QANUN MEDIKA Vol 10 | No 2 July 2026
DOI: 10.30651/jqm.v10i02.31842

QANUN MEDIKA
Jurnal Kedokteran
Fakultas Kedokteran FKUM Surabaya
http://journal.um-surabaya.ac.id/index.php/qanunmedika

Research Article

Post-Pandemic Measles Resurgence in Indonesia: Longitudinal Evidence of Immunization Debt Across 34 Provinces, 2018–2024

Dwiva Wulan Guri[1]*, Anggita Rana Sasmita Lestari[1]

1) Biomedical Sciences Program, Faculty of Medicine, Syarif Hidayatullah State Islamic University Jakarta, Jakarta, Indonesia

A R T I C L E I N F O

Submitted : *26 th May 2025*
Accepted : *21 st July 2026*
Published : *25 th July 2026*

Keywords:

measles; measles-rubella vaccination; post-pandemic resurgence; immunisation debt; outbreak

****Correspondence:***

dwivawguri@gmail.com

ABSTRACT

The COVID-19 pandemic disrupted routine immunization services globally, potentially creating immunization debt that may contribute to measles resurgence. This longitudinal ecological study examined measles outbreak frequency and MR1 vaccination coverage across 34–38 Indonesian provinces from 2018 to 2024, divided into pre-pandemic (2018–2019), pandemic (2020–2021), and post-pandemic (2022–2024) phases. Data were extracted from the Indonesian health profile reports (2018–2024), published annually by the Indonesian Ministry of Health. Outbreak frequency differed significantly across phases (Kruskal-Wallis $H = 32.530$, $p < 0.001$): pandemic-era outbreak was suppressed to 6–8 events/year, then rebounded to pre-pandemic levels in 2022–2024 (Mann-Whitney $U = 3563.5$, $p = 0.578$) despite lower MR1 coverage, peaking at 137 events in 2023. To account for within-province temporal correlation, Poisson Generalized Estimating Equations (GEE) with exchangeable correlation structure were fitted alongside negative binomial regression; results were consistent across both approaches. The pandemic phase was associated with an 87.7% reduction in outbreak frequency (GEE $IRR = 0.123$, $p < 0.001$). Exploratory Spearman correlation between MR1 coverage and outbreak frequency was non-significant across all strata (pooled $r_s = +0.089$, $p = 0.165$). Sensitivity analyses excluding Papua provinces yielded consistent results. Post-pandemic outbreak trends are temporally compatible with the immunization debt hypothesis, though alternative explanations, including restoration of surveillance capacity, cannot be excluded. Targeted catch-up vaccination and province-specific strategies for Aceh and Papua are urgently needed.

QANUN MEDIKA
Jurnal Kedokteran
Fakultas Kedokteran FKUM Surabaya
http://journal.um-surabaya.ac.id/index.php/qanunmedika

INTRODUCTION

Measles is a highly contagious viral disease that remains a leading cause of vaccine-preventable childhood morbidity and mortality globally despite the availability of a safe, effective, and inexpensive vaccine (WHO, 2025). The COVID-19 pandemic created unprecedented disruption to routine immunization services worldwide, with global measles vaccination coverage declining for the first time in decades in 2020 (Minta et al., 2023, 2024). The resulting accumulation of unvaccinated children, termed 'immunization debt,' has been identified as a primary driver of post-pandemic measles resurgence across multiple regions (Burgess et al., 2024; Minta et al., 2023, 2024). Globally, an estimated 10.3 million measles cases and 107,500 measles-attributable deaths were recorded in 2023, representing a 20% increase from 2022, with the number of countries experiencing large outbreaks rising from 36 to 57 (Dabbagh et al., 2018; Minta et al., 2024).

Indonesia, the world's fourth most populous country with over 270 million inhabitants spread across more than 17,000 islands, faces unique challenges in achieving and sustaining universal measles vaccination coverage. The national Measles-Rubella (MR) immunization program provides the first dose (MR1) to infants at nine months of age, with a second dose at 18 months (Chacko et al., 2023; Kemenkes, 2020). Despite sustained efforts, national MR1 coverage has remained below the WHO-recommended 95% herd immunity threshold in multiple provinces, creating pockets of immunological vulnerability that facilitate periodic outbreak occurrence (Chacko et al., 2023; WHO, 2023).

The COVID-19 pandemic, which began in Indonesia in March 2020, severely disrupted routine immunization services through a combination of healthcare facility closures, population movement restrictions, healthcare worker redeployment, and community reluctance to attend healthcare facilities(Chacko et al., 2023). Global evidence demonstrated that pandemic-era immunization disruption created substantial susceptibility gaps that, once NPIs were lifted, facilitated measles resurgence across multiple countries (Minta et al., 2023, 2024).

Indonesia experienced this post-pandemic resurgence pattern acutely. WHO issued a Disease Outbreak News notification for Indonesia in 2023 documenting a substantial increase in measles outbreaks following the pandemic period. (WHO, 2023) Yet despite the clear epidemiological signal of resurgence, no longitudinal ecological study has systematically characterized the province-level outbreak trajectory across the full pre-pandemic to post-pandemic arc, assessed the temporal consistency of outbreak patterns with the immunization debt hypothesis, or identified which provinces bear the greatest post-pandemic outbreak risk using Indonesia's complete national surveillance dataset.

This study aimed to address this gap by conducting a multi-year longitudinal ecological analysis of measles outbreak frequency and MR1 vaccination coverage trajectories across Indonesian provinces from 2018 to 2024, with the following specific objectives: (i) to characterized the temporal trajectory of outbreak frequency and MR1 coverage across the pre-pandemic, pandemic, and post-pandemic phases; (ii) to quantify phase-level differences in outbreak frequency and assess their consistency with the immunisation debt hypothesis using Kruskal-Wallis analysis and negative binomial regression; (iii) to identify high-risk provinces defined by chronically low MR1 coverage and concurrent outbreak occurrence; and (iv) to provide evidence-based

QANUN MEDIKA
Jurnal Kedokteran
Fakultas Kedokteran FKUM Surabaya
http://journal.um-surabaya.ac.id/index.php/qanunmedika

policy recommendations for Indonesia's post-pandemic immunisation recovery programme.

METHODS

Study Design

This study employed a multi-year longitudinal ecological study design using province as the unit of analysis. The study period spanned seven calendar years from 2018 to 2024, encompassing three pre-defined epidemiological phases: the pre-pandemic phase (2018–2019), the COVID-19 pandemic phase (2020–2021), and the post-pandemic phase (2022–2024). This study was conducted and reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for ecological studies (Von Elm et al., 2007).

Data Sources and Study Population

All data were derived from the Indonesian Health Profile, an annual official publication of the Ministry of Health of the Republic of Indonesia (*Kementerian Kesehatan RI*), for the years 2018 through 2024 (Kemenkes, 2019, 2020, 2021, 2022, 2023, 2024, 2025). This publication compiles national health statistics from all provincial health offices and represents the most comprehensive official source of immunization and disease surveillance data in Indonesia. The study population comprised all 34 Indonesian provinces for the years 2018 to 2022, and 38 provinces from 2023 to 2024, following the administrative establishment of four new Papua provinces (South Papua, Central Papua, Highland Papua, and Southwest Papua) in 2022. The total analytical dataset comprised 246 province-year observations.

Variables

The primary dependent variable was outbreak frequency (count), defined as the number of measles outbreak events reported to the national center per province per year, extracted from the measles outbreak appendix of each annual publication. This operational definition is consistent with the national regulatory framework for outbreak classification in Indonesia (Kemenkes, 2010). Outbreak frequency was selected as the primary outcome because it represents the only consistently available province-year measure of measles outbreak activity across the full 2018–2024 study period in official Indonesian surveillance publications. It is explicitly acknowledged that outbreak frequency is a measure of surveillance-detected outbreak activity and not equivalent to measles incidence or disease burden; the implications of this distinction are discussed in the limitations section. A computed binary variable, high risk, was derived as equal to 1 when a province recorded concurrent MR1 coverage <80% and outbreak frequency >0 in the same year, and 0 otherwise (Minta et al., 2023; WHO, 2025).

Statistical Analysis

Prior to primary analyses, normality of both study variables was assessed using the Shapiro-Wilk test stratified by year. Descriptive statistics (mean, standard deviation [SD], median, interquartile range [IQR], range) were computed by year and epidemiological phase. The primary analytical approach assessed differences in outbreak frequency across the three epidemiological phases using the Kruskal-Wallis test, followed by post-hoc pairwise Mann-Whitney U tests with Bonferroni correction (adjusted $\alpha = 0.017$). Negative binomial regression was used to model outbreak frequency as count data, given significant overdispersion, as indicated by the alpha parameter. Two models were fitted: Model 1 (unadjusted: outbreak - MR1) and Model 2 (adjusted: outbreak - MR1 + Phase), with pre-pandemic as the reference category. Results are expressed as incidence rate ratios (IRR) with 95% confidence intervals. As an

QANUN MEDIKA
Jurnal Kedokteran
Fakultas Kedokteran FKUM Surabaya
http://journal.um-surabaya.ac.id/index.php/qanunmedika

exploratory secondary analysis, Spearman's rank correlation (rs) was computed between MR1 coverage and outbreak frequency per year, pooled, and stratified by phase, to evaluate the ecological association at the provincial aggregate level. Lag analyses examined MR1 coverage at year t versus outbreak frequency at year t+1 (lag-1) and year t+2 (lag-2), restricted to the 34-province panel. A sensitivity analysis capped MR1 values at 100% to assess the influence of administrative over-reporting on exploratory correlation and regression findings. Coverage values exceeding 100% occurred in 57 of 246 observations (23.2%), predominantly in the post-pandemic phase (2022: 16 provinces; 2023: 9 provinces; 2024: 12 provinces) and were highest in 2024 (maximum: 210.67% in South Sumatra). These values likely reflect numerator-denominator inconsistencies stemming from provincial health offices using different population projections as denominators, potentially exacerbated by post-pandemic administrative changes. Values exceeding 100% are implausible as true vaccination rates and are retained as reported to preserve the original data structure, consistent with the WHO methodology for administrative coverage data.(Burton, 2009) Correlation strength was interpreted per Schober et al. (2018):(13) $|rs| < 0.20$ = negligible, 0.20–0.39 = weak, 0.40–0.59 = moderate, ≥0.60 = strong. To address the repeated-measures structure of the data and within-province temporal correlation, Poisson Generalized Estimating Equations (GEE) with exchangeable working correlation structure were fitted as a supplementary analysis alongside the negative binomial regression, using robust sandwich standard errors. Model fit was assessed using the Quasi-likelihood Information Criterion (QIC). A sensitivity analysis excluding all six Papua provinces was performed to assess the influence of the 2022 administrative restructuring on the primary findings. Kruskal-Wallis, Mann-Whitney U, Shapiro-Wilk, and descriptive analyses were performed in SPSS Version 26 (IBM Corp., Armonk, NY, USA). Negative binomial regression, GEE, and lag analyses were performed in Python 3.11 (statsmodels 0.14, scipy.stats 1.11.0).

Ethical Considerations

This study used exclusively secondary, publicly available, aggregate-level data derived from official government publications. No individual-level patient data were accessed. No personal identifiers were used at any stage of the analysis. In accordance with applicable Indonesian and international guidelines for secondary data analyses of publicly available aggregate data, formal approval from an ethics review committee was not required for this study (Jaya Prasad TRIPATHY, 2013).

RESULTS

Preliminary Assessment: Tests of Normality

Prior to primary analyses, the distributional properties of both study variables were assessed using the Shapiro-Wilk test stratified by year. MR1 vaccination coverage violated the normality assumption in six of seven study years ($p < 0.05$), with only 2020 meeting normality criteria ($W = 0.953$, $p = 0.148$). Outbreak frequency demonstrated significant non-normality in all seven study years ($p < 0.001$ for all years), consistent with its nature as a non-negative, right-skewed count variable. Based on these findings, non-parametric methods were confirmed as appropriate for all subsequent analyses, including the exploratory Spearman rank correlation.

QANUN MEDIKA
Jurnal Kedokteran
Fakultas Kedokteran FKUM Surabaya
http://journal.um-surabaya.ac.id/index.php/qanunmedika

Temporal Trends in MR1 Coverage and Outbreak Frequency

Table 1 presents descriptive statistics for MR1 coverage and outbreak frequency by year and phase. National mean MR1 coverage peaked in 2019 (90.03% ± 12.08), declined during the pandemic (2020: 81.35% ± 12.94; 2021: 83.54% ± 13.12), rebounded in 2022 (98.06% ± 13.14), declined sharply in 2023 (88.31% ± 18.42), then partially recovered in 2024 (94.36% ± 43.45). The high standard deviation in 2024 reflects extreme inter-provincial heterogeneity (range: 3.35%–210.67%). Outbreak frequency followed a markedly different trajectory, declining from 85 events in 2018 to a nadir of 6 events in 2020, before rebounding to 137 events in 2023, the highest recorded during the study period.

Table 1. Descriptive Statistics of MR1 Coverage (%) and outbreak Frequency by Year and Phase, Indonesia 2018–2024

			MR1 Coverage (%)				KLB Frequency	
Year	**Phase**	**n**	**Mean (SD)**	**Median (IQR)**	**Min**	**Max**	**Total**	**Mean (SD)**
2018	Pre-pandemic	34	86.62 (14.44)	90.60 (26.95)	57.1	108.4	85	2.50 (3.25)
2019	Pre-pandemic	34	90.03 (12.08)	90.95 (17.75)	50.2	104.8	32	0.94 (1.69)
2020	Pandemic	34	81.35 (12.94)	82.30 (17.58)	43.3	100.6	6	0.18 (0.39)
2021	Pandemic	34	83.54 (13.12)	87.10 (17.20)	43.8	103.2	8	0.24 (0.61)
2022	Post-pandemic	34	98.06 (13.14)	99.60 (14.00)	52.9	121.4	79	2.32 (4.85)
2023	Post-pandemic	38	88.31 (18.42)	88.90 (16.35)	25.9	118.4	137	3.61 (6.84)
2024	Post-pandemic	38	94.36 (43.45)	89.25 (32.19)	3.35	210.67	65	1.71 (2.70)

SD=Standard Deviation; IQR=Interquartile Range. MR1 >100% reflects administrative over-reporting; retained as reported (Burton et al., 2009) Source: Indonesian Health Profile 2018–2024 (Kemenkes RI, 2019-2025)

QANUN MEDIKA
Jurnal Kedokteran
Fakultas Kedokteran FKUM Surabaya
http://journal.um-surabaya.ac.id/index.php/qanunmedika

Figure 1. Temporal Trends in MR1 Vaccination Coverage (A) and Measles Outbreak Frequency (B) Across Indonesian Provinces, 2018–2024

Panel A: mean provincial MR1 coverage (%) by year. Red dashed line = WHO 95% herd immunity threshold; orange dotted line = 80% minimum threshold. Panel B: total national outbreak frequency by year. Background shading: pre-pandemic (2018–2019, blue), pandemic (2020–2021, red), post-pandemic (2022–2024, green). MR1 = Measles-Rubella first dose; Outbreak = Kejadian Luar Biasa (Outbreak Event). Source: Indonesia Health Profile 2018–2024, Ministry of Health of the Republic of Indonesia.

Phase-Level Differences in Outbreak Frequency: Temporal Patterns Consistent with Immunisation Debt

The Kruskal-Wallis test revealed significant differences in outbreak frequency across the three phases ($H = 32.530$, $df = 2$, $p < 0.001$), with mean ranks of 134.71, 85.74, and 139.92 for pre-pandemic, pandemic, and post-pandemic phases, respectively (Table 3). Post hoc pairwise comparisons demonstrated that outbreak frequency was significantly lower during the pandemic than the pre-pandemic phase ($U = 3250.5$, $p < 0.001$), consistent with NPI-mediated suppression of measles transmission. Critically, outbreak frequency during the post-pandemic phase was statistically indistinguishable from the pre-pandemic baseline ($U = 3563.5$, $p = 0.578$), indicating statistical equivalence to pre-pandemic outbreak levels despite lower prevailing MR1 coverage. Outbreak frequency was significantly higher during the post-pandemic phase than during the pandemic phase ($U = 2110.5$, $p < 0.001$), consistent with post-pandemic measles resurgence.

QANUN MEDIKA
Jurnal Kedokteran
Fakultas Kedokteran FKUM Surabaya
http://journal.um-surabaya.ac.id/index.php/qanunmedika

Table 3. Kruskal-Wallis Test and Post-Hoc Mann-Whitney U Analysis of Outbreak Frequency Across Phases

Comparison	n_1	n_2	Mann-Whitney U	Mean Rank (1 vs 2)	p-value	Interpretation
Pre-pandemic vs Pandemic	68	68	3250.5	134.71 vs 85.74	**<0.001**	Significant -NPI suppression
Pre-pandemic vs Post-pandemic	68	110	3563.5	134.71 vs 139.92	0.578	Not significant - complete rebound
Pandemic vs Post-pandemic	68	110	2110.5	85.74 vs 139.92	**<0.001**	Significant - post-pandemic surge

Bonferroni-corrected α = 0.017. Phases: 1=Pre-pandemic (2018–2019), 2=Pandemic (2020–2021), 3=Post-pandemic (2022–2024). Green=significant; Grey=not significant. H=32.530, df=2, p<0.001.

Negative Binomial Regression: Predictors of Outbreak Frequency

Negative binomial regression was performed to model outbreak frequency as count data, given significant overdispersion confirmed by the alpha parameter in all models (Table 4). In Model 1 (unadjusted), MR1 coverage was not a significant predictor of outbreak frequency (IRR = 1.008, 95% CI: 0.995–1.021, p = 0.227). In Model 2 (adjusted for epidemiological phase), MR1 coverage remained non-significant (IRR = 1.000, 95% CI: 0.988–1.013, p = 0.961), while the pandemic phase was associated with an 88.0% reduction in outbreak frequency relative to the pre-pandemic baseline (IRR = 0.120, 95% CI: 0.056–0.256, p < 0.001). The post-pandemic phase did not differ significantly from the pre-pandemic baseline (IRR = 1.480, 95% CI: 0.877–2.500, p = 0.142), consistent with the Kruskal-Wallis post-hoc findings. Model 2 demonstrated substantially better fit than Model 1 (AIC: 760.94 vs 801.71), suggesting that the epidemiological phase is the dominant ecological predictor of outbreak frequency in this dataset. The low pseudo-R^2 (0.058) indicates that a large proportion of variance remains unexplained, consistent with the ecological study design and the absence of adjustment for important provincial-level confounders, including population density, health-system capacity, socioeconomic status, and surveillance quality. These models are therefore interpreted as descriptive rather than explanatory, and the phase effect should not be construed as a causal estimate in the absence of adjustment for confounders.

Generalized Estimating Equations (GEE) Analysis

To address the longitudinal structure of the data and within-province temporal correlation, Poisson GEE with an exchangeable correlation structure was fitted as a supplementary analysis. The working correlation coefficient was 0.078, indicating modest within-province correlation across years. Results were consistent with the negative binomial regression: in the unadjusted model, MR1 coverage was not a significant predictor of outbreak frequency (GEE IRR = 1.014, 95% CI: 0.994–1.035, p = 0.174). In the adjusted model, MR1 coverage remained non-significant (GEE IRR = 1.006, 95% CI: 0.991–1.022, p = 0.424), while the pandemic phase remained strongly associated with reduced outbreak frequency (GEE IRR = 0.123, 95%

QANUN MEDIKA
Jurnal Kedokteran
Fakultas Kedokteran FKUM Surabaya
http://journal.um-surabaya.ac.id/index.php/qanunmedika

Table 4. Negative Binomial Regression: Association Between MR1 Vaccination Coverage and Outbreak Frequency, Indonesia 2018–2024 (n = 246)

Variable	Model 1 Unadjusted IRR (95% CI)	p	Model 2 Adjusted IRR (95% CI)	p	Interpretation
MR1 Coverage (%)	1.008 (0.995–1.021)	0.227	1.000 (0.988–1.013)	0.961	Not significant in both models
Pandemic vs Pre-pandemic	—	—	0.120 (0.056–0.256)	**<0.001**	88.0% lower KLB during pandemic *
Post-pandemic vs Pre-pandemic	—	—	1.480 (0.877–2.500)	0.142	Not significantly different from baseline
Dispersion (alpha)	26.677	**<0.001**	10.536	**<0.001**	Significant overdispersion confirmed
AIC	801.71	—	760.94	—	Model 2 better fit
Pseudo-R^2 (McFadden)	0.002	—	0.058	—	Phase explains most variance

*IRR = Incidence Rate Ratio; 95% CI = 95% Confidence Interval. Reference category: Pre-pandemic phase (2018–2019). Model 1: unadjusted (OUTBREAK ~ MR1 only). Model 2: adjusted (outbreak ~ MR1 + Phase). * Pandemic phase (2020–2021) associated with 88.0% reduction in outbreak frequency relative to pre-pandemic phase. Green rows = statistically significant (p < 0.05).*

CI: 0.060–0.249, $p < 0.001$), corresponding to an 87.7% reduction. The post-pandemic phase did not differ significantly from the pre-pandemic baseline (GEE IRR = 1.485, 95% CI: 0.827–2.669, $p = 0.186$). QIC values confirmed superior fit of the adjusted over the unadjusted model (QIC: 1021.31 vs 1147.21). The consistency of GEE and negative binomial regression findings supports the robustness of the primary results.

Sensitivity Analysis: Exclusion of Papua Provinces

To assess the potential influence of the administrative restructuring of Papua provinces on the results, a sensitivity analysis was conducted excluding all six Papua provinces (Papua, West Papua, South Papua, Central Papua, Highland Papua, and Southwest Papua), reducing the dataset to 224 province-year observations across 32 provinces. Results were fully consistent with the primary analysis:

QANUN MEDIKA
Jurnal Kedokteran
Fakultas Kedokteran FKUM Surabaya
http://journal.um-surabaya.ac.id/index.php/qanunmedika

MR1 coverage remained non-significant (NBR IRR = 0.998, p = 0.833; GEE IRR = 0.999, p = 0.901), and the pandemic phase effect remained large and significant (NBR IRR = 0.104, p < 0.001; GEE IRR = 0.104, p < 0.001). Post-pandemic phase findings were directionally consistent (NBR IRR = 1.530, p = 0.135; GEE IRR = 1.514, p = 0.180). These results indicate that the structural discontinuity introduced by the creation of new Papua provinces in 2022 did not materially influence the primary findings.

Exploratory Analysis: Ecological Correlation Between MR1 Coverage and Outbreak Frequency

As an exploratory secondary analysis, Spearman's rank correlation was computed between provincial MR1 coverage and outbreak frequency across all analytical strata (Table 2). No statistically significant association was detected in any individual year or analytical stratum (all p > 0.05). Correlations were negative in 2018 (rs = −0.093, p = 0.599) and 2019 (rs = −0.121, p = 0.495), and positive from 2020 onwards (range: +0.031 to +0.203). All correlations were negligible in magnitude (|rs| < 0.20) (Schober et al., 2018). The pooled analysis (n = 246) returned a non-significant, negligible correlation (rs = +0.089, p = 0.165). Phase-stratified analyses were consistent: rs = −0.142 (p = 0.246) pre-pandemic, +0.056 (p = 0.653) pandemic, and +0.068 (p = 0.483) post-pandemic. The scatter plot of the relationship between MR1 coverage and outbreak frequency is shown in Figure 2. These findings are interpreted in the context of ecological study design limitations discussed in Section 4.2.

Lag analyses did not detect a statistically significant linear lagged association between MR1 coverage and outbreak frequency at the provincial aggregate level: pooled lag-1 (MR1 at year t vs outbreak at year t+1): rs = +0.062, p = 0.419 (n = 170); pooled lag-2 (MR1 at year t vs outbreak at year t+2): rs = −0.111, p = 0.197 (n = 136). The absence of significant lagged associations is consistent with the non-linear and multi-year nature of susceptibility accumulation at the population level, which may not be adequately captured by bivariate lag correlation at the provincial aggregate level.

Sensitivity analysis with MR1 values capped at 100% (affecting 57 of 246 observations, 23.2%) yielded results fully consistent with the primary analysis (pooled rs = +0.079, p = 0.215), confirming robustness against administrative over-reporting.

High-Risk Province Identification

A total of 31 province-year observations met the high-risk criteria (MR1 <80% AND Outbreak >0). These were distributed across 13 unique provinces and concentrated in the post-pandemic phase. Aceh (3 observations: 2018, 2020, 2022), Papua (3 observations: 2020, 2021, 2022), and West Sumatra (3 observations: 2022, 2023, 2024) recorded the highest frequency of high-risk classifications. In 2023, all four newly established Papua provinces were simultaneously classified as high-risk, reflecting acute vulnerability of newly autonomous regions. Aceh province recorded MR1 coverage below 80% across all seven study years (range: 42.05%–60.0%), making it the most chronically low-coverage province. Longitudinal trajectories of MR1 coverage and outbreak frequency for selected high-risk provinces are illustrated in Figure 3.

QANUN MEDIKA
Jurnal Kedokteran
Fakultas Kedokteran FKUM Surabaya
http://journal.um-surabaya.ac.id/index.php/qanunmedika

Table 5. Exploratory Spearman Rank Correlation Between MR1 Vaccination Coverage and Outbreak Frequency, Indonesia 2018–2024

Year / Period	Phase	n	Spearman rs	p-value	Sig.?	Interpretation
2018	Pre-pandemic	34	−0.093	0.599	No	Negligible; no sig. association
2019	Pre-pandemic	34	−0.121	0.495	No	Negligible; no sig. association
2020	Pandemic	34	+0.031	0.860	No	Negligible; no sig. association
2021	Pandemic	34	+0.065	0.715	No	Negligible; no sig. association
2022	Post-pandemic	34	+0.085	0.632	No	Negligible; no sig. association
2023	Post-pandemic	38	+0.037	0.827	No	Negligible; no sig. association
2024	Post-pandemic	38	+0.203	0.221	No	Negligible; no sig. association
POOLED AND PHASE-LEVEL ANALYSIS						
Pooled 2018–2024	All phases	246	+0.089	0.165	No	Negligible; no sig. association
Pre-pandemic 2018–2019	Pre-pandemic	68	−0.142	0.246	No	Negligible; no sig. association
Pandemic 2020–2021	Pandemic	68	+0.056	0.653	No	Negligible; no sig. association
Post-pandemic 2022–2024	Post-pandemic	110	+0.068	0.483	No	Negligible; no sig. association

rs = Spearman rank correlation coefficient (two-tailed). Significance: $p < 0.05$. Strength criteria: Schober et al. (2018) (Schober et al., 2018) |rs| <0.20=Negligible.

QANUN MEDIKA
Jurnal Kedokteran
Fakultas Kedokteran FKUM Surabaya
http://journal.um-surabaya.ac.id/index.php/qanunmedika

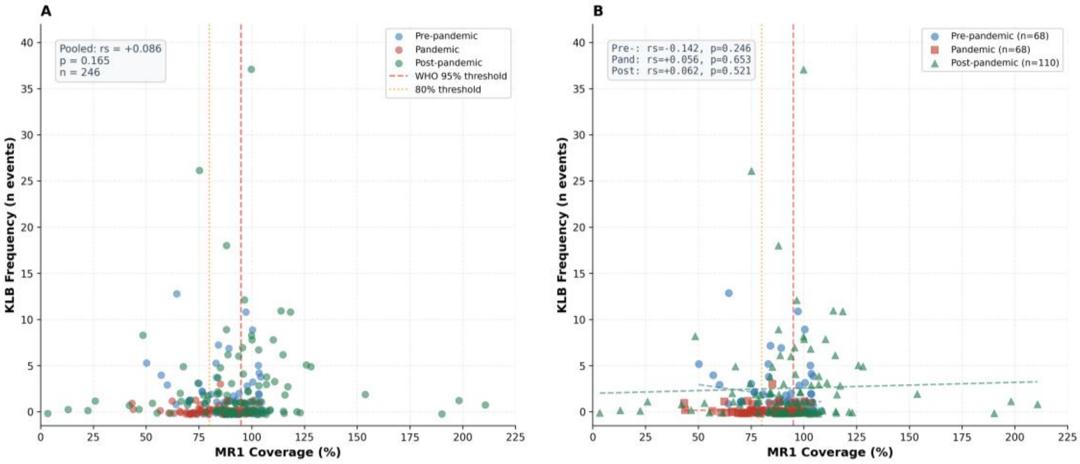

Figure 2. Scatter Plot of MR1 Vaccination Coverage vs Measles Outbreak Frequency Across Indonesian Provinces: Pooled (A) and Stratified by Epidemiological Phase (B), 2018–2024

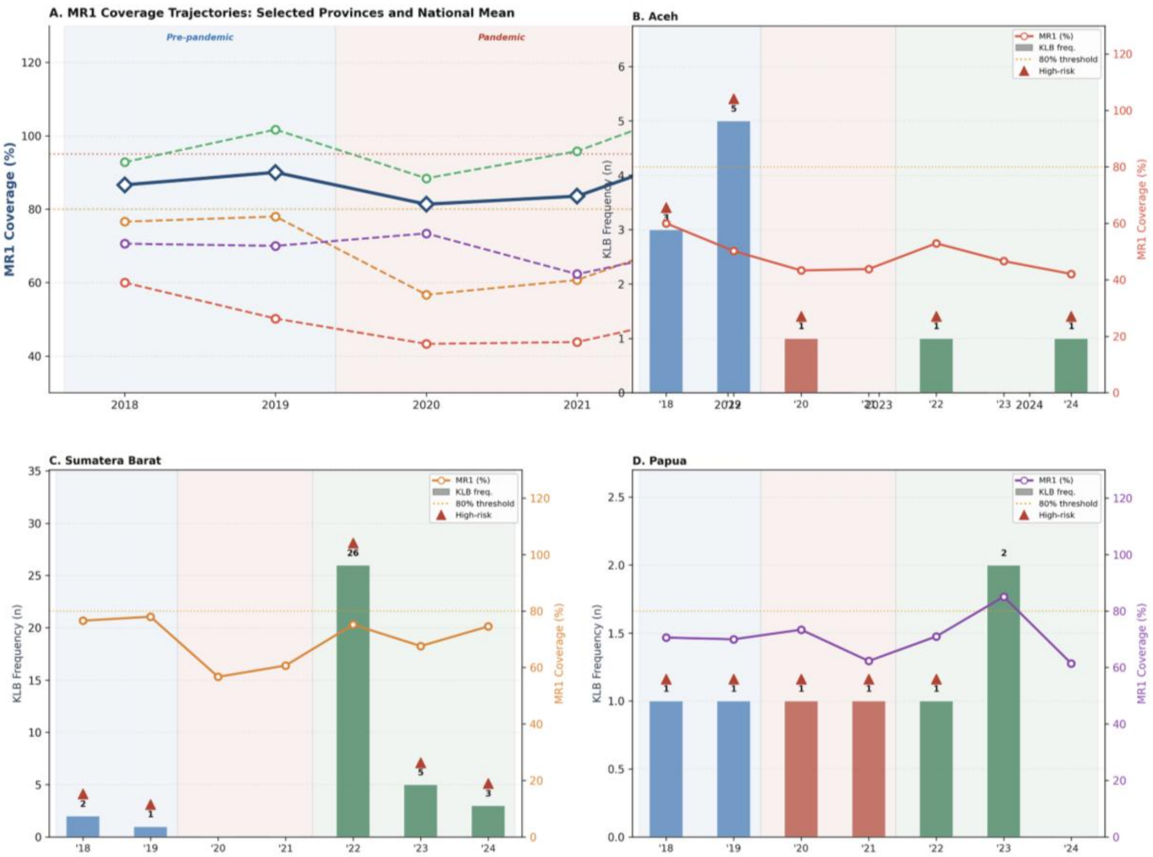

Figure 3. Longitudinal Trajectories of MR1 Vaccination Coverage and Measles Outbreak Frequency in Selected Indonesian Provinces, 2018–2024

QANUN MEDIKA
Jurnal Kedokteran
Fakultas Kedokteran FKUM Surabaya
http://journal.um-surabaya.ac.id/index.php/qanunmedika

Panel A: MR1 coverage trajectories for selected provinces and the national mean, 2018–2024. Dashed lines = individual provinces; solid line = national mean. Panels B–D: dual-axis plots of MR1 coverage (line, right axis) and outbreak frequency (bars, left axis) for Aceh, Sumatera Barat, and Papua, respectively. Bar colours: blue = pre-pandemic (2018–2019), red = pandemic (2020–2021), green = post-pandemic (2022–2024). Triangle markers (▲) indicate high-risk observations (MR1 <80% with outbreak >0). Orange dotted line = 80% minimum coverage threshold. Source: Indonesia Health Profile 2018–2024, Ministry of Health of the Republic of Indonesia.

DISCUSSION

This study provides longitudinal ecological data consistent with post-pandemic measles resurgence and the immunization debt hypothesis in Indonesia. Five principal findings are summarized. First, outbreak frequency was dramatically suppressed during the COVID-19 pandemic (6–8 events/year) but rebounded to statistically equivalent pre-pandemic levels in 2022–2024, peaking at 137 events in 2023 despite lower prevailing MR1 coverage, a temporal pattern compatible with the hypothesized effects of immunization debt. Second, negative binomial regression indicated that epidemiological phase, not concurrent MR1 coverage, was the dominant predictor of outbreak frequency (pandemic IRR = 0.120, $p < 0.001$). Third, MR1 coverage declined substantially during the pandemic and remained below the WHO 95% threshold in most provinces throughout the study period. Fourth, exploratory Spearman correlation between MR1 coverage and outbreak frequency was non-significant across all analytical strata, consistent with ecological design limitations and the expected non-linear temporal lag between coverage gaps and outbreak occurrence. Fifth, 31 high-risk province-year observations were concentrated in chronically low-coverage provinces, particularly Aceh and Papua.

The non-significant ecological correlation between MR1 coverage and outbreak frequency is best understood as a design characteristic rather than a substantive finding. In ecological studies of this type, four mechanisms systematically attenuate the detectable association between aggregate coverage and outbreak events. First, the relationship between vaccination gaps and outbreak occurrence operates through the gradual accumulation of susceptible individuals over multiple years, a non-linear process that bivariate provincial-level correlation cannot adequately capture (Von Elm et al., 2007). Lag analyses at one- and two-year intervals were similarly non-significant, consistent with susceptibility accumulation dynamics that extend beyond two-year windows. Second, provincial aggregate MR1 data conceal substantial within-province heterogeneity: outbreak events originate in specific sub-districts and villages, not at the provincial average, a manifestation of ecological fallacy (Von Elm et al., 2007). Third, surveillance sensitivity co-varies with health system capacity: provinces with stronger systems may both achieve higher coverage and more effectively detect and report outbreak events. Fourth, small per-stratum sample sizes (n = 34–38) limit statistical power. These design characteristics do not diminish the central finding of this paper: that Indonesia's post-pandemic outbreak trajectory is consistent with national-level immunization debt.

The central observation of this study is the post-pandemic rebound of outbreak frequency to statistically equivalent pre-pandemic levels despite lower prevailing MR1 coverage. This temporal pattern is compatible with the immunization debt hypothesis, the accumulation of susceptible individuals during a period of vaccination disruption, followed by outbreak resurgence once transmission-suppressing NPIs are lifted (Minta et al., 2023, 2024; Torjesen, 2021). However, it is important to

QANUN MEDIKA
Jurnal Kedokteran
Fakultas Kedokteran FKUM Surabaya
http://journal.um-surabaya.ac.id/index.php/qanunmedika

acknowledge that this ecological study cannot exclude alternative explanations. The observed pandemic-era suppression and subsequent rebound may partly reflect a surveillance artifact: the COVID-19 pandemic severely disrupted health service utilization, potentially reducing outbreak detection and reporting during 2020–2021 rather than reflecting true transmission suppression (Chacko et al., 2023). Similarly, the post-pandemic increase in outbreak frequency may partly reflect the restoration of surveillance capacity, increased healthcare utilization, and resumed outbreak investigation activities, rather than purely reflecting an increase in true disease incidence. Stochastic outbreak clustering, changes in outbreak declaration practices, and catch-up campaign dynamics may further contribute to the observed temporal patterns. These alternative explanations are plausible and cannot be excluded without individual-level susceptibility data, cohort-specific vaccination records, or serological survey data. The findings of this study should therefore be interpreted as generating hypotheses about immunization debt dynamics in Indonesia rather than confirming them.

Aceh province's persistently low MR1 coverage (42.05%–60.0%) across all seven study years reflects the well-documented intersection of religious vaccine hesitancy, halal-certification concerns, and structural access barriers in this region (Murphy et al., 2025). Murphy et al. (2025) demonstrated that religious concerns and safety perceptions were primary drivers of vaccine refusal in Aceh (Murphy et al., 2025). Consistent with this, Hermawan et al. (2025) identified rural residence, low maternal education, and lack of health insurance as key sociodemographic predictors of sub-optimal measles vaccination coverage among Indonesian children (Hermawan et al., 2025). The simultaneous classification of all four new Papua provinces as high-risk in 2023, with coverage as low as 3.35% in Highland Papua, reflects the institutional fragility of newly established administrative units and the extreme geographic barriers to cold chain maintenance in Highland Papua (Kemenkes, 2019, 2020, 2021, 2022, 2023, 2024, 2025).

This is the first longitudinal ecological study to characterize post-pandemic measles outbreak trajectories consistent with immunization debt at a national scale in Indonesia, covering 34–38 provinces over seven years across three distinct epidemiological phases. A recent cross-sectional ecological study by Purnomo et al. (2025) identified significant correlations between school-based immunization coverage and measles incidence at the provincial level but did not account for temporal dynamics or the pandemic's impact on the immunization–outbreak relationship (Lindra Anggorowati et al., 2025). The present study extends this work by demonstrating that the relationship between vaccination coverage and outbreak frequency is temporally mediated and cannot be adequately characterized by cross-sectional analysis alone. Global evidence from Minta et al. (2024) confirmed that countries with pre-existing coverage gaps experienced disproportionate post-pandemic measles resurgence (Dabbagh et al., 2018; Minta et al., 2024). Indonesia's trajectory mirrors this pattern with particular severity: unlike many countries that experienced transient post-pandemic surges, Indonesia's outbreak peak in 2023 (137 events) substantially exceeded its pre-pandemic baseline (85 events in 2018), suggesting that immunization debt is compounding pre-existing structural vulnerabilities in the immunization program. Comparable post-pandemic trajectories have been documented in European settings: Ristić et al. (2025) reported that MCV I coverage in Vojvodina, Serbia, declined to 72.1% in

QANUN MEDIKA
Jurnal Kedokteran
Fakultas Kedokteran FKUM Surabaya
http://journal.um-surabaya.ac.id/index.php/qanunmedika

2021 with subsequent measles resurgence in 2024 (Ristić et al., 2025), mirroring Indonesia's pattern and reinforcing the global generalisability of immunization debt dynamics. The longitudinal trajectory plots (Figure 3) provide province-specific visual evidence: Aceh maintained persistently low MR1 coverage across all seven years with concurrent outbreak events in five of seven years; Sumatera Barat experienced a dramatic outbreak spike (26 events) in 2022, coinciding with its lowest post-pandemic coverage; and Papua exhibited a persistent high-risk classification throughout the study period.

Fifth, and most critically, outbreak frequency is a measure of surveillance-detected outbreak activity and not equivalent to measles incidence or disease burden. outbreak declaration is influenced by surveillance capacity, healthcare access, healthcare worker training, and local reporting practices, all of which vary substantially across Indonesian provinces and may have changed systematically during and after the COVID-19 pandemic. Specifically, the dramatic reduction in outbreak frequency during 2020–2021 may partly or substantially reflect reduced surveillance and reporting capacity rather than genuine transmission suppression, and the post-pandemic increase may partly reflect restored surveillance rather than solely reflecting true resurgence. A related and equally important limitation is the absence of population denominators. Provincial outbreak counts were modeled without adjusting for population size; consequently, a single outbreak event in Highland Papua (population ~400,000) and in West Java (population ~48 million) is treated as equivalent observations. The preferred analytical approach would model measles incidence rates or use province population as an offset term in the regression model; however, consistent annual population denominators by province were not available for the full study period in the data sources used. This limits the comparability of outbreak rates across provinces and may bias regression coefficients. Future studies should incorporate population-based denominators to enable incidence rate analysis.

The findings of this study carry several specific policy implications for Indonesia's national immunization program. First, catch-up vaccination campaigns targeting children aged 2–6 years at the time of writing, the birth cohorts of 2020–2022 who missed scheduled MR doses during the pandemic, must be prioritized, adequately resourced, and sustained beyond single campaign cycles. The statistical equivalence of post-pandemic and pre-pandemic outbreak frequencies ($p = 0.578$), despite lower coverage, is consistent with the hypothesis that accumulated immunization debt contributed to measurable outbreak risk.

Second, province-specific strategies are essential given the extreme geographic heterogeneity documented in this study. In Aceh, where MR1 coverage has remained below 80% across all seven study years, community engagement through religious and community leaders has demonstrated effectiveness and should be scaled up (Murphy et al., 2025). In Papua and its four newly established provinces, where coverage reached as low as 3.35% in 2024, priority must be given to cold chain infrastructure strengthening, community health worker capacity building, and outreach programs for geographically isolated communities (Kemenkes, 2019, 2020, 2021, 2022, 2023, 2024, 2025).

Third, the non-significant ecological correlations between MR1 coverage and outbreak frequency should not be interpreted as evidence that vaccination coverage is unrelated to outbreak risk at the individual or sub-district level. Rather, these findings should motivate

QANUN MEDIKA
Jurnal Kedokteran
Fakultas Kedokteran FKUM Surabaya
http://journal.um-surabaya.ac.id/index.php/qanunmedika

investment in district-level ecological analyses and individual-level studies with greater statistical power to inform more precise, targeted interventions. The phase-level finding that epidemiological context, rather than concurrent coverage, drives aggregate outbreak frequency underscores the importance of addressing the structural determinants of immunization gaps alongside coverage improvement campaigns.

CONCLUSIONS

This longitudinal ecological study presents national-scale ecological data consistent with post-pandemic measles resurgence and the immunization debt hypothesis. The rebound in outbreak frequency to statistically equivalent pre-pandemic levels, despite lower prevailing MR1 coverage and after near-complete suppression during the COVID-19 pandemic, suggests that accumulated vaccination gaps contribute to measurable outbreak risk. Negative binomial regression indicated that epidemiological phase, rather than concurrent MR1 coverage, was the dominant ecological predictor of outbreak frequency, with the pandemic phase associated with an 88.0% reduction relative to the pre-pandemic baseline (IRR = 0.120, $p < 0.001$). The 2023 peak of 137 outbreak events, the highest recorded in the study period, underscores the urgency of the post-pandemic immunization recovery challenge. Thirty-one high-risk province-year observations concentrated in Aceh and Papua highlight persistent geographic vulnerabilities that require province-specific interventions. Sustained catch-up vaccination campaigns targeting pandemic-era birth cohorts, community engagement strategies for vaccine-hesitant regions, and urgent institutional strengthening for the newly established Papua provinces are essential to reverse Indonesia's post-pandemic measles trajectory and progress toward national measles elimination.

AUTHOR CONTRIBUTIONS

Conceptualization, D.W.G.; methodology, D.W.G. and A.R.; software, D.W.G.; validation, A.R.; formal analysis, D.W.G.; investigation, D.W.G.; data curation, D.W.G.; writing original draft preparation, D.W.G.; writing - review and editing, D.W.G. and A.R.; supervision, A.R. All authors have read and agreed to the published version of the manuscript.

DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are derived from the Indonesian Health Profile 2018–2024, an annual official publication of the Ministry of Health of the Republic of Indonesia (Kementerian Kesehatan Republik Indonesia), which is publicly available at https://www.kemkes.go.id. The compiled dataset used for analysis is available from the corresponding author upon reasonable request.

REFERENCES

Burgess, C., Lisul, B., Pawaskar, M., Petigara, T., Murtagh, J., Kanazir, M., Loncarevic, G., & Carias, C. (2024). Impact of the COVID-19 pandemic on measles vaccination coverage and estimated catch-up efforts for Serbia. Pediatric Infectious Disease Journal, 43(10), 1011–1017. https://doi.org/10.1097/INF.0000000000004487

Burton, A., Monasch, R., Lautenbach, B., Gacic-Dobo, M., Neill, M., Karimov, R., Wolfson, L., Jones, G., & Birmingham, M. (2009). WHO and UNICEF estimates of national infant immunization coverage: Methods and processes. Bulletin of the World Health Organization, 87(7), 535–541. https://doi.org/10.2471/BLT.08.053819

QANUN MEDIKA
Jurnal Kedokteran
Fakultas Kedokteran FKUM Surabaya
http://journal.um-surabaya.ac.id/index.php/qanunmedika

Chacko, S., Kamal, M., Hastuti, E. B., Mildya, F., Kelyombar, C., Voronika, V., Yosephine, P., Tandy, G., Anisiska, D., Karolina, S., Dewi, L. A., Khanal, S., Bahl, S., Wijayanti, F., Merrill, R. D., Hsu, C. H., & Morales, M. (2023). Progress toward measles and rubella elimination — Indonesia, 2013–2022. Morbidity and Mortality Weekly Report, 72(42), 1134–1139. https://doi.org/10.15585/mmwr.mm7242a2

Dabbagh, A., Laws, R. L., Steulet, C., Dumolard, L., Mulders, M. N., Kretsinger, K., Alexander, J. P., Rota, P. A., & Goodson, J. L. (2018). Progress toward regional measles elimination — Worldwide, 2000–2017. Morbidity and Mortality Weekly Report, 67(47), 1323–1329. https://doi.org/10.15585/mmwr.mm6747a6

Hermawan, A., Irawan, I. R., Widiyanti, M., Rosnani, R., & Arifin, H. (2025). Association of socio-demographic factors with measles vaccination coverage among Indonesian children aged 12–23 months. Turkish Journal of Pediatrics, 67(3), 304–316. https://doi.org/10.24953/turkjpediatr.5886

Kementerian Kesehatan Republik Indonesia. (2010). Peraturan Menteri Kesehatan No. 1501/Menkes/Per/X/2010 tentang jenis penyakit menular tertentu yang dapat menimbulkan wabah dan upaya penanggulangan. Kemenkes RI.

Kementerian Kesehatan Republik Indonesia. (2019). Profil Kesehatan Indonesia 2018. Kemenkes RI. https://www.kemkes.go.id

Kementerian Kesehatan Republik Indonesia. (2020). Profil Kesehatan Indonesia 2019. Kemenkes RI. https://www.kemkes.go.id

Kementerian Kesehatan Republik Indonesia. (2021). Profil Kesehatan Indonesia 2020. Kemenkes RI. https://www.kemkes.go.id

Kementerian Kesehatan Republik Indonesia. (2022). Profil Kesehatan Indonesia 2021. Kemenkes RI. https://www.kemkes.go.id

Kementerian Kesehatan Republik Indonesia. (2023). Profil Kesehatan Indonesia 2022. Kemenkes RI. https://www.kemkes.go.id

Kementerian Kesehatan Republik Indonesia. (2024). Profil Kesehatan Indonesia 2023. Kemenkes RI. https://www.kemkes.go.id

Kementerian Kesehatan Republik Indonesia. (2025). Profil Kesehatan Indonesia 2024. Kemenkes RI. https://www.kemkes.go.id

Minta, A. A., Ferrari, M., Antoni, S., Portnoy, A., Sbarra, A., Lambert, B., Hatcher, C., Hsu, C. H., Ho, L. L., Steulet, C., Gacic-Dobo, M., Rota, P. A., Mulders, M. N., Bose, A. S., Perea Caro, W., O'Connor, P., & Crowcroft, N. S. (2023). Progress toward measles elimination — Worldwide, 2000–2022. Morbidity and Mortality Weekly Report, 72(46), 1262–1268. https://doi.org/10.15585/mmwr.mm7246a3

Minta, A. A., Ferrari, M., Antoni, S., Lambert, B., Sayi, T. S., Hsu, C. H., Steulet, C., Gacic-Dobo, M., Rota, P. A., Mulders, M. N., Wimmer, A., Bose, A. S., O'Connor, P., & Crowcroft, N. S. (2024). Progress toward measles elimination — Worldwide, 2000–2023. Morbidity and Mortality Weekly Report, 73(45), 1036–1042. https://doi.org/10.15585/mmwr.mm7345a4

Murphy, A. A., Indah, R., Yufika, A., Wardati, F., Fitriani, F., Mulyani, L., Harahap, I. U., Sari, C., Asrizal, F., & Harapan, H. (2025). Understanding the influence of religious and safety concerns on childhood measles and pertussis vaccination in Aceh, Indonesia. BMC Infectious Diseases, 25,

QANUN MEDIKA
Jurnal Kedokteran
Fakultas Kedokteran FKUM Surabaya
http://journal.um-surabaya.ac.id/index.php/qanunmedika

1140. https://doi.org/10.1186/s12879-025-11540-8

Ristić, M., Ilić, S., Rajčević, S., Štrbac, M., Medić, S., Pustahija, T., Vuković, V., Koprivica, M., Dragovac, G., & Petrović, V. (2025). Measles epidemiology and coverage of immunization against measles in the Autonomous Province of Vojvodina, Serbia: Local trends in a regional context. Vaccines, 13(7), 711. https://doi.org/10.3390/vaccines13070711

Torjesen, I. (2021). Measles outbreaks likely as COVID pandemic leaves millions of world's children unvaccinated, WHO warns. BMJ, 375, n2755. https://doi.org/10.1136/bmj.n2755

Tripathy, J. P.(2013). Secondary data analysis: Ethical issues and challenges. Iranian Journal of Public Health, 42(12), 1478–1479. https://pmc.ncbi.nlm.nih.gov/articles/PMC4441947/

von Elm, E., Altman, D. G., Egger, M., Pocock, S. J., Gøtzsche, P. C., & Vandenbroucke, J. P. (2007). The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: Guidelines for reporting observational studies. The Lancet, 370(9596), 1453–1457. https://doi.org/10.1016/S0140-6736(07)61602-X

World Health Organization. (2023). Disease outbreak news: Measles-Indonesia. https://www.who.int/emergencies/disease-outbreak-news/item/2023-DON462

World Health Organization. (2025). Measles. https://www.who.int/news-room/fact-sheets/detail/measles