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Disaster Preparedness as a Health System Performance Indicator: An RR-Based Pathway Modeling Framework for School-Based Disaster Risk Reduction Program Implementation in Indonesia

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ABSTRACT

Background: Disasters disproportionately affect children, yet school-based preparedness—an essential health system performance domain—remains underdeveloped in many lower-middle-income countries. In Indonesia, child vulnerability is exacerbated by suboptimal implementation of the Disaster Safe Education Units program (SPAB), with limited population-level evidence on its performance gaps. **Objective:** This study assessed school health preparedness capacity and developed optimized SPAB implementation pathways stratified by education level. **Methods:** A cross-sectional analysis was conducted using secondary data from the BNPB INARISK registry, covering 1,775 schools in Banten, DKI Jakarta, and West Java. Twelve SPAB indicators across prevention, mitigation, and preparedness-response domains were analyzed. Relative risk (RR) with 95% confidence intervals was calculated for indicator associations. Optimized implementation pathways were constructed using maximum-RR criteria and validated through multivariate ANOVA. **Results:** Only 48.3% of schools received SPAB socialization. Prevention indicators were notably low: vulnerability assessment (16.4%), structural safety assessment (18.0%), and monitoring (18.9%). Disparities were observed by education level (RR=1.39; 95%CI: 1.23–1.57) and school ownership (RR=1.15; 95%CI: 1.03–1.28). Two four-stage implementation pathways were identified for elementary and secondary schools, with SPAB socialization showing the strongest association with preparedness outcomes (RR=2.06–4.95). **Conclusion:** Significant gaps persist in school-based disaster preparedness in Indonesia. The proposed RR-based pathway model provides a scalable and replicable framework to strengthen health system resilience and reduce child vulnerability in disaster-prone settings.

Highlights:

- Only 48.3% of schools received SPAB socialization; child disaster vulnerability is compounded by critically low prevention domain implementation (16–27%).
- Statistically significant health preparedness disparities by school level and status indicate structural health equity gaps in LMIC settings.
- Two differentiated four-stage optimized implementation pathway models provide evidence-based guidance for health system strengthening.
- A scalable monitoring framework is proposed for integration into national health system performance reporting in disaster-prone LMIC contexts.

INTRODUCTION

Natural disasters constitute a significant and growing public health burden globally, with children representing one of the most biologically, psychologically, and socially vulnerable populations.[1,2,3] Child disaster vulnerability is not merely a function of physical exposure: children face disproportionate morbidity from disrupted preventive care, displacement-related communicable disease, malnutrition, and long-term psychosocial harm — consequences that are particularly severe in lower-middle-income country (LMIC) contexts where health system recovery capacity is limited.[4,5] Schools, as the primary institutional setting concentrating child populations, function both as sites of heightened disaster health risk and as platforms for community health preparedness and LMIC health system resilience building.[6]

Indonesia exemplifies the scale of this challenge. As of October 2024, BNPB recorded 1,270 disaster events and 391 fatalities in 2024 alone, with 500 educational facilities damaged.[7] The country's high child disaster vulnerability is compounded by geographic exposure to active seismic fault lines and the escalating frequency of hydrometeorological events linked to climate change.[8] Children's adaptive capacity in disaster settings is shaped by resilience across family, school, community, and governance systems[9] — positioning schools as the most accessible leverage point within Indonesia's LMIC health system architecture for scalable preparedness interventions.

The World Health Organization's Health Systems Framework identifies health service delivery, health promotion, and population protection as core functions of a performing health system.[10] The preparedness of educational institutions to prevent disaster-related health harm constitutes a measurable health system performance domain. The Sendai Framework for Disaster Risk Reduction 2015–2030[11,12] articulates school safety as a cross-sectoral priority with explicit linkages to health system resilience. Despite this policy convergence, integration of school-based preparedness into health system performance monitoring — as a scalable monitoring framework applicable to LMIC settings — remains largely absent. Figure 1 presents the integrated conceptual framework guiding this study.

In Indonesia, formal DRR for the education sector is institutionalized through the Disaster Safe Education Units program (Satuan Pendidikan Aman Bencana, SPAB), mandated by Ministry of Education and Culture Regulation No. 33 of 2019. However, evaluative evidence consistently documents suboptimal implementation, constrained by insufficient budgetary allocation and limited programmatic continuity.[13,14,15,16,17]

Comparative evidence from LMIC settings corroborates persistent implementation gaps in the Philippines,[18] Bangladesh,[19] Nepal,[20] and Thailand.[21,22] These studies frame DRR implementation as a community health resilience challenge, recognizing that school preparedness directly mediates child disaster health burden and shapes LMIC health system resilience at the population level.

This study addresses key gaps using national BNPB SPAB registry data from 1,775 schools. Objectives: (1) assess school health preparedness capacity across all domains; (2) identify health equity gaps in SPAB coverage; (3) apply an RR-based pathway modeling framework to construct optimized implementation sequences; and (4) propose a scalable monitoring framework for LMIC health system integration.

METHODS

Conceptual Framework

This study applies the WHO Health System Performance Framework[10] integrated with the Disaster Risk Management cycle[5] to conceptualize school health preparedness as a composite health system output. SPAB activities were classified into three domains: (1) Prevention — 7 indicators including policy, RKAS activation, structural and vulnerability assessments, and monitoring; (2) Mitigation — DRR training for staff and students; (3) Preparedness-Response — emergency SOP, response team, and simulation. The integrated conceptual framework is presented in Figure 1.

Study Design and Data Source

A cross-sectional study was conducted using secondary data from the BNPB INARISK SPAB dashboard (inarisk.bnpb.go.id). Data were extracted in 2024. No ethics review was required for publicly available secondary administrative data.

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Study Population

All schools registered in the BNPB INARISK SPAB dashboard in Banten, DKI Jakarta, and West Java were eligible. These provinces represent Indonesia's most densely populated regions with medium BNPB-classified disaster management capacity (2023) and proximity to the Sunda Strait megathrust zone. After data cleaning, 1,775 schools were retained.

Variables

Primary independent variable: SPAB socialization status (binary). Secondary variables: education level (elementary vs secondary), ownership (public/private), province. Twelve SPAB activity indicators were binary outcome variables.

Statistical Analysis

Three-stage analysis using IBM SPSS Version 25: (i) descriptive analysis; (ii) chi-square tests and RR (95% CI) for health equity disparities; (iii) RR-based pathway modeling.

RR-Based Pathway Modeling Framework

Optimized implementation pathway models were constructed using maximum-RR optimization: (i) RR calculated for all pairwise indicator associations; (ii) directed pathways drawn from each indicator to its highest-RR downstream indicator; (iii) MANOVA validation; (iv) model adjustment for non-significant segments.

The use of RR as the optimization criterion requires justification. RR was selected because all SPAB indicators are binary, making RR the most interpretable association measure for program planning. RR maximization identifies implementation pairings with the greatest empirical co-occurrence — operationalizing 'highest leverage' for practitioners. Critically, these models are explicitly descriptive and associational — not causal. They represent optimized implementation sequences derived from cross-sectional co-occurrence patterns. No structural equation model or causal assumptions are invoked. The framework is better characterized as an RR-based pathway modeling framework — an evidence-prioritized sequencing tool — rather than a causal modeling approach.

Reporting Standards

This study is reported in accordance with the STROBE checklist for cross-sectional studies.[23]

Conceptual Framework Diagram

Figure 1 presents the integrated conceptual framework, positioning the SPAB RR-based pathway modeling framework within the WHO Health System Performance architecture and Sendai Framework. The three SPAB domains (prevention, mitigation, preparedness-response) are mapped as health system outputs generating gains in child disaster vulnerability reduction, LMIC health system resilience, and scalable monitoring capacity.

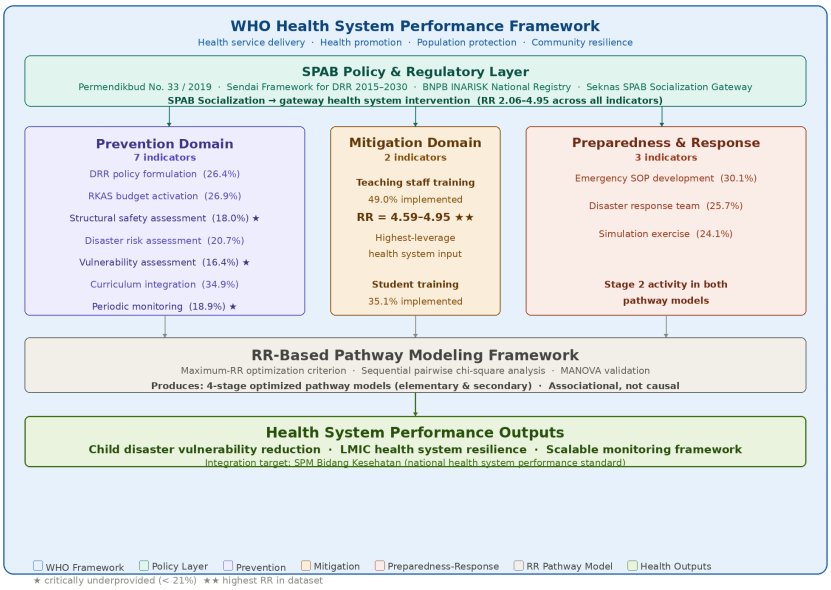

Figure 1. Integrated conceptual framework: WHO Health System Performance Framework and SPAB RR-based pathway modeling framework. Blue outer layer = WHO Health System Framework. Teal = SPAB

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policy layer. Purple/Amber/Coral = three SPAB implementation domains. Gray = RR-based pathway modeling framework. Green = health system performance outputs. ★ = critically underprovided indicators (< 21%); ★★ = highest RR in dataset. SPAB = Satuan Pendidikan Aman Bencana; RKAS = School Activity and Budget Plan; LMIC = Lower-Middle-Income Country.

Ethical Considerations

This study used publicly available secondary data. No individual-level data were accessed. Institutional ethics review was not required.

RESULTS

School Profile and Health Preparedness Coverage

Table 1 presents the distribution of 1,775 schools. Elementary schools constituted the majority (56.2%), with public schools predominating (69.4%). Only 48.3% had received SPAB socialization — more than half the school population in these high-risk provinces remained unreached.

Table 1. School profile and SPAB socialization coverage (n = 1,775)

Characteristic	Category	n	%
Education level	Early childhood (PAUD/KB/TK)	265	14.9
	Elementary school (SD)	998	56.2
	Junior secondary (SMP)	289	16.3
	Senior secondary (SMA/SMK)	223	12.6
Ownership	Public	1,232	69.4
	Private	543	30.6
Province	Banten	247	13.9
	DKI Jakarta	85	4.8
	West Java	1,443	81.3
SPAB socialization	Received	857	48.3
	Not yet received	918	51.7

PAUD = early childhood; KB = Kelompok Belajar; TK = kindergarten; SD = elementary; SMP = junior secondary; SMA/SMK = senior/vocational secondary.

Child Disaster Vulnerability and Health Equity Disparities

Table 2 presents bivariate associations. Elementary schools were 1.39 times more likely to have not received SPAB socialization (RR=1.39; 95%CI: 1.23–1.57; p<0.001) — an inverted equity gradient where the most vulnerable child populations receive the least protection. Public schools were 1.15 times more likely to have received socialization (RR=1.15; 95%CI: 1.03–1.28; p=0.013). No significant provincial disparity was observed (p=0.852), indicating these gaps are organizationally rather than geographically determined.

Table 2. Child disaster vulnerability: health preparedness disparities in SPAB socialization (n = 1,775)

Characteristic	Not Socialized n (%)	Socialized n (%)	RR (95% CI)	p-value
Education level				
Elementary (ref.)	663 (52.5%)	600 (47.5%)	1.39 (1.23–1.57)	< 0.001

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Secondary	194 (37.9%)	318 (62.1%)	Reference	
Ownership status				
Public (ref.)	619 (50.2%)	613 (49.8%)	1.15 (1.03–1.28)	0.013
Private	238 (43.8%)	305 (56.2%)	Reference	
Province				
Banten & DKI Jakarta	159 (47.9%)	173 (52.1%)	0.99 (0.88–1.10)	0.852
West Java	698 (48.4%)	745 (51.6%)	Reference	

RR = Relative Risk. Elementary includes PAUD, KB, TK, SD. Secondary includes SMP, SMA, SMK.

Health Preparedness Capacity Across SPAB Domains

Table 3 presents implementation proportions. Prevention domain indicators were critically underprovided: vulnerability assessment (16.4%), structural safety assessment (18.0%), and periodic monitoring (18.9%) all below 21%. Teaching staff training approached 50% (49.0%) as the highest-implemented indicator. Preparedness-response activities remained below 31%.

Table 3. Implementation rates across SPAB health preparedness domains (n = 1,775)

Domain & Indicator	Not implemented n (%)	Implemented n (%)
PREVENTION DOMAIN		
DRR policy formulation	1,306 (73.6%)	469 (26.4%)
DRR curriculum integration	1,155 (65.1%)	620 (34.9%)
DRR school budget (RKAS) activation	1,298 (73.1%)	477 (26.9%)
Structural safety assessment	1,455 (82.0%)	320 (18.0%)
Disaster risk assessment	1,408 (79.3%)	367 (20.7%)
Vulnerability assessment	1,484 (83.6%)	291 (16.4%)
Periodic monitoring	1,440 (81.1%)	335 (18.9%)
MITIGATION DOMAIN		
DRR training for teaching staff	906 (51.0%)	869 (49.0%)
DRR training for students	1,152 (64.9%)	623 (35.1%)
PREPAREDNESS-RESPONSE DOMAIN		
Emergency SOP development	1,241 (69.9%)	534 (30.1%)
Disaster response team formation	1,318 (74.3%)	457 (25.7%)
Disaster simulation exercise	1,348 (75.9%)	427 (24.1%)

SOP = Standard Operating Procedure; RKAS = School Activity and Budget Plan.

SPAB Socialization as Activation Lever (RR Analysis)

Table 4 presents RR values conditional on socialization status. RR values ranged from 2.06 to 4.95 across all 12 indicators and both strata. Teaching staff training recorded the highest RR (elementary: 4.59; secondary: 4.95), confirming it as the highest-leverage health system input. All 95% CIs excluded 1.00.

Table 4. Relative risk of SPAB activity implementation by socialization status, stratified by education level (n = 1,775)

SPAB Indicator	RR Elementary (95% CI)	RR Secondary (95% CI)
PREVENTION		
DRR policy formulation	2.55 (2.09–3.11)	2.55 (1.77–3.68)
DRR curriculum integration	2.43 (2.04–2.90)	2.06 (1.59–2.65)
RKAS activation	2.92 (2.36–3.62)	2.74 (1.91–3.92)
Structural safety assessment	2.77 (2.18–3.52)	2.64 (1.72–4.04)
Disaster risk assessment	3.64 (2.68–4.95)	2.58 (1.67–3.99)
Vulnerability assessment	3.38 (2.49–4.58)	2.11 (1.38–3.25)
Periodic monitoring	3.32 (2.50–4.42)	2.77 (1.79–4.29)
MITIGATION		
Teaching staff training	4.59 (3.84–5.47)	4.95 (3.65–6.72)
Student training	3.08 (2.53–3.76)	3.01 (2.26–4.01)
PREPAREDNESS-RESPONSE		
Emergency SOP development	3.11 (2.53–3.83)	3.33 (2.31–4.78)
Response team formation	3.44 (2.70–4.39)	3.13 (2.13–4.60)
Simulation exercise	3.24 (2.54–4.12)	2.97 (1.99–4.43)

All RR values statistically significant ($p < 0.05$) with 95% CIs excluding 1.00.

Optimized Implementation Pathway Models

The RR-based pathway modeling framework produced two distinct four-stage optimized implementation models (Figures 2 and 3). Both share Stage 1 initiation with RKAS budgetary activation and structural safety assessment. They diverge in subsequent stages, reflecting the distinct organizational contexts of each school type.

Elementary School Pathway Model (Figure 2)

Stage 1 (Initiation): RKAS and structural assessment simultaneously post-socialization. Stage 2 (Institutional Mobilization): RKAS activates 7 concurrent activities — staff training, student training, simulation, DRR policy, response team, curriculum integration, emergency SOP. Stage 3 (Evidence-Based Planning): Policy → vulnerability assessment; response team → risk assessment. Stage 4 (Monitoring): All three assessments converge as evidence base for periodic monitoring — the scalable performance feedback mechanism.

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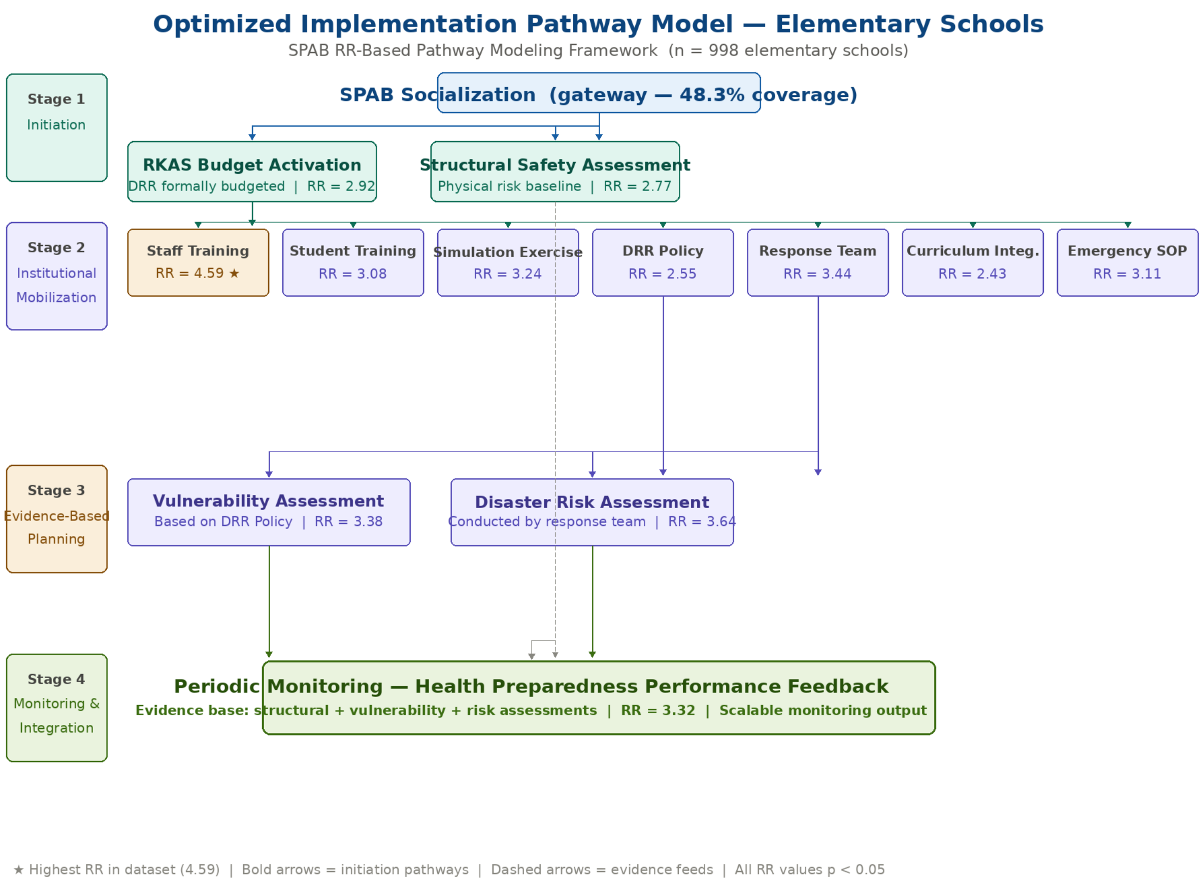

Figure 2. Optimized four-stage implementation pathway model for SPAB in elementary schools. Solid arrows = initiation/activation pathways; dashed arrows = evidence-to-action feeds. All RR values statistically significant ($p < 0.05$). ★ = highest RR indicator (4.59). RKAS = School Activity and Budget Plan; SOP = Standard Operating Procedure; RR = Relative Risk.

Secondary School Pathway Model (Figure 3)

Stage 1 (Initiation): Three parallel activities — RKAS, structural assessment, and vulnerability assessment (added vs elementary, reflecting occupant diversity). Stage 2 (Structural Response): 5 activities including DRR policy, emergency SOP, response team, simulation, and risk assessment. Stage 3 (Governance & Monitoring): Policy + structural + vulnerability data activate monitoring; staff training initiated under policy authorization. Stage 4 (Adaptive Learning): Monitoring drives student training calibrated to vulnerability data and curriculum integration responsive to monitoring outputs — the scalable adaptive feedback loop.

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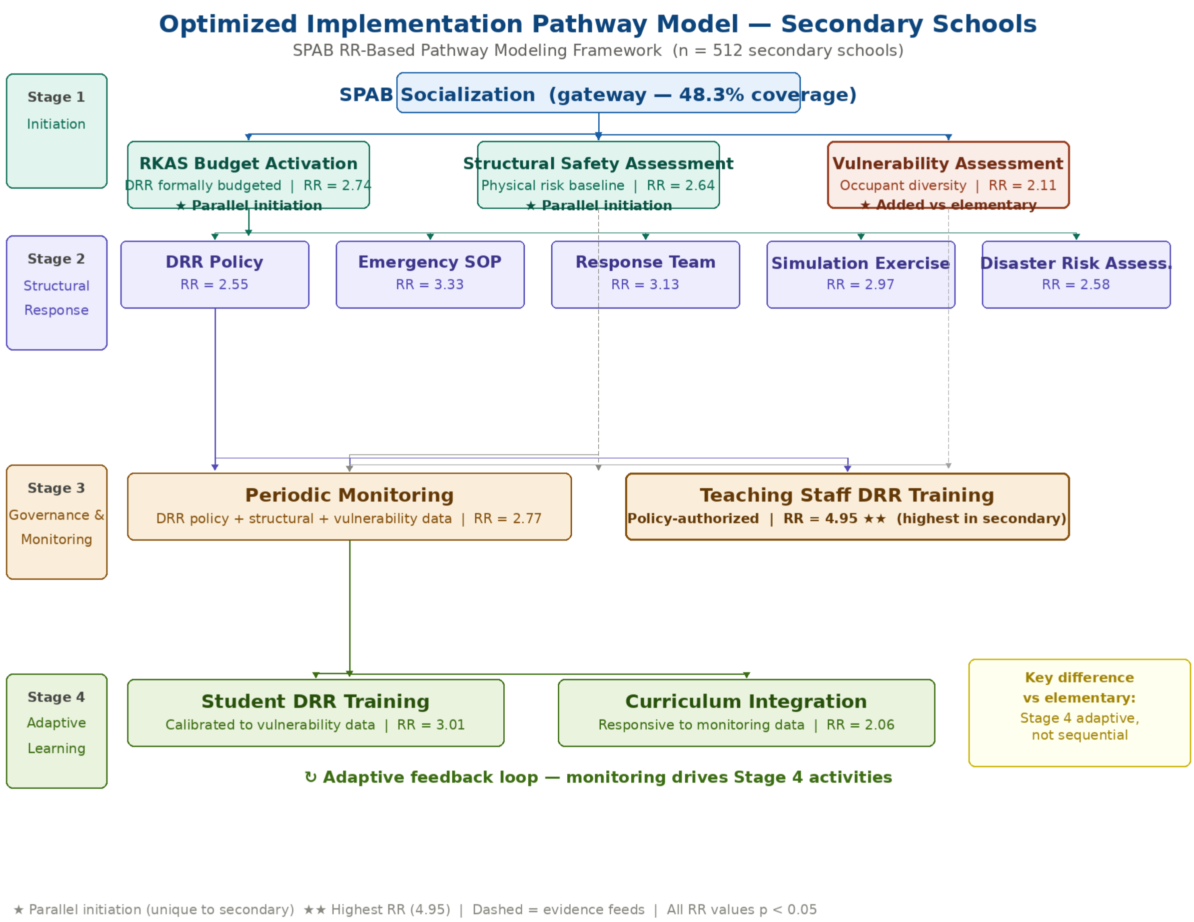

Figure 3. Optimized four-stage implementation pathway model for SPAB in secondary schools. Solid arrows = initiation/activation pathways; dashed arrows = monitoring feedback loops. All RR values statistically significant ($p < 0.05$). ★ = parallel Stage 1 activities unique to secondary model; ★★ = highest RR (4.95). RKAS = School Activity and Budget Plan; SOP = Standard Operating Procedure; RR = Relative Risk.

DISCUSSION

A Critical Health System Performance Gap in LMIC Settings

Fewer than half (48.3%) of schools across three of Indonesia's most populous provinces had received SPAB socialization, which represents the minimum entry point for disaster and health preparedness at the school level. This finding indicates a substantial gap in preparedness coverage and reflects broader limitations in health system performance for child populations in one of the world's largest low- and middle-income country (LMIC) settings.[10,24] The 500 educational facilities damaged by disasters in 2024 underscore the health system cost. Comparable preparedness gaps have been documented across LMIC school systems from Dhaka[19] to coastal Philippines,[18] indicating a structural LMIC-level challenge.

Prevention domain activities — child vulnerability assessment (16.4%), structural safety assessment (18.0%), and periodic monitoring (18.9%) — constitute the risk intelligence infrastructure without which health system planners cannot identify which children face greatest disaster health risk or whether protective measures are achieving intended effects. Mirzaei et al. demonstrated that school resilience assessment directly determines health-protective capacity[25,26] — a finding with particular force in resource-constrained LMIC contexts.

Child Disaster Vulnerability and Health Equity

The inverted health equity gradient — elementary schools serving the most biologically vulnerable child populations are significantly less likely to receive SPAB socialization — represents a structural policy failure. Elementary-aged children's limited self-protective capacity makes this underinvestment particularly consequential.[9,27] The absence of provincial disparities confirms these equity gaps are organizationally tractable: they arise from program delivery architecture, not geographic limitations. This finding supports targeted program redesign as the priority health system intervention rather than geographic expansion.

The RR-Based Pathway Modeling Framework

The two four-stage optimized pathway models produced by the RR-based pathway modeling framework — visualized in Figures 2 and 3 — represent the first registry-based, evidence-prioritized implementation roadmaps for SPAB as a health system intervention. Their interpretive directness (RR expressed in units directly meaningful to program managers), scalability (replicable with any national binary indicator registry), and explicit associational framing (not causal) make them practical tools for LMIC health system strengthening without requiring high-cost primary data collection.

Teaching staff DRR training's consistently highest RR in both models (elementary: 4.59; secondary: 4.95) confirms educator capacity building as the highest-leverage health system input — consistent with Shiwaku's cross-national analysis.[29] This strong effect is theoretically consistent with the role of teachers as institutional change agents and first responders within school systems. Teachers not only transmit disaster risk knowledge but also operationalize preparedness through daily supervision, coordination of emergency response, and integration of DRR into classroom and school routines. In resource-constrained LMIC settings, where external response capacity may be delayed, teacher preparedness effectively determines the immediate protective capacity of the school environment. RKAS budgetary activation as a universal Stage 1 activity in both models directly operationalizes the political will requirement: preparedness gains are not achievable through training alone if DRR is not embedded in the school's formal resource allocation cycle.

Towards a Scalable Monitoring Framework

Three integration mechanisms are recommended. First, SPAB indicators — particularly structural safety assessment, monitoring rates, and vulnerability assessment — should be incorporated into Indonesia's national health system performance standard (SPM Bidang Kesehatan) as proxy indicators for child population health resilience.[28] Second, the RR-based pathway modeling framework should be operationalized as a real-time BNPB INARISK dashboard tool enabling continuous comparison of actual implementation profiles against optimized benchmarks. Third, SPAB coverage disaggregated by school level and ownership should be institutionalized in BNPB national reporting as a health equity indicator. All three mechanisms are directly replicable in other LMIC settings with national school registry infrastructure.[30]

While this study focuses on western Indonesian provinces, caution is required in generalizing findings to eastern Indonesia, where infrastructure constraints, geographic fragmentation, and lower health system capacity may further limit SPAB implementation. Schools in these regions may face additional barriers, including limited access to trained personnel, logistical challenges for program delivery, and weaker institutional support systems. Consequently, the RR-based pathway framework remains applicable as a conceptual and planning tool, but its operationalization may require adaptation to local capacity conditions, including phased implementation and targeted resource allocation strategies.

Limitations

Limitations include: (1) self-report bias in BNPB INARISK data may inflate implementation rates; (2) cross-sectional design and associational RR framework preclude causal inference — pathway models represent co-occurrence sequences, not temporal mechanisms; (3) restriction to three western Java provinces limits LMIC generalizability; (4) binary operationalization does not capture implementation intensity or quality; (5) prospective validation of pathway models is needed before predictive use. Future policy implementation should incorporate random field audits to validate dashboard-reported SPAB indicators, ensuring alignment between reported implementation and on-the-ground preparedness conditions

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CONCLUSION

Indonesian schools in Banten, DKI Jakarta, and West Java exhibit critically low health preparedness capacity, with fewer than half receiving SPAB socialization and prevention activities — the health intelligence foundation of child disaster protection — implemented in fewer than one in five schools. This constitutes a measurable health system performance gap of direct relevance to child disaster vulnerability in one of the world's largest LMIC settings.

The inverted health equity gradient — elementary and private school children receiving the least protection despite comparable or greater vulnerability — is organizationally tractable: targeted program redesign, not geographic expansion, is the priority health system intervention.

The RR-based pathway modeling framework produced two evidence-based, differentiated four-stage optimized implementation models (visualized in Figures 2 and 3), grounded in maximum-RR sequencing of national registry data. Both models converge on RKAS budgetary activation and structural safety assessment as universal Stage 1 actions. Teaching staff DRR training consistently emerges as the highest-RR implementation lever (RR 4.59–4.95) in both models.

The proposed scalable monitoring framework — integrating SPAB implementation indicators into national health system performance reporting — offers a replicable, LMIC-adapted tool for sustaining institutional accountability, tracking child disaster vulnerability equity, and enabling adaptive management of school health resilience programs. Future research should prospectively validate the pathway models, extend analysis to additional disaster-prone provinces, and assess health outcome linkages between SPAB implementation and child disaster-related morbidity data.

ABBREVIATIONS

BNPB: Badan Nasional Penanggulangan Bencana (National Disaster Management Agency)
BPBD: Badan Penanggulangan Bencana Daerah (Regional Disaster Management Agency)
DKI: Daerah Khusus Ibukota (Special Capital Region)
DRR: Disaster Risk Reduction
LMIC: Lower-Middle-Income Country
MANOVA: Multivariate Analysis of Variance
RKAS: Rencana Kegiatan dan Anggaran Sekolah (School Activity and Budget Plan)
RR: Relative Risk
SPAB: Satuan Pendidikan Aman Bencana (Disaster Safe Education Units)
SOP: Standard Operating Procedure
STROBE: Strengthening the Reporting of Observational Studies in Epidemiology
WHO: World Health Organization

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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