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Original Research Article

Health system determinants of vaccine cold chain performance at the primary healthcare facilities in Nasarawa State, Nigeria: a mixed-methods study

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ABSTRACT

Background: Preserving vaccine potency through a robust cold chain is essential for immunization success. This study evaluates the health system determinants of vaccine cold chain performance at primary healthcare (PHC) facilities in Nasarawa State, Nigeria.

Methods: A mixed-methods, cross-sectional study was conducted between August and September 2025. Quantitative data were collected from 147 healthcare workers using structured questionnaires, while qualitative insights were gathered from 10 key informant interviews with immunization and cold chain officers. Data were analyzed using IBM SPSS version 31 and NVivo 15.

Results: Findings revealed a successful transition to renewable energy, with 82.3% of facilities utilizing solar power. However, infrastructure gaps persist, as 22.4% of refrigerators were non-functional, 41.5% of facilities face daily power outages, and 38.8% lack backup power systems. A significant workforce gap was identified. While 81.0% of facilities had Standard Operating Procedures, 50.3% of health workers had never attended formal cold chain training. Qualitative data highlighted that low sunlight causes temperatures to rise to +10°C to +11°C, and faulty equipment force workers to incur out-of-pocket expenses for vaccine transport.

Conclusions: While Nasarawa State has modernized its cold chain equipment, performance is undermined by inadequate training, poor maintenance, and lack of backup power. To secure immunization gains, the state must prioritize regular supportive supervision, systematic equipment maintenance, and comprehensive capacity-building for healthcare workers.

Keywords: Immunization, Nasarawa State, Primary healthcare, Solarization, Vaccine cold chain

INTRODUCTION

Immunization is widely recognized as one of the most effective and cost-efficient public health interventions globally.[1,2] Its success, however, fundamentally relies on preserving vaccine potency throughout a strong cold chain system.[3] Vaccines are temperature-sensitive biological products that must be maintained strictly within a recommended range of to +2°C to +8°C from the point of manufacture to administration.[4-6] Exposure to temperatures outside this range, even for short durations, can result in an irreversible loss of efficacy and increased vaccine wastage.[4] Consequently, proper vaccine storage and continuous temperature monitoring are fundamental components of safe and effective immunization service delivery.

Despite global efforts and substantial investments to strengthen cold chain infrastructure in low- and middle-income countries, including Nigeria, maintaining an effective cold chain remains a significant challenge.[7-10] While the availability of equipment has improved, evidence suggests that infrastructure expansion alone may not guarantee effective temperature control under routine service conditions.[11-13] Studies in various Nigerian states have consistently documented persistent deficiencies, such as malfunctioning refrigerators, a lack of alternative power sources, and operational weaknesses at the primary healthcare (PHC) level.[7,14-16] These system weaknesses indicate that procedural compliance often coexists with operational risk, undermining the quality of immunization services.[17]

The effective performance of the cold chain is determined by a complex interaction of infrastructure reliability, human capacity, and system-level governance.[3,18,19] In Nasarawa State, immunization services are delivered largely through PHCs dependent on solar refrigeration systems.[20,21] However, there has been a limited recent, facility-level empirical evidence examining how infrastructure reliability and operational challenges interact to influence vaccine storage performance at this level of care.[1,22] The absence of such context-specific data limits the ability of programme managers to identify priority gaps and design targeted interventions.

Therefore, this study aimed to assess the health system determinants of vaccine cold chain performance at primary healthcare facilities in Nasarawa State, Nigeria using a mixed-methods approach.

METHODS

Study design and setting

This study employed a mixed-methods, cross-sectional design to evaluate the health system determinants of vaccine cold chain performance. The research was conducted across selected primary healthcare facilities in Nasarawa State, North-Central Nigeria. The setting included a diverse range of rural and urban PHCs providing routine immunization services under the supervision of the Nasarawa State Primary Healthcare Development Agency.[23] Data collection was carried out between August 2025 and September 2025.

Ethical consideration

Ethical approval for the study was obtained from the Nasarawa State Ministry of Health Research Ethics Committee. Administrative permission was further secured from the state's primary healthcare authorities. Prior to data collection, all participants were briefed on the study's purpose, and written informed consent was obtained. To ensure confidentiality, all identifiers were removed during data processing, and key informant interviews were conducted in private settings.

Participants and eligibility criteria

The study population for the quantitative component consisted of 147 healthcare workers directly involved in the Expanded Programme on Immunization (EPI), including nurses, midwives, and Community Health Extension Workers (CHEWs). For the qualitative component, 10 key informants were recruited, including State and Local Government Area (LGA) Immunization Officers and Cold Chain Officers. Eligible facilities were those actively providing routine immunization services and equipped with at least one vaccine storage unit.

Sampling and sample size

A multistage sampling design was utilized to ensure a representative sample. In the first stage, LGAs within Nasarawa State were selected via simple random sampling. In the second stage, PHCs were randomly identified from official facility registers. The minimum sample size of 127 was calculated using Cochran's formula, based on a 90.9% expected proportion of cold chain component availability derived from previous regional studies. To account for potential non-response and enhance statistical power, a total of 147 healthcare workers were purposively enrolled from the selected facilities.

Data collection and study instruments

Quantitative data were collected using a structured facility-level self-administered questionnaire. These tools documented the availability and functional status of equipment, including refrigerators, solar-direct drive units, and backup power systems. Qualitative data were gathered through semi-structured key informant interviews (KIIs). These interviews explored contextual barriers and enablers, such as maintenance schedules, power supply stability, and governance structures. The data collection instruments were pre-tested for validity and reliability prior to the main study.

Data analysis and integration

Quantitative data were processed and analysed using IBM SPSS Statistics (version 31). Descriptive statistics (frequencies and percentages) were used to summarize equipment functionality, while Pearson's chi-square tests ($p<0.05$) were applied to assess associations between infrastructure reliability and storage outcomes. Qualitative recordings were transcribed verbatim and analysed using NVivo 15 for thematic categorization. The findings were integrated through triangulation, where qualitative insights from stakeholders were used to explain and contextualize the quantitative gaps identified in the facility assessments.

RESULTS

A total of 147 healthcare workers from primary healthcare facilities in Nasarawa State participated in the study and 10 key informant interview participants. The characteristics of the survey respondents are summarized in Table 1.

Table 1: Sociodemographic and professional characteristics of respondents (n=147).

Variables	Number (n=147)	Frequency (%)
Sex		
Male	49	33.3
Female	98	66.7
Age (years)		
26-30 (Model group)	41	27.9
Others (20-25, 31-51+)	106	72.1
Years of service		
<7 years	86	58.6
7-10 years	50	34.0
10 years and above	11	7.5
Education		
Diploma	116	78.9
Degree (BSc/HND/MSc)	30	20.4
SSCE	1	0.7

The majority of respondents were female (n=98, 66.7%) and aged between 26 and 30 years (27.9%). In terms of educational attainment, 78.9% held a Diploma, while 19.7% possessed a BSc or HND. Professionally, the largest group of respondents had between 7 and 10 years of service (34.0%), indicating a sample with significant professional experience.

Analysis of the cold chain infrastructure (Table 2) revealed that the majority of refrigerators were functional (n=114, 77.6%), though nearly one-quarter (22.4%) were out of service at the time of the study.

Table 2: Cold chain equipment and power reliability in Nasarawa State, Nigeria.

Indicator	Category	Number (n=147)	Frequency (%)
Functionality of refrigerator	Functional	114	77.6
	Non-functional	33	22.4
Primary power source	Solar	121	82.3
	National grid/ generator/other	26	17.7
Backup power	Available	90	61.2
	Not available	57	38.8
Outage frequency	Daily	61	41.5
	< Daily	86	58.5

The energy landscape was dominated by renewable sources, with 82.3% of facilities utilizing solar power as their primary energy source, while only 17.7% relied on the national grid or generators.

The assessment of management practices (Table 3) showed a significant gap between documentation and human resource capacity. While hundred and nineteen of facilities (81.0%) had Standard Operating Procedures (SOPs) available, seventy-four respondents (50.3%) reported they had never attended formal cold chain management training.

Table 3: Cold chain management and challenges in the study area.

Variable	Key finding	Number	Frequency (%)
Training	Never attended cold chain training	74	50.3
Guidelines	SOPs available in facility	119	81.0
Maintenance	Equipment serviced in last 3 months	81	55.1
Top challenges	Equipment, Training, and supervision gaps	69	46.9
Primary need	Regular supportive supervision	51	34.7

Qualitative findings from key informant interviews

Key informant profiles

To complement the quantitative data, 10 key informants were interviewed. These participants were purposively selected based on their leadership roles and specialized expertise in Immunization program. To ensure strict participant confidentiality, specific demographic details and job titles have been aggregated. The informants included ten senior-level professionals, comprising six males and four females, each possessing a minimum of 15 years of professional experience. This group provided the qualitative context necessary to triangulate the Table 2 survey findings.

Seven overarching themes emerged from the key informant interviews, describing the status of cold chain systems, temperature monitoring practices, human resource capacity, supervision mechanisms, and contextual barriers and enablers influencing cold chain performance at primary healthcare level in Table 4.

Table 4: Themes, sub-themes, and illustrative quotations from key informant interviews on vaccine cold chain management in primary healthcare facilities in Nasarawa State, Nigeria.

Theme	Sub-theme	Illustrative quotation	Source
Availability, functionality and reliability of cold chain equipment	Solar-powered equipment	"Majority of facilities in the state now have solarized systems which provide reliable backup for vaccine storage."	KII_State_02
	Standby generators	"We have a standby generator provided by the chairman about three months ago."	KII_LGA_01
	Equipment breakdown	"Our refrigerator is faulty, so I must go to the LGA cold room to collect vaccines for each fixed/outreach session."	KII_PHC_01
	Insufficient power supply	"When there is not enough sunlight, the temperature may rise above the recommended level."	KII_PHC_02
	Functional equipment	"Most facilities have functional refrigerators and maintenance booklets to track equipment issues."	KII_State_02
	Non-functional equipment	"Some refrigerators are faulty and no longer working properly."	KII_LGA_02
Types of cold chain equipment	Cold boxes and carriers	"Cold boxes are commonly used for temporary vaccine storage and transportation."	KII_LGA_01
	Refrigerators/Deep freezers	"We have deep freezers used mainly for freezing ice packs for cold chain operations."	KII_LGA_03
Training and human resource capacity	Staff shortage	"The main barrier is the low number of trained staff within the cold chain unit."	KII_State_01
	Adequate staffing	"Yes, we have enough staff managing cold chain activities in our facility."	KII_LGA_03
Supervision mechanisms	Supportive supervision	"Supervisors provide feedback and correct mistakes during round-table discussions."	KII_PHC_01
	Peer-to-peer learning	"Supervision visits often include peer learning among staff on documentation and vaccine management."	KII_PHC_02
Policy and reporting practices	Adherence to national guidelines	"Yes, we follow the standard operating procedures for vaccine storage."	KII_LGA_03
Barriers to effective cold chain management	Inadequate funding	"Lack of funds makes it difficult to repair refrigerators or maintain equipment."	KII_State_02
	Faulty or obsolete equipment	"Some refrigerators are obsolete and no longer functioning effectively."	KII_LGA_01
	Insufficient power supply	"Power outages sometimes disrupt vaccine storage when there is no enough sunlight, the solar fridge temperatures rise to +10°C or +11°C."	KII_LGA_01
	Staff shortage	"There are few trained personnel responsible for managing cold chain activities."	KII_State_01
Recommendations for improvement	Increased funding	"More funding should be allocated for cold chain equipment maintenance."	KII_LGA_01
	Increased manpower	"More staff should be recruited to strengthen cold chain management."	KII_PHC_02
	Provision of backup power	"Facilities need generators or solar systems to ensure continuous refrigeration."	KII_LGA_03
	Regular training	"Healthcare workers need proper training in cold chain management."	KII_State_02
	Timely maintenance	"Regular servicing of refrigerators is necessary to prevent vaccine spoilage."	KII_LGA_01

DISCUSSION

The findings of this study reveal a significant transition toward sustainable energy in Nasarawa State's immunization program, alongside persistent operational and human resource challenges that threaten vaccine potency. A major strength identified is the widespread adoption of renewable energy, with 82.3% of primary healthcare facilities utilizing solar power as their primary energy source. This shift, supported by international partners like Gavi and UNICEF, represents a critical advancement in overcoming the historical barrier of unreliable national grid electricity in Nigeria. This high rate of solarization in Nasarawa consistent with findings reported by Kamala in Tanzania where equipment availability has improved through targeted regional assessments.[1] However, in contrast to this modernization, the data shows a resilience gap, where 41.5% of facilities still face daily power outages and 38.8% lack any backup power systems. This mirrors challenges identified by To et al. (2019) in Osun State where logistics management deficiencies persisted despite infrastructure pushes.[2] Furthermore, the observation that solar fridge temperatures rise to +10°C or +11°C during low sunlight aligns with findings by Falcón et al (2020) in Mexico where environmental factors frequently caused excursions outside the required +2°C to +8°C recommended range.[17]

A critical finding is the stark disconnect between the availability of guidelines and staff capacity. While 81.0% of facilities had standard operating procedures available, 50.3% of healthcare workers reported never attending formal cold chain management training. This high rate of untrained personnel is in alignment with systemic weaknesses identified by Dairo and Osizimete (2016) in Ibadan where provider practices were found to be more critical than equipment availability.[16] This also mirrors the operational risks documented by Sow et al (2018) in Burkina Faso where procedural knowledge did not always translate to effective temperature monitoring.[4] In contrast to the optimism expressed by Sasetu et al (2023) regarding the acceptability of peer learning in Nasarawa.[21] This study suggests that informal support cannot replace formal capacity-building, as half the workforce remains untrained in core protocols.

Equipment maintenance remains a severe weakness, with only 55.1% of refrigerators serviced in the three months prior to the study. This confirms the findings of Babatunde et al (2020) in Oyo State where infrastructure expansion alone failed to guarantee effective control under routine conditions.[14] The 22.4% non-functionality rate forces health workers to incur out-of-pocket expenditures for vaccine transport, a barrier that is in contrast to the more generalized system weaknesses cited by Burstein et al (2013) in their multi-country African study.[5] Ultimately, the benefits of renewable energy are being lost due to a lack of human resource capacity and technical oversight. To secure the gains made in infrastructure, Nasarawa State must prioritize regular supportive supervision and systematic maintenance schedules to ensure vaccines remain potent from storage to administration.

The implications of these findings for vaccine potency and public health are substantial. The high frequency of power outages, combined with the lack of reliable backup power sources and limited human resource capacity evidenced by the large proportion of respondents without formal cold chain training (50.3%), creates a high-risk environment for temperature excursions and potential vaccine potency loss. This suggests that despite the solarization of cold chain infrastructure in the state, the benefits of renewable energy systems may not be fully realized without adequate technical oversight and trained personnel. Strengthening supportive supervision, identified by 34.7% of respondents as a key need, is therefore critical to improving compliance with cold chain management practices. From a policy and programmatic perspective, these findings highlight the need for targeted investments in workforce training, routine supportive supervision, and timely maintenance of cold chain equipment. In addition, strengthening backup power systems and ensuring sustained technical support for solar refrigeration systems would enhance the resilience of vaccine storage systems and help safeguard immunization programme performance at the primary healthcare level.

While this study provides valuable data on vaccine cold chain performance in Nasarawa State, it has some limitations. The survey relied on health workers reporting their own experiences, which could lead to social desirability bias where they might overstate their adherence to protocols. Second, the cross-sectional design only captured a "snapshot" of equipment functionality and power outages at one point in time, which may not reflect seasonal changes in sunlight affecting solar-powered systems.

CONCLUSION

The vaccine cold chain in Nasarawa State is characterized by a successful transition to renewable energy through widespread solar power adoption. However, significant gaps in human resource capacity and infrastructure reliability remain, as many staff members lack formal training, and numerous facilities operate without backup power systems. To ensure vaccine potency and program success, the state must move beyond equipment provision and prioritize regular supportive supervision, consistent equipment maintenance, and comprehensive capacity-building for healthcare workers.

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