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BARRIERS AND ENABLERS TO VACCINE DEPLOYMENT DURING PUBLIC HEALTH EMERGENCIES IN JIGAWA STATE, NIGERIA: A MIXED-METHODS CROSS-SECTIONAL STUDY

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Abstract

Background: Effective vaccine deployment during public health emergencies requires robust health system capacities and favorable socio-behavioral conditions. This study identified and analyzed the health system barriers and enablers influencing the effectiveness of emergency vaccine deployment in Jigawa State, Nigeria.

Methods: A mixed-methods cross-sectional study was conducted. Quantitative data were collected from 619 healthcare workers, selected using stratified random sampling across five emirate councils in Jigawa State. A structured questionnaire, guided by the WHO Health System Building Blocks framework, was administered to assess associations between facility-level readiness indicators and vaccine deployment outcomes. Qualitative data were collected through 41 key informant interviews (KIIs) and focus group discussions (FGDs), analyzed thematically using NVivo 15, and guided by the Socio-Ecological Model (SEM). The two strands were integrated using a sequential explanatory strategy.

Results: Quantitative analysis identified key health system barriers and enablers. At the bivariate level, ten factors, including emergency committee presence, functional cold chain equipment, regular supervisory support, dedicated emergency budgets, and structured community engagement, were each significantly associated with timely vaccine rollout. Multivariate logistic regression identified three independent predictors: absence of an emergency committee and absence of structured community engagement were independent barriers, while regular supervisory support was an independent enabler. The model demonstrated acceptable fit (Hosmer-Lemeshow p = 0.538) and fair discrimination (AUC-ROC = 0.731). Qualitative findings further identified governance fragmentation, supply chain disruptions, community mistrust, and workforce limitations as barriers. In contrast, traditional and religious leadership engagement, adaptive frontline practices, and integrated community microplanning emerged as key enablers.

Conclusion: Governance structures, particularly emergency committee functionality and regular supervisory support, and community engagement are the strongest independent determinants of timely emergency vaccine deployment in Jigawa State. Addressing these barriers and leveraging these enablers through integrated, context-sensitive strategies is essential. This study contributes novel subnational, mixed-methods evidence from a high-need setting, offering an operational model transferable to similar low-resource contexts across Sub-Saharan Africa.

Keywords: Vaccine Deployment; Public Health Emergencies; Health Systems Readiness; Barriers; Enablers

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Introduction

Public health emergencies have repeatedly exposed systemic deficiencies in health systems' capacity to efficiently, timely, and equitably deliver vaccines. Between 2000 and 2023, the World Health Organization (WHO) recorded over 1,500 disease outbreaks worldwide, many of which disproportionately affected low- and middle-income countries (LMICs) with weak health systems.[1] Vaccines remain among the most cost-effective public health interventions, yet their deployment during emergencies is consistently undermined by health system failures rather than by vaccine shortages alone.[2] The COVID-19 pandemic starkly illustrated this reality. Despite the unprecedented speed of vaccine development, global inequities in deployment meant that low-income countries administered fewer than 1% of vaccine doses in the first months of rollout, exposing the fragility of health system readiness as the binding constraint on emergency immunization.[3]

The Sub-Saharan African region bears a disproportionate burden of this vulnerability. Despite sustained investments through Gavi, the Vaccine Alliance, and the Expanded Program on Immunization (EPI), the region continues to record the world's lowest routine immunization coverage, averaging 72% for DTP3, well below the 95% threshold required for herd immunity.[4] Emergency vaccine campaigns across the region have been systematically hindered by cold chain failures, supply chain disruptions, governance fragmentation, and community resistance, resulting in preventable outbreaks of measles, meningitis, cholera, and yellow fever.[5] Nigeria, the most populous country in Africa with over 220 million people, exemplifies these systemic vulnerabilities. The country has experienced recurrent outbreaks of cholera, meningitis, measles, Lassa fever, mpox, and COVID-19 over the past two decades, with emergency vaccine responses consistently falling below targets.[6] National immunization coverage for key antigens remains critically low, with only 57% of children under five completing the full DTP3 schedule as of 2023, and significant subnational disparities concentrated in the Northwest and Northeast geopolitical zones.[7]

Jigawa State, located in Nigeria's Northwest geopolitical zone, epitomizes these subnational disparities and offers a compelling, underexplored context for examining emergency vaccine deployment. With a projected population of approximately 6.9 million, Jigawa is predominantly rural, socially conservative, and structurally under-resourced.[8] The state records some of the poorest health indicators in the country: routine immunization coverage for DTP3 stands at approximately 42%, among the lowest nationally, while skilled birth attendance remains below 30%, reflecting deep structural deficits in health service delivery.[8] Structural weaknesses in emergency preparedness, including inconsistent cold-chain maintenance, limited disease surveillance capacity, chronic health workforce shortages, and inadequate community engagement, have repeatedly hindered rapid vaccine rollout during outbreaks.[9] During the COVID-19 pandemic, Jigawa recorded a vaccination coverage rate of less than 5% of its eligible population as of December 2021, one of the lowest in Nigeria despite receiving federal and international partner support, underscoring the severity of systemic barriers to emergency immunization in the state.[10] Yet, despite this well-documented burden, the health system determinants of emergency vaccine deployment in Jigawa State remain poorly understood and largely

unstudied. Existing literature on vaccine deployment in Nigeria is predominantly national in scope, quantitative in design, and focused on routine immunization rather than emergency response contexts.[7] There is a critical absence of subnational, mixed-methods evidence that simultaneously examines both the structural health system factors and the socio-behavioral determinants shaping emergency vaccine deployment outcomes at the facility and community levels.[11] Without this evidence, policy interventions risk being generic, non-contextual, and ultimately ineffective in high-need, low-resource settings like Jigawa. This study, therefore, aimed to identify and analyze the health system barriers and enablers influencing the effectiveness of emergency vaccine deployment in Jigawa State. Guided by the WHO Health System Building Blocks framework to assess institutional and operational readiness, and the Socio-Ecological Model (SEM) to examine social and behavioral determinants of vaccine uptake, this study generates context-specific, actionable evidence to inform emergency preparedness policy and practice in Jigawa State and comparable low-resource settings across Sub-Saharan Africa.

Materials And Methods

Study design

This study employed a mixed-methods research approach, integrating a quantitative cross-sectional survey design and a qualitative exploratory-descriptive design to examine barriers and enablers to emergency vaccine deployment in Jigawa State. The quantitative strand administered a structured self-administered questionnaire to 619 healthcare workers across selected health facilities, assessing associations between facility-level readiness indicators and vaccine deployment outcomes, guided by the WHO Health System Building Blocks framework. The qualitative strand conducted key informant interviews (KIIs) and focus group discussions (FGDs) with purposively selected stakeholders to elicit in-depth contextual, social, and behavioral insights into the factors shaping emergency vaccine deployment, guided by the Socio-Ecological Model (SEM). The two strands were integrated using a sequential explanatory strategy, whereby quantitative data were collected and analyzed first to establish the magnitude and statistical associations of health system readiness indicators, followed by qualitative data collection and analysis to contextualize, interpret, and explain the quantitative findings within the socio-cultural and governance realities of Jigawa State.

Study settings and population

The study was conducted in Jigawa State, a predominantly rural state in Nigeria's Northwest geopolitical zone, with a projected 2023 population of approximately 6.9 million.[12] Target populations included healthcare workers employed within health facilities across selected LGAs, as well as community members, religious and traditional leaders, and policymakers directly involved in or affected by emergency vaccine deployment in the state.

Sample Size Determination

Qualitative Component: The sample size was guided by thematic saturation. Data collection via KIIs and FGDs continued until no new themes emerged, yielding 41 participants. Rigor was ensured through triangulation, member checking, and reflective memoing.

Quantitative Component: The minimum sample size was determined using Cochran's formula for estimating proportions in large populations:[14]

$n_0 = Z^2 \times p(1-p) / e^2$

Where Z = 1.96 (95% confidence level), p = 0.5 (maximum variability assumption, adopted conservatively given the absence of prior prevalence data on facility readiness in Jigawa State, as this value maximizes the required sample size and minimizes the risk of under-sampling), and e = 0.05 (5% margin of error). This yields $n_0 = (1.96)^2 \times 0.5 \times 0.5 / (0.05)^2 = 384$.

Since the target population of eligible healthcare workers (N = 11,795) was known and finite, a finite population correction (FPC) was applied: n = 384 / [1 + (383/11,795)] ≈ 372. Accounting for stratification across five emirate councils and an anticipated non-response rate of approximately 15%, the minimum adjusted sample was N = 440. The study enrolled 619 participants, exceeding this minimum, thereby strengthening statistical precision. It is important to note that sample size determination (Cochran's formula) and sampling method (stratified random sampling) are distinct methodological components: the former determines how many participants are required; the latter determines how they are selected.

Study Sampling

The study employed distinct sampling strategies for each methodological strand. For the quantitative strand, stratified random sampling was used. The sampling frame comprised the complete enumerated list of 11,795 eligible healthcare workers across selected LGAs, derived from the Jigawa State Government Human Resource for Health Stock Analysis 2021.[13] Participants were stratified proportionally across five emirate councils to ensure subnational representativeness. This probability-based approach enables statistically valid inferences about health facility readiness across the state.

Ethical Approval and Informed Consent

Ethical approval was obtained from the Jigawa State Ministry of Health Research Ethics Committee (Reference: JGHREC/2024/213) before data collection. All procedures complied with the Declaration of Helsinki and the Nigerian National Code for Health Research Ethics. Written informed consent was obtained from all quantitative strand participants before questionnaire administration and from KII participants before interviews. Verbal informed consent, read aloud and confirmed by each participant, was obtained before each FGD. Participants were informed of their right to withdraw, the confidentiality of their responses, and the research-only use of data. No personally identifiable information was collected or reported.

Data Collection

Quantitative data were collected using a structured self-administered questionnaire, developed and validated against the WHO Health System Building Blocks framework, administered to 619 healthcare workers across health facilities in the five emirate councils. The questionnaire assessed facility-level readiness indicators across six domains: leadership and governance, health workforce, health information systems, medical products and technology, health financing, and service delivery.

Qualitative data were collected through KIIs and FGDs with purposively selected stakeholders, frontline healthcare workers, LGA and state-level immunization officers, community and religious leaders, and policymakers, to

explore in-depth perceptions, lived experiences, and contextual factors related to emergency vaccine deployment in Jigawa State.

Data Analysis

Qualitative data from KIIs and FGDs were transcribed verbatim and imported into NVivo 15 for systematic thematic analysis guided by the SEM, progressing through: familiarization with the data; generation of initial codes; identification and review of themes; and interpretation in relation to the research questions. Rigor was ensured through data source triangulation, member checking, and reflective memoing.

Quantitative data were coded and analyzed using SPSS version 28. Descriptive statistics summarized sociodemographic characteristics and facility readiness indicators. Chi-square tests (χ^2) assessed bivariate associations between categorical readiness indicators and vaccine deployment outcomes, with effect sizes reported using Cramer's V. Binary logistic regression was subsequently conducted to identify independent predictors of timely vaccine deployment, controlling for potential confounders. Model fit was assessed using the Hosmer-Lemeshow goodness-of-fit test, and discriminatory ability was assessed using the AUC-ROC statistic. Statistical significance was set at $p < 0.05$.

Results

Participant Characteristics

A total of 619 healthcare workers completed the structured self-administered questionnaire. All respondents were directly involved in vaccine deployment activities and were therefore well-positioned to provide informed responses on facility-level preparedness. The majority of respondents (n = 535, 86.4%) had between 5 and 10 years of experience, followed by those with over 10 years (n = 78, 12.6%), and those with fewer than 5 years (n = 6, 1.0%). Respondents were predominantly male (n = 393, 63.5%) and aged 36–45 years (n = 416, 67.2%) (Table I).

Health Facility Readiness Across the WHO Health System Building Blocks

Across the six WHO Health System Building Blocks, respondents reported consistent but moderate levels of health facility readiness, with most indicators ranging from 58% to 61% reporting adequate preparedness at their respective facilities. Governance, financing, and logistics were reported as the weakest domains, with approximately 40% of respondents indicating their facilities lacked functional emergency committees, written deployment guidance, functional cold chain systems, or reliable stock management procedures. These findings reflect the self-reported perceptions of 619 healthcare workers and should be interpreted as proxy indicators of facility-level readiness rather than objectively verified facility assessments (Table II).

Bivariate Analysis: Barriers and Enablers to Timely Vaccine Rollout

Chi-square analyses examined the associations between ten health system readiness indicators and timely vaccine rollout. All ten factors were statistically significant ($p < 0.001$), with odds ratios ranging from 2.51 to 5.03. Factors whose presence was significantly associated with timely rollout are classified as enablers; their absence constitutes barriers. At the bivariate level, the following were identified as enablers: emergency committee presence (OR

= 2.51, V = 0.221), functional cold chain equipment (OR = 3.43, V = 0.293), structured community engagement (OR = 2.58, V = 0.228), dedicated emergency budget (OR = 4.68, V = 0.355), staff training on the National Vaccine Deployment Plan (OR = 4.75, V = 0.359), past emergency funding (OR = 5.01, V = 0.369), backup power supply (OR = 5.03, V = 0.369), regular supervisory support (OR = 4.62, V = 0.358), immunization registers (OR = 4.67, V = 0.355), and outreach to hard-to-reach areas (OR = 4.68, V = 0.355). The absence of each of these factors constitutes a structural barrier to timely vaccine rollout (Table III).

Multivariate Logistic Regression: Independent Predictors of Timely Vaccine Rollout

To identify independent predictors of timely vaccine rollout while controlling for confounding among health system factors, a binary logistic regression model was fitted, with all 10 significant bivariate predictors entered simultaneously. The model demonstrated acceptable calibration (Hosmer-Lemeshow $\chi^2 = 2.169$, $p = 0.538$), fair discriminatory ability (AUC-ROC = 0.731), an overall classification accuracy of 70.0%, and a McFadden Pseudo R^2 of 0.139.

After adjusting for all other variables, three independent predictors of timely vaccine rollout were identified (Table V). Two factors functioned as independent barriers through their absence: lack of an emergency vaccine deployment committee (AOR = 0.24, 95% CI: 0.10–0.54, p = 0.001) and absence of structured community engagement (AOR = 0.47, 95% CI: 0.25–0.89, p = 0.021) were each independently associated with significantly reduced odds of timely rollout. One factor functioned as an independent enabler: regular supervisory support from LGA or state teams (AOR = 2.05, 95% CI: 1.09–3.87, p = 0.026) was independently associated with more than twice the odds of achieving timely rollout.

While cold chain functionality, backup power supply, staff training, past emergency funding, dedicated budgets, immunization registers, and outreach to hard-to-reach areas were all significant at the bivariate level, none retained independent significance in the multivariate model. This indicates that their effects are likely mediated by, or shared with, governance structures and supervisory systems, underscoring the primacy of governance as the foundational determinant of the effectiveness of emergency vaccine deployment in Jigawa State.

Table I: Sociodemographic Characteristics of Participants

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	393	63.5%
	Female	226	36.5%
Age Group	<24 years	1	0.2%
	25–35 years	128	20.7%
	36–45 years	416	67.2%
	46–55 years	74	12.0%
Role in Facility	Community Health Officer	139	22.5%
	Vaccinator	170	27.5%
	Community volunteers	89	14.4%
	LGA health officer	39	6.4%
	Nurse	22	3.6%
	Pharmacist	4	0.6%
	Rural health worker	144	23.3%
	State health officer	8	1.3%
	Other healthcare provider	4	0.7%
Years of Experience	<5 years	6	1.0%
	5–10 years	535	86.4%
	>10 years	78	12.6%
Emirate Council	Dutse	220	35.5%
	Kazaure	106	17.1%
	Gumel	106	17.1%
	Hadejia	179	28.9%
	Ringim	76	12.3%

Table IIa: Self-Reported Health Facility Readiness Indicators Across the WHO Health System Building Blocks (N = 619 Healthcare Workers), Jigawa State, Nigeria

Building Block	Key Indicator	Findings (% of respondents reporting availability at their facility)	Implications for Readiness
Leadership and Governance	Emergency vaccine committee in place	58.8% Yes (n=364), 41.2% No (n=255)	A significant proportion of respondents reported the absence of emergency coordination structures, reflecting moderately weak governance readiness.
	Written guidance for emergency vaccine deployment	59.4% Yes (n=368), 40.6% No (n=251)	The absence of standard guidelines, reported by 40.6%, leads to inconsistent decision-making during emergencies.
	Staff trained on the National Vaccine Deployment Plan	60.1% Yes (n=372), 39.9% No (n=247)	Training gaps reported by 39.9% reduce facilities' capacity to implement national emergency protocols.
	Supportive supervision from LGA/state teams	55.3% Regular (n=343), 44.7% Irregular (n=276)	Irregular oversight reported by nearly half of respondents weakens accountability and operational readiness.
Health Workforce	Facilities meeting staffing ratio for campaigns	59.6% Yes (n=369), 40.4% No (n=250)	40.4% reported insufficient staffing, compromising surge response capacity.
	Staff trained in emergency response (past 2 years)	61.0% Yes (n=378), 39.0% No (n=241)	Persistent training gaps reported by 39.0% limit emergency deployment readiness.
Health Information Systems	Immunization registers/tally sheets available	60.3% Yes (n=373), 39.7% No (n=246)	Missing documentation reported by 39.7% undermines data consistency and accuracy.
	Timely data reporting to LGA/state	60.0% Yes (n=371), 40.0% No (n=248)	Suboptimal timeliness of reporting, reported by 40.0%, reduces real-time situational awareness.
	AEFI forms/tools in use	59.7% Yes (n=370), 40.3% No (n=249)	Poor safety monitoring tools reported by 40.3% increases risk of delayed adverse event reporting.
	Digital/paper-based vaccine monitoring tools	59.1% Yes (n=366), 40.9% No (n=253)	Weak monitoring systems reported by 40.9% affect vaccine accountability and planning.

Table IIb: Self-Reported Health Facility Readiness Indicators Across the WHO Health System Building Blocks (N = 619 Healthcare Workers), Jigawa State, Nigeria

Building Block	Key Indicator	Findings (% of respondents reporting availability at their facility)	Implications for Readiness
Medical Products, Vaccines, and Technology	Functional cold chain equipment (refrigerators/freezers)	58.5% Yes (n=362), 41.5% No (n=257)	Cold chain gaps reported by 41.5% threaten vaccine potency, particularly in rural LGAs.
	Facilities with a backup power supply	60.8% Yes (n=377), 39.2% No (n=242)	The reported lack of power redundancy among 39.2% heightens the risk of cold chain failure during outages.
	Facilities with a stock management system	58.2% Yes (n=360), 41.8% No (n=259)	Weak inventory tracking, as reported by 41.8%, increases the risk of shortages and waste.
	Vaccine stockouts in the past 3 months	47.8% Yes (n=296), 52.2% No (n=323)	The 47.8% reported stockout level reflects persistent supply chain inefficiencies.
Health Financing	Dedicated budget for emergency response	59.7% Yes (n=370), 40.3% No (n=249)	Limited budgetary autonomy reported by 40.3% undermines local preparedness.
	The facility received funding for past emergency campaigns	60.5% Yes (n=375), 39.5% No (n=244)	39.5% reported receiving no emergency campaign funding, weakening financial resilience.
Service Delivery	Outreach to hard-to-reach areas	60.0% Yes (n=371), 40.0% No (n=248)	Limited outreach reported by 40.0% undermines equitable coverage during emergencies.
	Availability of PPE for vaccinators/staff	60.4% Yes (n=374), 39.6% No (n=245)	Inadequate PPE reported by 39.6% affects safety and continuity in outbreak conditions.
	Reverse logistics for expired/damaged vaccines	59.3% Yes (n=367), 40.7% No (n=252)	Weak waste management, as reported by 40.7%, increases the risk of unsafe disposal.
	Availability of functional cold boxes/carriers	58.6% Yes (n=363), 41.4% No (n=256)	Insufficient mobility reported by 41.4% constrains the ability to conduct safe outreach sessions.

Table III: Bivariate Chi-Square Analysis, Barriers and Enablers to Timely Vaccine Rollout (N = 619), Jigawa State, Nigeria

Independent Variable	Dependent Variable	$\chi^2(1, N=619)$	p-value	Effect Size (Cramer's V)	Classification and Interpretation
Emergency committee present	Timely vaccine rollout	30.13	<0.001	0.221	ENABLER — Presence significantly associated with timely rollout (OR=2.51); absence constitutes a key governance barrier.
Functional cold chain equipment	Timely vaccine rollout	53.15	<0.001	0.293	ENABLER — Functional cold chain strongly associated with timeliness (OR=3.43); absence is a critical supply barrier.
Structured community engagement	Timely vaccine rollout	32.06	<0.001	0.228	ENABLER — Community engagement is significantly associated with timely rollout (OR=2.58); absence constitutes a socio-behavioral barrier.
Dedicated emergency budget	Timely vaccine rollout	78.15	<0.001	0.355	ENABLER — Dedicated budget strongly associated with timeliness (OR=4.68); absence is a financing barrier.
Staff trained on NVDP	Timely vaccine rollout	79.60	<0.001	0.359	ENABLER — Staff training is strongly associated with timely rollout (OR=4.75); absence is a workforce barrier.
Past emergency funding received	Timely vaccine rollout	84.19	<0.001	0.369	ENABLER — Past funding is significantly associated with timeliness (OR = 5.01); funding absence is a financing barrier.
Backup power supply	Timely vaccine rollout	84.26	<0.001	0.369	ENABLER — Backup power is strongly associated with timely rollout (OR=5.03); absence is a logistics barrier.
Regular supervisory support	Timely vaccine rollout	79.50	<0.001	0.358	ENABLER — Regular supervision is significantly associated with timeliness (OR=4.62); irregular supervision is a governance barrier.
Immunization registers available	Timely vaccine rollout	78.10	<0.001	0.355	ENABLER — Register availability associated with timely rollout (OR=4.67); absence is an information system barrier.
Outreach to hard-to-reach areas	Timely vaccine rollout	78.15	<0.001	0.355	ENABLER — Structured outreach is significantly associated with timeliness (OR=4.68); absence is a service delivery barrier.

Note: All associations are significant at $p < 0.001$. OR = Odds Ratio; V = Cramer's V effect size. Enablers are factors that facilitate timely rollout; their absence constitutes a barrier.

Table V: Multivariate Logistic Regression — Independent Predictors of Timely Vaccine Rollout (N = 619), Jigawa State, Nigeria

Predictor Variable	AOR	95% CI	p-value	Statistical Significance	Classification
Emergency Committee Present	0.24	0.10 – 0.54	0.001	***	**BARRIER (absence)**
Community Engagement Implemented	0.47	0.25 – 0.89	0.021	*	**BARRIER (absence)**
Regular Supervisory Support	2.05	1.09 – 3.87	0.026	*	**ENABLER**
Functional Cold Chain Equipment	1.14	0.60 – 2.16	0.698	ns	Not independent
Staff Trained on NVDP	2.85	0.95 – 8.59	0.062	ns	Not independent
Backup Power Supply	3.41	0.87 – 13.42	0.079	ns	Not independent
Past Emergency Funding Received	2.78	0.75 – 10.36	0.128	ns	Not independent
Dedicated Emergency Budget	0.65	0.17 – 2.48	0.527	ns	Not independent
Immunization Registers Available	0.62	0.16 – 2.44	0.492	ns	Not independent
Outreach to Hard-to-Reach Areas	1.64	0.56 – 4.76	0.364	ns	Not independent

*Note: AOR = Adjusted Odds Ratio; 95% CI = Confidence Interval; ns = not significant; *p < 0.05; ***p < 0.001. Model fit: McFadden Pseudo R^2 = 0.139; Hosmer-Lemeshow χ^2 = 2.169, p = 0.538; Classification accuracy = 70.0%; AUC-ROC = 0.731. Reference category: Delayed rollout.*

Qualitative Findings: Contextualizing Barriers and Enablers

Thematic analysis of 41 KIIs and FGDs, guided by the Socio-Ecological Model, generated six themes that contextualize and explain the quantitative findings across individual, interpersonal, community, organizational, and policy levels (Table IV).

At the individual level, Theme 1 (Knowledge, Motivation, and Trust) revealed that community mistrust of vaccines, rooted in religious concerns, rumors, and historical distrust of health authorities, was a significant socio-behavioral barrier to vaccine uptake. Conversely, health workers' intrinsic motivation and professional commitment functioned as individual-level enablers, with staff often working without compensation to ensure campaign delivery. At the interpersonal level, Theme 2 (Workforce Responsiveness and Social Influence) highlighted that peer accountability and supervisory relationships were critical enablers: facilities with regular supervisory engagement reported stronger campaign outcomes, corroborating the multivariate finding of regular supervision as an independent enabler (AOR = 2.05).

At the community level, Theme 3 (Collective Action, Leadership, and Local Ownership) identified governance fragmentation and siloed operations across the health,

information, and local government sectors as the most prominent barrier. Traditional and religious leader engagement, particularly the combination of town crier announcements and religious endorsements, emerged as a powerful community-level enabler. Theme 4 (Service Readiness and System Adaptation) revealed adaptive informal practices, such as WhatsApp-based stock alert systems, as organizational-level enablers that compensated for formal system deficiencies.

At the policy level, Theme 5 (Governance, Financing, and Coordination) confirmed governance fragmentation and donor-dependent financing as the dominant structural barriers, with facilities losing operational capacity when donor funding terminated and state funds were delayed. Theme 6 (Resilience, Learning, and Future Preparedness) underscored the absence of systematic inter-epidemic preparedness as a policy-level barrier, with stakeholders calling for institutionalized routine preparedness investments independent of outbreak trigge

Table IVa: SEM-Aligned Qualitative Themes — Barriers and Enablers to Emergency Vaccine Deployment, Jigawa State, Nigeria

Theme	Description	Participants (n)	Indicators (n)	Empirical Evidence (Selected Quotes)
Theme 1: Knowledge, Motivation, and Trust in Vaccination	How individuals' perceptions, fears, or cultural beliefs shape vaccine acceptance and participation during emergencies — BARRIER when negative; ENABLER when positive.	21	113	*"When the town crier and religious leader announced it together, people believed it more than when health workers alone spoke." (Community Leader, Dutse)*
Theme 2: Workforce Responsiveness and Social Influence	How interactions between health workers, supervisors, and community members influence campaign delivery and trust — ENABLER through adaptive frontline practices.	22	80	*"Even when there was no fuel or allowance, our staff still moved on foot to reach the wards. They said: If we don't do it, who will?" (PHC In-Charge, Kazaure)*
Theme 3: Collective Action, Leadership, and Local Ownership	How community structures, local leaders, and social networks facilitate or hinder campaign success — BARRIER when siloed; ENABLER through coordinated local leadership.	20	100	*"Everyone worked in silos — health, information, and local government councils. That delayed our rollout." (LGA Immunization Officer, Gumel)*

Table IVb: SEM-Aligned Qualitative Themes — Barriers and Enablers to Emergency Vaccine Deployment, Jigawa State, Nigeria

Theme	Description	Participants (n)	Indicators (n)	Empirical Evidence (Selected Quotes)
Theme 4: Service Readiness and System Adaptation	How health facilities, supply chains, and adaptive management systems respond to deployment challenges — ENABLER through improvisation; BARRIER through system rigidity.	19	93	*"We used WhatsApp to alert each other when vaccines were running out — no need for paper reports." (PHC In-Charge, Maigatari)*
Theme 5: Governance, Financing, and Coordination	How national and subnational health system factors, funding flows, leadership, and intersectoral coordination shape deployment outcomes — BARRIER through fragmentation.	17	117	*"When partners leave, or donors terminate projects, activities stop because the state does not release funds on time." (State Immunization Officer, Ringim)*
Theme 6: Resilience, Learning, and Future Preparedness	How the system learns from crises, generating institutional memory, accountability, and sustainability — ENABLER through systematic preparedness investment.	15	60	*"We should not wait for outbreaks to train people; preparedness must be routine. Additional state and LGA allocations toward public health emergencies are key." (State Immunization Officer, Dutse)*

Discussion

This study is among the first subnational, mixed-methods investigations of barriers and enablers to emergency vaccine deployment in Northwest Nigeria, combining quantitative facility-level readiness data from 619 healthcare workers with qualitative insights from 41 key informants. The findings make two distinct contributions: first, they identify, through multivariate analysis, the independent health system determinants of timely vaccine deployment; second, they provide qualitative depth to explain the mechanisms through which these determinants operate. Together, these findings challenge the prevailing focus on technical fixes such as cold chain investment and instead elevate governance, supervision, and community engagement as the primary drivers of deployment effectiveness.

Emergency committee presence is the strongest independent barrier when absent (AOR = 0.24, p = 0.001), meaning that facilities lacking emergency vaccine deployment committees had nearly four times the odds of delayed rollout compared to those with committees, even after controlling for cold chain functionality, financing, and workforce training. This finding is consistent with global evidence demonstrating that governance structures, not technical inputs, are the foundational determinants of health system

resilience during emergencies.[15] The qualitative data illuminate why: committees operating as bridging structures between state-level directives, facility-level management, and community leadership achieved the highest effectiveness, while those functioning as administrative formalities without cross-level connectivity showed limited operational impact. This distinction between formal committee existence and functional governance capacity is a novel contribution of this study to the Sub-Saharan African health systems literature.

Regular supervisory support emerged as the only independent enabler in the multivariate model (AOR = 2.05, p = 0.026), conferring more than twice the odds of timely rollout. This aligns with evidence from immunization programs across West Africa demonstrating that supportive supervision, distinct from punitive monitoring, strengthens frontline worker performance, accountability, and adaptive problem-solving capacity.[16] The qualitative findings reinforce this: supervisory relationships created accountability channels that compensated for resource deficits, with workers in supervised facilities more likely to devise informal solutions such as using personal funds for transportation or communicating stockouts through informal networks. The interaction between supervision and committee functionality, where both must be present for governance to be effective, suggests that supervision without governance structures and governance without supervisory accountability are each insufficient on their own.[17]

Community engagement was identified as an independent barrier when absent (AOR = 0.47, p = 0.021), indicating that structured community engagement nearly halves the odds of achieving timely rollout. This finding challenges the common framing of community engagement as a secondary or optional component of vaccine campaigns.[18] In Jigawa State's socially conservative and predominantly Muslim context, traditional and religious leaders are not merely complementary stakeholders; they are gatekeepers whose endorsement determines community-level vaccine acceptance and mobilization speed.[19] The qualitative evidence confirms this: combined announcements by town criers and religious leaders produced faster community response than health worker communication alone, consistent with evidence on the role of trusted intermediaries in vaccine confidence across Muslim-majority communities in West Africa. [20]

Notably, functional cold chain equipment, the most prominent predictor in the original bivariate analysis (OR = 3.43) and the most discussed factor in existing literature, did not retain independent significance in the multivariate model (AOR = 1.14, p = 0.698). This does not diminish the operational importance of cold chain integrity; rather, it reveals that cold chain effectiveness is mediated by governance and supervision: facilities with functional equipment but weak governance structures and irregular supervision still experienced deployment delays, while well-governed facilities with regular supervision showed better deployment outcomes even when compensating for cold chain deficiencies through adaptive logistics. This finding supports integrated approaches where cold chain investments are embedded within, rather than substituted for, governance strengthening.[21]

The health financing building block revealed a pattern of donor dependency that constitutes a structural vulnerability

in Jigawa's emergency vaccine deployment system.[22] While 60.5% of facilities reported receiving past emergency campaign funding, 39.5% operated without any financial resources for immunization, with rural and hard-to-reach LGAs disproportionately excluded. Qualitative evidence confirmed that operational paralysis followed donor withdrawal, with state funds consistently delayed beyond emergency response timelines. This aligns with findings from Nigeria and comparable LMICs, demonstrating that vertical, externally funded immunization programs create fragile financing architectures that collapse in the absence of sustained domestic resource mobilization.[23] The policy implication is clear: sustainable emergency vaccine financing requires dedicated subnational budget lines, not supplementary donor funding.[24]

Health information system deficiencies, with 39.7% of respondents reporting absent immunization registers and 40.0% reporting delayed reporting to LGA and state levels, represent a cross-cutting barrier that undermines situational awareness, real-time decision-making, and post-campaign accountability. Rural facilities experienced these deficits more severely, with a disproportionate absence of digital monitoring tools. Qualitative findings revealed that informal digital workarounds, particularly WhatsApp-based stock alert groups among facility in-charges, compensated for formal information system gaps, demonstrating that frontline health workers' adaptive capacity can partially substitute for system-level deficiencies. However, these informal solutions are neither systematic nor sustainable and cannot replace the accountability functions of formal health information systems.[25]

The SEM framework provides the theoretical architecture that explains why multivariate regression found governance and community engagement as the independent determinants: individual-level worker motivation and interpersonal supervisory relationships are necessary but insufficient without community-level trust, organizational-level management capacity, and policy-level financing and governance coordination. The layered interaction among these levels means that technical interventions implemented at a single SEM level, such as cold chain upgrades and workforce training, yield limited returns without corresponding investments across all levels. This multi-level theoretical insight, grounded in empirical data from a high-burden subnational context, is the study's primary theoretical contribution.

Conclusion

This study provides robust, evidence-based insights into the structural and social determinants that shape vaccine deployment during public health emergencies in Jigawa State, Nigeria. Health facility readiness was the strongest determinant of effective vaccine deployment, highlighting the multi-dimensional nature of a health system: effective vaccine rollout depends on coherent performance across multiple health system building blocks, rather than a single input.

Conflict of interest

The authors have declared no competing interests.

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