness, equity, retention, and data quality. The recovery trajectory following pandemic-related disruptions offers lessons for other rapidly urbanising contexts. Sustaining gains and closing remaining gaps will require integrated, equity-focused strategies aligned with IA2030 and the Addis Ababa Declaration, with deliberate attention to timely completion, accurate monitoring, and reaching underserved populations.

Limitations

This study has several limitations. First, vaccination coverage denominators were estimated using the EPI convention that children under five years constitute approximately 4% of the total population.

While this approach is widely used for routine programme monitoring, it may not fully capture district-level demographic variation, potentially affecting the precision of coverage estimates. Second, the use of aggregated routine data precluded assessment of individual-level timeliness of vaccine administration and limited the ability to examine vaccination sequences at the child level. Third, the absence of individual-level socioeconomic and demographic variables restricted exploration of underlying factors contributing to observed disparities in coverage and completion across districts.

Conclusion

The Greater Accra Region demonstrated substantial programmatic resilience and effective recovery of routine immunisation services following the sharp declines observed during the COVID-19 pandemic, underscoring the critical role of integrated primary healthcare in maintaining essential services and establishing “crisis-proofing” mechanisms against future public health emergencies. Despite these gains, two persistent threats to immunisation success remain: sub-regional inequities and systemic data quality limitations. Addressing these challenges will require strengthening routine data systems through regular data quality audits, targeted capacity-building at district level, and improved reconciliation of population denominators using recent housing and demographic data. To improve equity, programme resources should be deliberately targeted towards consistently underperforming districts, such as Ningo-Prampram and Kpone-Katamanso, through expanded outreach strategies, including mobile vaccination units and strengthened Community-based Health Planning and Services (CHPS) delivery. In addition, sustaining coverage gains will require institutionalising crisis-resilient approaches, such as dedicated contingency funding for routine immunisation and the integration of vaccination services with other essential health services during periods of disruption. Strengthening equity-focused implementation and robust surveillance systems is therefore essential for sustaining Ghana’s immunisation gains and achieving national and global immunisation targets.

List of Abbreviations

- BCG: Bacillus Calmette–Guérin
- DHIMS2: District Health Information Management System 2
- EPI: Expanded Programme on Immunisation

- 406 • FIC: Fully Immunised Child
- 407 • GAR: Greater Accra Region
- 408 • GDHS: Ghana Demographic and Health Survey
- 409 • GSS: Ghana Statistical Service
- 410 • IA2030: Immunization Agenda 2030
- 411 • IPV: Inactivated Polio Vaccine
- 412 • JRF: Joint Reporting Form
- 413 • MenA: Meningococcal A Vaccine
- 414 • MR: Measles–Rubella Vaccine
- 415 • MR2: Measles–Rubella Second Dose
- 416 • OPV: Oral Polio Vaccine
- 417 • PCV: Pneumococcal Conjugate Vaccine
- 418 • Penta: Pentavalent Vaccine
- 419 • QGIS: Quantum Geographic Information System
- 420 • VPDs: Vaccine-Preventable Diseases
- 421 • WHO: World Health Organization

422 **Declarations**

423 **Ethical Approval:** This study was conducted under the Ghana Field Epidemiology and Laboratory
 424 Training Programme (GFELTP) and the Ghana Health Service as part of routine public health
 425 programme monitoring and evaluation activities. The study was conducted in accordance with the
 426 ethical principles of the Declaration of Helsinki. Permission to access and analyse routine
 427 immunisation data was obtained from the Ghana Health Service. The study utilised anonymised,

428 aggregated data extracted from the District Health Information Management System 2 (DHIMS2), and
429 no personally identifiable information was collected, accessed, or reported. As the study involved
430 secondary analysis of routinely collected programme data, individual informed consent was not
431 required.

432 **Consent for Publication:** Not applicable.

433 **Availability of data and materials:** The datasets analysed during the current study are not publicly
434 available because they contain routine health programme data obtained from the Ghana Health Service.
435 The datasets are, however, available from the corresponding author on reasonable request and with
436 permission from the Ghana Health Service.

437 **Competing interests:** The authors declare that they have no competing interests.

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440 **Authors' contributions:** DAK and CNL conceptualised and designed the study. DAK and JL
441 contributed to data acquisition and curation. DAK conducted the data analysis, interpretation,
442 geospatial analysis, and visualisation, with support from JL and EAA. DAK drafted the initial
443 manuscript. GB, RD, IK, CNL, and EK critically reviewed the manuscript and provided important
444 intellectual input. GB, CNL, and EK provided technical oversight, supervision, and mentorship
445 throughout the study. All authors reviewed, revised, and approved the final manuscript and agree to be
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