Published by
Saidu Medical College

OPEN ACCESS

ISSN (P): 1819-4583
ISSN (E): 3007-9470

Copyright © Copyright (c) 2026 The authors retain the copyrights. Authors are permitted and encouraged to post their work online (e.g. in institutional repositories or on their website), as it can lead to productive exchanges, as well as greater citation of published work.

Citation:
Khan I, Sadiq N. Routine Immunization Coverage Trends Before, During, and After the COVID-19 Pandemic: A Retrospective Ecological Analysis of Administrative Surveillance Data from Khyber Pakhtunkhwa, Pakistan. *J Saidu Med Coll.* 2026;16(3):558–567.

Corresponding Author:
Dr. Naveed Sadiq
Associate Professor,
Institute of Public Health & Social Sciences, Khyber Medical University, Peshawar, Pakistan
naveedsadiq@gmail.com

Funding:
The publication charges for this article are fully borne from the Khyber Medical University Publication Fund (Ref. No. DIR/RIC/Ref/25/00045).

Conflicts of Interests:
The authors have declared that no competing interests exist.

Data Sharing Statement:
The data that support the findings of this study are available on request from the corresponding author. The data is not publicly available due to privacy or ethical restrictions.

Received: December 10, 2025
1st Revision: January 30, 2026
2nd Revision: March 31, 2026
3rd Revision: May 02, 2026
Accepted: June 13, 2026

Check for updates

Original Article

Routine Immunization Coverage Trends Before, During, and After the COVID-19 Pandemic: A Retrospective Ecological Analysis of Administrative Surveillance Data from Khyber Pakhtunkhwa, Pakistan

Imran Khan[1] & Naveed Sadiq[2]
[1]World Health Organization, KP, Pakistan
[2]Institute of Public Health & Social Sciences, Khyber Medical University, Peshawar, Pakistan

https://doi.org/10.52206/jsmc.2026.16.3.1474

Abstract

Background: Maintaining routine health services during public health emergencies is essential for health system resilience. The COVID-19 pandemic disrupted immunization services worldwide, increasing concerns about declining vaccine coverage, zero-dose children, and resurgence of vaccine-preventable diseases. Evidence from Pakistan using administrative surveillance data remains limited.

Objective: To describe temporal changes in routine immunization coverage among children aged under 24 months across pre-COVID-19, intra-COVID-19, and post-COVID-19 periods in Khyber Pakhtunkhwa, Pakistan.

Methodology: A retrospective descriptive ecological study was conducted using aggregated secondary data from the Expanded Programme on Immunization Management Information System. Immunization records from all 28 reporting districts of Khyber Pakhtunkhwa from January 2019 to April 2022 were analyzed across three periods: pre-COVID-19, January 2019–February 2020; intra-COVID-19, March 2020–September 2021; and post-COVID-19, October 2021–April 2022.

Results: Routine immunization coverage indicators demonstrated variation across the study periods. The proxy indicator for fully immunized children increased from 74% during the pre-COVID-19 period to 88% during the post-COVID-19 period, while the proportion of zero-dose children declined from 16% to 4%. Coverage for the major vaccine antigens also increased during the post-pandemic period, although BCG coverage exceeded 100%, reflecting administrative denominator limitations and programmatic factors rather than true population coverage.

Conclusion: Routine immunization indicators derived from administrative surveillance data demonstrated improved programmatic coverage during the post-COVID-19 period in Khyber Pakhtunkhwa. These findings describe temporal patterns in routine immunization service delivery within a provincial immunization programme during and after the COVID-19 pandemic and provide evidence that may inform immunization programme planning and health system preparedness for future public health emergencies. The results should be interpreted in the context of aggregated administrative data and do not imply causal relationships between programme interventions and observed coverage changes.

Keywords: Administrative Data, COVID-19, Ecological Study, Expanded Programme on Immunization, Health Systems, Khyber Pakhtunkhwa, Pakistan, Routine Immunization.

Introduction

Resilient health systems are characterized by their ability to maintain essential health services while simultaneously responding to public health emergencies. During crises, health systems must rapidly mobilize resources, adapt service delivery, and ensure continuity of priority interventions to minimize indirect morbidity and mortality resulting from disruptions in routine healthcare services [1]. Sustaining essential preventive services, particularly childhood immunization programmes, is therefore recognized as a key indicator of health system resilience and preparedness [2,3].

The COVID-19 pandemic posed unprecedented challenges to healthcare systems worldwide. Public health restrictions, lockdown measures, diversion of healthcare resources, workforce shortages, interruptions in vaccine supply chains, and reduced healthcare-seeking behaviour collectively affected routine immunization programmes across both high-income and low- and middle-income countries [3,4]. Declines in routine childhood vaccination raised concerns regarding increasing numbers of zero-dose children and the potential resurgence of vaccine-preventable diseases (VPDs), threatening decades of progress achieved through national immunization programmes [5].

Pakistan faced similar challenges during the COVID-19 pandemic. In addition to movement restrictions and temporary suspension of selected health services, caregivers were often reluctant to visit healthcare facilities because of concerns about SARS-CoV-2 transmission. Reduced public transportation, logistical constraints, and competing public health priorities further complicated routine immunization service delivery during the pandemic [6,7]. These disruptions were of particular concern because Pakistan continues to face endemic transmission of several vaccine-preventable diseases, making uninterrupted immunization services essential for maintaining population immunity.

Although numerous international studies have documented reductions in routine immunization coverage during the COVID-19 pandemic, comparatively limited evidence is available from Pakistan using provincial administrative immunization surveillance systems. Furthermore, relatively few studies have described immunization trends across the pre-pandemic, pandemic, and post-pandemic recovery phases using routinely collected programme data. Understanding these temporal patterns is important for evaluating programme performance, identifying service recovery following major health emergencies, and informing future preparedness strategies for maintaining essential health services. The Expanded Programme on Immunization Management Information System (EPI-MIS) provides routinely collected administrative data that allow population-level monitoring of immunization programme performance across districts. While such surveillance data do not permit assessment of individual vaccination histories or causal inference, they provide valuable programmatic information regarding coverage trends over time and support routine monitoring of immunization service delivery.

Therefore, this retrospective descriptive ecological study used aggregated administrative surveillance data from the provincial EPI-MIS to describe routine immunization coverage indicators among children younger than 24 months across the pre-COVID-19, intra-COVID-19, and post-COVID-19 periods in Khyber Pakhtunkhwa, Pakistan. By characterizing temporal changes in key immunization indicators, this study contributes evidence on routine immunization programme performance during a major public health emergency and may inform future health system planning and immunization programme strengthening in Pakistan and other low- and middle-income countries.

Methodology

Study Design

This retrospective descriptive ecological study was conducted using secondary aggregated administrative data obtained from the Expanded Programme on Immunization Management Information System (EPI-MIS) of Khyber Pakhtunkhwa (KP), Pakistan. The study followed the recommendations of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement for observational studies. The ecological unit of analysis was the district rather than the individual child, and all analyses were based on aggregated district-level administrative data routinely collected through the provincial immunization programme. The study was designed to describe temporal changes in routine immunization coverage before, during, and after the COVID-19 pandemic and was not intended to establish causal relationships between the pandemic and immunization outcomes.

Ethics

The study utilized anonymized secondary administrative data routinely collected by the Expanded Programme on Immunization for monitoring programme performance. The EPI-MIS database contains only aggregated district-level information and does not include personal identifiers or individual vaccination records. Permission to access and analyze the data was obtained from the Directorate General of Health Services, Khyber Pakhtunkhwa. As the study involved analysis of routinely

collected, anonymized administrative data without direct participant involvement, informed consent was not required.

Setting

The study was conducted in Khyber Pakhtunkhwa, Pakistan, where routine childhood immunization services are delivered through the provincial Expanded Programme on Immunization (EPI). Vaccination services are provided through fixed immunization centres, outreach sessions, and mobile vaccination teams. Health facilities submit routine monthly immunization reports to district EPI offices, which are subsequently compiled into the provincial EPI-MIS database. Data were extracted for the period from 1 January 2019 to 30 April 2022. To evaluate temporal changes associated with the COVID-19 pandemic, the study period was categorized into three predefined intervals:

- Pre-COVID-19 period: 1 January 2019 to 29 February 2020
- Intra-COVID-19 period: 1 March 2020 to 30 September 2021
- Post-COVID-19 period: 1 October 2021 to 30 April 2022

These periods were defined before analysis to facilitate consistent comparisons of routine immunization programme performance across different phases of the pandemic.

Data Source

Secondary administrative data were obtained from the provincial Expanded Programme on Immunization Management Information System (EPI-MIS), the official electronic database used for routine monitoring of immunization activities throughout Khyber Pakhtunkhwa. The EPI-MIS compiles district-level monthly reports on vaccine doses administered, target populations, and immunization coverage indicators submitted by public-sector immunization facilities. The database contains aggregated programmatic information only and does not permit identification or longitudinal follow-up of individual children. For this study, cumulative district-level data for all routine reporting districts were extracted for each predefined study period. Administrative target populations used within the EPI-MIS are based on official census-derived population projections employed by the provincial immunization programme for planning and performance monitoring.

Participants/Units of Analysis

As this was an ecological study, no individual participants were recruited. The unit of analysis was the district. All 28 districts that consistently reported routine immunization data to the provincial EPI-MIS throughout the study period were included. No sampling strategy was applied because the study analyzed the complete population of eligible reporting districts. Newly merged districts were excluded because complete and consistent administrative reporting was unavailable during the entire observation period.

Variables

The primary outcome variables were routine immunization indicators routinely reported within the EPI-MIS database. These included Bacille Calmette-Guérin (BCG) coverage, Pentavalent-III (Penta-III) coverage, Measles-Rubella first-dose (MR-1) coverage, zero-dose children, fully immunized children (FIC), and the BCG-to-MR-1 dropout rate. BCG coverage represented the proportion of the administrative target population receiving BCG vaccination and served as an indicator of access to routine immunization services. Zero-dose children were defined programmatically as children who had not received BCG vaccination and therefore had not entered the routine immunization programme. Pentavalent-III coverage represented receipt of the third dose of pentavalent vaccine according to Pakistan's national immunization schedule and was used as an indicator of continued utilization of immunization services. MR-1 coverage represented receipt of the first dose of measles-rubella vaccine and reflected progression through the routine immunization schedule. Because individual vaccination histories were unavailable in the aggregated EPI-MIS database, MR-1 coverage was used as a proxy indicator for fully immunized children. This indicator reflects programme-level completion of the routine immunization schedule rather than confirmed complete immunization of individual children. The dropout indicator was calculated as the difference between BCG and MR-1 administrative coverage. Since aggregated data do not permit linkage of individual vaccination records, this indicator represents programme-level differences in vaccine coverage rather than confirmed individual dropout from the immunization schedule.

Data measurement

Monthly district-level reports were aggregated for each predefined study period before analysis. Administrative immunization coverage for each vaccine antigen was calculated using the number of vaccine doses administered as the numerator and the corresponding administrative target population reported in the EPI-MIS as the denominator, expressed as a percentage.

Coverage (%) = (Number of vaccine doses administered ÷ Administrative target population) × 100

The administrative target populations were derived from official census-based population projections routinely used by the provincial EPI programme. Because these projections are periodically updated to reflect revised census estimates and population growth assumptions, denominator values differed across study periods. Consequently, administrative coverage estimates could exceed 100%, particularly during periods of intensive catch-up vaccination activities, migration, or vaccination of children outside their district of residence. Such values were retained because they represent routine programme performance as reported through the EPI-MIS rather than computational errors.

Bias

Several potential sources of bias were considered. Administrative databases are susceptible to reporting errors, delayed reporting, incomplete reporting, transcription inaccuracies, and duplicate recording during outreach or catch-up campaigns. In addition, administrative target populations are derived from projected census estimates rather than contemporaneous population counts, which may introduce denominator inaccuracies and influence calculated coverage estimates. Because the study analyzed aggregated district-level data, the findings are subject to ecological bias. Associations observed at the district level cannot be interpreted as representing vaccination behaviors or outcomes at the individual level. Furthermore, differences in the duration of the predefined study periods and the absence of adjustment for seasonal variation in immunization activities may affect comparisons between periods.

Study size

No formal sample size calculation was performed because the study included all districts that met the eligibility criteria. The complete dataset from all 28 reporting districts was analyzed, thereby maximizing representativeness of routine immunization programme performance within Khyber Pakhtunkhwa during the study period.

Quantitative variables

All immunization indicators were analyzed as continuous percentage variables derived from aggregated administrative counts. Coverage estimates for BCG, Pentavalent-III, MR-1, zero-dose children, fully immunized children, and dropout rates were summarized separately for each of the three predefined study periods. Because these indicators were calculated using administrative target populations, they represent programme performance rather than direct estimates of true population vaccination coverage.

Statistical methods

Data were entered, cleaned, and analyzed using Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA, USA). Descriptive statistical methods were used throughout the analysis. Cumulative frequencies, administrative coverage percentages, proportions, and dropout rates were calculated for each immunization indicator across the three study periods. Temporal comparisons were performed descriptively between the pre-COVID-19, intra-COVID-19, and post-COVID-19 periods. Figures were generated to illustrate trends in BCG, Pentavalent-III, MR-1, fully immunized children, zero-dose children, and dropout indicators. No inferential statistical analyses, regression modelling, hypothesis testing, or interrupted time-series analyses were performed because the objective of the study was to describe programme-level trends using aggregated ecological data rather than to evaluate causal associations. Likewise, no adjustment was made for seasonal variation in immunization service delivery because the analysis was based on cumulative administrative data reported for each predefined pandemic period.

Results

Participants

The analysis included aggregated routine immunization data from all 28 districts of Khyber Pakhtunkhwa that consistently reported to the provincial Expanded Programme on Immunization Management Information System (EPI-MIS) during the study period. District-level administrative data were summarized across the predefined pre-COVID-19 (1 January 2019–29 February 2020), intra-COVID-19 (1 March 2020–30 September 2021), and post-COVID-19 (1 October 2021–30 April 2022) periods.

Descriptive data

Routine immunization indicators were summarized using cumulative administrative coverage percentages for the three predefined study periods. The evaluated indicators included Bacille Calmette-Guérin (BCG) coverage, Pentavalent-III (Penta-III) coverage, Measles-Rubella first-dose (MR-1) coverage, the proxy indicator for fully immunized children (FIC), zero-dose children, and the BCG-to-MR-1 dropout indicator. Antigen-specific cumulative frequencies and administrative coverage percentages are presented in Table 1, while overall temporal patterns of FIC, zero-dose children, and dropout indicators are illustrated in Figure 1. Trends in BCG, Penta-III, and MR-1 coverage are presented in Figure 2. As shown in Table 1 and Figure 2, administrative coverage for all three major vaccine antigens varied across the three study periods. During the pre-COVID-19 period, administrative coverage was 84% for BCG, 79%

for Pentavalent-III, and 78% for MR-1. During the intra-COVID-19 period, the corresponding coverage values were 86% for BCG and 84% for both Pentavalent-III and MR-1. During the post-COVID-19 period, administrative coverage reached 107% for BCG and 98% for both Pentavalent-III and MR-1 (Table 1, Figure 2).

Outcome data

Overall routine immunization indicators across the three study periods are summarized in Figure 1. The proxy indicator for fully immunized children (based on MR-1 coverage) was 74% during the pre-COVID-19 period and remained 74% during the intra-COVID-19 period before increasing to 88% during the post-COVID-19 period (Figure 1). The BCG-to-MR-1 dropout indicator was 10% during the pre-COVID-19 period, 8% during the intra-COVID-19 period, and 19% during the post-COVID-19 period (Figure 1). The proportion of zero-dose children was 16% during the pre-COVID-19 period, 14% during the intra-COVID-19 period, and 4% during the post-COVID-19 period (Figure 1).

Main results

Descriptive comparison of the three study periods demonstrated variation in administrative routine immunization indicators over time. Compared with the pre-COVID-19 period, the post-COVID-19 period showed higher administrative coverage for BCG (107% vs. 84%), Pentavalent-III (98% vs. 79%), MR-1 (98% vs. 78%), and the proxy indicator for fully immunized children (88% vs. 74%). Over the same periods, the proportion of zero-dose children decreased from 16% to 4%, while the BCG-to-MR-1 dropout indicator changed from 10% to 19% (Table 1, Figure 1, and Figure 2). These findings describe temporal patterns in administrative immunization indicators across the three predefined pandemic periods. Because the analyses were based on aggregated ecological administrative data, the observed differences represent programme-level changes over time and should not be interpreted as evidence of causal relationships or individual-level vaccination outcomes.

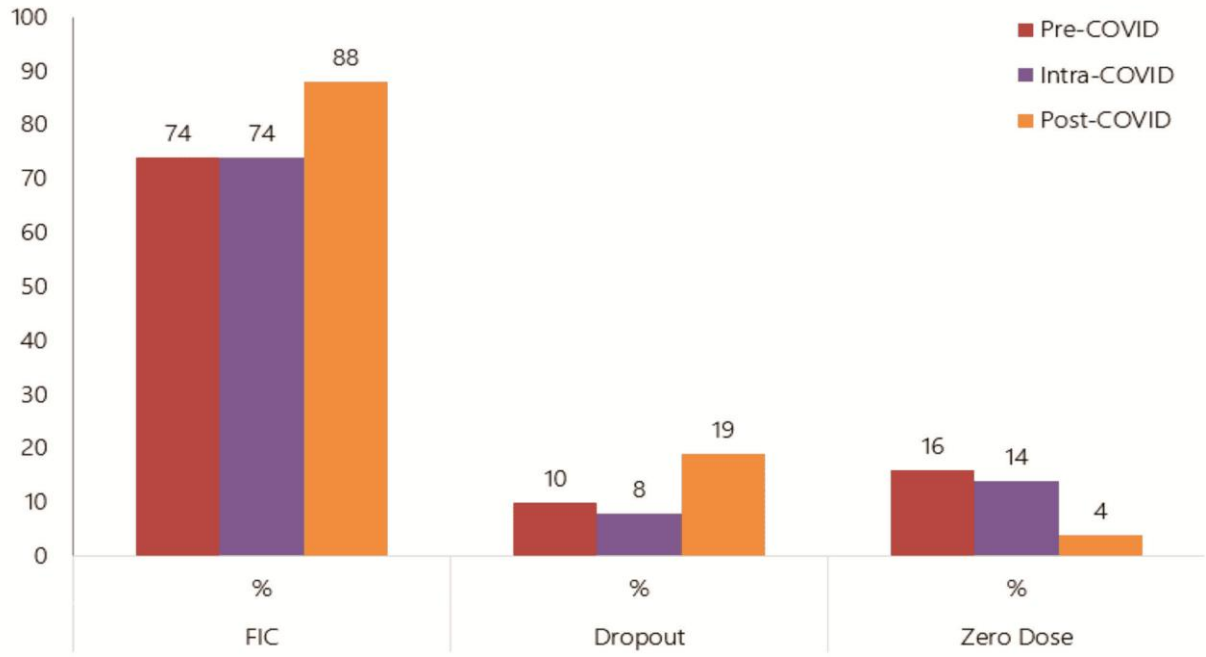


Figure 1: Overall Provincial Immunization Situation during Pre-, Intra-, and Post-COVID-19 Period.

Table 1: Antigen-wise Coverage during Pre-, Intra-, and Post-COVID-19 Periods

Vaccine Type	Pre-COVID-Target	Percentage during Pre-COVID	Intra-COVID-Target	Percentage during Intra-COVID	Post-COVID-Target	Percentage during Post-COVID
BCG	1135767	958008 (84%)	1793973	1537011 (86%)	1024003	1093854 (107%)
Penta-III	1069897	842079 (79%)	1689922	1418072 (84%)	968299	952886 (98%)
MR-1	1069897	830704 (78%)	1689922	1413112 (84%)	968299	945334 (98%)

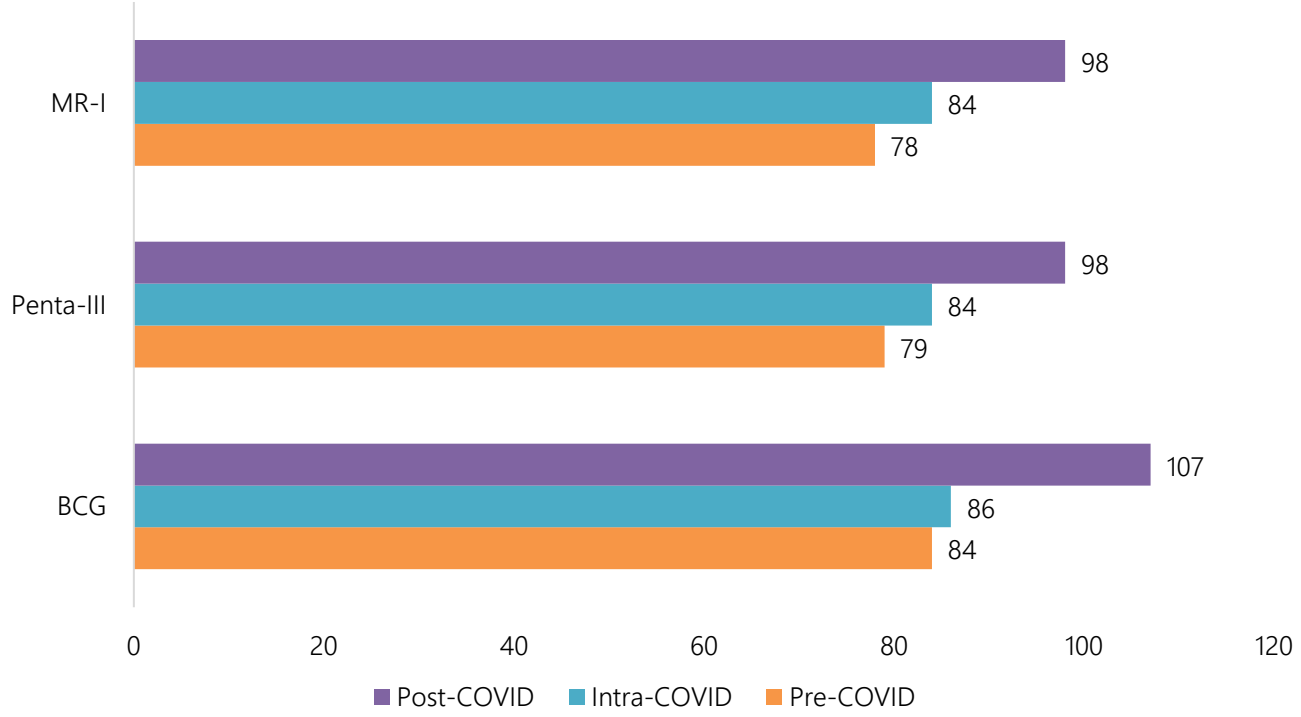


Figure 2: Antigen-wise Coverage during the Pre-, Intra-, and Post-COVID-19 Periods

Discussion

This retrospective descriptive ecological study used provincial administrative surveillance data to describe temporal patterns in routine immunization coverage before, during, and after the COVID-19 pandemic in Khyber Pakhtunkhwa (KP), Pakistan. Overall, administrative coverage indicators suggested relative stability in routine immunization performance during the intra-COVID-19 period, followed by improvements in several programme indicators during the post-COVID-19 period. Because the study relied on aggregated administrative data, these findings should be interpreted as programme-level observations rather than estimates of individual vaccination status or direct measures of population immunization coverage.

The observed trends differ from those reported in many countries where routine childhood immunization services experienced substantial disruptions during the COVID-19 pandemic, resulting in declines in vaccine coverage and increasing numbers of under-immunized children [8-11]. Similar reductions have been reported across both high-income and low- and middle-income countries, reflecting widespread interruptions in healthcare delivery during the pandemic [12,13]. In contrast, the administrative EPI-MIS data from KP demonstrated relatively stable coverage during the pandemic and higher reported coverage during the recovery period. These differences may reflect variations in health system organization, programme recovery strategies, administrative reporting systems, or population denominator estimation rather than true differences in vaccination uptake. Consequently, direct comparisons with population-based studies should be interpreted cautiously.

The proxy indicator for fully immunized children, derived from MR-1 coverage, increased during the post-COVID-19 period, while the proportion of zero-dose children declined substantially. Because MR-1 coverage was used as a proxy measure, these findings represent programme completion within the administrative reporting system rather than confirmation that individual children received every vaccine according to the national immunization schedule. Likewise, the BCG-MR-1 dropout indicator reflects differences between aggregated vaccine coverage estimates rather than true individual-level attrition from the immunization schedule. These inherent characteristics of ecological administrative data should be considered when interpreting programme performance.

Several programmatic initiatives implemented during and after the pandemic may plausibly explain the observed temporal trends; however, the descriptive ecological design does not permit causal inference regarding their effectiveness. During the pandemic, the Government of Khyber Pakhtunkhwa implemented multiple service delivery strategies, including intensified outreach activities, catch-up immunization campaigns, and expanded outreach sessions across districts. Previous studies have demonstrated that outreach-based immunization strategies can improve access to vaccination services, particularly among underserved

populations [14]. Similarly, financial incentives provided to Expanded Programme on Immunization (EPI) staff to conduct vaccination activities during weekends and holidays may have supported service continuity and facilitated efforts to identify zero-dose and defaulting children during a period of considerable health system strain [15]. While these interventions coincide temporally with improvements in programme indicators, the present study cannot determine the magnitude of their individual contributions.

An important finding was the observation of BCG administrative coverage exceeding 100% during the post-COVID-19 period. Coverage estimates greater than 100% are well recognized in administrative immunization data and generally indicate limitations in denominator estimation, changes in target population projections, reporting practices, or successful catch-up vaccination activities rather than true population coverage. Several factors may have contributed to this observation in KP. First, EPI coverage estimates are calculated using administrative targets rather than verified population counts, and vaccination performance may exceed projected targets when additional eligible children are vaccinated. Second, revisions in population projections following the transition from the 1997 to the 2017 census altered estimated target populations, reducing projected denominators and increasing calculated administrative coverage percentages [16]. Third, implementation of the Birth Dose Initiative during the latter phase of the pandemic increased the provision of BCG vaccination immediately after institutional delivery, potentially increasing administrative coverage while reducing the number of newborns classified as zero-dose children. Evidence suggests that facility-based birth-dose vaccination programmes improve early vaccine uptake [17]. Finally, intensive catch-up vaccination activities targeting children who missed immunizations during earlier phases of the pandemic may also have contributed to higher administrative coverage estimates. These explanations are plausible but cannot be confirmed within the present study because individual-level vaccination histories were unavailable.

The increase in the BCG-MR-1 dropout indicator during the post-pandemic period, despite improvements in overall antigen coverage, highlights the complexity of interpreting aggregated programme indicators. Catch-up vaccination activities may increase early-dose coverage more rapidly than completion of subsequent vaccine doses, thereby widening the difference between early and later antigen coverage. Because dropout calculations were derived from aggregated administrative data rather than longitudinal follow-up of individual children, these findings should not be interpreted as direct measures of individual vaccine completion.

The programme recovery strategies implemented in Khyber Pakhtunkhwa appear broadly consistent with recommendations issued by the World Health Organization for maintaining essential immunization services during the COVID-19 pandemic [18-20]. Strengthened outreach activities, catch-up vaccination campaigns, targeted efforts to identify zero-dose children, workforce support through financial incentives, and implementation of innovative service delivery approaches such as the Birth Dose Initiative represent examples of adaptive programme responses intended to maintain immunization service delivery during periods of health system disruption. Although the present study cannot establish whether these interventions directly resulted in improved coverage, the descriptive findings suggest that adaptive programme management may facilitate continuity of essential preventive services during future public health emergencies.

Several strengths should be acknowledged. This study analyzed routinely collected administrative surveillance data from all reporting districts within the province over more than three years, allowing comprehensive assessment of programme-level trends before, during, and after the COVID-19 pandemic. The use of provincial surveillance data reflects real-world programme performance and provides valuable evidence for public health planning, monitoring, and evaluation. Furthermore, inclusion of multiple immunization indicators enabled a broader assessment of programme performance than reliance on a single vaccine antigen alone.

However, several important limitations should be considered when interpreting these findings. First, this was an ecological study using aggregated administrative data; therefore, associations observed at the district or provincial level cannot be assumed to apply at the individual level, introducing the possibility of ecological fallacy. Second, administrative coverage estimates depend on the completeness and accuracy of routine programme reporting and may be influenced by reporting errors, delayed data entry, duplicate reporting during catch-up campaigns, or inconsistencies in target population estimates. Third, immunization coverage was calculated using projected administrative denominators rather than verified census populations, which may explain coverage estimates exceeding 100% and affect comparisons across study periods. Fourth, individual vaccination histories were unavailable; consequently, MR-1 coverage was used as a proxy indicator for fully immunized children, and dropout rates reflected programme-level differences rather than confirmed individual vaccine completion. Fifth, unequal durations of the three study periods and the absence of adjustment

for seasonal variation may have influenced comparisons across periods. Finally, because the analysis was descriptive and no inferential statistical modelling or interrupted time-series analysis was performed, the study cannot determine whether observed changes were statistically significant or attributable to specific programme interventions. Accordingly, the findings should be interpreted as descriptive surveillance observations rather than evidence of programme effectiveness or causal relationships.

Despite these limitations, the findings have important public health implications. Routine immunization programmes should remain a priority component of emergency preparedness planning to minimize indirect health consequences during future crises. Strengthening immunization surveillance systems, improving the accuracy of denominator population estimates, expanding electronic immunization registries, and ensuring timely identification of zero-dose children may enhance programme monitoring and facilitate rapid recovery following service disruptions. Continued investment in adaptive service delivery strategies, including outreach vaccination, catch-up campaigns, and strengthened primary healthcare infrastructure, may further improve resilience of immunization programmes in low- and middle-income countries [21,22].

The COVID-19 pandemic highlighted both vulnerabilities and adaptive capacities within health systems worldwide. As Pakistan continues to strengthen preparedness for future public health emergencies, understanding programme performance using routinely collected surveillance data can inform evidence-based policy development and resource allocation [23-25]. Future research using individual-level longitudinal data, electronic immunization registries, and robust analytical designs such as interrupted time-series or quasi-experimental studies would complement administrative surveillance findings and provide a more comprehensive understanding of the impact of public health emergencies on routine immunization services.

Limitations

This study has several limitations that should be considered when interpreting the findings. First, the analysis included data from 28 of the 37 districts in Khyber Pakhtunkhwa because the newly merged districts were excluded due to incomplete administrative reporting during the study period. Consequently, the findings may not be fully generalizable to the entire province. Second, this study relied on secondary aggregated administrative data obtained from the Expanded Programme on Immunization Management Information System (EPI-MIS). The accuracy and completeness of the findings therefore depend on the quality of routine data recorded and reported by health facilities. Administrative datasets may be affected by reporting delays, data entry errors, incomplete reporting, duplicate recording during catch-up vaccination campaigns, and inaccuracies in target population estimates. Third, because the study used aggregated ecological data, individual-level vaccination histories were unavailable. Accordingly, MR-1 coverage was used as a proxy indicator for fully immunized children and should be interpreted as a programmatic approximation of vaccination schedule completion rather than confirmation that individual children received all recommended vaccine doses. Similarly, the BCG-MR-1 dropout indicator was derived from aggregated administrative coverage data and reflects programme-level differences between vaccine coverage estimates rather than true individual-level dropout from the immunization schedule. Fourth, coverage estimates were calculated using projected administrative population denominators, which are subject to uncertainty and may result in coverage values exceeding 100%. Changes in census-based population projections across the study period may also affect the comparability of administrative coverage estimates over time. Fifth, the three study periods were of unequal duration, and the analysis did not adjust for potential seasonal variation in immunization service delivery. Consequently, temporal comparisons should be interpreted cautiously. Sixth, because this was a retrospective descriptive ecological study without a comparison group, the findings describe programme-level trends only and do not permit causal inference regarding the impact of the COVID-19 pandemic or specific programme interventions on routine immunization coverage. Furthermore, ecological analyses are subject to ecological fallacy, whereby associations observed at the population level may not reflect relationships at the individual level. Finally, the analysis was descriptive and did not include inferential statistical methods such as regression modelling, interrupted time-series analysis, or other analytical approaches to evaluate the statistical significance of observed changes. In addition, the study was not designed to assess long-term consequences of pandemic-related disruptions, including subsequent outbreaks of vaccine-preventable diseases or delayed completion of childhood immunization schedules.

Future studies integrating individual-level electronic immunization records, population-based coverage surveys, and longitudinal analytical designs would provide a more comprehensive assessment of routine immunization programme performance and recovery following public health emergencies, denominator inaccuracies, potential duplicate counting during catch-up campaigns, and the exclusion of newly merged

districts. The analysis was descriptive and did not include inferential statistical models such as regression or time-series analysis because the study relied on aggregated administrative coverage data.

Conclusion

This retrospective descriptive ecological study used provincial administrative surveillance data to characterize routine immunization coverage trends across the pre-COVID-19, intra-COVID-19, and post-COVID-19 periods in Khyber Pakhtunkhwa, Pakistan. The administrative data demonstrated variation in immunization programme indicators over time, with higher reported coverage for major vaccine antigens and lower proportions of zero-dose children during the post-COVID-19 period compared with earlier study periods. These findings represent programme-level trends derived from aggregated administrative data and should be interpreted within the context of the limitations of administrative coverage estimates, including denominator uncertainty and the absence of individual-level vaccination records. The findings highlight the importance of maintaining robust routine immunization services during public health emergencies and highlight the value of continuous programme monitoring through surveillance systems such as the Expanded Programme on Immunization Management Information System (EPI-MIS). Strengthening health system resilience requires sustained investment in routine immunization infrastructure, timely surveillance, adaptive service delivery models, and effective strategies to identify and reach zero-dose and under-immunized children during periods of disruption. From a policy perspective, improving the quality and completeness of immunization information systems should remain a priority. Expansion of the National Electronic Immunization Registry (NEIR), improved accuracy of target population estimates, enhanced routine data quality assurance, strengthened monitoring of programme performance, and continued capacity building of EPI personnel in data management, analysis, geographic mapping, and evidence-informed decision-making may improve programme monitoring and support more accurate interpretation of immunization coverage.

Authors' Contributions:

All authors meet the ICMJE criteria for authorship.

Author 1: Substantial contribution to conception and design, data acquisition, drafting the manuscript, final approval, agreed to be accountable for all the work.
Author 2: Substantial contribution to conception and design, supervision, drafting the manuscript, final approval, agreed to be accountable for all the work.

References

1. Mohammad S, Apatu E, Kapiriri L, Alvarez E. A comparative analysis of COVID-19 physical distancing policies in South Africa and Uganda. *PLOS Glob Public Health*. 2024;4(7):e0003170. https://doi.org/10.1371/journal.pgph.0003170
2. Rana S, Shah R, Ahmed S, Mothabbir G. Post-disruption catch-up of child immunisation and health-care services in Bangladesh. *Lancet Infect Dis*. 2021;21(7):913. https://doi.org/10.1016/S1473-3099(21)00148-1
3. Iqbal M, Zahidie A, Jumani Y, Asif S, Shahid B. Responding to the COVID-19 pandemic in a resource-constrained country: the case of Pakistan. *J Ayub Med Coll Abbottabad*. 2021;33(Suppl 1)(4).
4. Jain R, Chopra A, Falézan C, Patel M, Dupas P. COVID-19 related immunization disruptions in Rajasthan, India: a retrospective observational study. *Vaccine*. 2021;39(31):4343-4350. https://doi.org/10.1016/j.vaccine.2021.06.022
5. Toor J, Li X, Jit M, Trotter CL, Echeverria-Londono S, Hartner AM, et al. COVID-19 impact on routine immunisations for vaccine-preventable diseases: projecting the effect of different routes to recovery. *Vaccine*. 2022;40(31):4142-4149. https://doi.org/10.1016/j.vaccine.2022.05.074
6. Middeldorp M, van Lier A, van der Maas N, Veldhuijzen I, Freudenburg W, van Sorge NM, et al. Short-term impact of the COVID-19 pandemic on incidence of vaccine-preventable diseases and participation in routine infant vaccinations in the Netherlands in the period March-September 2020. *Vaccine*. 2021;39(7):1039-1043. https://doi.org/10.1016/j.vaccine.2020.12.080
7. Wang Z, Qu G. Qualitative comparative analysis of policies implemented by 26 European countries during the 2020 great lockdown. *Front Public Health*. 2024;12:1396013. https://doi.org/10.3389/fpubh.2024.1396013
8. Ji C, Piché-Renaud PP, Apajee J, Stephenson E, Forte M, Friedman JN, et al. Impact of the COVID-19 pandemic on routine immunization coverage in children under 2 years old in Ontario, Canada: a retrospective cohort study. *Vaccine*. 2022;40(12):1790-1798. https://doi.org/10.1016/j.vaccine.2022.02.008
9. Alves JG, Figueiroa JN, Urquia ML. Impact of COVID-19 on immunization of Brazilian infants. *Int J Infect Dis*. 2021;107:252-253. https://doi.org/10.1016/j.ijid.2021.04.089
10. Osei I, Sarwar G, Hossain I, Sonko K, Ceesay L, Baldeh B, et al. Attendance and vaccination at immunization clinics in rural Gambia before and during the COVID-19 pandemic. *Vaccine*. 2022;40(44):6367-6373. https://doi.org/10.1016/j.vaccine.2022.09.031
11. Shapiro GK, Gottfredson N, Leask J, Wiley K, Ganter-Restrepo FE, Jones SP, et al. COVID-19 and missed or delayed vaccination in 26 middle- and high-income countries: an observational survey. *Vaccine*. 2022;40(6):945-952. https://doi.org/10.1016/j.vaccine.2021.12.041

12. Chelo D, Nguefack F, Enyama D, Nansseu R, Feudjo Tefoueyet G, Mbassi Awa HD, et al. Impact and projections of the COVID-19 epidemic on attendance and routine vaccinations at a pediatric referral hospital in Cameroon. *Arch Pediatr*. 2021;28(6):441-450. https://doi.org/10.1016/j.arcped.2021.05.006
13. Abbas K, Procter SR, van Zandvoort K, Clark A, Funk S, Mengistu T, et al. Routine childhood immunisation during the COVID-19 pandemic in Africa: a benefit-risk analysis of health benefits versus excess risk of SARS-CoV-2 infection. *Lancet Glob Health*. 2020;8(10). https://doi.org/10.1016/S2214-109X(20)30308-9
14. Sharma M, Singh SK, Sharma L, Dwivedi MK, Agarwal D, Gupta GK, et al. Magnitude and causes of routine immunization disruptions during COVID-19 pandemic in developing countries. *J Family Med Prim Care*. 2021;10(11):3991-3997. https://doi.org/10.4103/jfmpc.jfmpc_1102_21
15. Muthuri RNDK, Senkubuge F, Hongoro C. Determinants of motivation among healthcare workers in the East African Community between 2009-2019: a systematic review. Healthcare (Basel). 2020;8(2):164. https://doi.org/10.3390/healthcare8020164
16. Wazir MA, Goujon A. Assessing the 2017 census of Pakistan using demographic analysis: a sub-national perspective. *VID Working Paper.* 2019;(6):1-44. https://doi.org/10.1553/0x003cb42c
17. Malik AA, Ahmed N, Shafiq M, Elharake JA, James E, Nyhan K, et al. Behavioral interventions for vaccination uptake: a systematic review and meta-analysis. *Health Policy.* 2023;137:104894. https://doi.org/10.1016/j.healthpol.2023.104894
18. Harris RC, Chen Y, Côte P, Ardillon A, Nievera MC, Ong-Lim A, et al. Impact of COVID-19 on routine immunisation in South-East Asia and Western Pacific: disruptions and solutions. *Lancet Reg Health West Pac.* 2021;10:100140. https://doi.org/10.1016/j.lanwpc.2021.100140
19. Qazi U, Malik S, Raza UA, Saad M, Zeeshan MF, Anwar S. Compliance to timely vaccination in an Expanded Program on Immunization center of Pakistan. *Vaccine*. 2019;37(32):4618-4622. https://doi.org/10.1016/j.vaccine.2018.01.044
20. Rahman SU, Haq FU, Imran M, Shah A, Bibi N, Khurshid R, et al. Impact of the COVID-19 lockdown on routine vaccination in Pakistan: a hospital-based study. *Hum Vaccin Immunother*. 2021;17(12):4934-4940. https://doi.org/10.1080/21645515.2021.1979380
21. Sim JY, Chung JH, Oh JY, Yi JE, Lee YH, Choi SW, et al. Global measles outbreaks. *Jugan Geongang Gwa Jilbyeong.* 2024;17(34):1432-1448. https://doi.org/10.56786/PHWR.2024.17.34.2
22. Nawaz A, Saeed A, Rahman S, Haider N. Hematological and biochemical assessment of children infected with measles virus: 2022 outbreak in Pakistan. *Proc Pak Acad Sci B Life Environ Sci*. 2023;60(S):55-63. https://doi.org/10.53560/PPASB(60-sp1)791
23. Crankson S, Pokhrel S, Anokye N. Effectiveness of Ghana's COVID-19 policy responses and lessons learnt for the future: a multi-methods evaluation. medRxiv. 2024:2024.09.16.24313785. https://doi.org/10.1101/2024.09.16.24313785
24. Limaye RJ, Singh P, Fesshaye B, Karron RA. Lessons learned from COVID-19 vaccine acceptance among pregnant and lactating women from two districts in Kenya to inform demand generation efforts for future maternal RSV vaccines. *BMC Pregnancy Childbirth.* 2024;24(1):221. https://doi.org/10.1186/s12884-024-06425-y
25. Ugwu GO, Odii A, Bisi-Onyemaechi A, Ezema GU, Okeke C, Uzochukwu B, et al. Digital technology tool for routine immunization: lessons learned from Open Data Kit intervention and way forward. *Niger J Clin Pract.* 2023;26:65. https://doi.org/10.4103/njcp.njcp_561_22