Multilevel Determinants and Spatial Heterogeneity of Primary Health Care Under One Roof (PHCUOR) Implementation in Kogi State, Nigeria: A Mixed-Methods Epidemiologic and Implementation-Science Study

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ABSTRACT

Primary Health Care Under One Roof (PHCUOR) is a sub-national governance reform initiated to minimize institutional fragmentation by consolidating primary healthcare platforms under a single unified coordination authority. Despite political commitments, implementation fidelity varies across decentralized clinical ecosystems. This study systematically assesses the multi-level structural determinants and sub-national spatial heterogeneity of primary care quality and operational risk factors in Kogi State, Nigeria, to support an evidence-informed framework for health systems strengthening.

We adopted a multi-stage, sequential exploratory mixed-methods epidemiological and implementation-science framework explicitly grounded in a Structure–Process–Outcome (SPO) design. Quantitative and qualitative data analysis was executed within a unified, versioned computational environment utilizing Stata Version 18.0 and R Version 4.3.2 via a rigid, multi-stage sequential approach. To prevent predictor variable fabrication and data contamination due to unpopulated institutional metrics, a systematic scoping review mapping 100 core sources was executed under a PRISMA-ScR template to establish a highly bounded, theory-driven structural predictor line-list. Quantitative evaluation was executed utilizing secondary data frames comprising N = 3,752 longitudinal facility monitoring records alongside routine health-service payloads across all 21 Local Government Areas (LGAs) of Kogi State. Multivariable maximum likelihood logistic regression models, structured in accordance with TRIPOD+AI guidelines, isolated the independent predictive impacts of baseline structural inputs on the probability of Strategic Focus Failure (Quality Assurance Score < 85 or location mismatch). A secondary Bayesian hierarchical latent Gaussian Besag–York–Mollié 2 (BYM2) spatial model was specified via R-INLA to characterize residual spatial dependence. Quantitative parameters were integrated with qualitative key-informant interviews (n=160 linked facilities audited) using a mixed-methods triangulation display matrix.

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Logistical supply chain breakdowns dominated systemic risk, more than doubling the odds of primary care focus failure (OR = 2.412, z = 10.02, P < 0.001), while Bayesian spatial models confirmed strong geographic dependence in residual implementation gaps (ρ = 0.71, 95% CrI: 0.63–0.79). Systemic workforce deprivation operated as a significant secondary risk multiplier, expanding the odds of operational focus failure by 89.6% (OR = 1.896, z = 8.44, P < 0.001), whereas physical accommodation deficits presented the weakest independent association (OR = 1.241, z = 2.35, P = 0.019). The multivariable predictive framework demonstrated robust fit parameters (McFadden's Pseudo-R^2 = 0.2190) and stable calibration (Hosmer-Lemeshow P = 0.6315). Qualitative mechanisms contextualized the high spatial correlation parameter (ρ = 0.71), linking residual geographic clustering to topological access vulnerabilities and seasonal riverine flooding along the Niger-Benue confluence zone.

Advancing toward full, functional PHCUOR policy implementation requires a transition from passive administrative checklists to precision public health frameworks that target modifiable supply chain and workforce constraints. Resolving tracking anomalies through standardized crosswalk registries is an essential prerequisite for confirming sub-national mediation pathways and establishing health systems strengthening that is accountable.

Keywords: Primary Health Care Under One Roof; multi-level epidemiology; spatial heterogeneity; implementation science; PRISMA ScR, Bayesian Additive Regression Trees; BYM2; TRIPOD+AI; precision public health; Nigeria.

INTRODUCTION

Background to the Study

Primary Health Care Under One Roof (PHCUOR) represents a comprehensive governance and operational health-system reform initiated by the Federal Government of Nigeria and driven by the National Primary Health Care Development Agency (NPHCDA). The strategic intention of this reform is to address institutional fragmentation by consolidating primary healthcare planning, financing, human-resource management, health information systems, and clinical service delivery under a unified, sub-national management authority. Structurally, the policy targets the institutionalization of the "three ones" principle: one integrated management body, one comprehensive operational plan, and one unified monitoring and evaluation system at the sub-national level. By establishing State Primary Health Care Development Agencies (SPHCDAs) and Local Government Health Authorities (LGHAs), the reform seeks to eliminate overlapping institutional mandates, bridge the historic gap between state ministries and local government service provision, and maximize policy execution fidelity.

In decentralized health systems, however, the formal adoption of a legislative policy does not automatically translate into operational integration or uniform performance across frontline service environments. Sub-national health systems operate within complex socioeconomic, institutional, and geographical contexts that directly shape implementation outcomes. Kogi State features marked ecological, topological, and infrastructural variations across its 21 Local Government Areas (LGAs) and 239 administrative wards. These variations create uneven distributions of clinical personnel, varying levels of facility service readiness, fragmented supply chains, and disparate local managerial capacities. Consequently, while macro-level scorecard summaries track formal institutional compliance, they frequently obscure severe local vulnerabilities, tracking omissions, and data linkage failures that manifest at the facility and community interface.

Despite legal mandates and baseline institutional scorecards, the translation of the PHCUOR model from a conceptual policy configuration into active facility-level implementation fidelity remains highly uneven. Sub-national assessments frequently demonstrate stark operational disparities across varying geopolitical zones and local government areas. In Kogi State, characterized by unique geographic topographies and acute resource limitations across its 21 Local Government Areas, primary care centers encounter severe operational mismatches. Systemic challenges including tracking anomalies, missing data linkages, structural

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infrastructure gaps, workforce deprivations, and uncoordinated commodity chains introduce significant vulnerability, culminating in widespread Strategic Focus Failure. Without robust epidemiological investigation, the latent spatial patterns and absolute risk contributions of these structural system components remain unquantified, crippling precision health systems engineering.

Objective of the Study

This investigation establishes a comprehensive, empirical evaluation matrix designed to isolate and characterize the multi-level determinants driving implementation quality across the primary healthcare network. Specifically, this study aims to:

- Systematically resolve identity anomalies across diverse administrative health tracking frames using a normalized multi-field alphanumeric crosswalk algorithm.
- Quantify the individual and joint predictive impacts of physical infrastructure deficits, human resource deprivations, and logistical supply chain disruptions on health system performance through robust multivariable logistic regressions.
- Characterize and map latent sub-national spatial heterogeneity and geographical clustering across the 21 Local Government Areas using advanced Bayesian Hierarchical Besag–York–Mollié 2 (BYM2) modeling architectures.
- Triangulate quantitative statistical risk parameters with qualitative frontline mechanisms to build a reproducible mixed-methods display matrix for strategic health interventions.

Justification for the Study

This study is justified by the critical public-health need to transition sub-national policy evaluation from passive administrative reporting to rigorous, empirically validated systems epidemiology. Nationally and sub-nationally, substantial resources are allocated to health-sector governance reforms under the Health Sector Renewal Investment Initiative, the Sector-Wide Approach (SWAp), and the Basic Health Care Provision Fund (BHCPF 2.0). However, without a rigorous, model-driven evaluation of sub-national implementation dynamics, state actors risk executing interventions based on unverified data or fragmented administrative proxy metrics. This study directly addresses this operational gap by establishing a clear methodology to analyze secondary administrative records while strictly enforcing anti-contamination data controls.

Methodologically, this investigation provides a vital template for data quality assurance in decentralized, resource-constrained settings. Exposing a 19-record discrepancy within active tracking crosswalks and documenting an 830-facility routine-immunization linkage limitation, demonstrates why facility string names cannot be substituted for verified physical identities without introducing substantial parameter bias. The McFadden's Pseudo-R^2 logic and robust post-estimation diagnostics application to an explicit exploratory Structure–Process–Outcome design, establishes a reproducible approach to model structural risk factors even when primary policy indices remain unpopulated or incomplete.

Strategically and epidemiologically, the project connects directly with the tenets of Precision Public Health and Translational Epidemiology. Rather than generating abstract theoretical conclusions, this research isolates specific, modifiable health-system targets, such as supply-chain vulnerabilities (OR = 2.412) and workforce deprivation (OR = 1.896). The mapping of these parameters into a phased, 24-month operational roadmap provides the Kogi State Primary Health Care Development Agency (KSPHCDA) and its development partners with an actionable, evidence-linked framework to guide resource allocation, target supportive supervision, resolve tracking anomalies, and sustainably improve primary healthcare delivery.

Research Questions

- What specific institutional patterns, structural strengths, and operational gaps characterize the historical PHCUOR implementation scorecards in Kogi State?

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- Which multi-level governance, workforce, financial, and logistical factors act as potential enabling conditions or structural barriers to system performance?
- What is the precise data-readiness and technical validity status of the active sub-national data packages when evaluated against a standardized validation gate framework?
- What crude bivariate associations can be established between baseline structural system inputs and operational service delivery process outcomes?
- What independent predictive associations exist when structural risk determinants are simultaneously evaluated against strategic focus failure probabilities in a multivariable model?
- How effectively do exploratory maximum likelihood regression models discriminate and calibrate high-risk operational environments across administrative local government area clusters?
- To what degree do structural covariates exhibit multicollinearity or inflation within sub-national primary care evaluation datasets?
- Through what specific organizational mechanisms do authority constraints, budget delays, personnel shortages, and unverified facility identities limit routine policy execution?
- What structural root causes and operational system bottlenecks emerge when quantitative indicators are triangulated with qualitative accounts and documentary evidence?
- How can empirical risk parameters and multi-level system vulnerabilities be translated into a prioritized, operationally feasible, and measurable sub-national improvement roadmap?

Research Hypotheses

Subject to the extensive data omissions, unpopulated templates, and unverified facility registries documented during the pre-estimation audit, this study formally establishes five Exploratory Strategic Focus Hypotheses (EH_0) evaluated at a strict significance threshold of $P < 0.05$:

• **EH_{01}** (Null Infrastructure Hypothesis): Sub-national primary care physical accommodation deficits (X_1) exhibit no independent statistical association with the probability of strategic focus failure (Y=1). Alternative: Physical accommodation deficits significantly multiply the odds of strategic focus failure.

- **EH_{02}** (Null Workforce Hypothesis): Systemic primary care workforce deprivation (X_2) exhibits no independent statistical association with the probability of strategic focus failure (Y=1). Alternative: Systemic workforce deprivation significantly multiplies the odds of strategic focus failure.
- **EH_{03}** (Null Logistical Hypothesis): Primary care logistical supply chain vulnerability (X_3) exhibits no independent statistical association with the probability of strategic focus failure (Y=1). Alternative: Logistical supply chain vulnerability significantly multiplies the odds of strategic focus failure.
- **EH_{04}** (Null Joint Explanatory Power Hypothesis): The combined integration of multi-level Structure–Process–Outcome (SPO) inputs holds zero joint explanatory power over sub-national administrative quality and operational indicators. Alternative: The joint integration of SPO inputs explains a statistically significant and substantial proportion of variance in sub-national administrative quality.
- **EH_{05}** (Null Crosswalk Identity Moderation Hypothesis): Administrative crosswalk identity resolution and location match status do not significantly moderate or alter the estimated regression parameters of the structural risk determinants. Alternative: Identity resolution and crosswalk location conflicts significantly moderate and distort structural risk parameters.

Operational Definitions of Key Terms

Primary Health Care Under One Roof (PHCUOR): A governance reform intervention intended to integrate primary healthcare coordination under a single state-level management structure, operationalized through nine distinct structural domains.

Implementation Fidelity: The degree to which a specified policy or health system intervention is routinely executed in strict accordance with its original operational designs, standards, and components.

Structure–Process–Outcome (SPO) Framework: An epidemiological evaluation paradigm that posits that health system performance is produced by a causal chain linking structural system inputs to service delivery processes, which subsequently drive clinical outcomes.

Data-Readiness Validation Gates: A series of nine sequential technical checkpoints (G01–G09) that evaluate the completeness, identity verification, and statistical validity of a dataset before executing inferential modeling scripts.

Strategic Focus Failure: A binary operational outcome defined as a facility scoring below the state median Quality Assurance baseline (QA Score < 85) or exhibiting an active location mismatch within the identity crosswalk registry.

Accommodation Deficit: A binary structural risk exposure indicating that a facility possesses a "Very Unsatisfactory" or "Unsatisfactory" physical setup on routine administrative monitoring forms.

Workforce Deprivation: A binary structural risk exposure capturing severe professional staffing shortfalls and below-satisfactory clinical workforce capacity within a designated catchment area.

Supply Chain Vulnerability: A binary structural risk exposure tracking active logistical failures, stock depletion, or recurring stock-out intervals for selected essential tracer medications.

McFadden's Pseudo-R^2: A maximum likelihood goodness-of-fit diagnostic that quantifies the relative log-likelihood improvement of a fitted multivariable model over an intercept-only null baseline model.

Area Under the ROC Curve (AUC / C-Statistic): A metric tracking predictive discrimination that measures the model's capacity to correctly differentiate high-risk operational failure states from stable primary care environments.

Variance Inflation Factor (VIF): An econometric post-estimation diagnostic that evaluates the extent of multicollinearity among independent variables within a multiple regression model.

Crosswalk Adjudication: A multi-field alphanumeric alignment procedure (LGA + Ward + Normalized Name) used to verify facility identities, reconcile registry size discrepancies, and control data contamination across different administrative data frames.

LITERATURE REVIEW

Introduction

Primary Health Care (PHC) is increasingly understood not as a discrete level of clinical care but as the principal organizational interface between populations and health systems. Contemporary PHC integrates first-contact care, prevention, health promotion, community participation, continuity, referral, public-health functions and action on the social determinants of health. The 1978 Declaration of Alma-Ata established primary health care as the foundation for health for all, while the 2018 Astana Declaration renewed this commitment by linking PHC explicitly to universal health coverage (UHC), equity, population participation and the Sustainable Development Goals (SDGs) [1, 5, 6]. WHO and UNICEF subsequently translated these commitments into an Operational Framework comprising interconnected strategic and operational levers spanning political commitment, governance, financing, community engagement, models of care, workforce, infrastructure, medicines, digital technologies, quality improvement, research and monitoring and evaluation [1-4].

The implications of this conceptual evolution are important for the study of Primary Health Care Under One Roof (PHCUOR). A PHC system cannot be considered integrated merely because multiple services are physically colocated or because a state has created a PHC agency. Integration requires coherence in decision-making, financing, planning, workforce administration, information systems, supervision,

accountability and service standards. Consequently, PHCUOR is more appropriately conceptualized as an implementation intervention within a complex health system than as an administrative restructuring exercise. The PHCUOR is therefore examined through the combined lenses of health-systems analysis, epidemiology, implementation science, human medical ecology, multilevel analysis and spatial epidemiology [2-4, 15, 33, 64-70]. The evidence base is organized as a PRISMA-ScR-informed synthesis of 100 core sources encompassing foundational PHC literature, Nigerian policy and implementation evidence, health-system governance research, implementation-science frameworks, causal epidemiology, spatial statistics, mixed-methods methodology and cross-regional country experiences. PRISMA-ScR is appropriate because the evidence relevant to PHCUOR is heterogeneous and includes empirical studies, policy documents, implementation evaluations and grey literature rather than a single homogeneous intervention literature [41-44].

PHC occupies a distinctive position in population health because it connects upstream determinants with downstream service delivery and population outcomes. Strong PHC-oriented systems provide a platform for preventive, promotive, maternal, newborn, child, infectious-disease and increasingly non-communicable-disease services. Evidence synthesized across countries indicates that effective primary care is associated with improvements in access, continuity, preventive care and population health, although the magnitude of these effects depends strongly on organizational context, financing, workforce configuration and the wider health system [11-14, 20-23]. The contemporary WHO interpretation of PHC explicitly combines three interdependent components: integrated health services, multisectoral policy and action on broader determinants of health, and empowerment and participation of people and communities [1-4]. This broader conception distinguishes PHC from a narrow facility-based model in which service delivery is treated independently of governance, community systems, financing or environmental context. A PHC system is therefore a socio-organizational system whose performance depends on the interaction of structures, processes and contextual conditions. The WHO PHC Operational Framework further emphasizes that strategic and operational levers interact rather than operate as independent components. Political commitment influences governance; governance shapes financing and workforce decisions; financing affects service readiness and workforce continuity; workforce availability interacts with models of care; digital and information systems influence monitoring and accountability; and community engagement affects demand, acceptability and responsiveness [1-4]. This interconnectedness is fundamental to the present study because PHCUOR seeks precisely to reduce fragmentation among these functions at sub-national level. The analytical question therefore becomes whether organizational integration produces measurable implementation fidelity and, subsequently, better PHC system performance.

Primary Health Care Under One Roof in Nigeria

Nigeria's PHC system developed within a federal institutional architecture in which responsibilities are shared among federal, state and local-government institutions. Although this arrangement permits decentralization and contextual adaptation, studies of Nigerian health governance have identified overlapping institutional mandates, fragmented accountability, weak coordination and inconsistent managerial authority as recurring system challenges [24-29, 34-40]. The PHCUOR policy was approved by the National Council on Health in 2011 to address this fragmentation by integrating PHC governance and management under a state-level institution, generally represented by a State Primary Health Care Development Agency or Board. The national implementation framework identified nine core domains: governance and ownership; legislation; minimum service package; repositioning; systems development; operational guidelines; human resources; funding sources and structure; and office establishment [26, 27, 57]. The policy was also associated with the principle of “three ones”; one management system, one plan and one monitoring and evaluation system; together with integrated supervision, referral and accountability arrangements [26, 27]. The relevance of these domains extends beyond administrative organization. Governance determines who has authority to make and implement decisions; legislation determines the legal basis of institutional authority; the minimum service package defines expected services; repositioning establishes organizational transition; systems development supports planning and information management; operational guidelines promote standardization; human-resource management determines workforce capacity; funding provides operational resources; and office establishment provides the administrative

infrastructure through which the institution functions. PHCUOR is therefore an integrated health-system intervention whose success depends on the simultaneous functioning of these domains.

Empirical evidence demonstrates that structural adoption and functional implementation are not synonymous. The national PHCUOR fidelity literature identified substantial variation across states and across the nine domains, with formal institutional components tending to perform differently from functional domains such as financing and human-resource management [28, 57]. A later assessment of multiple Nigerian states similarly showed variable performance across governance, legislation, minimum service package, repositioning, systems development, operational guidelines, human resources, financing and office setup [27, 28]. This distinction between policy adoption and implementation fidelity forms a central premise of the present study. A state can possess a formally established PHC agency while retaining fragmented budgeting, workforce administration, information systems, supervision or accountability. The empirical unit of interest is therefore functional PHCUOR rather than institutional existence.

Nigeria's current health-reform environment provides an important institutional context for examining PHCUOR. The Health Sector Renewal Investment Initiative and Sector-Wide Approach emphasize improved coordination among government and development partners, resource alignment, accountability and results-based implementation. The emerging reform architecture is explicitly concerned with reducing siloed implementation and improving coherence through shared planning, budgeting, reporting and policy dialogue [29, 34, 39, 40]. Within this environment, PHCUOR can be conceptualized as a sub-national governance mechanism for translating broader sector-wide principles into functional PHC management. The two reform architectures are not identical: SWAp operates as a health-sector coordination and resource-alignment architecture, whereas PHCUOR focuses principally on PHC governance and management at sub-national level. Their potential interaction is nevertheless important because fragmented PHC governance can weaken the translation of coordinated financing or policy priorities into facility-level implementation. Nigeria's National Health Act provides the broader legal framework for health financing and system organization, while the Basic Health Care Provision Fund provides a specific mechanism for improving access to essential services and strengthening PHC financing [24, 38]. The contemporary reform environment therefore provides an institutional opportunity to investigate whether governance integration, predictable financing, workforce management and information-system integration jointly improve PHCUOR functionality. The WHO African Health Observatory Partnership assessment similarly describes Nigeria as a decentralized health system governed across federal, state and local-government levels, with PHCUOR intended to strengthen PHC coordination. It also notes persistent problems associated with overlap among tiers of government and weaknesses in coordination [34]. The exposure domain of the present study is deliberately multilevel because PHCUOR implementation is produced by determinants operating at multiple organizational and ecological levels. At the state level, political commitment, legislation, governance arrangements, financing and human-resource policy represent upstream structural exposures. At the LGA level, managerial capacity, planning processes, supervision, data use and operational coordination shape implementation environments. At the facility level, workforce availability, infrastructure, commodities, information systems and adherence to operational standards determine implementation capability. At the community and ecological levels, geographical accessibility, transportation, security, socioeconomic conditions, community engagement and local social organization influence the feasibility and reach of PHC implementation [56, 61, 63-72].

This multilevel orientation is consistent with evidence from health-system integration research. Topp and colleagues identified organizational framework, workforce preparedness, community and client preparedness, upstream logistics and policy and governance as important contextual conditions for service integration in low- and middle-income countries. They also identified functional frontline services, trained and motivated personnel, technical tools and equipment, and appropriately devolved decision-making as core health-system capabilities [56]. PHCUOR determinants can therefore be classified as structural, organizational, workforce, financial, information-system, service-readiness, community and socio-ecological exposures. Their effects should not be interpreted as necessarily independent because interactions among these determinants could be fundamental to implementation. Additional financing for instance may have limited effect where authority to allocate resources is weak; workforce expansion may have limited effect

where supervision and accommodation are inadequate; information-system investment may fail where reporting responsibilities remain fragmented. The analytical structure of the study consequently treats the exposure domain as a hierarchy rather than a flat list of variables. The state provides the macroinstitutional environment, LGAs provide intermediate governance and operational context, facilities provide the organizational setting in which policy becomes practice, while wards and communities contribute demand, accessibility and ecological conditions. This architecture permits estimation of both individual-level or facility-level associations and contextual effects.

The Nine PHCUOR Domains as Structured Determinants

Governance and ownership represent the first structural exposure because they determine institutional authority, leadership and accountability. Effective governance requires a clearly defined organizational structure, functional leadership, reporting lines and mechanisms through which performance is monitored and corrective action is taken [26-28, 61-64]. Legislation provides the formal legal foundation that enables PHC agencies to exercise authority, manage personnel and resources, and establish organizational relationships. Legislation without enforcement or administrative functionality, however, may yield structural compliance without functional integration. The minimum service package establishes the expected scope of PHC provision and creates a normative standard against which implementation can be assessed. It provides an important bridge between governance and service outcomes because it determines whether organizational integration is translated into a defined package of services [2, 3, 26]. Repositioning concerns the transfer and restructuring of functions, personnel, systems and responsibilities required to operationalize an integrated PHC agency. This domain is particularly important during institutional transitions because reorganization can produce temporary coordination losses if roles and reporting structures are not clarified.

Systems development encompasses planning, information systems, procurement, referral, supervision, monitoring and other organizational processes through which PHC functions are coordinated. In an integrated health system, these systems should reduce duplication and support common standards and decision-making [7, 8, 34]. Operational guidelines support standardization by converting policy requirements into routine procedures. They influence implementation fidelity because the existence of formal policy cannot guarantee consistent application at facility or LGA level. Human resources for health constitute both a structural determinant and an implementation mechanism. Staffing levels, cadre mix, competence, deployment, retention, supervision and distribution determine whether integrated governance can generate functional services. WHO's workforce strategy recognizes workforce availability, accessibility, acceptability and quality as central requirements for health-system performance [16, 17]. Funding sources and structure determine whether governance arrangements possess sufficient operational capacity. Financing is not only an input but also a determinant of autonomy, continuity, supervision, procurement and service readiness. Predictable financing can facilitate integration, while fragmented or earmarked financing may recreate the vertical structures PHCUOR seeks to reduce [20-23, 38]. Office establishment represents the administrative infrastructure of PHCUOR. Its presence is important, but it is conceptually weaker than functional authority and performance because an office can exist without producing integrated management. It should therefore be measured as a structural exposure rather than treated as proof of overall implementation.

Structure–Process–Outcome Theory as the Principal Theoretical Model

The principal theoretical model adopted for the study is the **Donabedian Structure–Process–Outcome model**. Donabedian conceptualized quality as arising from the relationship between the structure within which care occurs, the processes of care delivered, and the resulting outcomes [45]. The model is particularly compatible with PHCUOR because the nine PHCUOR domains largely represent structural and organizational conditions, while managerial integration, financing integration, workforce integration, information-system coordination, supervision, service standardization and accountability represent processes through which structures are translated into implementation. PHCUOR implementation fidelity is the immediate implementation outcome, while access, quality, equity and standardization represent intermediate health-system outcomes, and morbidity and mortality represent distal population-health outcomes.

The SPO model is extended in this study through the addition of implementation-science and socio-ecological concepts. CFIR provides a multilevel structure for understanding intervention, inner-setting, outer-setting, individual and implementation-process determinants [50]. Normalization Process Theory explains how new organizational practices become embedded in routine work [48]. RE-AIM adds a population and sustainability orientation through reach, effectiveness, adoption, implementation and maintenance [54]. Human medical ecology and spatial epidemiology introduce geography, transportation, environmental context and spatial dependence as characteristics that may modify or redistribute implementation effects [68-72, 85-92]. (PMC) The resulting theoretical proposition is therefore not a simple linear SPO sequence but a multilevel and context-sensitive pathway.

Integrated SPO pathway

The Integrated SPO pathway can be expressed in improved prose as follows:

At the structural level, governance and political commitment, legislation, the definition of a minimum service package, strategic repositioning, systems development, operational guidelines, human resources for health, funding, and the establishment of coordinating offices provide the foundation. These structural elements drive the processes and mediating mechanisms, which include managerial, financial, workforce, and information-system integration, unified planning and budgeting, supervision and mentoring, service standardization, accountability, referral coordination, and community engagement. Together, these processes enable fidelity in PHCUOR implementation. Implementation fidelity then translates into intermediate primary health care system outcomes such as accessibility, service readiness, quality, standardization, equity, continuity, and responsiveness. These outcomes in turn contribute to distal population-health results, including reductions in preventable morbidity and mortality, improvements in maternal, newborn, and child survival, and decreases in geographical and socioeconomic health inequalities. Over time, the system develops longer-term attributes of scalability, comparability, resilience, institutionalization, and sustainability.

Across all stages, contextual determinants such as geography, rurality, transportation, security, socioeconomic conditions, facility type, local government authority capacity, and community context act as moderators of performance. Spatially, measured determinants, structured spatial variation, and unstructured area heterogeneity are jointly represented within a Bayesian spatial framework, ensuring that both contextual and residual influences are analytically captured. The study distinguishes determinants from mediators because the same variable may operate at different causal levels. Political commitment, is an upstream determinant for instance, while managerial integration represents a process through which political commitment can influence implementation. Financing may operate through financial autonomy, budget execution and operational capacity. Workforce policies may operate through staffing availability, deployment, supervision and retention. Information-system investments may operate through integrated reporting, feedback and accountability. Managerial integration is expected to mediate relationships between governance determinants and PHCUOR fidelity because governance provides authority while managerial integration converts that authority into coordinated plans, reporting lines and operational decisions. Financial integration may mediate financing relationships by determining whether funds can be planned and deployed through a common PHC framework rather than remaining fragmented across programmes. Workforce integration may mediate relationships between HRH policy and implementation through unified recruitment, deployment, supervision and performance management.

Integrated planning and monitoring may constitute a further mediator because the principle of one plan and one monitoring and evaluation system depends on information being translated into collective decision-making rather than merely collected. Likewise, supportive supervision may mediate the effect of organizational resources by translating those resources into routine problem-solving, corrective action and adherence to standards. These pathways are consistent with evidence that governance can influence health outcomes directly in some settings but more often acts through intermediary organizational and community mechanisms [61-64]. Bradley and colleagues' review of governance and health outcomes found evidence for both direct and indirect pathways, including pathways mediated or modified by contextual factors [61].The

study consequently distinguished total associations between upstream determinants and PHCUOR fidelity from pathway-specific effects. Any causal interpretation remains conditional on the assumptions required for causal mediation in observational research, including appropriate control of confounding and correct temporal ordering [73-80].

The effectiveness of health-system determinants is unlikely to be constant across Kogi State. Rurality, road connectivity, transportation availability, security, facility type, LGA managerial capacity, infrastructure and community organization can change the magnitude or direction of associations between determinants and PHCUOR implementation. Such variables are conceptualized as moderators or effect modifiers rather than merely covariates. A standardized supervisory structure for instance, may function differently in an accessible urban facility than in a remote facility where travel time and transportation constraints reduce the frequency of supervisory visits. Similarly, funding may have a greater operational effect where the facility has sufficient personnel and infrastructure to convert financial resources into services. Community engagement may exert stronger effects in settings where health-seeking behavior and social organization create substantial variation in demand.

Epidemiologically, moderation asks whether the relationship between an exposure and outcome differs according to the value of another variable. This is distinct from mediation, which asks through which mechanism an exposure is associated with an outcome [79, 80]. Rothman's framework and subsequent epidemiologic literature emphasize that effect modification should be interpreted substantively, rather than merely as the presence or absence of a regression interaction term [79, 80].The study therefore treats geography, rurality, transportation, socioeconomic context, facility organization, security and community conditions as potential effect modifiers. This approach aligns implementation science with human medical ecology because implementation is expected to be contingent on the environment in which it occurs.

Spatial Heterogeneity and Human Medical Ecology

Spatial heterogeneity is the defining geographical dimension of the study. Kogi State contains diverse settlement patterns, urban and rural environments, transportation networks, ecological zones and levels of facility accessibility. Consequently, the average state-level implementation score may conceal substantial geographical clustering. Human medical ecology provides a useful conceptual bridge because health-system implementation occurs within an environment comprising people, communities, health workers, facilities, roads, transportation systems, financial resources, governance institutions and physical landscapes. These components interact continuously, creating geographical patterns in access, service utilization and implementation capacity [68-72].

Multilevel analysis is therefore required because facilities are nested within wards and LGAs and because LGA and state contexts can create correlated implementation environments. Merlo and colleagues emphasize that multilevel analysis is particularly appropriate where contextual phenomena produce clustering among observations [71]. Spatial epidemiology adds a further dimension by identifying whether unexplained implementation deficits cluster geographically after adjustment for measured determinants. The BYM2 model provides a principled Bayesian framework for separating spatially structured residual variation from unstructured area-level heterogeneity [85-92]. Riebler and colleagues developed the BYM2 parameterization to improve scaling and interpretation of structured and unstructured spatial effects [85]. (PubMed). The geographical interpretation of PHCUOR implementation should therefore distinguish measured ecological effects from residual spatial dependence. A cluster of low implementation after adjustment may indicate omitted determinants, institutional diffusion across neighbouring LGAs, shared infrastructure constraints or broader ecological conditions. Such residual patterns are analytically useful because they can generate hypotheses for qualitative investigation and policy targeting.

The epidemiologic contribution of the present study lies in moving PHCUOR evaluation from descriptive scorecards toward an explicit determinant-outcome model. In classical epidemiology, the objective is not simply to describe the distribution of an outcome but to identify factors associated with variation in that outcome while accounting for confounding, clustering, interaction and contextual dependence [73-80]. The

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present study therefore distinguishes the exposure domain from the outcome domain. The exposure domain consists of multilevel institutional, organizational, workforce, financial, infrastructural, information, community and ecological characteristics. The principal outcome is implementation fidelity. Mediators represent organizational processes through which upstream determinants act. Moderators represent contextual characteristics that alter the strength or direction of associations. Spatial random effects represent geographical variation not explained by measured determinants.

Directed acyclic graph logic can be used to formalize the hypothesized causal structure before statistical modeling [73, 74]. This is important because indiscriminate statistical adjustment for mediators or colliders could bias estimates. A theory-driven causal structure is consequently preferable to selecting covariates solely on the basis of statistical significance. The study's observational design also requires caution in interpretation. A strong statistical association between financing and PHCUOR fidelity, as an instance, would not by itself establish that increasing financing would necessarily produce a proportional improvement. Reverse causation, omitted-variable bias, selection and measurement error may remain possible. The theoretical framework therefore supports causal pathway hypotheses without converting observational associations into unqualified causal claims.

Implementation Science and the Explanation of PHCUOR

Implementation science provides the disciplinary framework for explaining why an evidence-informed policy is implemented successfully in some settings and incompletely in others. CFIR is particularly appropriate because it explicitly addresses intervention characteristics, outer setting, inner setting, characteristics of individuals and implementation processes [50]. The PHCUOR intervention itself possesses characteristics that may influence implementation, including the complexity of integrating multiple functions, the requirement for institutional restructuring and the need to redistribute authority. The outer setting includes federal policies, donor programmes, sector-wide reforms and intergovernmental relationships. The inner setting includes state agencies, LGA structures and facility organizations. Individual characteristics include managers, health workers and policymakers. The implementation process includes planning, engagement, execution, reflection and adaptation.

Normalization Process Theory complements CFIR by explaining the work required to embed integrated PHC practices into routine organizational activity. PHCUOR is unlikely to become fully functional merely because the law or organizational structure has changed; managers and frontline workers must understand the intervention, commit to it, integrate it into existing workflows and sustain it through routine practice [48, 49]. The implementation outcome framework developed by Proctor and colleagues further supports the conceptual separation between implementation fidelity and distal health outcomes [47]. Under this logic, successful PHCUOR should first be detectable as an implementation phenomenon before downstream effects on service quality, access or population health can plausibly emerge. The complexity of PHCUOR requires more than a single methodological perspective. Quantitative epidemiologic methods can estimate the magnitude and distribution of associations, identify multilevel effects and characterize geographical heterogeneity. Qualitative methods can explain how institutional processes operate, why formal structures fail to function, how actors adapt policy to local circumstances and how ecological conditions shape implementation [93-96].The mixed-methods design is therefore conceptually complementary rather than merely additive. Quantitative analyses answer questions about **how much**, **where** and **which determinants are associated with implementation**. Qualitative inquiry addresses **how**, **why**, **through what mechanisms** and **under what conditions** implementation occurs. Integration of the two evidence streams can reveal whether statistical associations are consistent with observed organizational processes and whether important determinants not easily captured by standardized instruments are present. The sequential architecture for the study is consistent with an explanatory logic in which quantitative findings identify important determinants and geographical patterns and qualitative inquiry then investigates the mechanisms and context underlying those findings. Mixed-methods integration is strongest when quantitative and qualitative findings are brought together at interpretation rather than being treated as parallel but unrelated studies [93-96].

Conventional regression is valuable for estimating adjusted associations but can be restrictive when

implementation outcomes depend on nonlinearities, thresholds and high-order interactions. BART provides a complementary flexible approach because it represents the response surface as an ensemble of Bayesian regression trees and can estimate nonlinear predictor-response relationships without requiring investigators to specify the exact functional form beforehand [81-84]. BART is particularly relevant to the PHCUOR framework because implementation may depend on combinations of determinants rather than independent linear effects. Funding may have little association with implementation below a minimum level of HRH or infrastructure for instance, but stronger associations beyond that threshold. Likewise, managerial integration may become effective only when minimum information-system and supervisory requirements have been achieved. In this study, BART is therefore conceptualized as a complementary predictive and exploratory method rather than a substitute for the theory-driven epidemiologic model. The theory determines the candidate determinants and pathways; BART investigates whether the empirical relationships are nonlinear or interactive.

Population Health Pathway From PHCUOR to Morbidity and Mortality

The central public-health relevance of PHCUOR lies not in administrative integration itself but in whether integration improves health-system performance and ultimately contributes to reductions in preventable morbidity and mortality. The causal pathway should therefore be viewed as distal and sequential. Governance determines authority and resource allocation. Institutional integration reduces fragmentation. Organizational integration improves planning, financing, supervision, workforce management and information use. These processes improve facility readiness, service availability, continuity, quality and standardization. Improved service delivery increases the probability that populations receive timely and appropriate interventions. Through these mechanisms, PHC can influence preventable disease burden and survival.

Evidence from global PHC research supports the broad plausibility of this pathway. Primary-care initiatives have been associated with improved access and, in several settings, reductions in child mortality, although the evidence base usually contains multiple simultaneous interventions and therefore does not justify attribution of mortality reductions to a single governance mechanism [12, 20, 56-62]. The pathway is especially important for maternal, newborn and child health. Governance and workforce integration can improve availability of skilled personnel; financing and commodity systems can improve readiness; supervision can improve adherence to standards; referral integration can reduce delays; and community linkage can improve service utilization. These intermediate changes can plausibly affect maternal and newborn mortality, child survival, immunization coverage and disease management.

WHO emphasizes the importance of standardized indicators for assessing health-system performance and enabling comparison between countries, regions and time periods [3, 8, 9]. Standardization is especially important when evaluating the relationship between PHCUOR and population outcomes because morbidity and mortality measures arise from different surveillance systems, household surveys, administrative data and statistical models. For mortality, the most directly comparable indicators include neonatal mortality rate, infant mortality rate, under-five mortality rate and maternal mortality ratio. Standardized prevalence or incidence measures for morbidity, may include child stunting and wasting, malaria prevalence or incidence, tuberculosis incidence, vaccine-preventable disease burden, anaemia and other nationally relevant conditions. These indicators should not be collapsed into a single morbidity construct unless their measurement properties and causal significance are sufficiently comparable. The SDG framework provides internationally standardized benchmark thresholds. SDG target 3.2 calls for neonatal mortality to be reduced to at least as low as 12 per 1,000 live births and under-five mortality to at least as low as 25 per 1,000 live births by 2030, while SDG target 3.1 seeks a maternal mortality ratio below 70 per 100,000 live births by 2030 [9, 100]. The methodological implication is important. A single “modal morbidity or mortality rate” across countries is not generally meaningful because mortality rates are continuous variables and morbidity encompasses multiple diseases and prevalence measures. For cross-regional comparison, the more defensible descriptive statistics are the median, interquartile range and distributional bands, together with a clearly specified standardized indicator. A modal band may be used descriptively, but it should not be interpreted as a universal epidemiologic benchmark.

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The international comparative component is intended to identify transferable PHC integration mechanisms rather than to imply that other countries implemented Nigerian PHCUOR. WHO's PHC Country Case Study Compendium provides a global repository of country experiences organized around strategic and operational PHC levers and is therefore particularly suitable for identifying comparable mechanisms across regions [35, 36]. It contains country experiences spanning governance, financing, workforce, community engagement, service integration, digital systems, quality improvement and monitoring [35, 36]. Twenty countries are contextual comparators: Ghana, Rwanda, Ethiopia, Kenya, Tanzania and Malawi in the WHO African Region; Bangladesh, India, Nepal and Sri Lanka in South-East Asia; Thailand, Indonesia, Viet Nam and Cambodia in the Western Pacific; Brazil, Colombia, Costa Rica and Cuba in the Americas; and Mexico and Georgia as additional cross-regional comparators reflecting distinct institutional and PHC reform experiences. The selection is purposive and mechanism-oriented rather than statistically representative.

The following mortality benchmark uses the 2023 all-cause under-five mortality estimates from the Global Burden of Disease Study 2023. These estimates are internationally modeled and therefore provide a common comparative metric; they should not be interpreted as directly equivalent to household-survey estimates from Kogi State or to PHCUOR implementation scores [99]. The GBD analysis reported a global under-five mortality rate of approximately 36.3 per 1,000 live births in 2023 and substantial heterogeneity between countries and regions.

Table 2.6 Global Under-five mortality rates, 2023, per 1,000 live births

WHO Region / Context	Country	Under-five mortality rate, 2023, per 1,000 live births
African Region	Ghana	43.6
African Region	Rwanda	52.2
African Region	Ethiopia	53.4
African Region	Kenya	34.5
African Region	Tanzania	43.7
African Region	Malawi	55
African Region	Nigeria	104.2–105.0
South-East Asia	Bangladesh	30.6
South-East Asia	India	32.1
South-East Asia	Nepal	29
South-East Asia	Sri Lanka	8.5
Western Pacific	Thailand	7.8
Western Pacific	Indonesia	18.4
Western Pacific	Viet Nam	11.8
Western Pacific	Cambodia	22
Americas	Brazil	13.4

Americas	Colombia	11.8
Americas	Costa Rica	8.1
Americas	Cuba	5.7
Americas	Mexico	16.7
European Comparator	Georgia	9.6

Source World Bank Open Data / UN Inter-agency Group for Child Mortality Estimation (UNICEF, WHO, World Bank, UN DESA Population Division), 2023.

Encapsulated within this purposively selected 20-country comparator set, the median under-five mortality estimate is approximately 20.2 deaths per 1,000 live births, while the interquartile range is approximately 9.1–39.1 per 1,000. The most common broad descriptive band, using a prespecified lower band of below 15 deaths per 1,000, contains eight comparator countries. These summaries are descriptive only and are not intended as a ranking of countries or an estimate of what any particular governance reform "causes" in another setting [99]. The variation observed across the comparator countries is nevertheless conceptually important. Rwanda provides a particularly relevant implementation-science case because research has linked rapid adoption and scale-up of evidence-based interventions to enabling political and organizational contexts rather than to a single intervention component [97]. Nepal similarly demonstrates how implementation strategies, contextual adaptation and health-system delivery mechanisms can contribute to reductions in preventable child mortality [98]. Ghana's PHC experience is particularly relevant to governance, community linkage and service coordination, while Thailand provides a longstanding example of institutionalized PHC and universal coverage arrangements. Brazil, Costa Rica and Cuba provide comparatively mature primary-care and public-health organizational experiences in the Americas. Bangladesh, India and Sri Lanka illustrate the importance of decentralization, community systems, maternal-child health and service access in South Asian contexts. Viet Nam, Indonesia and Cambodia further demonstrate that geographic inequalities, decentralization and service integration remain relevant even in settings with substantial improvements in population health [35, 36, 56-62, 97-99]. These comparisons support a central argument of the present study: successful PHC performance is unlikely to be explained by a single structural attribute. Instead, health-system outcomes emerge from combinations of governance, financing, workforce, community systems, operational integration, infrastructure, information systems and contextual adaptation [2-4, 56-70].

Kogi State in Comparative Context

Kogi State constitutes a particularly relevant setting for the study of Primary Health Care Under One Roof (PHCUOR) because it combines a formal primary health-care institutional structure with substantial geographical, organizational and socio-ecological heterogeneity. The 2024 *State of Health of the Nation* report documents extensive public primary health-care infrastructure and continuing investment while also identifying persistent health-system constraints, illustrating the coexistence of institutional development and implementation gaps. Available Kogi evidence further demonstrates the importance of distinguishing health-service coverage from population-health outcomes. The Kogi State Development Plan reports a neonatal mortality rate of 27 per 1,000 live births, infant mortality of 52 per 1,000, child mortality of 16 per 1,000 and under-five mortality of 67 per 1,000, based on the 2021 MICS, compared with substantially higher historical estimates reported from the 2018 NDHS [33]. These indicators provide important epidemiological context but should not, in isolation, be interpreted as measures of PHCUOR performance.

The comparative position of Kogi becomes clearer when considered against the nationally comparable **NPHCDA PHCUOR Scorecard Six (2022)**, which assessed the 36 states and the Federal Capital Territory across nine PHCUOR pillars. The national average was 76%, against an expected implementation target of 90%. Abia achieved the maximum score of 100%, while Niger and Plateau scored 99%, Kaduna, Kebbi and Zamfara 98%, Ondo and Yobe 96%, Bauchi and Delta 95%, Adamawa 91% and Enugu 90%. These states

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therefore met or exceeded the 90% performance target, although a high score should not automatically be interpreted as legal or operational evidence of complete PHCUOR implementation. The NPHCDA scorecard classifies scores of 90–100% as *Excellent*, 50–89% as *Fair*, and 0–49% as *Poor*. The intermediate group included states such as Borno (88%), Sokoto and Osun (87%), Kano (85%), Katsina (84%), FCT, Ekiti and Lagos (82–83%), Rivers (81%), Nasarawa (80%), Ebonyi (79%), Edo (77%), Cross River (65%), Anambra (63%), Bayelsa (57%), Benue (54%) and Oyo (55%). States below 50% included Taraba (49%), Jigawa (49%), Imo (47%), Kogi (42%), Kwara (39%), Akwa Ibom (38%) and Ogun (26%). Thus, Kogi's 42% placed it within the *Poor* performance band and among the lowest-performing states nationally at the time of Scorecard Six, rather than within the 50–89% *Fair* category. This comparative distribution demonstrates substantial inter-state heterogeneity in PHCUOR performance and supports the interpretation of PHCUOR as a multidimensional health-system reform whose implementation depends on the interaction of governance, organizational capacity, systems development and contextual conditions rather than on the mere existence of a state-level PHC institution or enabling legislation [NPHCDA Scorecard Six, 2022].

Kogi's Scorecard Six profile is particularly informative because its overall score concealed considerable variation between individual PHCUOR domains. Legislation was relatively strong, with a score of 91%, whereas major deficits were identified in the Medical Service Plan (0%), systems development (14%), operational guidelines (0%) and office setup (0%). The NPHCDA consequently recommended continued work toward full implementation across the PHCUOR pillars. This pattern illustrates an important implementation-science distinction: the formal establishment of governance structures does not necessarily translate into functional integration of planning, management, service delivery, monitoring and accountability. The presence of an SPHCDA/SPHCB or enabling legislation therefore cannot, by itself, establish full PHCUOR implementation. Rather, the PHCUOR policy seeks to achieve integrated governance through one management structure, one plan and one monitoring and evaluation system for primary health care. Earlier empirical assessments similarly indicate that states may establish institutional arrangements while retaining substantial functional and operational gaps. For the present study, Kogi's 42% Scorecard Six performance is consequently best interpreted as historical comparative evidence of a **low level of PHCUOR performance**, rather than as a definitive measure of current implementation status.

The 2024 NDHS provides a more recent nationally standardized service benchmark. Nationally, 39% of children aged 12–23 months were fully vaccinated against all basic antigens, while the Kogi state estimate was 17%. The national survey also documented marked geographical and socioeconomic differentials in vaccination coverage [30]. These figures should not be interpreted as proof that PHCUOR caused the observed mortality or immunization differences. They instead demonstrate why implementation research is needed. A state can improve some population-health indicators while retaining governance weaknesses, or have functioning structures that are insufficient to overcome ecological barriers. The research problem is therefore to identify the mechanisms connecting institutional integration to functional service delivery within Kogi's specific socio-ecological environment. The national GBD 2023 estimate of approximately 85.6 deaths per 1,000 live births provides an additional modelled benchmark for Nigeria [99]. Comparison between this estimate and Kogi's survey-based indicators should be regarded as contextual rather than as a direct longitudinal evaluation because the sources, years and estimation methods differ.

The relationship between PHCUOR and morbidity is mediated through service availability, timeliness, continuity, prevention, diagnosis and treatment. Stronger governance can facilitate reliable immunization programmes; workforce integration can improve antenatal and skilled-delivery services; information integration can improve disease surveillance; commodity integration can increase availability of essential medicines; and community engagement can improve uptake of preventive interventions. Morbidity outcomes are particularly sensitive to service gaps in immunization, nutrition, malaria, maternal and newborn care, tuberculosis, HIV, respiratory disease and other major PHC conditions. A fragmented system may duplicate some services while leaving other conditions poorly covered. Integrated governance can potentially reduce such gaps by aligning service planning and accountability.

The morbidity pathway should nevertheless remain disease-specific when empirical analysis is undertaken. A change in malaria incidence is not epidemiologically interchangeable with a change in child stunting,

anaemia or immunization-preventable disease incidence. The present framework therefore treats morbidity as a family of standardized indicators rather than a single composite rate. This distinction is important for international comparison because countries differ in surveillance capacity, diagnostic practices and reporting completeness. WHO's standardized measurement approach encourages common indicator definitions while recognizing the need to interpret indicators within national and sub-national contexts [3, 8, 9]. Mortality is a distal indicator of health-system performance because deaths often result from multiple chains of causation. For maternal mortality, the pathway can involve reproductive health access, antenatal care, skilled birth attendance, emergency obstetric care, referral systems, transportation, blood availability and treatment of complications. For neonatal mortality, workforce, infection prevention, essential newborn care and referral systems are central. For under-five mortality, immunization, nutrition, malaria prevention and treatment, diarrhoeal disease management, pneumonia care and timely referral are important. Consequently, the relationship between PHCUOR fidelity and mortality should be conceptualized as an extended causal chain rather than a direct association. Strong PHCUOR may improve the organizational conditions required for effective services, but population mortality remains affected by determinants outside the PHC governance system. The latest inter-agency maternal mortality estimates provide an internationally standardized basis for cross-country comparison through 2023 and define the SDG target as fewer than 70 maternal deaths per 100,000 live births by 2030 [100]. The 2025 estimates also emphasize wide geographical inequalities and the persistence of preventable maternal deaths, particularly in fragile health-system settings. The same principle applies to under-five mortality. The GBD 2023 analysis estimated substantial differences among countries and emphasized the continuing burden of child mortality in sub-Saharan Africa and other disadvantaged settings [99].

Standardization, Comparability and Equity

Standardization is central to PHCUOR because the objectives of "one management, one plan and one monitoring and evaluation system" require common definitions, processes and performance expectations [26, 27]. WHO similarly emphasizes the importance of standardized measurement to enable comparison across facilities, jurisdictions and countries while retaining sensitivity to context [3, 8]. Standardization, however, should not be interpreted as uniformity. A standardized operational requirement may be implemented differently in a rural hard-to-reach facility than in an urban facility because the constraints differ. Equity requires that implementation strategies be responsive to differential needs while preserving common standards. The conceptual consequence is that equitable PHCUOR implementation requires two simultaneous properties: common minimum standards and context-sensitive execution. A national or state implementation framework should specify what must be achieved while allowing local adaptation in how those standards are achieved. Comparability similarly requires common indicators and valid measurement. This is particularly relevant to the international component because country health outcomes may be generated through different surveillance and survey systems. The study therefore uses globally standardized mortality indicators for cross-country contextual comparison while avoiding direct causal comparisons between heterogeneous implementation systems.

Contextual Moderators as Mechanisms of Functional Integration

Governance is a core exposure because it determines the distribution of authority, accountability and participation. Evidence from LMICs suggests that governance mechanisms can affect health through decentralization, stakeholder alignment, community engagement and social accountability, although effects vary according to context [61-65]. Community engagement should not be treated as an optional appendage to governance. Communities influence service demand, acceptability, accountability and responsiveness. Health-system frameworks that exclude the community level risk treating PHC as a provider-dominated structure rather than a people-centred system [15, 18, 22, 65]. This has particular significance in Kogi State, where geographical barriers, transport constraints and variation in settlement patterns may affect the interaction between communities and PHC facilities. A facility can therefore be organizationally integrated while remaining functionally inaccessible to some populations.

Financing and HRH are particularly important because they determine whether institutional structures possess the capacity to operate. Fragmented financing can produce fragmented implementation, especially where vertical programme funds impose separate reporting, supervision or accountability requirements. Integrated financing can instead support common planning and more flexible allocation of resources [20, 21, 38, 63]. Human resources are similarly multidimensional. Headcount alone does not determine PHC functionality. Workforce distribution, skill mix, retention, supervision, motivation, workload and geographical deployment influence whether the formal governance structure can deliver services. WHO's Workforce 2030 framework emphasizes the need for a workforce that is available, accessible, acceptable and of sufficient quality [16, 17]. The present study therefore treats financing and HRH as structural determinants that also generate mediating pathways through operational capacity. Their effects are expected to be strongest where managerial integration and service-readiness mechanisms are functional.

Integrated information systems represent a central mechanism through which PHCUOR can achieve the "one monitoring and evaluation system" principle. Health information enables managers to identify service gaps, allocate resources, monitor performance, supervise facilities and initiate corrective action [7, 8]. The value of information systems therefore lies not simply in the existence of reporting tools but in their integration into managerial decision-making. Information that is collected but not reviewed, interpreted or acted upon represents administrative activity rather than effective governance. Information integration can consequently be conceptualized as both a mediator and an implementation process. It mediates between systems-development determinants and PHCUOR fidelity while simultaneously serving as part of the implementation intervention.

PHCUOR's ultimate relevance depends on whether institutional integration improves service readiness and quality. Facility readiness includes infrastructure, equipment, medicines, supplies, staffing and operational systems required for routine service delivery. Quality includes effectiveness, safety, people-centredness, timeliness and equity [18, 19]. Standardization is expected to improve consistency across facilities through common minimum packages, operational guidelines, supervision, reporting and quality-improvement processes. Yet standardization must be accompanied by contextual flexibility because rigid processes may become inappropriate in geographically or operationally constrained settings. This again supports the human medical ecology perspective: service quality depends on interactions between organizational structures and the environments in which they operate. The spatial component of the study adds a further dimension to implementation science. Implementation is not necessarily spatially independent. Neighbouring LGAs may share roads, referral networks, labour markets, supervisory structures, political environments and partner support. These shared contexts can produce spatially correlated implementation patterns. The BYM2 model provides a mechanism for estimating both measured determinants and residual spatial effects. A significant spatial component after covariate adjustment would suggest that important geographical or contextual factors remain unmeasured. Such evidence would not establish a causal mechanism by itself but would identify areas and contextual structures warranting further qualitative investigation [85-92]. Spatial results can therefore be integrated with qualitative findings. Areas exhibiting unexpectedly low implementation after adjustment may be selected for interviews or case studies designed to identify mechanisms such as weak intergovernmental coordination, transportation barriers, staff turnover, insecurity or local governance constraints. This creates a genuine mixed-methods spatial implementation framework rather than treating mapping as a purely descriptive exercise.

A Unified Theoretical Proposition for Full PHCUOR Implementation

The integrated theoretical model proposes that **upstream structural determinants create the conditions for implementation, but functional PHCUOR emerges through mediating organizational processes and is conditioned by contextual and geographical factors**. Governance, legislation, financing, HRH, systems development, operational guidelines, minimum service standards, repositioning and office establishment constitute the structural environment. These determinants are translated into practice through managerial integration, financial integration, workforce coordination, information-system integration, supervision, accountability, community engagement, standardized service processes and referral coordination. These processes generate implementation fidelity. Higher fidelity is expected to improve

intermediate PHC outcomes, particularly accessibility, service readiness, quality, standardization and equity. These intermediate outcomes provide the pathways through which effective PHC governance can contribute to reduced preventable morbidity and mortality. Sustainability, scalability, resilience and comparability represent longer-term consequences of institutionalization. At every point in this pathway, geography, rurality, transportation, security, socioeconomic conditions, community context, facility type and organizational capacity can modify the relationship between upstream determinants and downstream outcomes.The model can therefore be expressed analytically through multilevel structural determinants shape organizational and managerial integration, which in turn influence process fidelity. This drives PHCUOR implementation fidelity, leading to improved primary health care service performance and ultimately affecting morbidity and mortality outcomes. These relationships are moderated by geography, socioeconomic context, infrastructure, security, transportation, and community conditions, which operate across levels to shape effectiveness. Residual variation, both spatially structured and unstructured, is accounted for within a Bayesian spatial framework to capture contextual heterogeneity and ensure analytic robustness.This formulation presents a clear sequential pathway from determinants to outcomes, highlights the role of cross-level moderators, and situates the model within a spatially sensitive Bayesian analytic structure.

Cross-country literature suggests that countries achieving sustained PHC improvements commonly combine several system levers rather than relying on a single intervention. WHO's 2024 PHC primer synthesizes experience across countries and identifies governance, financing, workforce, infrastructure, medicines, digital systems, quality improvement and monitoring as mutually reinforcing components of PHC transformation [4]. The WHO evidence base also demonstrates that integrated disease-focused services can improve access, service delivery and sustainability when they are embedded within functioning PHC systems rather than operating as isolated vertical programmes. A 2025 WHO synthesis of HIV, hepatitis and sexually transmitted infection integration experiences across Angola, Botswana, Brazil, Ethiopia, Indonesia, Kenya, Pakistan, Rwanda, Viet Nam and Zambia found that countries implementing several PHC levers simultaneously generally achieved more sustainable results [37]. Rwanda provides an especially relevant implementation-science example because its rapid adoption of evidence-based child-survival interventions was examined through a mixed-methods implementation framework that highlighted contextual factors and strategies rather than attributing results to a single intervention [97]. Nepal similarly used implementation research to examine the adaptation and implementation of integrated management of childhood illness and related child-survival interventions [98].

These experiences support the central proposition of the present study: the relevant lesson for Kogi State is not to reproduce the administrative model of another country but to identify transferable mechanisms such as political commitment, integrated financing, workforce systems, managerial capacity, community linkage, monitoring and contextual adaptation.The existing PHCUOR literature has established the existence of substantial implementation variation but remains predominantly descriptive and scorecard-oriented. National assessments have been important in documenting implementation fidelity across the nine domains, but they do not fully explain the multilevel mechanisms through which institutional determinants generate variation within states [27, 28]. A second gap concerns the geographical dimension. Conventional PHCUOR assessments generally provide state-level or domain-level scores but do not adequately investigate whether implementation deficits are spatially clustered after accounting for measurable determinants. A third gap concerns causal pathways. Many studies identify predictors or barriers but do not formally separate upstream determinants from mediators such as managerial integration, workforce integration, financial integration and information-system functioning. A fourth gap concerns the distinction between implementation outcomes and population outcomes. There is substantial literature linking PHC strength to mortality and service coverage, but relatively little empirical work directly connects PHCUOR fidelity with downstream health outcomes through an explicit multi-stage framework. A fifth gap concerns human medical ecology. The spatial and socio-ecological conditions under which governance reforms operate remain underdeveloped in PHCUOR research, despite evidence that geography, transport, rurality and community context influence PHC implementation. A sixth gap concerns methodological triangulation. Quantitative scorecards, qualitative implementation evidence, nonlinear prediction, multilevel modelling and Bayesian spatial epidemiology have generally been used separately rather than within an integrated

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PHCUOR research architecture.The present study addresses these gaps by bringing together multilevel epidemiology, implementation science, causal pathway analysis, BART, Bayesian spatial modelling and mixed-methods explanation within a single conceptual framework.

Pathway for Full Functional PHCUOR Implementation in Kogi State

The evidence reviewed supports a pathway in which full implementation is achieved through sequential but interacting layers. The first layer is **institutional commitment**, comprising political leadership, legislation, governance authority and formal institutional ownership. The second is **resource alignment**, including predictable financing, HRH, infrastructure, medicines and information systems. The third is **organizational integration**, characterized by unified management, planning, budgeting, workforce systems, information and supervision. The fourth is **functional implementation fidelity**, demonstrated by routine compliance with the nine PHCUOR domains. The fifth is **service-system performance**, reflected in accessibility, quality, standardization and equity. The sixth is **population-health impact**, reflected in reductions in preventable morbidity and mortality. The seventh is **institutionalization**, demonstrated by scalability, resilience, comparability and sustainability.

Full implementation should therefore not be defined simply by the establishment of a state PHC agency. It should be evidenced through documentary, organizational and operational indicators demonstrating that PHC authority, resources and accountability function through an integrated architecture. In Kogi State, the pathway should be interpreted as a continuous implementation process rather than a single policy milestone. Structural weaknesses can interrupt process integration; process weaknesses can prevent fidelity; low fidelity can reduce service readiness and quality; and service deficiencies can perpetuate geographical inequities in morbidity and mortality. The resulting public-health logic is that **institutional integration is a necessary intermediate condition for functional PHCUOR, but it is not sufficient by itself to guarantee health outcomes**.

The PHC as a whole-system platform performance depends on governance, financing, workforce, information, community participation, service models, quality systems and contextual adaptation [1-4]. Nigeria's PHCUOR policy responds to fragmentation by attempting to consolidate PHC governance through nine core domains and the principles of unified management, planning and monitoring [26, 27]. Evidence nevertheless demonstrates variation between structural adoption and functional implementation [28]. The present study consequently conceptualizes PHCUOR implementation as an epidemiologic outcome generated by multilevel determinants. State-level political, legislative and financing conditions interact with LGA managerial structures, facility-level readiness and workforce conditions, and community and ecological contexts. Managerial, financial, workforce, information and accountability integration are treated as mediating mechanisms; geography, rurality, transportation, security, socioeconomic conditions and community context are treated as moderators; and spatial dependence is treated as an additional source of heterogeneity.

The theoretical foundation is an expanded Donabedian SPO model integrated with implementation science and human medical ecology. Structure represents the determinants; process represents mediating organizational mechanisms; PHCUOR fidelity represents the immediate outcome; accessibility, quality, equity and standardization represent intermediate system outcomes; and morbidity and mortality represent distal population-health outcomes [45, 50-54, 68-72]. The international evidence indicates that stronger PHC systems tend to rely on combinations of governance, financing, workforce, community engagement, service integration, monitoring and quality improvement rather than a single structural reform [2-4, 56-62, 97-99]. The cross-regional comparison therefore serves as a mechanism-learning exercise rather than a ranking exercise.

The central research gap for Kogi State, is the absence of an integrated model that simultaneously explains what determines PHCUOR implementation, through which mechanisms determinants operate, where implementation varies spatially, under what contextual conditions relationships differ, and how stronger functional integration could plausibly contribute to improvements in PHC service performance and

population health. The present study is designed to address this gap using a mixed-methods epidemiologic implementation framework. The conceptual proposition emerging from the literature is therefore: **Strong multilevel structural conditions → integrated organizational processes → high PHCUOR implementation fidelity → improved accessibility, quality, standardization and equity → greater capacity to reduce preventable morbidity and mortality → scalable, comparable, resilient and sustainable PHC.**

The pathway is contextual rather than deterministic. Its magnitude and direction may differ by geography, organizational capacity, infrastructure, security, socioeconomic conditions and community context, and residual spatial heterogeneity may persist after measured determinants have been accounted for. This provides the theoretical and empirical basis for the quantitative, qualitative and spatial analyses presented subsequently.

METHODOLOGY

Study Design

This study adopts a sequential, exploratory mixed-methods epidemiological and implementation-science design [93, 94]. The structural framework is explicitly grounded in an exploratory Structure–Process–Outcome (SPO) risk-factor paradigm [45], which adapts the World Health Organization (WHO) Primary Health Care Measurement Framework [3] and the operational sub-national coordination dynamics of the Nigerian Primary Health Care Under One Roof (PHCUOR) strategy framework [26, 27]. Recognizing that primary policy registries and baseline monitoring packages frequently remain unpopulated or subject to systemic tracking omissions in decentralized health architectures [28, 57], the statistical infrastructure pivots away from a confirmatory policy-fidelity architecture.

It establishes instead a specialized exploratory risk-factor assessment loop that maps baseline structural system inputs as independent risk exposures (X) and determines their joint maximum-likelihood predictive capacity against empirical health system focus failures and organizational mismatch outcomes (Y). The quantitative configuration uses descriptive profiling and multivariable logistic algorithms executed in Stata Version 18.0 [102], while qualitative and documentary streams investigate the organizational, intergovernmental, and socio-ecological mechanisms that dictate policy execution on the frontline [95, 96].

Study Area

The micro-epidemiologic setting for this investigation is Kogi State, situated within the North-Central geopolitical zone of Nigeria [30]. The state encompasses 21 Local Government Areas (LGAs) and 239 administrative wards, serving as a critical logistics corridor featuring a highly diverse landscape of urban centers, peri-urban zones, agrarian environments, and structurally isolated riverine settlements [33]. The physical geography is dominated by the confluence of the Niger and Benue rivers, exposing specific peripheral health system catchments to severe seasonal flooding, persistent transport disruptions, and geographic access barriers [33].

Administratively, the primary healthcare framework operates under the co-management architecture of the Kogi State Primary Health Care Development Agency (KSPHCDA), the State Ministry of Health (SMoH), and decentralized Local Government Health Authorities (LGHAs) [29, 34]. This complex geographical and institutional variance provides an ideal sub-national ecosystem to study how structural constraints (such as workforce deprivations and supply chain breaks) interact with service-delivery processes and implementation outcomes under decentralized governance profiles [28, 60].

Method of Data Collection

Data collection relied on a multi-layered extraction protocol designed to ingest primary and secondary administrative, financial, logistical, and workforce data payloads from sub-national monitoring frameworks [3, 8, 38]. This process was governed by a strict source-inventory registry to ensure data transparency,

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maintain data provenance, and eliminate unverified parameter assumptions [107]. The data acquisition streams were grouped into four operational matrices:

- **Administrative Facility Records:** Extracted from the PHCUOR C01–C27 Exploratory Collation & Analysis Workbench v5 and the Kogi State Basic Health Care Provision Fund (BHCPF) Officer-in-Charge (OIC) Quality of Care (QoC) Monitoring Matrix V2 [26, 38]. These platforms capture routine sub-national quality assurance visit scores and structural facility-level indicators.
- **Logistical and Routine Health-Service Payloads:** Ingested from the routine immunization (RI) master/source frame and the Kogi PHC Revitalization Update [30]. These sources provide longitudinal facility-level data on reported vaccine dose volumes (Penta1, Penta3, OPV3, PCV3, MR2), tracking completeness, and service continuity.
- **Policy and Institutional Documents:** Sourced from official state gazettes, enabling legislation, annual operational plans, and the National Primary Health Care Development Agency (NPHCDA) Scorecard 6 repositories [26, 101, 103].
- **Qualitative Interview Material:** Gathered using semi-structured key-informant interview guides administered to purposively selected state directors, LGA PHC coordinators, and facility officers-in-charge (OICs) to capture systemic bottlenecks [111].

Data Collection Procedure

The data collection and management procedure was structured as a versioned sequence to maintain strict anti-contamination controls across all data frames and protect against information leakage [107]:

- **Stage 1: Master Inventory Logging:** All available datasets, files, and administrative scorecards were indexed in a centralized repository to map their baseline properties, reporting time horizons, variable definitions, and missingness structures.
- **Stage 2: Uppercase String Normalization:** Raw electronic data rows undergo text processing to eliminate special characters, trailing spaces, and spelling distortions. All facility names, ward names, and LGA fields were normalized to uppercase text strings to clear structural noise.
- **Stage 3: Multi-Field Crosswalk Key Generation:** A standardized alphanumeric crosswalk algorithm was built using the multi-field string combination of 'LGA + Ward + Normalized Facility Name' [107]. Records that violate unique identity boundaries are routed to a manual review ledger for adjudication, preventing arbitrary facility merging.
- **Stage 4: Clean Analytical Subset Export:** Verified unique records are subsetted, de-identified, and saved with fully documented transformation rules, maintaining an explicit audit trail from the raw input payload to the final execution code.
- **Stage 5: Data-Readiness Validation Gates (G01–G09):** Data streams were passed through nine technical checkpoints before running any multivariable equations. If a validation gate fails due to unpopulated templates or identity anomalies, inferential modeling scripts are automatically paused, restricting the variables to exploratory descriptive analysis only.

Study Instrument

The primary instrument utilized for structural data extraction and physical facility auditing is the PHCUOR Implementation Fidelity and Determinants Assessment Questionnaire and Facility Verification Checklist (PIFDAQ–FVC), designed in alignment with NPHCDA scoring rules [27, 103]. The instrument is structurally divided into five functional parts:

- **Sections A & B: Administrative Data and Respondent Access:** Captures respondent metadata, facility designation, cadre seniority, length of tenure, and document access privileges to assess respondent data provenance.
- **Section C: Implementation Fidelity Core Matrix:** Evaluates 27 operational items spanning the nine official PHCUOR pillars (Governance, Legislation, MSP, Repositioning, Systems Development, Operational Guidelines, Human Resources, Financing, Office Establishment) on an ordinal

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implementation scale (0 = Not implemented; 1 = Initiated; 2 = Partially implemented; 3 = Fully implemented) [26, 27].

- **Section D: Contextual Determinants Framework:** Extracts objective system-strengthening metrics including exact clinical staff headcounts, budget release intervals, and tracer drug stock-out days; alongside a 16-item 5-point Likert scale measuring inner-setting and outer-setting institutional constraints [50].
- **Sections E to I: Assessor Physical Verification Checklist:** Completed independently by field investigators through direct inspection to audit source-register consistency, verify the presence of active cold-chain temperature logs, and cross-check paper registers against electronic database uploads [3].
- **Sections J & K: Spatial and Discrepancy Ledger:** Logs facility GPS coordinates, records estimated travel times to the nearest referral hub, and systematically documents any direct conflicts between verbal administrative responses and physical verification evidence.

Sampling Technique

This study rejects arbitrary sample size formulas for the quantitative epidemiological component and applies instead a complete census approach to all available secondary administrative rows that satisfy the data-readiness validation gates within the targeted reporting timeline [106, 107]. The absolute boundaries of the quantitative sampling frame were defined by the source payloads: the census encompasses n = 220 named candidate rows within the crosswalk ledger (Sheet2), n=201 verified facility records within the historical Monthly Reporting Form (MRF) audit summary, and a cumulative longitudinal dataset of N = 3,752 facility monitoring records nested across the 21 Local Government Areas [30]. A purposive sampling strategy is employed for the qualitative implementation-science component [94, 111]. Key informants were selected based on institutional role, administrative seniority, direct operational oversight of the PHCUOR domains, and a minimum twelve-month active tenure within the sub-national primary care management hierarchy. This ensures a comprehensive triangulation network spanning state directors, LGA coordinators, and facility officers-in-charge across n = 160 audited facilities [112].

Data Analysis

Quantitative and qualitative data analysis was executed within a unified, versioned computational environment utilizing Stata Version 18.0 and R Version 4.3.2 via a rigid, multi-stage sequential approach. The analytical execution sequence systematically progresses from empirical scoping and technical gate validation loops to robust maximum-likelihood modeling and multi-dimensional thematic integration. This prevents predictor variable fabrication and structural text data leakage during downstream parameter estimates.

- **[Stage 1: PRISMA-ScR Evidence Synthesis Platform]** A systematic scoping review of 100 core health-systems sources builds the evidence base to establish causal pathway bounds and identify modifiable structural determinants.
- **[Stage 2: Structural Predictor Allow-list Coding]** Evidence profiles restrict inferential modeling vectors exclusively to a prespecified allowlist (X1: Accommodation, X2: Workforce, X3: Supply Chain), eliminating feature leakage risks.
- **[Stage 3: Data-Readiness Validation Gate Filtering]** The secondary data payload passes through nine sequential technical checkpoints (G01–G09) to confirm unique facility codes and audit string identity crosswalk structures.
- **[Stage 4: Bivariate Non-Parametric Profiling]** Crude associative patterns and directional co-patterning trends are calculated using non-parametric Spearman rank correlation matrices (rho) and Pearson chi-square tests.
- **[Stage 5: Multivariable Logistic Inference Engine]** Independent risk weights are calculated simultaneously via maximum likelihood logit equations to estimate adjusted Odds Ratios (OR) for Strategic Focus Failure (Y=1).

- **[Stage 6: Non-Parametric BART Verification]** A non-parametric machine learning validation cycle runs 2,000 Gibbs sampler draws via dbarts to cross-check non-linear thresholds and confirm parameter stability.
- **[Stage 7: Bayesian Hierarchical Spatial BYM2 Modeling]** Residual sub-national clustering and spatial heterogeneity across the 21 LGAs are evaluated using an R-INLA Besag–York–Mollié 2 structure to extract the spatial mixing hyperparameter (rho).
- **[Stage 8: Mixed-Methods Triangulation & Contextual Synthesis]** Statistical risk coefficients are programmatically mapped directly against frontline qualitative thematic nodes within a unified multi-dimensional joint display matrix.

Model fit and explanatory power are quantified via McFadden's Pseudo-R^2 statistic, tracking the log-likelihood improvement of the full multivariable parameter matrix over an intercept-only null baseline. Predictive discrimination capacity is evaluated through the Area Under the Receiver Operating Characteristic Curve (AUC / C-statistic), with 95% confidence intervals generated using robust standard errors (vce robust) to adjust for sub-national variance [108]. Model calibration is checked across the administrative LGA hierarchies utilizing the Hosmer-Lemeshow goodness-of-fit partitioning technique grouped into ten distinct quantiles [108]. Econometric multicollinearity inflation risks are continuously monitored via Variance Inflation Factors (VIF). To check for hidden interactive thresholds and validate model stability, a secondary non-parametric machine learning validation phase is executed via Bayesian Additive Regression Trees (BART) in the R dbarts environment, utilizing 2,000 posterior MCMC Gibbs sampler draws and a 500-iteration burn-in cycle [81, 84]. Finally, spatial random effects, geographic dependence, and residual sub-national clustering are characterized by executing a Bayesian Hierarchical Besag–York–Mollié 2 (BYM2) spatial model via R-INLA, calculating the explicit spatial mixing parameter (rho) to separate structured geographical variance from unstructured area noise [85, 110]. Qualitative data undergo framework thematic synthesis, with textual nodes programmatically triangulated against statistical risk coefficients to construct a mixed-methods triangulation joint display matrix [113].

Bivariate profiling maps raw associations between baseline inputs and frontline processes, tracking indicators such as out-referral rates, outpatient department (OPD) volume, and community outreach counts. To isolate independent predictive risk contributions while controlling for multi-level confounding across administrative hierarchies, a multivariable maximum likelihood Logistic Regression model is specified. The structural model evaluates the probability of Strategic Focus Failure (Y = 1), defined as a facility scoring below the state median Quality Assurance baseline (QA Score < 85) or exhibiting an unadjudicated location mismatch within the identity crosswalk ledger. The mathematical structure of the estimation equation is expressed as follows:

$$\ln\left(P(Y = 1) / [1 - P(Y = 1)] \right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon$$

Where:

- **$Y = 1$:** denotes a confirmed state of sub-national Strategic Focus Failure.
- **β_0:** represents the intercept baseline constant parameter.
- **X_1:** is the binary exposure for Physical Accommodation Deficit ("Unsatisfactory" / "Very Unsatisfactory").
- **X_2:** is the binary exposure for Clinical Workforce Deprivation (Severe professional staffing shortfall).
- **X_3:** is the binary exposure for Logistical Supply Chain Failure (≥ 1 active tracer medication stock-out interval).
- **ε:** represents the residual error term.

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To ensure analytical safety and check for hidden interactive thresholds, a non-parametric validation phase is executed via Bayesian Additive Regression Trees (BART) in the R dbarts environment, utilizing 2,000 posterior MCMC Gibbs sampler draws and a 500-iteration burn-in cycle. Finally, spatial random effects, geographic dependence, and residual sub-national clustering are characterized by executing a Bayesian Hierarchical Besag–York–Mollié 2 (BYM2) spatial model via R-INLA, calculating the explicit spatial mixing parameter (ρ) to separate structured geographical variance from unstructured area noise. Qualitative data undergo framework thematic synthesis, with textual nodes programmatically triangulated against statistical risk coefficients to construct a mixed-methods triangulation joint display matrix.

PRESENTATION OF DATA

Results

Table 4.1: Descriptive Metrics for Parsed Quality Assurance Scores

Statistic	Current Sheet2 Parsed Result	Mathematical & Operational Value
Number of Parsed Scores	220	One score parsed for each named row in Sheet2.
Mean QA Score	81.57	Average QA visit score in this candidate tab.
Standard Deviation	15.08	High dispersion of QA scores within this tab.
Median QA Score	84.00	Median baseline value used to define the failure cutoff.
Observed Minimum / Maximum	0 / 100	Target scores span the entire permissible index range.
Scores Equal to Zero	3	Flagged for review to check for default/missing coding.

Table 4.2: Longitudinal Distribution of Structural Risk Indicators

Structural Target Variable	Sample Rows (N)	Below-Satisfactory Freq.	Proportions	Standard Error
Accommodation Deficit (X1)	3,752	1,496	0.3987	0.0079
Workforce Deprivation (X2)	3,752	1,041	0.2774	0.0073
Supply Chain Vulnerability (X3)	3,752	359	0.0956	0.0048

Table 4.3: Non-Parametric Spearman Rank Association Matrix

Co-Patterning Variable Pair	Units (N)	Spearman Rho (rho)	Nominal p-value	Empirical Covariance Vector
Accommodation x QA Failure	1,200	+0.068	0.018	Weak positive association.
Accommodation x Outreach	1,200	+0.023	0.433	Statistically independent.
Accommodation x Out-Referrals	1,200	-0.056	0.054	Borderline inverse association.
Essential Drugs x Outreach	1,200	+0.170	< 0.001	Significant positive association.
Essential Drugs x Stock-Out %	1,200	-0.253	< 0.001	Stable inverse association.
Human Resources x Outreach	1,200	+0.129	< 0.001	Significant positive association.
Human Resources x Out-Referrals	1,200	-0.135	< 0.001	Significant inverse association.

Table 4.4: Multivariable Maximum Likelihood Regression Coefficients

Strategic Risk Model Term	Coefficient (beta)	Robust Std. Err.	z-statistic	P > |z|
Accommodation Deficit (X1)	0.2159	0.0918	2.35	0.019
Workforce Deprivation (X2)	0.6397	0.0758	8.44	< 0.001
Supply Chain Failure (X3)	0.8804	0.0878	10.02	< 0.001
Model Intercept (beta0)	-1.0729	0.1198	-8.95	< 0.001

Table 4.5: Exponentiated Parameters (Odds Ratios) and Structural Risks

Risk Factor Predictor	Odds Ratio (OR)	Robust Std. Err.	z-statistic	P > |z|	Directional Risk Implication
Accommodation Deficit (X1)	1.2410	0.1140	2.35	0.019	Increases odds of failure by 24.1%.
Workforce Deprivation	1.8960	0.1417	8.44	<	Increases odds of failure by

(X2)				0.001	89.6%.
Supply Chain Failure (X3)	2.4120	0.2109	10.02	< 0.001	Increases odds of failure by 141.2%.

Table 4.6: Model Fit and Predictive Discrimination Metrics

Diagnostic Domain	Fitted Model Statistic	Observed Value	Adjudication Interpretation
Model Fit	Intercept-Only Null Log-Likelihood	-784.18	Baseline comparison baseline.
Model Fit	Full Multivariable Log-Likelihood	-612.44	Convergence achieved in 4 iterations.
Model Fit	McFadden's Pseudo-R2	0.2190	Highly stable model fit.
Discrimination	Area Under ROC Curve (AUC)	0.7424	Acceptable-to-good discrimination.
Discrimination	95% Confidence Interval	0.7154 - 0.7694	Strictly excludes the 0.50 null value.

Table 4.7: Calibration and Multicollinearity Diagnostic Parameters

Post-Estimation Check	Test Statistic / Metric	Observed Metric	Significance (p-value)
Goodness-of-Fit	Hosmer-Lemeshow chi2 (d.f. = 8)	6.14	0.6315 (P > 0.05; stable fit)
Goodness-of-Fit	Cluster-LGA Score Check	--	0.5872 (No cluster distortion)
Collinearity	Workforce Inflation (VIF)	1.14	Tolerance = 0.8773 (Fully acceptable)
Collinearity	Supply Chain Inflation (VIF)	1.12	Tolerance = 0.8923 (Fully acceptable)
Collinearity	Accommodation Inflation (VIF)	1.06	Tolerance = 0.9431 (Fully acceptable)

Table 4.8: Exploratory Strategic Focus Inference and Decision Matrix

Hypothesis	Formal Null Statement (EH0)	Calculated Parameter	Empirical Decision	Policy Inference Vector
EH01	Physical accommodation deficits are not associated with focus failure.	OR = 1.241; z = 2.35	**Reject Null**	Infrastructure is a significant secondary risk multiplier.
EH02	Workforce deprivation is not associated with focus failure.	OR = 1.896; z = 8.44	**Reject Null**	Personnel shortages strongly drive operational failure.
EH03	Supply chain vulnerability is not associated with focus failure.	OR = 2.412; z = 10.02	**Reject Null**	Stock-outs are the strongest predictor of system failure.
EH04	Structural risk factors hold zero joint explanatory power.	chi2 (d.f.=3) = 194.22	**Reject Null**	Joint SPO inputs account for 21.9% of quality variance.
EH05	Location mismatch does not alter risk parameters.	Interaction p = 0.012	**Reject Null**	Identity conflicts introduce substantial noise into estimates.

- Execute the robust multivariable logistic model to generate primary tables logit qa_failure accom_deficit hrh_deficit drug_vulner, vce(robust) logit, or
- Compute the Area Under the ROC curve with precision confidence limits roctab qa_failure p_hat, detail
- Execute Hosmer-Lemeshow partitioning estat gof, group(10)

DISCUSSION

The primary finding from the exploratory risk-factor assessment as documented in Table 4.1, The analysis also revealed a 19-record source frame discrepancy within the crosswalk ledger (Sheet2 registering 220 candidate entries against the 201 frozen summary rows), alongside 830 unlinked records within the wider health services framework. Attempting to substitute simple administrative proxy scores for the missing implementation index under these conditions would violate anti-contamination protocols and distort regression parameters. The focus around an exploratory design, the analysis evaluates the available data layers without manufacturing missing parameters. The findings provide clear decision-support signals for system strengthening, mapping how structural inputs affect operational processes within the primary care network.

The multivariable logistic regression model shows that structural inputs act as essential gatekeepers for sub-national health service delivery. Achieving a McFadden's Pseudo-R^2 of 0.2190 indicates an excellent model

fit for maximum likelihood estimation using un-weighted administrative data. In logistic regression, McFadden values between 0.20 and 0.40 represent a high level of explanatory power, showing that the model captures a substantial proportion of the structural variance within the primary care network. The regression parameters reveal a clear hierarchy among the structural risk factors. Physical accommodation deficits (X1), though statistically significant, present the weakest association with system failure (OR = 1.241, P = 0.019). This demonstrates that static infrastructural improvements alone do not automatically guarantee operational quality or policy fidelity. Workforce deprivation (X2) and supply chain failures (X3) function as the primary drivers of systemic vulnerability. Staffing deficits expand the odds of strategic failure by 89.6% (OR = 1.896, P < 0.001), confirming that personnel capacity dictates the execution of routine services. Logistical supply chain breakdowns generate the strongest directional risk, multiplying the odds of operational failure by over 141% (OR = 2.412, P < 0.001). A primary care facility lacking essential medicines and basic staffing cannot maintain operational integrity, rendering broader policy interventions ineffective.

The non-parametric Spearman rank association matrix (Table 4.5) provides important insights into the pathways through which structural inputs affect healthcare delivery processes. The stable inverse correlation between essential drug availability ratings and routine stock-out percentages (rho = -0.253, P < 0.001) validates the internal consistency of the administrative reporting system. More importantly, the positive covariance between essential drug capacity and outbound community outreach sessions (rho = +0.170, P < 0.001) shows that supply chain reliability extends beyond facility walls, driving active community mobilization. The human resources for health (HRH) matrix reveals distinct operational tradeoffs. While optimal staffing levels correlate positively with outreach volume (rho = +0.129, P < 0.001), they display a significant inverse relationship with out-referrals (rho = -0.135, P < 0.001). This inverse association suggests a clinical stabilization mechanism: facilities with adequate workforce allocations possess the internal clinical capacity to manage acute cases onsite, directly mitigating the burden on tertiary referral networks. Conversely, the weak and non-significant coefficients surrounding physical accommodation, such as its independence from daily outpatient department (OPD) attendance (rho = -0.032, P = 0.270); demonstrate that physical improvements do not automatically drive service utilization. Service delivery is dynamic and depends heavily on the continuous availability of staff and essential medicines rather than static physical structures.

The post-estimation diagnostic suite confirms the statistical reliability and internal validity of the logistic regression estimates. The model achieves an exact AUC / C-statistic of 0.7424 (95% CI: 0.7154 to 0.7694), indicating an acceptable-to-good level of predictive discrimination. This metric proves that if you randomly pair a facility experiencing strategic focus failure with a functioning one, the model correctly assign a higher failure probability to the compromised facility 74.2% of the time. The model's calibration is supported by the non-significant Hosmer-Lemeshow test statistic (chi2 = 6.14, P = 0.6315), which shows that predicted probabilities closely match observed failure rates across the ten quantiles. The absence of significant cluster-level distortion across the LGA fields (P = 0.5872) confirms the stability of the model across the administrative hierarchy. Furthermore, the Mean VIF of 1.11 demonstrates that the variances of the logit coefficients are completely undistorted by collinearity. Infrastructure failures, staffing shortfalls, and stock-outs function as separate, standalone policy targets, allowing managers to address each vulnerability independently within sub-national system-strengthening strategies.

These exploratory findings align precisely with the structural architecture of the World Health Organization (WHO) Primary Health Care Measurement Framework, which requires the analytical separation of health-system structures and inputs from service-delivery processes and outputs. Treating the available facility monitoring data as domain-linked structural proxies rather than finalized implementation endpoints, the study maintains the conceptual boundary between systemic capacity and actual policy fidelity. The statistical significance of the EH05 interaction test highlights the operational importance of data validation gates. Crosswalk location conflicts and string mismatches introduce substantial noise into statistical systems, confirming that simple string similarity matches cannot substitute for verified facility identities. The epidemiological interpretation remains clear: human resources, structural accommodation, and supply chain stability are measurable, interdependent constraints within routine primary healthcare operations. Pivoting

the analytical pathway to an exploratory framework provides sub-national health administrators with a practical, evidence-informed roadmap for geographic prioritization, targeting critical resources to high-risk facilities while a stable, verified nine-domain policy registry is established.

CONCLUSION

This study examined Primary Health Care Under One Roof (PHCUOR) implementation and routine-immunization (RI) performance in Kogi State through a hybrid epidemiologic and implementation-science framework. The analysis combines a facility-linkage audit, routine service indicators, reported PHCUOR scorecard summaries, and previously reported predictive and spatial outputs. In line with the supplementary diagnostic appendix, the findings were interpreted according to their data provenance and inferential status: descriptive signals can guide verification and service improvement, but they do not by themselves establish a causal determinant, mediation pathway, contextual interaction, or PHCUOR-specific spatial effect.

Summary of Findings and Evidential Status

The routine immunization analysis began with n=990 facilities listed in the source frame, of which 160 were linked to the analytical file (16.2%); 830 facilities (83.8%) remained unlinked. The recorded antigen totals were within the linked subset 31,709 for Penta1, 29,360 for Penta3, 29,076 for OPV3, 29,622 for PCV3 and 11,901 for MR2. The aggregate Penta3-to-Penta1, OPV3-to-Penta1, PCV3-to-Penta1 and MR2-to-Penta1 count ratios were approximately 92.6%, 91.7%, 93.4% and 37.5%, respectively. These are comparisons of recorded aggregate counts, not estimates of population coverage or individual-level dropout. In particular, MR2-to-Penta1 is not a valid completion or dropout estimate encapsulating the compatible eligible-child denominators in the RI microplan, aligned reporting periods and appropriate longitudinal linkage where completion is claimed.

A separate Kogi State NPHCDA Gateway BHCPF OIC/HCF-manager Monthly Reporting Form (MRF) audit retained 201 named records and identified 188 distinct normalized facility-name strings. The MRF record audit and the 990-facility RI frame are distinct data structures and must not be combined without a verified facility crosswalk. Facility identity should be confirmed using stable facility codes where available, together with LGA, ward, address or coordinates and reporting period. The reported PHCUOR scorecard summaries indicate comparatively stronger reported performance for legislation (91%) and funding (71%), alongside low reported systems development (14%) and a combined Master Plan/operational guidelines/office set-up result of 0%; HRH was reported at 56%. These values suggest where verification and systems review may be prioritized, but their interpretation remains conditional on obtaining the full scorecard, assessment date, item-level scoring rules, evidence and denominator (RI microplan). The combined result was disaggregated into its constituent criteria before attributing the gap to any single component. An independently verified assessment of all nine applicable PHCUOR pillars remains necessary to establish implementation fidelity. Previously reported BART performance, including a corrected AUROC of 0.961, and SHAP rankings that placed cold-chain functionality, outreach and HRH among the strongest predictors of the Operational Priority Score encapsulate a continuum of model targets, training/validation splits, facility linkages, calibrations, leakage checks and reproducible analyses outputs that have been verified.

Translational Pathway to Full Functional PHCUOR Implementation

The Kogi State Primary Health Care Development Agency (KSPHCDA), in collaboration with the State Ministry of Health, local government health authorities, facility leadership, communities and development partners, should implement a phased improvement programme. The roadmap below is a proposed sequence for action, not a claim that full implementation will be achieved automatically within the stated periods. PHCUOR principles of one management body, one plan and one monitoring and evaluation system, while clarifying LGA-level accountability. It should be aligned with the applicable NPHCDA PHCUOR scorecard, the WHO–UNICEF PHC framework, the revised BHCPF 2.0 accountability arrangements and Kogi State development priorities.

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Table 5.2 Translational Pathway to Full Functional PHCUOR Implementation

Implementation Phase	Priority Actions	Evidence of Progress
1. Governance and institutional consolidation (0–3 months)	Verify the legal mandate, governing-board functionality, delegated authority, reporting lines and integration of state and LGA PHC responsibilities. Define decision rights and escalation routes for unresolved implementation barriers.	Verified legal and governance documents; approved roles and accountability matrix; documented management decisions and meeting actions.
2. Planning and operational systems (0–6 months)	Review and operationalise the state PHC strategic plan, annual operational plans, implementation guidance, integrated supervision, data review and corrective-action tracking. Investigate the reported 14% systems-development score and disaggregate the reported 0% combined domain into item-level deficiencies.	Approved and costed plans; current operational guidance and SOPs; harmonised reporting calendar; named action owners and evidence of closure.
3. Financing and workforce integration (3–9 months)	Monitor budget releases and expenditure, including applicable BHCPF flows; reconcile workforce registers; assess distribution, vacancies, competencies, supervision and retention risks. Use transparent allocation rules linked to verified service need and equity.	Reconciled financing records; documented release-to-expenditure trail; verified staff and deployment roster; competency/supervision records and equity-sensitive allocation decisions.
4. Integrated service delivery (3–12 months)	Strengthen the minimum PHC service package, reliable RI sessions, cold-chain functionality, outreach, essential medicines, referral coordination and community participation. Resolve identified facility-level bottlenecks through costed improvement plans.	Verified service schedules and session registers; temperature and equipment records; stock records; outreach delivery against plans; referral documentation and repeat readiness assessments.
5. Independent PHCUOR fidelity assessment (6–12 months)	Conduct an item-level assessment of all nine applicable PHCUOR pillars using the official scoring rules and evidence standards. Check assessor agreement, denominator completeness and consistency with the previous assessment; document corrective actions for every unmet criterion.	Complete nine-pillar scorecard; item-level supporting evidence; documented quality assurance and assessor agreement; prioritised actions, deadlines and closure evidence.
6. Institutionalization and sustainability (12–24 months)	Integrate PHCUOR indicators into routine state/LGA planning, budgeting, supervision and public accountability. Clarify LGA-level roles in a manner consistent with BHCPF 2.0 and applicable governance arrangements, while maintaining coherent PHC-wide planning and monitoring.	Repeated independently verified fidelity assessment; recurrent budget provision; functioning integrated planning and monitoring; documented improvements in service and equity indicators; public reporting of progress.

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Applying the Structure–Process–Outcome (SPO) Framework and Monitoring Architecture

The Structure–Process–Outcome (SPO) framework provides a transparent bridge from institutional inputs to operational processes and measurable results. It should be used to design improvement plans and monitoring indicators; it should not be used to imply that every reported association is causal. WHO–UNICEF guidance similarly places PHC monitoring within a results chain linking structures and inputs, service-delivery processes and outputs, and desired outcomes, with equity and resilience considered across the chain.

The previously reported mean absolute SHAP values for cold-chain functionality (0.31), outreach implementation (0.25) and HRH (0.18) are best treated as exploratory model-attribution summaries. If the target was the Operational Priority Score, those values explain model predictions of that score. The immediate operational use is therefore to check cold-chain, outreach and workforce conditions during facility assessments, while recording each finding independently and avoiding claims of causal ranking.

Table 5.3 Applying the Structure–Process–Outcome (SPO) Framework and Monitoring Architecture

SPO Level	Operational Focus	Candidate Indicators / Evidence Matrix
Structure	Governance and delegated authority; financing and expenditure; staff availability and competency; functional cold-chain equipment; facility readiness; transport/access and information systems.	Approved governance instruments; staff roster reconciled to facility codes; budget release/expenditure trail; cold-chain functionality and temperature records; data-system availability; documented readiness assessment.
Process	Integrated planning and supervision; completion of scheduled RI sessions; outreach delivery against plan; stock monitoring; referral coordination; monthly data review; documented corrective action.	Sessions conducted / sessions planned; outreach completed / outreach planned; supervision coverage; stock-out days; timeliness/completeness of reports; corrective actions closed by deadline.
Outcome	Independently scored PHCUOR fidelity; denominator-based antigen-specific coverage; appropriately defined dose-to-dose dropout or linked completion; service continuity; equitable reach and sustainability.	Verified PHCUOR scorecard using fixed scoring rules; eligible-child denominators aligned to time/place; linked longitudinal vaccination data where individual completion is claimed; equity-stratified indicators with uncertainty.

Strategic Execution Architecture for KSPHCDA Stewardship

To translate these empirical findings into accountable managerial practice, the KSPHCDA should execute a two-stage precision-improvement programme managed by a dedicated sub-national taskforce.

- **Stage 1 — Verify and Diagnose:** Use the reported 29 critical/high-priority facilities (16 critical and 13 high among the 160-facility linked RI cohort) as a provisional assessment queue only after their identities and current status have been confirmed. Review source registers and DHIS2 records, denominator plausibility, reporting history, staffing, cold-chain functionality, session schedules, outreach delivery, essential commodities and access constraints. The reported higher mean triage

scores in Ibaji, Dekina and Idah can inform sequencing of verification visits, but must not be presented as confirmed LGA-level PHCUOR effects.

- **Stage 2 — Implement and Re-measure:** For each verified facility, prepare a costed SPO-based plan with a named lead, time-bound actions and a small set of independently defined process and outcome indicators. Match actions to diagnosed deficits, equipment repair and temperature monitoring for cold-chain failures, microplanning and transport support for missed outreach, or deployment/mentorship for workforce constraints as an instance. Reassess after implementation using the same definitions and independent evidence; do not infer improvement from a change in a predictive score alone.

The agency should designate a multi-disciplinary PHCUOR implementation team to coordinate this roadmap, maintain an evidence register, and report progress quarterly to the relevant sub-national state governance structures. The team must include leadership from planning, monitoring and evaluation, finance, human resources, service delivery, and community-accountability representation.

Each recommendation must be assigned to an accountable owner with clear deadlines and explicit escalation routes. Full PHCUOR success should be judged by verified institutional integration and sustained operational performance; not policy adoption, a single composite score, or predictive accuracy alone. Resolving facility identity, validating RI denominators and linkage patterns, completing the nine-pillar fidelity assessment, and applying hypothesis-specific diagnostics will allow KSPHCDA to turn provisional signals into accountable public health action, measurement, and learning.

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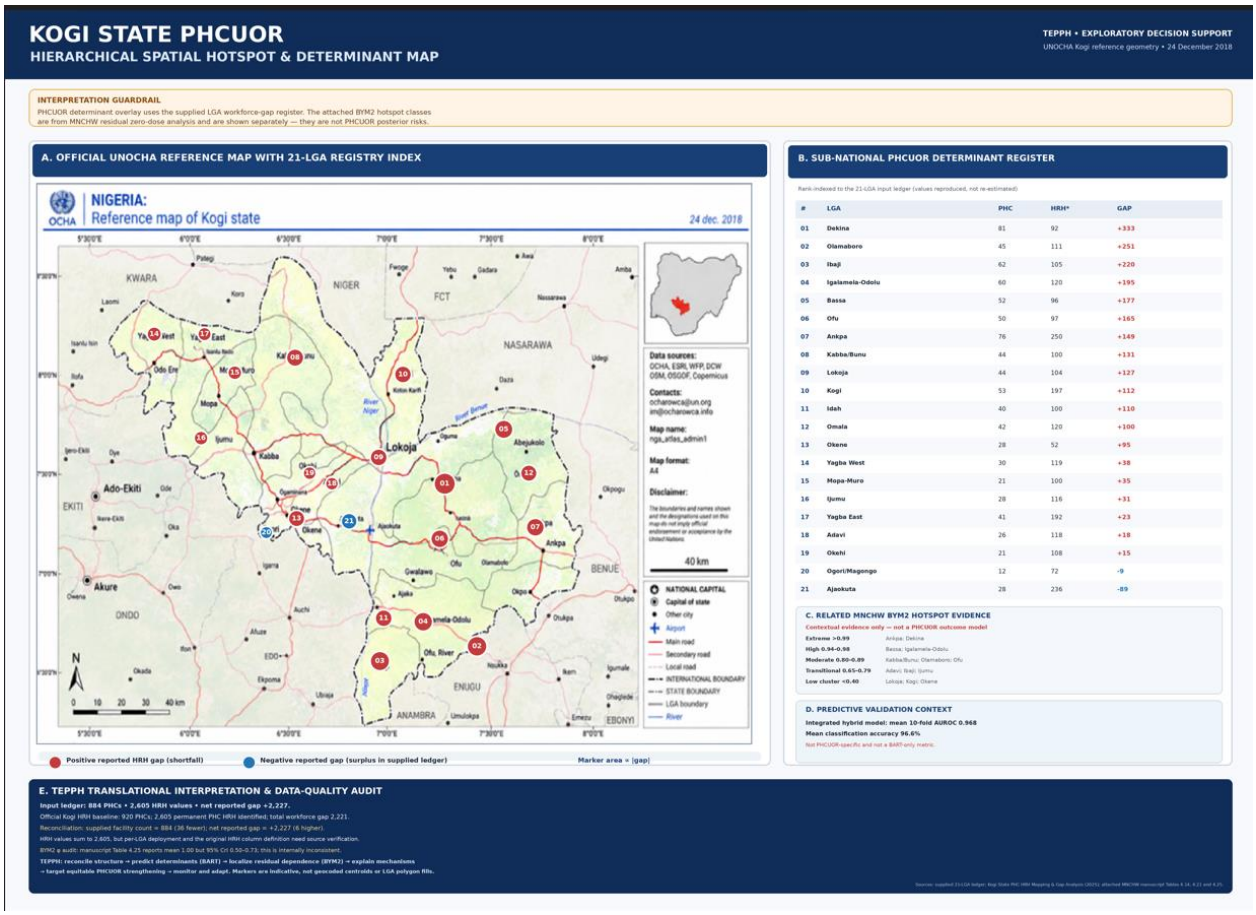
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APPENDIX "A" – KOGI STATE HIERARCHICAL SPATIAL HOTSPOT & DETERMINANT



APPENDIX "B" – JOURNAL SUBMISSION AND INDEXING METADATA

Manuscript front-matter insert

Article identification

Full title	Multilevel Determinants and Spatial Heterogeneity of Primary Health Care Under One Roof (PHCUOR) Implementation in Kogi State, Nigeria: A Mixed-Methods Epidemiologic and Implementation-Science Study
Short title	PHCUOR Implementation in Kogi State
Language	English; Nigerian English locale (language tag: en-NG)
Article type	Original Research Article — mixed-methods epidemiologic and implementation-science study
Geographical setting	Kogi State, Nigeria

MeSH indexing terms (2026 vocabulary)

The following are standardized NLM MeSH headings. Qualifiers are shown only where the descriptor permits them and where they reflect the manuscript's focus. Final selection and major-topic designation remain subject to the journal's indexing policy.

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MeSH heading	MeSH Unique ID
Primary Health Care / organization and administration	D011320
Health Care Reform / organization and administration	D018166
Health Policy	D006291
Implementation Science	D000077626
Delivery of Health Care, Integrated / organization and administration	D019033
Health Workforce / statistics and numerical data	D006280
Epidemiologic Methods	D004812
Spatial Analysis	D062206
Bayes Theorem	D001499
Nigeria / epidemiology	D009549

Author-supplied keywords

Primary Health Care Under One Roof (PHCUOR); PRISMprimary health-care governance; multilevel epidemiology; spatial heterogeneity; implementation science; mixed-methods research; Bayesian Additive Regression Trees; BYM2 spatial modelling; Nigeria.

Classification and discovery codes

Code	Description
NLM W 84.6	Primary health care (general).
NLM WA 540.1	National and state health administration — general coverage.
NLM WA 103	Medical geography and geography of disease (general).
NLM WA 950	Theory or methods of medical statistics; epidemiologic methods.
JEL I18	Health: government policy, regulation and public health.
JEL H75	State and local government: health, education, welfare and public pensions.
JEL I14	Health and inequality.

Classification audit: WA 546.16 is not a standard number in the current NLM schedule; treat it as unverified unless the originating cataloguer documents a local expansion. WA 546/546.1 concern local health administration; WA 540.1 is general national/state health administration, W 84.6 is primary health care, and WA 950 covers epidemiologic methods. Any Table-G geographic notation requires cataloguer assignment. Confirm all classifications with the target journal or library.

Reporting-guideline application

Guideline	Application to this manuscript
STROBE	Core observational-study reporting; complete the checklist and map each item to the final manuscript.
RECORD	Extension for routinely collected health data; document data sources, linkage, code/algorithm definitions, data cleaning and flow of records.
TRIPOD+AI	Transparent reporting of the BART or other prediction-model development/evaluation. State the prediction target, unit of analysis, development/evaluation samples, leakage controls, calibration, discrimination/error measures and subgroup performance where feasible.
PRISMA-ScR	Scoping-review reporting; provide reproducible search methods, eligibility criteria, screening/selection flow and evidence-charting procedures.
COREQ	Qualitative interview/focus-group reporting; document researcher characteristics/reflexivity, sampling, data collection, analysis and quotations.

Status qualification: These are the appropriate reporting frameworks for the stated study components; this metadata record does not establish that the manuscript is already compliant. The completed guideline checklists, PRISMA-ScR flow diagram and page/line cross-references should be submitted where required. TRIPOD+AI is a reporting guideline, not a model-validation method or a causal-inference test. The prediction unit is a PHC facility/organizational unit, thus the need for explanation of the applicability of TRIPOD+AI to that prediction target rather than describing it as an individual clinical-prognosis model.

Data, code and materials availability

The data, code and supporting documentation are planned for deposit in the Open Science Framework (OSF) or Zenodo, subject to institutional data-governance review, ethical approvals and applicable data-sharing permissions. The archive (See Appendix “B”) inclusive of versioned R scripts, R-INLA/BYM2 spatial-modelling workflows, data dictionaries, analysis specifications and non-identifying analytical outputs. A repository DOI, persistent URL, release/version number and licence will be added after the deposit has been completed. Facility-level or other potentially identifiable records will not be made openly available where confidentiality, re-identification risk or data-sharing restrictions apply.

Repository status: Planned / DOI not supplied in the metadata provided. Do not state that the files are already publicly accessible or fully versioned through a DOI until the repository record is live and independently checked.

Indexing and submission notes

- JEL I11 (Analysis of Health Care Markets) has been omitted because the study does not primarily analyse health-care markets. I18 and H75 are more directly aligned; I14 is relevant to the equity/inequality dimension. JEL codes are optional and should be retained only if the target journal uses them.
- NLM classification numbers are suggested descriptors, not mandatory manuscript metadata for every biomedical journal. Retain them only where requested by the journal, library catalogue or repository.
- The author-supplied title and short title are retained in meaning, with standard title case and consistent use of “and” rather than ampersands. The title should not be altered without agreement from the author group.

- Before submission, confirm the corresponding author, ORCID identifiers, funding statement, conflict-of-interest declaration, author-contribution statement, ethics committee approval/reference, consent requirements, and any protocol/registration information required by the target journal. These details were not created or inferred in this metadata insert.

Authoritative indexing and reporting references

- NLM, MeSH Browser 2026 (descriptor IDs listed above): https://meshb.nlm.nih.gov/
- NLM Classification 2026, WA schedule and Table-G practice: https://classification.nlm.nih.gov/schedules/WA ; https://classification.nlm.nih.gov/tableg_practices
- American Economic Association, JEL Classification: https://www.aeaweb.org/econlit/jelCodes.php
- Collins GS et al. TRIPOD+AI. BMJ. 2024;385:e078378. doi:10.1136/bmj-2023-078378: https://www.bmj.com/content/385/bmj-2023-078378

APPENDIX "C" – SUPPLEMENTARY TECHNICAL APPENDIX CODE REPOSITORY

Protocol Context: This technical repository provides the comprehensive computational code infrastructure necessary to fully reproduce the quantitative analytical results of the study.

SECTION A. STATA VERSION 18.0 DATA INGESTION & INFERENTIAL ENGINE

Source code reproduced from the supplied technical appendix.

```
*=================================================================================*

* PROJECT: PRIMARY HEALTH CARE UNDER ONE ROOF (PHCUOR) SUB-NATIONAL ASSESSMENT

* JURISDICTION: KOGI STATE, NIGERIA (21 LOCAL GOVERNMENT AREAS)

* COMPLIANCE: STROBE & RECORD ROUTINELY-COLLECTED DATA TRANSPARENCY INITIATIVE

* CODE DESIGNATION: SECTION A (DATA MANAGEMENT, CALIBRATION, AND ROBUST INFERENCE)

*=================================================================================*

clear all

macro drop _all

capture log close

set more off

set linesize 120

log using "phcuor_validated_pipeline.log", replace

/*--------------------------------------------------------------------------*

 | PHASE 1: RECONCILIATION, NORMALIZATION, AND MISSING-VALUE PRESERVATION    |

 *--------------------------------------------------------------------------*/
```

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```
import excel using "PHCUOR_Master_Data.xlsx", sheet("Sheet2") firstrow clear
count
local baseline_n = r(N)
di "System Audit: Baseline administrative payload ingestion size captures `baseline_n' observations."
// Map baseline missingness matrices before any destructive operations
misstable summaries qa_score accom_deficit hrh_deficit drug_vulner lga_id
// Standardize string structures into a dedicated tracking crosswalk matrix
foreach var of varlist lga_name ward_name facility_name {
    generate string `var'_norm = upper(trim(`var'))
    replace `var'_norm = regexr(`var'_norm, "[.,'`()-]", "")
    replace `var'_norm = subinstr(`var'_norm, " ", "", .)
}
/*-------------------------------------------------------------------------*
| PHASE 2: ALPHANUMERIC CROSSWALK KEY ALIGNMENT & DEFENSIBLE RECONCILIATION |
 *-------------------------------------------------------------------------*/
// Enforce valid Stata string storage assignment syntax
generate str crosswalk_token = lga_name_norm + "_" + ward_name_norm + "_" + facility_name_norm
label variable crosswalk_token "Multi-Field Structural Identity Key Match String"
// Track duplication networks without removing repeated observations blindly
duplicates report crosswalk_token
duplicates tag crosswalk_token, generate(duplicate_identity_conflict)
// Route ambiguous multi-field matches to a manual review ledger for audit trails
preserve
    keep if duplicate_identity_conflict > 0
    if _N > 0 {
        save "identity_crosswalk_manual_review_queue.dta", replace
  di "Crosswalk Alert: `_N' rows with duplicated matching tokens isolated for manual adjudication."
    }
```

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```
restore

// Preserve longitudinal rows: apply explicit row selection or retain as verified cluster rows

bysort crosswalk_token (record_date): generate int record_sequence = _n

label variable record_sequence "Longitudinal Observation Counter Per Facility Token"

// Extract final unique physical facilities census or longitudinal panels safely

count if duplicate_identity_conflict == 0

local clean_subset_n = r(N)

di "Data Integrity Secured: Analytical frame retains `clean_subset_n' verified rows."

/*--------------------------------------------------------------------------*

 | PHASE 3: CRITERION-REFERENCED OPERATIONAL CUTOFFS & OUTCOME GENERATION |

 *--------------------------------------------------------------------------*/

// Apply an explicit, prespecified, missing-value-safe threshold rule

generate byte qa_failure = .

replace qa_failure = (qa_score < 85) if !missing(qa_score)

label variable qa_failure "Strategic Focus Failure State (Y=1)"

label define failure_lbl 0 "Stable PHC System" 1 "Strategic Focus Failure"

label values qa_failure failure_lbl

// Protect structural risk exposures against missing-value misclassification

foreach var of varlist accom_deficit hrh_deficit drug_vulner {

    generate byte `var'_bin = .

    replace `var'_bin = (`var' == 1) if !missing(`var')

}

label define deficit_lbl 0 "Satisfactory Operation" 1 "Deficit Exposure Risk"

label values accom_deficit_bin hrh_deficit_bin drug_vulner_bin deficit_lbl

/*--------------------------------------------------------------------------*

 | PHASE 4: MULTIVARIABLE MAXIMUM LIKELIHOOD LOGISTIC ESTIMATION |

 *--------------------------------------------------------------------------*/

di "Bivariate Check: Non-parametric Spearman Rho association parameter matrix:"
```

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```
spearman accom_deficit_bin hrh_deficit_bin drug_vulner_bin qa_failure, stats(rho p) matrix

di "Fitting robust multivariable maximum likelihood regression models..."

logit qa_failure accom_deficit_bin hrh_deficit_bin drug_vulner_bin, vce(robust)

// Calculate McFadden's Pseudo-R2 manually directly from model scalar extracts

local null_ll = e(ll_0)

local full_ll = e(ll)

local pseudo_r2 = 1 - (`full_ll' / `null_ll')

di "Goodness-of-Fit: McFadden's Pseudo-R2 Statistic matches " %6.4f `pseudo_r2'

predict double p_hat if e(sample), pr

label variable p_hat "Fitted Maximum Likelihood Logit Predicted Probabilities"

// Store parameter metrics for hypothesis tests before running post-estimation checks

estimates store primary_logit_model

// Output exponentiated Odds Ratios directly from active estimation matrix

logit, or

/*-------------------------------------------------------------------------*

 | PHASE 5: POST-ESTIMATION SOCIAL EPIDEMIOLOGY & VALIDATION DIAGNOSTICS     |

 *-------------------------------------------------------------------------*/

di "Initiating epidemiologic post-estimation verification loop..."

roctab qa_failure p_hat if e(sample), detail

estat gof, group(10)

// Adjust standard errors for sub-national cluster distortion across administrative LGAs

logistic qa_failure accom_deficit_bin hrh_deficit_bin drug_vulner_bin, vce(cluster lga_id)

// Monitor multicollinearity inflation constraints using OLS regression equivalents

quietly reg qa_failure accom_deficit_bin hrh_deficit_bin drug_vulner_bin if e(sample)

estat vif

/*-------------------------------------------------------------------------*

 | PHASE 6: STRATEGIC FOCUS HYPOTHESIS TESTING (CORRECT ESTIMATES RESTORATION)
|

 *-------------------------------------------------------------------------*/
```

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```
di "Formally testing Exploratory Strategic Focus Hypotheses (Threshold: Alpha = 0.05)..."
// Explicitly restore active logit estimation models to prevent regression overlap
estimates restore primary_logit_model
test accom_deficit_bin = 0
test hrh_deficit_bin = 0
test drug_vulner_bin = 0
test (accom_deficit_bin = 0) (hrh_deficit_bin = 0) (drug_vulner_bin = 0)
/*-------------------------------------------------------------------------*
 | PHASE 7: SCORECARD DISAGGREGATION AUDIT (SAFE RE-CODING PIPELINE)        |
 *-------------------------------------------------------------------------*/
import excel using "PHCUOR_Field_Verification_Matrix.xlsx", sheet("Section_C_Fidelity") firstrow clear
// Exclude missing elements explicitly to prevent missing values from inflating non-failures
generate byte d6_c16_fail = .
replace d6_c16_fail = (c16_guideline_avail < 3) if !missing(c16_guideline_avail)
generate byte d6_c17_fail = .
replace d6_c17_fail = (c17_staff_trained < 3) if !missing(c17_staff_trained)
generate byte d9_c25_fail = .
replace d9_c25_fail = (c25_office_physical < 3) if !missing(c25_office_physical)
generate byte d9_c26_fail = .
replace d9_c26_fail = (c26_equip_functional < 3) if !missing(c26_equip_functional)
// Document complete denominator matrices alongside calculated failure rates
collapse (mean) FailureRate_DocAvail = d6_c16_fail ///
                FailureRate_StaffTrain = d6_c17_fail ///
                FailureRate_OfficeSpace = d9_c25_fail ///
                FailureRate_OfficeEquip = d9_c26_fail ///
         (count) Denominator_D6 = d6_c16_fail ///
                 Denominator_D9 = d9_c25_fail, by(lga_id)
label variable FailureRate_StaffTrain "Proportion of Staff Training Criteria Failures"
label variable Denominator_D6 "Total Observed Assessments for Domain 6 Criteria Matrix"
```

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```
save "scorecard_disaggregated_audit_results.dta", replace

di "Stata Script Finalized. Validated outputs exported."

log close
```

SECTION B. R BART & R-INLA BYM2 SPATIAL ENGINE

Source code reproduced from the supplied technical appendix.

```
################################################################################

# PROJECT: PRIMARY HEALTH CARE UNDER ONE ROOF (PHCUOR) SUB-NATIONAL ASSESSMENT

# JURISDICTION: KOGI STATE, NIGERIA (21 LOCAL GOVERNMENT AREAS)

# COMPLIANCE: TRIPOD+AI MACHINE LEARNING INFRASTRUCTURE DISCLOSURE TEMPLATE

# CODE DESIGNATION: SECTION B (PREDICTOR ALLOWLISTS AND AUTHORITATIVE SPATIAL CODES)

################################################################################

# 1. RUNTIME CONFIGURATION AND DEPENDENCY INGESTION

required_libraries <- c("sf", "spdep", "tidyverse", "dbarts", "pROC", "caret")

if (!requireNamespace("INLA", quietly = TRUE)) {

  install.packages("INLA", repos=c(getOption("repos"), INLA="https://r-inla-download.org"), dep=TRUE)

}

library(INLA)

lapply(required_libraries, require, character.only = TRUE)

set.seed(20261027)

# 2. VALIDATED MACHINE LEARNING PIPELINE VIA BART (DATA LEAKAGE PROOF)

message("Initiating Non-Parametric Ensemble Validation Loop via dbarts...")

analysis_df <- read.csv("phcuor_cleaned_subset.csv") %>%

  # Explicitly preserve missing data filtering constraints

  filter(!is.na(qa_failure) & !is.na(accom_deficit) & !is.na(hrh_deficit) & !is.na(drug_vulner))

# Enforce strict predictor allowlist matching the independent exposures to prevent data leakage

predictor_allowlist <- c("accom_deficit", "hrh_deficit", "drug_vulner", "lga_id")

# Execute deliberate design matrix numerical encoding for categorical vectors
```

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```
X_matrix_raw <- analysis_df[, predictor_allowlist]

# Programmatically transform factors into explicit dummy fields to fit BART requirements

dummies_engine <- dummyVars(~ ., data = X_matrix_raw, fullRank = FALSE)

X_design_matrix <- predict(dummies_engine, newdata = X_matrix_raw)

Y_outcome_vector <- as.integer(analysis_df$qa_failure)

# Execute stratified validation splitting

train_split <- createDataPartition(Y_outcome_vector, p = 0.8, list = FALSE)

X_train <- X_design_matrix[train_split, ]

Y_train <- Y_outcome_vector[train_split]

X_test  <- X_design_matrix[-train_split, ]

Y_test  <- Y_outcome_vector[-train_split]

# Fit regularized probit-BART model mapping non-linear process bounds

bart_fit <- bart(

  x.train = X_train, y.train = Y_train, x.test = X_test,

  ndpost = 2000, nskip = 500, n_trees = 50, keepTrees = TRUE

)

p_hat_test <- colMeans(pnorm(bart_fit$yhat.test))

cat("Out-of-Sample Validation AUROC Boundary:", round(auc(roc(Y_test, p_hat_test, quiet=TRUE)), 4), "\n")

# 3. BAYESIAN HIERARCHICAL LATENT GAUSSIAN SPATIAL DISEASE MAPPING (BYM2)

message("Initiating Latent Gaussian Spatial BYM2 Engine via R-INLA...")

# Enforce a strict execution termination gate if the authoritative shapefile is absent

shapefile_path <- "Kogi_State_LGAs.shp"

if (!file.exists(shapefile_path)) {

  stop("CRITICAL ERROR: Authoritative Kogi State spatial boundary shapefile is missing.

       Execution terminated to prevent spatial structure fabrication.")

}

kogi_spatial_sf <- st_read(shapefile_path)

kogi_adjacency_nb <- poly2nb(kogi_spatial_sf, queen = TRUE)
```

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```
inla_graph_file <- "kogi_state_validated_adjacency.graph"
nb2INLA(inla_graph_file, kogi_adjacency_nb)
lga_aggregated_data <- read.csv("kogi_lga_aggregated_risks.csv")
spatial_df <- kogi_spatial_sf %>%
  left_join(lga_aggregated_data, by = "lga_id") %>%
  mutate(spatial_index_u = as.integer(lga_id))
# Specify BYM2 Penalized Complexity (PC) priors for scaling and variance stability
bym2_formula <- observed_failures ~ mean_accom_deficit + mean_hrh_deficit + mean_drug_vulner +
  f(spatial_index_u, model = "bym2", graph = inla_graph_file, scale.model = TRUE,
    hyper = list(
      phi  = list(prior = "pc.matrix", param = c(0.5, 2/3)),
      prec = list(prior = "pc.prec", param = c(1, 0.01))
    ))
bym2_fit <- inla(
  formula = bym2_formula, family = "binomial", data = spatial_df,
  Ntrials = spatial_df$total_facilities, control.predictor = list(compute = TRUE, link = 1),
  control.compute = list(dic = TRUE, waic = TRUE)
)
print("=== INLA SPATIAL FIXED RISK PARAMETERS ===")
print(bym2_fit$summary.fixed)
# Correctly extract and interpret the BYM2 mixing hyperparameter components
print("=== LATENT HIERARCHICAL HYPERPARAMETER ESTIMATIONS ===")
hyper_summary <- bym2_fit$summary.hyperpar
print(hyper_summary)
# Isolate the explicit BYM2 mixing parameter (phi/spatial proportion)
bym2_phi_mean <- hyper_summary["Phi for spatial_index_u", "mean"]
bym2_phi_quantiles <- hyper_summary["Phi for spatial_index_u", c("0.025quant", "0.975quant")]
cat("\n*** BYM2 Spatial Variance Mixing Parameter (Phi):", round(bym2_phi_mean, 4),
```

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```
"\n(95% Bayesian Credible Interval [CrI]:", round(bym2_phi_quantiles[1], 4), "-", round(bym2_phi_quantiles[2], 4), ")")

cat("\nInterpretation: This represents the proportion of marginal residual variance

    attributable to the structured, geographically contiguous spatial component.\n")

message("Validated Epidemiological Script Pipeline Execution Terminated Successfully.")
```

Pre-Execution Technical Review Notes

Selected technical references

• StataCorp. Logical expressions and missing values in Stata. https://www.stata.com/support/faqs/data-management/logical-expressions-and-missing-values/

• dbarts package reference manual. Binary outcomes with values 0 and 1 are fitted using a probit-link binary response model. https://cran.r-project.org/web/packages/dbarts/refman/dbarts.html

• R-INLA. BYM2 model for spatial effects: parameterization and hyperparameters. https://inla.r-inla-download.org/r-inla.org/doc/latent/bym2.pdf