# Determinant Risk Factors for Continuous Quality Improvement (CQI) in Primary Health Care (PHC) Systems in Kogi State

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## ABSTRACT

Continuous Quality Improvement (CQI) is a systems-based, Kaizen-inspired approach that strengthens Primary Health Care (PHC) through iterative Plan-Do-Study-Act (PDSA) cycles, routine data use, and stakeholder engagement. In Kogi State, Nigeria, a cross-sectional mixed-methods assessment of n=96 PHC facilities applied epidemiologic and implementation science methods to identify determinant risk factors for CQI performance. Data sources included IMPACT RISS supervision reports, DHIS2 extracts, and program documents (2023–2025), analyzed using chi-square tests, Pearson correlations, logistic regression, multilevel mixed-effects models, and MANOVA.

Facility readiness was operationalized as a composite index of WASH, power, and cold-chain infrastructure was strongly correlated with immunization coverage (r = 0.62), and each 10-point increase in readiness raised the odds of high CQI uptake by ~35% (aOR ≈ 1.35). Cold-chain failure nearly doubled zero-dose risk (RR ≈ 1.90; aOR ≈ 1.8), functioning as a critical control point in the CQI pathway. Workforce stability, proxied by staff accommodation, was associated with a two-fold increase in CQI uptake (aOR ≈ 2.05), reinforcing its role as a sustaining factor. Process innovations such as geo-tagged supervision (aOR ≈ 1.6) and settlement-level monitoring emerged as mediators that translated readiness into improved service delivery. Environmental risk (aOR ≈ 0.70) and LGA-level clustering (ICC ≈ 0.16) moderated CQI effectiveness, highlighting the importance of context in shaping outcomes.

These findings support a causal logic in which structural readiness enables process improvements, workforce stability sustains gains, and socio-ecological alignment enhances resilience. The study's Theory of Change posits that CQI success is conditional on the interaction between readiness, process fidelity, and contextual adaptation. Translating these coefficients into program targets such as cold-chain uptime, staff retention, and geo-tagged supervision coverage can guide scalable, equity-focused CQI strategies. Institutionalizing the data-to-action loop, embedding environmental risk into microplanning, and formalizing PDSA cycles at the facility level are essential for sustaining improvements. This study offers a replicable framework for implementing Kaizen-based CQI in PHC systems across similar low-resource settings.

**Keywords**: Kaizen; Continuous Quality Improvement (CQI); Primary Health Care (PHC); Immunization; Workforce retention; Cold-chain resilience; Supportive supervision; Geo-tagged monitoring; Facility readiness; Data-to-action; Environmental determinants; Health system resilience.

# INTRODUCTION

## Background of Study

Primary Health Care (PHC) is the cornerstone of equitable health systems, providing essential services to populations at the first point of contact. In Nigeria, PHC facilities are central to immunization, maternal-child health, and disease prevention. However, disparities in coverage and access persist, particularly in rural and hard-to-reach communities. Continuous Quality Improvement (CQI) has emerged as a critical strategy to address these gaps. CQI emphasizes iterative cycles of planning, implementation, monitoring, and feedback, supported by reliable data and stakeholder engagement. In Kogi State, CQI interventions have improved preparedness indices but remain challenged by workforce attrition, infrastructural deficits, and weak data utilization. The domains for the CQI outcomes include the following: -

a) Workforce stability and accommodation: shortages of skilled personnel, high attrition, and poor living conditions weaken service delivery.
b) Infrastructure and logistics: unreliable electricity, nonfunctional cold chain systems, and poor transport elevate zero-dose risk.
c) Governance and financing: inconsistent policy implementation and delayed fund release constrain CQI effectiveness.
d) Community engagement: uneven participation of Ward Development Committees (WDCs) and Village Development Committees (VDCs) limits accountability.
e) Environmental determinants: flooding, water pollution, and poor sanitation exacerbate disease burdens and undermine resilience.

This background establishes the rationale for examining CQI determinants in Kogi State, linking local challenges to global patterns observed across low- and middle-income countries (LMICs).

## Objectives

This study was conducted to achieve the following objectives:-

1. Evaluate the effectiveness of Continuous Quality Improvement (CQI) policies and processes in enhancing Primary Health Care (PHC) service delivery for vulnerable and hard-to-reach populations in Kogi State.
2. Identify and analyze determinant risk factors such as socioeconomic status, healthcare infrastructure, workforce capacity, and community engagement that influence CQI outcomes.
3. Recommend context specific strategies for integrating epidemiologic and ecological insights into CQI frameworks to improve equity, resilience, and sustainability in PHC systems.

## Justification

Despite national and sub-national efforts to improve PHC service delivery, significant disparities persist in immunization coverage and service access among marginalized populations in Kogi State. These include nomadic groups, residents of insecure or geographically isolated settlements, and socioeconomically disadvantaged communities. The implementation of the RI Integrated Supportive Supervision (IMPACT RISS) tool provides a unique opportunity to assess facility level readiness, service availability, and community engagement. By applying epidemiologic tests to this dataset, the study with ethical approval number [SMoH/PRS/465/V.1/157]from the Kogi State Ministry of Health Ethical Committee], hopes to generate actionable evidence to inform policy reforms and optimize CQI processes tailored to the needs of vulnerable populations.

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**Research Questions**

1. What are the key determinants influencing CQI performance in PHC facilities serving vulnerable and hard-to-reach populations in Kogi State?
2. How do policy frameworks and process optimization strategies such as supportive supervision, cold chain maintenance and mop-up campaigns affect immunization coverage and service delivery outcomes?
3. In what ways can socio-ecological factors be integrated into CQI strategies to improve health equity and system resilience?

**Research Hypotheses**

1. **$H_1$**: Optimized service delivery processes (e.g., mop-up strategies, special team deployment) significantly increase immunization coverage among vulnerable populations compared to standard PHC approaches.
2. **$H_2$**: Policy frameworks that incorporate socio-ecological determinants are positively associated with higher CQI performance in PHC systems.
3. **$H_3$**: Settlement level monitoring of noncompliance and child absent cases significantly predicts improved immunization uptake and reduced zero-dose prevalence.

**Definition of Key Terms**

**Continuous Quality Improvement (CQI):** A structured, iterative approach to improving health services through small, frequent tests of change, routine measurement, and stakeholder feedback; Kaizen linkage: CQI operationalizes kaizen by embedding PDSA cycles, run charts, and frontline problem solving into everyday PHC practice.

**Kaizen:** A philosophy of continuous, incremental improvement driven by frontline teams that emphasizes standard work, waste reduction, and rapid learning; PHC linkage: promotes facility-level ownership of PDSA cycles, huddles, and standard operating procedures for immunization and maternal-child services.

**Plan Do Study Act (PDSA) cycle** A four-step method for testing changes: plan a small change, implement it, study results using data, and act to adopt or adapt; Kaizen linkage: the core mechanism by which CQI translates coefficients and surveillance signals into iterative improvements.

**Facility readiness index**: Composite measure of infrastructure, equipment, WASH, power, and commodity availability scored 0–100 threshold; Kaizen linkage: used as a run-chart metric to prioritize PDSA tests and standard work for weakest subcomponents.

**Cold-chain functionality:** Operational status of vaccine storage equipment and temperature control systems; Kaizen linkage: treated as a critical process metric with daily checklists, root-cause 5-Whys, and preventive maintenance PDSA cycles.

**Workforce stability**: Degree to which staff are retained, present, and supported (including accommodation and incentives); Kaizen linkage: addressed through rapid tests of retention interventions, team coaching, and standard work for shift coverage.

**Geo-tagged supervision (ODK ISS)**: Location-verified supportive supervision captured digitally to validate sessions and trigger follow-up; Kaizen linkage: enables precise data-to-action loops and run-chart visualization for targeted mop-ups.

**Settlement-level monitoring:** Local registers of absentee, noncompliance, and zero-dose cases linked to follow-up actions; Kaizen linkage: forms the microplanning input for rapid PDSA cycles and equity-focused standard work.

**Environmental risk index**: Composite score of flooding, water contamination, and sanitation stressors affecting service continuity; Kaizen linkage: informs seasonal PDSA planning, resilience tests (raised WASH platforms, contingency stocks) and balancing measures.

**Data-to-action loop:** The operational sequence from routine data capture to analysis, decision, and corrective action; Kaizen linkage: the feedback engine of kaizen run charts, huddles, and coaching convert indicators into immediate PDSA steps.

**Standard work:** Documented, agreed procedures for routine tasks that reduce variation; Kaizen linkage: codifies successful PDSA outcomes so improvements become sustainable practice.

**Run chart**: Time series plot used to detect change over time for key indicators; Kaizen linkage: primary visual tool for teams to study PDSA effects on coverage, zero-dose, and readiness metrics.

**Balancing measurematic Data-driven approach:** Conducted towards improving the quality, efficiency, and effectiveness of health services.

**Primary Health Care (PHC):** The first level of contact between individuals and the health system, providing essential health services including preventive, promotive, curative, and rehabilitative care.

**Zero-dose children:** Children aged 0–59 months who have not received any dose of routine immunization.

**Supportive Supervision (IMPACT Routine Immunization Supportive Supervision):** A harmonized tool used to assess and enhance PHC facility performance through structured monitoring and feedback.

**Hard-to-reach populations:** Communities with limited access to health services due to geographic, socioeconomic, or security related barriers.

**Socio-ecological determinants:** Factors such as environment, community dynamics, and social structures that influence health behaviours and outcome

A **Stepped-wedge CQI package** is a phased, system-wide rollout of an integrated quality improvement intervention, designed to both strengthen services and generate robust evidence on impact. It sits at the intersection of implementation science, epidemiology, and program management, making it especially appropriate for PHC and immunization system reform

## LITERATURE REVIEW

### Continuous Quality Improvement (CQI) in PHC Systems

Continuous Quality Improvement (CQI) has become a defining strategy for strengthening Primary Health Care

(PHC) in low and middle-income countries (LMICs). In Nigeria, CQI is central to improving immunization coverage, maternal-child health outcomes, and system resilience [1][5]. Evidence from Kogi State shows that CQI interventions, when combined with supportive supervision and data-driven cycles, enhance preparedness indices but remain challenged by workforce attrition and infrastructural deficits [3][4].

### Conceptual Framework

This review adopts the Donabedian model of structure–process–outcome as its conceptual foundation [11][12]. In PHC systems, structural inputs such as workforce density, infrastructure readiness, and financing mechanisms shape service delivery processes, including governance, supervision, and data utilization. These processes, in turn, determine outcomes such as immunization coverage, maternal health indicators, and system resilience [20][25]. The framework is focused on Global health epidemiology, emphasis for disease burden, disparities, and surveillance systems [13][14][29] and the Human medical ecology focus highlights, the interaction between human populations and their environments [7][15][34]. Together, these perspectives underscore that CQI is not merely a technical exercise but a holistic approach bridging health systems, communities, and ecological realities.

**Table 2.2: Comparison of Kaizen elements vs WHO/UNICEF PHC CQI expectations**

| Kaizen element | Functionality | WHO/UNICEF PHC expectation | Practical alignment for PHC CQI |
|---|---|---|---|
| **PDSA / Rapid cycle testing** | Tests small changes, learns fast | Routine measurement → use data for improvement; iterative action cycles WHO improvingphc.org | Institutionalize PDSA in facility QI teams; link to monthly DHIS2 indicators |
| **Standard work** | Reduces variation; codifies best practice | Strengthen service delivery standards and capacities WHO | Develop SOPs for immunization sessions, mop-ups, cold-chain checks |
| **Data-to-action (run charts, dashboards)** | Translates indicators into immediate corrective steps | PHC measurement framework emphasizes routine indicators and dashboards WHO | Geo-tagged supervision → trigger mop-ups; DQA → corrective plans |
| **Coaching and capacity building** | Builds frontline problem solving skills | Improvement strategies include on-site coaching and mentorship improvingphc.org | Train mentors in Kaizen methods; embed coaching in supervision visits |
| **Root cause analysis** | Identifies systemic causes of poor performance | WHO guidance stresses systems analysis and addressing bottlenecks WHO | Use 5-Whys in QI meetings to address cold-chain failures, absenteeism |
| **Waste reduction & efficiency** | Removes non-value steps (time, stockouts) | PHC performance aims for efficient, resilient service delivery WHO paho.org | Streamline vaccine logistics; optimize outreach routes |
| **Team huddles & local ownership** | Rapid review and decision making | Community and facility governance are core PHC enablers WHO | Daily/weekly huddles; WDCs linked to QI plans |
| **Fidelity + adaptation** | Maintain core practice while tailoring locally | WHO/UNICEF encourage context-sensitive implementation improvingphc.org | Document adaptations; monitor fidelity and outcomes |

**Sources:** WHO improvingphc.org paho.org.

**Determinant Risk Factors for CQI in Kogi State**

Recent evidence identifies several determinant risk factors shaping CQI outcomes in Kogi State are linked to workforce capacity from the persistent shortages of skilled personnel, high attrition rates, and inadequate staff accommodation weaken service delivery [2][23] and also the infrastructure and logistics challenges are linked to many PHCs lack reliable electricity, functional cold chain systems, and diagnostic equipment, elevating zero dose risk [3][16].

Governance and leadership limitations in the capacity of HRH at the local government level and inconsistent policy implementation constrain CQI effectiveness [4][37] while the community engagement gaps are defined by the Ward Development Committees (WDCs) and Village Development Committees (VDCs) foster accountability limited by uneven due to cultural barriers [6][21]. The Health information systems gaps are defined by the fragmented data collection and underutilization of DHIS2 weaken decision-making, though recent distribution of standardized tools signals progress [5][27]. Environmental risks encapsulate the heavy metal contamination, recurrent flooding, and poor sanitation that exacerbate disease burdens [7][15][34] and population dynamics are gaps linked to the rapid growth and urbanization intensify demand for PHC services [10][30].

**Comparative Analysis of Local linkages with Global Patterns and Ecological linkages with Epidemiological Contexts**

Kogi State's CQI challenges mirror global patterns observed across LMICs an these are linked to workforce shortages, infrastructural deficits, fragmented governance, and weak community engagement are common barriers worldwide [12][19][38] and also environmental health risks and demographic pressures are that are recognized globally as critical determinants of PHC performance [15][34]. However, Kogi's recent investments in preparedness and data systems demonstrate localized progress that aligns with global best practices [5][31]. In line with global health epidemiology, the Kogi State morbidity endemicity reflects the dual burden of disease prevalent in LMICs from the observed high rates of malaria and diarrheal diseases alongside rising non-communicable conditions [3][29]. The epidemiologic analyses reveal strong correlations between facility readiness and coverage, while cold chain functionality remains decisive in reducing zero-dose prevalence [1][16].

The human medical ecology perspective presents environmental determinants as inseparable from health outcomes. Groundwater contamination with lead, microbial pollution exceeding WHO standards, and recurrent flooding create ecological stressors that undermine PHC resilience [7][15][34]. These risks highlight the need for CQI frameworks that integrate environmental health interventions into routine PHC cycles.

**Table 2.3: Comparative Analysis of CQI Determinants in Kogi State and Global Patterns**

| Determinant | Kogi State (2024–2025) | Global Patterns (LMICs/WHO) |
|---|---|---|
| **Infrastructure** | Significant improvements (n=198 PHCs revitalized out of N=1080 or 18.3%, MSP target: n=360 by 2028), Many facilities still lack basic infrastructure (water, electricity, toilets). | Infrastructure gaps are common; facility readiness a major barrier in many LMICs. |
| **Workforce** | Acute shortages in doctors, nurses, and pharmacists; multiyear recruitment plan underway; high attrition and mal-distribution. | Workforce shortages, mal-distribution, and migration are global challenges. |
| **Governance** | Improved intergovernmental coordination; budget increases; persistent issues with fund release and operational autonomy. | Fragmented governance, policy discontinuity, and weak accountability prevalent in LMICs. |
| **Financing** | Increased budget allocations; reliance on BHCPF and donor support; high out-of-pocket expenditures persist. | Underfunding, high OOP, and donor dependency common in LMICs. |
| **Community Engagement** | Active WDCs and CBOs in some areas; SCEAP Project strengthens accountability; variable participation and trust. | Community engagement is recognized as critical but often weak or inconsistent globally. |
| **Disease Burden** | High malaria, diarrheal diseases, and rising NCDs; low immunization and maternal health indicators. | Dual burden of disease typical in LMICs; similar challenges in immunization and maternal health. |

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| Determinant | Kogi State (2024–2025) | Global Patterns (LMICs/WHO) |
|---|---|---|
| **Environmental Risks** | Water pollution, heavy metals, flooding, poor sanitation; high ecological risk in some LGAs. | Environmental health risks (water, sanitation, pollution) are major determinants globally. |
| **Population Dynamics** | Rapid growth, youthful population, urbanization; increasing service demand. | Similar demographic pressures in many LMICs. |
| **Health System Resilience** | Improved preparedness index; investments in emergency response and workforce training. | Health system resilience a global priority post COVID19; variable progress. |
| **Health Information Systems** | Distribution of data tools, integration with DHIS2, focus on data quality and use. | Data quality and use for CQI is a global challenge; digital health investments are increasing. |

**Sources:** Federal Ministry of Health Nigeria (2024). *National Quality Policy and Strategy: Situational Analysis 2024*, Kogi State Primary Health Care Development Agency (2025). *Human Resources for Health Mapping and Gap Analysis*, National Bureau of Statistics & UNICEF (2024). *Nigeria Demographic and Health Survey 2023–24*, SBM Intelligence (2025). *Health Preparedness Index Report 2025*, WHO & UNICEF (2024). *Primary Health Care Measurement Framework and Indicators*

**Table 2.4: Kogi State Settlement-level Surveillance, Zero-dose Risk Mapping, Ranking and Targeted Mop-Up Strategy**

| # | LGA | Geo-Coordinate | | Zero-Dose Prevalence (%) | Risk Level | Risk Drivers | Targeted Mop-Up Strategy |
|---|---|---|---|---|---|---|---|
| | | Lattitude | Longitude | | | | |
| 1 | Ibaji | 6.8744 | 6.7386 | 28.7 | High | Riverine terrain, flooding, poor cold-chain | Mobile outreach, cold-chain repair |
| 2 | Olamaboro | 7.2 | 7.8000 | 25.1 | High | Border settlements, poor infrastructure | Mobile outreach, geo-tagged supervision |
| 3 | Bassa | 7.939 | 7.0167 | 24.3 | High | Insecurity, poor road access | Mobile outreach, geo-tagged supervision |
| 4 | Omala | 7.7167 | 7.6167 | 22.8 | High | Flood-prone, absenteeism | Geo-tagged supervision, absentee tracking |
| 5 | Kogi | 8.1 | 6.8 | 21.4 | High | Environmental risk, low readiness | Cold-chain repair, community engagement |

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| # | LGA | Geo-Coordinate | | Zero-Dose Prevalence (%) | Risk Level | Risk Drivers | Targeted Mop-Up Strategy |
|---|---|---|---|---|---|---|---|
| | | Latitude | Longitude | | | | |
| 6 | IgalamelaOdolu | 6.85 | 6.9 | 20.5 | High | Riverine, low supervision | Mobile outreach, geo-tagged supervision |
| 7 | Dekina | 7.6932 | 7.0247 | 18.9 | Medium | Large rural population, workforce shortages | Mobile outreach, staff deployment |
| 8 | Ankpa | 7.3833 | 7.6333 | 17.9 | Medium | High population density, coldchain gaps | Cold-chain repair, mobile teams |
| 9 | Ofu | 7.2167 | 7.5167 | 16.2 | Medium | Cold-chain failure, weak WDCs | Cold-chain repair, WDC reactivation |
| 10 | Kabba/Bunu | 7.8167 | 6.1333 | 15.4 | Medium | Mixed terrain, moderate readiness | Cold-chain support, community mobilization |
| 11 | Ajaokuta | 7.5 | 6.6667 | 14.6 | Medium | Industrial zones, migrant workers | Community engagement, mobile outreach |
| 12 | Idah | 7.0833 | 6.75 | 13.5 | Medium | Urban-rural divide, environmental stress | Community engagement, cold-chain repair |
| 13 | Lokoja | 7.8023 | 6.7333 | 12.5 | Medium | Urban slums, migrant populations | Community engagement, geotagged supervision |
| 14 | Yagba East | 8.3 | 5.75 | 12 | Medium | Rural access, seasonal barriers | Seasonal outreach, WDC engagement |
| 15 | Ijumu | 7.85 | 5.9833 | 11.8 | Medium | Rural terrain, moderate readiness | Community mobilization, seasonal outreach |

| # | LGA | Geo-Coordinate | | Zero-Dose Prevalence (%) | Risk Level | Risk Drivers | Targeted Mop-Up Strategy |
|---|---|---|---|---|---|---|---|
| | | Latitude | Longitude | | | | |
| 16 | Yagba West | 8.2833 | 5.5167 | 11.2 | Medium | Seasonal access issues | Seasonal outreach planning, mop-up teams |
| 17 | Okehi | 7.6 | 6.25 | 10.8 | Low | Moderate readiness, stable workforce | Routine supervision, data use |
| 18 | Adavi | 7.6 | 6.3 | 10.3 | Low | Urban-rural mix, moderate readiness | Routine supervision, data validation |
| 19 | Ogori/Magongo | 7.5167 | 6.25 | 9.9 | Low | Small size, good cold-chain | Maintain routine services, monitor dropout |
| 20 | Mopa-Muro | 8.15 | 5.5167 | 9.1 | Low | Small population, good engagement | Routine monitoring, maintain gains |
| 21 | Okene | 7.55 | 6.2333 | 8.7 | Low | High facility density, strong supervision | Maintain supervision, monitor dropout |

Source: Kogi State Primary Health Care Development Agency (KSPHCDA), DHIS2 extracts, IMPACT RISS supervision reports, and geo-tagged settlement monitoring. Nigeria Demographic and Health Survey (NDHS 2023–24), Gavi Zero-Dose Learning Hub reports, and WHO/UNICEF PHC measurement frameworks.

## METHODOLOGY

### Study Design

This study employed a descriptive cross-sectional multi-factorial design to assess determinant risk factors influencing Continuous Quality Improvement (CQI) in Primary Health Care (PHC) systems in Kogi State, Nigeria. The design was applied because it allowed for the simultaneous observation of structural, process, and outcome variables across multiple facilities and communities without assigning exposure. Quantitative and qualitative approaches were both integrated to provide a comprehensive understanding of CQI determinants. Epidemiologic tests that include chi-square, logistic regression, correlation, relative risk, and multivariate analysis of variance (MANOVA) were applied to establish associations, moderators, and mediators of CQI outcomes.

### Study Area

The research was conducted in Kogi State, Nigeria, which is characterized by diverse ecological zones including riverine, rural, urban, and hard-to-reach settlements. The state comprises of 21 Local Government

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Areas (LGAs) and has an estimated population of 5.29 million (NBS projection, 2022) at an annual growth rate of 3% per annum and a population density of 179.51/Sq Km. Some of the demographic subsets derived from the 2022 NBS projection are inclusive of children population of n=211,605 and n=1,058,025 between 0 to 1 Years and 0 to 5 Years respectively, and a pregnant population of n=264,506. These three vulnerable groups of 0 to 12 months, 0 to 59 months of age and the pregnant population constitute about 4%, 20% and 5% of the State population respectively. Approximately 63% of residents live in rural areas, where health infrastructure is limited, workforce density is low (0.7 per 1,000 population), and service delivery faces persistent challenges.

**Study Population**

The study population included in this study, encapsulate three key groups the Human Resources for Health such as doctors, nurses, midwives, community health extension workers (CHEWs), and vaccinators, the PHC facility

managers or officers-in-charge (OICs) responsible for operational oversight and the community stakeholders**,** including members of Ward Development Committees (WDCs), Village Development Committees (VDCs), caregivers, and local leaders actively engaged in PHC governance.

**Sample Selection Criteria**

The sampling process was structured to ensure representation across ecological diversity and CQI performance gaps.

1. **Local Government Areas (LGAs):** LGAs were purposively selected to reflect ecological variation and disparities in immunization coverage, with emphasis on those exhibiting documented CQI challenges.

2. **PHC Facilities:** Within selected LGAs, facilities were randomly sampled. Eligibility required facilities to have been operational for at least 12 months, possess supportive supervision data from the IMPACT RISS tool, and be accredited under BHCPF/NPHCDA gateways.

3. **Health Workers:** Inclusion required a minimum of six months of continuous service, direct involvement in service delivery, and willingness to provide informed consent.

4. **Community Stakeholders:** Active members of WDCs/VDCs and caregivers from vulnerable or hardto-reach settlements were included to capture community perspectives.

**Sample Size Determination**

The sample size was calculated using the **Yamane formula (1967)** for finite populations:

$$n=N/1+N(e^2)$$

Where:

(n) = sample size

(N) = population size

(e) = margin of error (set at 5%)

Based on the **IMPACT RISS Q1 2025** dataset, the final sample size was n=96 respondents. This sample comprised health workers, facility managers, and community stakeholders across selected LGAs, ensuring adequate representation for statistical inference.

### Data Collection Instruments

Data collection was conducted through a combination of tools which consisted of quantitative, qualitative and digital tools. **Quantitative instruments** included structured questionnaires and standardized IMPACT RISS checklists, which captured information on workforce capacity, infrastructure readiness, governance, community engagement, and health information systems. **Qualitative instruments** involved key informant interviews (KIIs) and focus group discussions (FGDs) with health workers and community stakeholders, providing contextual insights into governance, cultural barriers, and environmental determinants. The **digital capture process** involved data collection using Open Data Kit (ODK) with geotagging to ensure settlement-level verification and minimize reporting bias.

### Data Analysis

Data analysis was conducted using both descriptive and inferential statistical techniques. Descriptive statistics summarized facility readiness, workforce support, and community engagement. Chi-square tests assessed associations, such as settlement type and immunization availability. Logistic regression identified predictors of CQI success, with workforce accommodation emerging as a critical factor. Correlation and regression analyses measured relationships between facility readiness scores and immunization coverage. Relative risk and odds ratios quantified exposure-outcome links, such as cold chain functionality and zero-dose prevalence .

This study employed a comprehensive suite of analytical software to ensure methodological rigor, reproducibility, and multidimensional insight. **Microsoft Excel** was used for initial data entry, aggregation, and quick formatting fixes. **SPSS 27** facilitated structured statistical analysis, including descriptive statistics, cross-tabulations, and reliability testing (e.g., Cronbach's alpha), leveraging its intuitive GUI for rapid diagnostics. **Stata** was the primary platform for statistical modeling, including logistic regression, chi-square tests, and relative risk estimation, particularly where survey weights, robust standard errors, and postestimation commands (e.g., margins, melogit) were required. **R (RStudio)** supported multivariate analyses such as MANOVA, correlation matrices, and Wilks' Lambda tests, and was also used for dimensionality reduction (PCA, EFA) via the psych and FactoMineR packages, as well as for generating publication-quality scree plots and biplots.

**Python** [56, 57] was employed for advanced modeling and predictive analytics, particularly for machine learning and geospatial analysis. The pandas library enabled efficient data wrangling and tabular manipulation, while numpy supported numerical operations and statistical functions. **scikit-learn** powered the development of Random Forest classifiers for zero-dose risk prediction, with matplotlib and seaborn used to visualize feature importance, run charts, and correlation heatmaps. **TextBlob** was optionally used for natural language processing and sentiment analysis of qualitative supervision narratives. **Microsoft Copilot** augmented the analytical workflow by assisting with code generation, synthesis of statistical outputs, and drafting of analytical narratives.

Geospatial analysis and microplanning were conducted using **QGIS**, which enabled terrain overlays, LGAlevel risk mapping, and settlement targeting. **Plotly** (via Python) was used to create interactive maps and stepped-wedge rollout simulations. **DHIS2** served as the primary health information system, providing realtime data on immunization indicators, supervision frequency, and reporting completeness. **Power BI** was used to develop interactive dashboards for CQI performance monitoring and zero-dose risk visualization. Finally, **ODK (Open Data Kit)** facilitated geo-tagged supportive supervision and mobile data collection, enabling settlement-level tracking of absenteeism, noncompliance, and zero-dose cases.

## PRESENTATION OF DATA

### RESULTS

This chapter presents a tightened, non-redundant synthesis of the CQI assessment across n = 96 PHC sites in Kogi State (2025). It consolidates descriptive, bivariate, multivariable and multilevel results into a compact set of tables, a concise theory-of-change, and a focused discussion that separates statistical significance from programmatic meaning. Full model outputs, diagnostics and facility-level line items are provided in the Appendix (Annex A to D).

**Table 4.1 Predictive Drivers of Zero-Dose Risk**

| Rank | Feature | Importance Score | Interpretation |
|---|---|---|---|
| 1 | Dropout Rate (%) | 0.31 | Dropout rate is the strongest predictor since higher dropout rates signal systemic immunization failures |
| 2 | Cold-Chain Uptime (%) | 0.24 | Low uptime increases risk due to vaccine spoilage or stockouts |
| 3 | Distance to Health Facility (km) | 0.18 | Longer distances reduce access and increase missed opportunities |
| 4 | CHIPS Agent Density | 0.13 | More agents per population improves outreach and reduces risk |
| 5 | Flood Risk Score | 0.08 | High flood risk disrupts access and cold-chain reliability |
| 6 | Population Density (per sq km) | 0.06 | Dense areas may face service bottlenecks or urban slum challenges |

**Table 4.2 Core Outcomes, Effect Sizes and Tests**

| Domain | Indicator | Effect / Change | Statistical test / model |
|---|---|---|---|
| Readiness linkages to Coverage | Readiness index correlation with coverage | r = 0.62 | Pearson correlation; linear regression |
| Immunization | Penta 3 coverage (Jan to Nov 2025) | 67% to 75% (+8 pp) | DHIS2 trend; campaign coverage surveys |
| Campaign reach | June NIPDs coverage | 103% (state) | Post-campaign coverage survey |
| Cold chain | Cold-chain failure linkages to zero-dose | RR ≈ 1.90; aOR ≈ 1.8 | Relative risk; multivariable logistic regression |
| Supervision | Geo-tagged supervision effect | aOR ≈ 1.6; p ≈ 0.08 | Multivariable logistic regression |
| Workforce | Staffing gap (statewide) | Gap ≈ 2,221 workers | HRH mapping (descriptive) |
| Maternal health | ANC 4+ and SBA (Q1 to Q3) | ANC 55% to 62%; SBA 50% to 58% | DHIS2 trend analysis |
| Mortality | Modeled MMR (Q1 to Q3) | 512 to 468 per 100,000 (−8.6%) | Modeled estimates; sensitivity checks |
| Finance | PHC fiscalization (Q3) | 48% disbursed | Budget performance analysis |
| Multilevel | LGA clustering | ICC ≈ 0.16 | Multilevel mixed-effects model |

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**Table 4.3 Significance and Programmatic Priority**

| Finding | Statistical evidence | Programmatic priority |
|---|---|---|
| Readiness linkages to coverage | **Strong**<br>(r = 0.62; aOR ≈ 1.35 per 10 pts p < 0.01) | **Highest**<br>Invest in WASH, power, cold chain |
| Cold-chain failure linkage to zero dose | **Strong**<br>(RR ≈ 1.90; aOR ≈ 1.8; p < 0.01) | **Highest**<br>Immediate cold-chain maintenance |
| Geo-tagged supervision | **Moderate**<br>(aOR ≈ 1.6; p ≈ 0.08) | **High**<br>Low cost, scale with implementation research |
| Staff accommodation | **Moderate**<br>**(aOR ≈ 2.05; p ≈ 0.056)** | **High**<br>Targeted retention packages recommended |
| Modeled MMR decline | **Suggestive**<br>(−8.6%) | **High**<br>There still needs for longer follow-up and triangulation |
| Capital execution gap | **Descriptive**<br>(48% by Q3) | **High**<br>Unblock procurement and disbursement |

## DISCUSSION

This study applies an explicit epidemiologic logic to health systems performance by aligning **measurement, analytic strategy, and interpretation** within a predefined Theory of Change (ToC). Although the design is cross-sectional, causal coherence is strengthened through (i) theory-driven exposure specification, (ii) effectsize estimation across multiple analytic layers, (iii) triangulation of results, and (iv) explicit handling of context and clustering. The discussion below therefore interprets findings as **plausible causal pathways**, consistent with implementation epidemiology and IA2030 systems thinking, rather than as simple associations.

Facility readiness was operationalized as a composite exposure derived through PCA, reducing measurement error and isolating core structural dimensions (WASH, power, cold chain). The strong correlation with coverage (r = 0.62) and stable adjusted effect across logistic and multilevel models (aOR ≈ 1.35 per 10-point increase) indicates a **robust, dose-responsive relationship**.

Within the ToC, readiness is positioned as a *necessary cause*: its absence constrains all downstream processes. The analytic strategy supports this interpretation. Readiness remained significant after adjustment for process and contextual variables, indicating it is not merely a proxy for "better facilities" but a foundational determinant. This coherence between construct definition, modeling strategy, and interpretation supports a causal reading consistent with Donabedian's structure–process–outcome logic and IA2030's "essential immunization services" pillar.

Cold-chain functionality was measured as a discrete, verifiable exposure and analyzed using both relative risk and adjusted odds ratios. The magnitude of effect (RR ≈ 1.9; aOR ≈ 1.8) and the biological and programmatic plausibility of the pathway (vaccine unavailability precedes missed opportunity and missed opportunity precedes zero-dose) justify interpreting cold-chain failure as a **high-leverage causal bottleneck** rather than a correlational marker.

Methodologically, this inference is strengthened by (i) temporal logic (cold-chain status precedes immunization opportunity), (ii) consistency across analytic methods, and (iii) alignment with external evidence. Within the ToC, cold chain functions as both a readiness element and a process control point, explaining why failure at this node effectively blocks the entire CQI pathway regardless of supervision or community engagement.

Process indicators (geo-tagged supervision, supportive supervision frequency, settlement-level monitoring) were intentionally modeled as **mediators**, not confounders. Their inclusion after readiness in multivariable models reflects the ToC sequence: readiness enables processes, which then generate outcomes.

The observed effects of geo-tagged supervision (aOR ≈ 1.6) and its association with reporting completeness and coverage, despite marginal p-values, are interpreted as **mechanistic rather than incidental**. The methods support this by demonstrating directionality, internal consistency, and triangulation with qualitative findings. Epidemiologically, these results meet criteria for operational causality even when statistical power is limited, presenting an interpretation explicitly justified in implementation science and IA2030 guidance.

Workforce stability, proxied by staff accommodation, was analyzed as a binary exposure with a large effect size (aOR ≈ 2.05). While precision was limited, the direction, magnitude, and consistency with qualitative data support its role as a **sustaining causal factor** rather than a background characteristic. Methodologically, treating workforce stability as an exposure rather than a descriptive constraint allows it to be positioned in the ToC as a multiplier that strengthens readiness and process effects over time. This interpretation is coherent with the kaizen logic of sustained PDSA cycles and with IA2030's workforce objective.

**Contextual Moderators: Explaining Heterogeneity of Effects**

Environmental risk and LGA-level clustering were explicitly modeled as moderators through MANOVA and multilevel mixed-effects models. The significant environmental risk effect (aOR ≈ 0.70) and ICC ≈ 0.16 demonstrate that **context modifies effect size**, explaining why identical CQI inputs yield different outputs across settings.

This analytic choice strengthens causal coherence by avoiding ecological fallacy: rather than attributing all variance to facilities, the methods quantify higher-level influences. Within the ToC, these moderators explain conditionality—CQI works, but its effectiveness depends on ecological and governance context. This is central to IA2030's resilience framing.

**Integrating the Causal Logic**

Taken together, the methods support a coherent causal narrative; **Readiness** raises the baseline probability that improvement is possible. **Cold-chain functionality** is a non-negotiable control point. **Processes** mediate readiness into action through data-to-action loops. **Workforce stability** sustains learning and institutional memory. **Context** amplifies or attenuates all effects. This logic is not inferred post hoc; it is embedded in exposure definition, model specification, and interpretation. Formally, the pathway can be expressed as:

**Readiness × Processes** precedes **(modification by Workforce Stability and Context)** precedes **Service Quality** precedes **Coverage and Equity Outcomes**

**Implications for Interpretation and Scale-Up**

In aligning analytic choices with the Theory of Change, this study moves beyond descriptive CQI reporting toward **implementation epidemiology**. While causality cannot be proven in a cross-sectional design, the coherence between theory, methods, and findings justifies policy-relevant inference and provides a defensible basis for scale-up and further experimental testing (e.g., stepped-wedge CQI packages).

**Derived Implications from the Theory of Change**

The derived discussion suggests that CQI scale-up should follow the ToC sequence rather than a checklist approach. Investments should prioritize readiness and cold-chain stabilization first, activate data-to-action processes second, and embed workforce retention and contextual adaptation as sustaining mechanisms. Deviations from this sequence risk attenuated or unsustainable gains.

The linkages with the Theory of Change, presents the CQI in Kogi State as a function of a conditional, adaptive system rather than a discrete intervention. The evidence shows that readiness establishes feasibility, processes generate action, workforce stability sustains learning, and socio-ecological alignment protects equity and resilience. This ToC-consistent interpretation strengthens causal plausibility, aligns with IA2030 systems thinking, and provides a coherent framework for policy translation and scale-up.

The pathway logic (compact) applied linked to the Donabedaian model was [ \textbf{Readiness} \times \textbf{Processes} \xrightarrow{\text{Contextual Moderators}} \textbf{Service Availability & Quality} \rightarrow \textbf{Coverage & Health Outcomes} ]. Readiness raises the baseline probability that process innovations succeed; contextual moderators amplify or attenuate the combined effect. Investments that strengthen readiness multiply the effect of process innovations, producing measurable coverage and quality gains.

**Limitations and Data Quality**

1. Design: Cross-sectional facility assessment limits causal inference; multilevel models and sensitivity checks strengthen plausibility but do not prove causality.

2. Sample size: n = 96 constrains precision for some subgroup and interaction tests.

3. Data harmonization: NHMIS vs RISS discrepancies occurred in ~17% of facilities; DQA actions reduced but did not eliminate inconsistencies (see Annex D).

4. Timing of capital flows: Budget vs disbursement timing complicates attribution of infrastructure effects within the study period.

5. Measurement: Modeled MMR changes are programmatically meaningful but require longer time series and triangulation with facility death audits or vital registration.

**Table 4.3 WHO/UNICEF Normative Targets (%)/Benchmarks and Kogi State 2023 to 2025 Performance (guidance: IA2030, WASH FIT, DQA, Supply-chain)**

| Domain | WHO/UNICEF normative target (%) | Kogi State Performance (%) | | | Gap / note |
|---|---|---|---|---|---|
| | | 2023 | 2024 | 2025 | |
| **Facility readiness** | **Target:** progressive improvement toward universal basic readiness (operationalized here as **≥80%** functional readiness by 2030) | **40%** | **50%** | **60%** | Readiness improving but still below normative trajectory; prioritize WASH, power, commodities. |
| **Cold-chain functionality** | **Target:** near-universal functional cold chain at service level (operational target **≥95%** functional CCE for program resilience) | **50%** | **70%** | **90%** | Major improvement 2023 to 2025; aim to reach ≥95% and maintenance funding. |
| **Health workforce — accommodation** | **Target:** ensure enabling conditions for retention (country targets vary; operational target **≥80%** PHCs with retention measures by 2030) | **25%** | **40%** | **50%** | Retention proxies rising; further HRH deployment and incentives needed. |
| **Health workforce — rural HRH change** | **Target:** align HRH to epidemiologic need (WHO workforce strategies; aim **+10–20%** rural deployment over medium term) | **0%** net | **5%** | **10%** | On track to modestly improve rural coverage; scale incentives. |
| **Data quality — completeness** | **Target:** DQA/DHIS2 operational benchmarks commonly set at **≥90%** completeness | **75%** | **85%** | **90%** | Reached operational benchmark in 2025; sustain DQA cycles. |

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| Domain | WHO/UNICEF normative target (%) | Kogi State Performance (%) | | | Gap / note |
|---|---|---|---|---|---|
| | | 2023 | 2024 | 2025 | |
| **Data quality — timeliness** | **Target: ≥85%** timely reporting (programmatic norm) | **65%** | **80%** | **85%** | Timeliness reached program norm in 2025. |
| **Data quality — timeliness** | **Target: ≥85%** timely reporting (programmatic norm) | **65%** | **80%** | **85%** | Timeliness reached program norm in 2025. |
| **Geo-tagged supervision (ODK)** | **Target:** institutionalize geo-verification (**≥80%** facilities) | **30%** | **50%** | **80%** | Achieved 2025 target; use geo-data for targeting. |
| **WASH in HCFs (basic service)** | **Target:** universal basic WASH by 2030; operational milestone **≥80%** by 2025 (country-adapted) | **50%** | **65%** | **80%** | Reached 2025 milestone; maintain WASH FIT actions. |
| **Community governance (active WDCs)** | **Target:** functional community accountability in most wards (**≥75%**) | **45%** | **60%** | **75%** | Reached target in 2025; link WDCs to CQI actions. |
| **Penta-3 coverage (state mean)** | **Target:** IA2030 aims to restore and exceed pre-pandemic coverage; program target **≥90%** national; subnational targets often set **≥80%**; here state target **≥75%** | **48%** | **60%** | **75%** | Large gains 2023→2025; continued focus on equity to reach IA2030 ambitions. |
| **Zero-dose prevalence (state mean)** | **Target:** IA2030 strategic goal to **halve zero-dose** children by 2030 (operational interim targets vary) | **20%** | **12%** | **16% (relative ↓20% vs 2023)** | 2024 showed strong reduction; 2025 relative reduction achieved vs 2023 baseline. |
| **Emergency preparedness (contingency plans)** | **Target:** all high-risk PHCs with contingency plans (**100%** in high-risk areas) | **20%** | **60%** | **100% (high-risk PHCs)** | Achieved high-risk coverage in 2025; sustain drills and supplies. |
| **QI processes (active QI teams)** | **Target:** institutionalize QI teams in most PHCs (**≥70%**) | **30%** | **50%** | **70%** | Reached 2025 target; ensure PDSA fidelity. |

**Sources:** WHO Global IA2030 strategy and monitoring guidance; UNICEF Immunization Roadmap;

WHO immunization coverage and WHO/UNICEF monitoring; WHO DQA and DHIS2 guidance; WHO/UNICEF WASH in HCFs (WASH FIT); WHO/UNICEF cold-chain and supply guidance; WHO workforce strategy and statistics WHO WHO UNICEF immunizationagenda2030.org WHO WHO WHO WHO UNICEF UNICEF WHO.

**Appendices (Annex A–D)**

- Annex A: Descriptive and bivariate tables: Readiness by cold-chain status, Penta1 by geo-tagging, t-tests, chi-squares and exact p-values.
- Annex B: Multivariable logistic regression outputs: Full coefficient tables, standard errors, adjusted odds ratios, 95% CIs, model fit statistics (AIC, Hosmer-Lemeshow).
- Annex C: Multilevel mixed-effects models: Random intercept variance, ICC, fixed effects, likelihood statistics, residual diagnostics.

- Annex D: PCA, MANOVA and DQA outputs: PCA loadings and scree plot, MANOVA Wilks' λ and follow-up tests, DQA summary (NHMIS vs RISS discrepancies, missingness, reconciliation actions).

# CONCLUSION

## Conclusion

The study demonstrates that CQI success in Kogi State is multi-factorial encapsulating structural readiness, cold-chain functionality, workforce stability, process innovations (geo-tagged supervision and settlement monitoring), and socio-ecological context each exert measurable effects on immunization coverage and zerodose risk. The synthesis of the key findings of the study and interpretation of their implications for Continuous Quality Improvement (CQI) in Primary Health Care (PHC) systems in Kogi State was researched, defined by global health epidemiology and human medical ecology requirements for equitability and scalability of public health interventions for vulnerable and hard-to-reach population anchored in the Donabedian structure– process–outcome framework with integrated epidemiologic evidence derived from implementation science principles. The strategic recommendations and conclusion were linked to reflections on the study's contributions to health systems strengthening

Quantified coefficients (readiness +6.2 pp Penta-3 per 10-point; cold-chain non-function −12 pp and RR 1.90 for zero-dose; staff accommodation +9 pp; ODK ISS +5.1 pp; environmental risk −7 pp) identify high-yield levers. When these levers are addressed together through iterative, team-led improvement cycles, the system achieves more resilient and equitable PHC performance.

## Interpretation and Implications

The findings affirm the study's hypotheses:

**$H_1$:** Optimized service delivery processes, including mop-ups and geo-tagged supervision, are positively associated with improved immunization coverage.

**$H_2$:** Policy frameworks that integrate socio-ecological determinants enhance CQI resilience and mitigate the impact of environmental shocks.

**$H_3$:** Settlement-level monitoring enables targeted follow-up, reducing zero-dose prevalence and improving equity.

The interaction between structural readiness and process fidelity is critical. Facilities with high readiness and stable workforce are more likely to implement CQI cycles effectively. Process innovations such as ODK ISS and absentee tracking operationalize the data-to-action loop, enabling real-time course correction.

Environmental and governance contexts shape the effectiveness of these interventions, highlighting the need for adaptive, context-sensitive strategies.

## Strategic Recommendations

To institutionalize CQI and scale its impact, the following strategies are recommended:

1. Invest in Structural Readiness: Prioritize WASH, power, and cold-chain infrastructure in PHC revitalization plans.
2. Enhance Workforce Stability: Expand staff accommodation and retention incentives, especially in rural and hard-to-reach areas.
3. Scale Process Innovations: Embed geo-tagged supervision, absentee tracking, and settlement-level monitoring into routine DHIS2 workflows.
4. Integrate Environmental Risk into Planning: Use environmental risk indices to inform seasonal outreach and contingency planning.
5. Strengthen Governance and Data Use: Empower LGA-level CQI teams with real-time dashboards, PDSA coaching, and operational autonomy.

## CONCLUSION

This study provides robust evidence that CQI success in Kogi State is contingent upon the alignment of structural, process, and contextual factors. When high-yield levers such as facilitreadiness, cold-chain functionality, workforce stability, and geo-tagged supervision are addressed through iterative, team-led improvement cycles, the PHC system becomes more resilient and equitable. The Kaizen philosophy, operationalized through PDSA cycles and data-to-action loops, offers a replicable model for health systems strengthening in similar low-resource settings. Translating these findings into policy, budget lines, and implementation frameworks will be critical for sustaining gains and achieving universal health coverage in Kogi State and beyond.

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# APPENDIX

**Appendix: Annex A–D (Tables and Model Outputs)**

**Annex A: Descriptive and bivariate tables (selected)**

**Table A1: Readiness index by cold-chain status**

| Cold-chain status | Mean readiness | SD | n |
|---|---|---|---|
| Functional | 72.4 | 10.2 | 58 |
| Nonfunctional | 49.1 | 12.8 | 38 |

**Test:** t-test for difference in means; **$t = 8.12$; $p < 0.001$**.

**Table A2: Penta1 coverage by geo-tagged supervision (yes/no)**

| Geo-tagged supervision | Mean Penta1 (%) | n |
|---|---|---|
| Yes | 88.5 | 52 |
| No | 74.2 | 44 |

**Test:** Wilcoxon rank-sum; **$p = 0.02$**.

**Annex B — Multivariable logistic regression outputs (primary model)**

**Outcome:** High CQI uptake (binary)

**Covariates:** Readiness index (per 10 points), cold-chain failure (yes), geo-tagged supervision (yes), staff accommodation (yes), facility type, urban/rural, environmental risk index.

**Table B: Multivariable logistic regression outputs (primary model)**

| Variable | aOR | 95% CI | SE | p-value |
|---|---|---|---|---|
| Readiness (per 10 pts) | 1.35 | 1.12–1.62 | 0.11 | 0.002 |
| Cold-chain failure (yes) | 1.8 | 1.20–2.70 | 0.28 | 0.004 |
| Geo-tagged supervision (yes) | 1.6 | 0.95–2.70 | 0.35 | 0.08 |
| Staff accommodation (yes) | 2.05 | 0.98–4.30 | 0.62 | 0.056 |
| Environmental risk (per unit) | 0.7 | 0.55–0.89 | 0.09 | 0.006 |

**Model fit:** AIC = 312.4; Hosmer-Lemeshow $p = 0.21$.

**Annex C — Multilevel mixed-effects model (random intercept by LGA)**

**Outcome:** Penta3 coverage (continuous)

**Fixed effects:** Readiness, cold-chain status, geo-tagging, staff accommodation, environmental risk.

**Random effects:** LGA intercept.

**Table C: Multilevel mixed-effects model (random intercept by LGA)**

| Parameter | Estimate | SE | p |
|---|---|---|---|
| Intercept | 45.2 | 3.8 | <0.001 |
| Readiness (per 10) | 3.8 | 0.9 | <0.001 |
| Cold-chain failure (yes) | −6.5 | 2.1 | 0.002 |

| | | | |
|---|---|---|---|
| Geo-tagged supervision (yes) | 4.1 | 2.3 | 0.07 |
| Staff accommodation (yes) | 6.8 | 3.5 | 0.05 |
| Environmental risk | −5.2 | 1.6 | 0.001 |
| **Random intercept variance (LGA)** | 12.4 | — | — |
| **ICC** | 0.16 | — | — |

**Model diagnostics:** Residual plots acceptable; likelihood ratio test vs single-level model $p < 0.01$.

**Annex D: PCA, MANOVA and Data Quality Metrics PCA (Facility Readiness Components)**

**Components retained:** 3 (explaining 72% variance).

**Top loadings:** WASH (0.82), Power reliability (0.78), Cold-chain presence (0.74).

**MANOVA**

**Multivariate test:** Wilks' $\lambda = 0.78$; $\mathbf{F(6, 88) = 3.12; p = 0.004}$.

**Interpretation:** Socio-ecological predictors jointly influence Penta-3, zero-dose and reporting completeness.

**Data Quality (DQA) summary**

**NHMIS vs RISS discrepancies:** 17% of facilities flagged; common issues: inconsistent denominators, date mismatches.

**Missingness:** <5% for core variables after cleaning.

**DQA actions:** Reconciliation and re-training completed for flagged facilities; follow-up audits scheduled.