

Article

Catchment-Level Inequities in Malaria Prevention during Pregnancy: Public–Private Differences in IPTp3 Delivery in Oyo State, Nigeria.

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Abstract

Intermittent preventive treatment in pregnancy (IPTp) remains a cornerstone of malaria control in sub-Saharan Africa, yet coverage gaps persist despite widespread antenatal care (ANC) attendance. In Nigeria's mixed health system, institutional differences between public and private facilities may contribute to uneven delivery of IPTp, but such disparities are poorly understood at operational spatial scales. This study employed a catchment-based spatial framework to evaluate IPTp3 delivery among pregnant women in Oyo State, Nigeria, using routine health facility data from DHIS2 for 2025. IPTp3 coverage was standardized against pregnancy stock derived from high-resolution WorldPop population estimates. Catchment-level indicators were compared between public and private facilities, and ownership effects were assessed using demand-adjusted regression models controlling for pregnancy burden, women-of-reproductive-age density, and catchment area. IPTp3 delivery exhibited extreme heterogeneity across catchments. Private facilities recorded substantially lower median IPTp3 coverage and a markedly higher prevalence of zero delivery despite non-zero pregnancy burden. After adjusting for demographic demand and spatial scale, private facility ownership was independently associated with significantly lower IPTp3 delivery ($p < 0.001$). Aggregated ward- and LGA-level summaries obscured these micro-scale inequities, highlighting the added value of catchment-level analysis. Malaria prevention during pregnancy in Oyo State is strongly shaped by institutional factors rather than demographic demand alone. Persistent under-delivery of IPTp3 in private facility catchments represents a critical equity gap that may undermine progress toward malaria elimination and maternal health goals. Strengthening private-sector integration into malaria prevention programs and adopting catchment-based monitoring frameworks are essential for achieving more equitable IPTp coverage.

Keywords: Malaria in pregnancy; Intermittent preventive treatment (IPTp); Spatial analysis.

1. Introduction

Malaria in pregnancy remains a persistent public health challenge across sub-Saharan Africa, with profound consequences for maternal health, fetal development, and neonatal survival. Despite decades of policy attention, pregnant women continue to face elevated risks of anemia, placental malaria, low birth weight, and stillbirth, particularly in high-transmission settings such as Nigeria (WHO, 2022; Rogerson et al., 2023). Intermittent preventive treatment in pregnancy using sulfadoxine–pyrimethamine (IPTp-SP) is a cornerstone of malaria control strategies and has been shown to substantially reduce adverse pregnancy outcomes when delivered consistently through antenatal care (ANC) platforms (Kayentao et al., 2022; Walker et al., 2021). However, translating national policy into equitable service delivery at the local level remains challenging, especially in health systems characterized by mixed public–private provision and uneven spatial access.

Nigeria accounts for a disproportionate share of the global malaria burden and exhibits marked subnational heterogeneity in maternal health service coverage (National Malaria Elimination Programme [NMEP], 2023; World Bank, 2022). Routine health system data increasingly reveal that aggregate coverage indicators can obscure substantial micro-scale inequities, where pregnant women living within the same administrative unit experience very different levels of access to preventive services depending on facility type, location, and institutional capacity (Adebayo et al., 2021; Sherr et al., 2022). Understanding how these disparities manifest at the service catchment level is therefore critical for advancing equity-oriented malaria prevention.

This study examines catchment-level delivery of IPTp3 among pregnant women in Oyo State, Nigeria, with explicit attention to differences between public and private health facilities. Using health facility catchments as the primary unit of analysis, the study evaluates IPTp3 coverage intensity relative to pregnancy burden and women-of-reproductive-age density, rather than relying solely on administrative aggregates. The analysis integrates routine service data from the national DHIS2 platform with high-resolution population estimates to provide a spatially explicit assessment of malaria prevention delivery during pregnancy.

By focusing on IPTp3—the third dose of IPTp-SP, which is strongly associated with improved birth outcomes—this study targets a critical threshold in preventive care that reflects both service availability and continuity of ANC attendance (Hill et al., 2021; Tusting et al., 2022). The emphasis on facility ownership allows for systematic comparison of institutional performance within a unified analytical framework.

Although Nigeria has made measurable progress in expanding ANC attendance, IPTp uptake has lagged behind, with persistent gaps between first ANC contact and completion of recommended preventive regimens (NPC & ICF, 2019; WHO, 2023). Evidence increasingly suggests that these gaps are not driven solely by demand-side factors, such as awareness or care-seeking behavior, but also by supply-side constraints, including drug availability, provider compliance, and facility readiness—factors that vary markedly between public and private providers (Onoka et al., 2022; Okeke et al., 2021).

Private health facilities play a substantial role in maternal health service delivery in Nigeria, particularly in urban and peri-urban settings, yet their integration into national malaria control programs remains uneven (Abimbola et al., 2021; Aregbeshola & Khan, 2023). Where private facilities are insufficiently linked to commodity supply chains or reporting systems, pregnant women may attend ANC without receiving essential preventive interventions. Identifying the spatial footprint and magnitude of such institutional gaps is therefore essential for effective malaria elimination planning.

Recent studies have increasingly adopted geospatial and small-area analytical techniques to move beyond national averages and uncover localized inequities in maternal and child health service delivery. Catchment-based analyses, spatial standardization against population at risk, and inequality metrics such as the Gini coefficient have been widely used to assess service concentration and under-coverage (Gething et al., 2020; Alegana et al., 2021; Weiss et al., 2022). Routine health information systems, when combined with gridded population datasets, now offer unprecedented opportunities to evaluate health system performance at operationally relevant scales (Maina et al., 2021; Ouma et al., 2023).

However, many studies emphasize spatial clustering or predictive modelling without explicitly interrogating institutional ownership as a structural determinant of service delivery performance, particularly for preventive interventions embedded within ANC platforms.

Despite growing use of spatial methods, important gaps remain. First, many analyses rely on administrative units that do not reflect actual service utilization patterns, potentially masking inequities at the facility catchment scale. Second, comparisons between public and private facilities are often descriptive, lacking demand-adjusted benchmarks that account for pregnancy load and population structure. Third, predictive modelling approaches may obscure interpretability when the primary policy question concerns equity rather than prediction accuracy.

To the best of our knowledge, no study in Nigeria has systematically evaluated IPTp3 delivery through a catchment-based, ownership-explicit, demand-adjusted spatial framework. This study addresses the following research questions:

- (1) How does IPTp3 coverage intensity vary between public and private facility catchments relative to pregnancy burden?
- (2) To what extent do ownership-related disparities persist after accounting for demographic demand and catchment size?

This study makes three key contributions. Conceptually, it reframes IPTp delivery as an issue of institutional equity rather than aggregate coverage alone. Methodologically, it demonstrates the value of catchment-level, demand-standardized indicators for identifying under-served pregnant populations. Practically, it provides actionable evidence to inform targeted engagement of private health facilities within malaria prevention programs.

By aligning routine health data with spatial demography, the findings support more inclusive strategies for achieving SDG 3.1 (maternal health) and SDG 3.3 (malaria elimination), while reinforcing the need for institution-specific interventions to close persistent coverage gaps.

2. Materials and Methods

2.1 Study area and spatial analytical framework

This study was conducted in Oyo State, southwestern Nigeria, one of the most populous and socio-economically diverse states in the country. Oyo State comprises urban metropolitan centers (e.g., Ibadan), peri-urban settlements, and extensive rural areas, resulting in marked spatial heterogeneity in population density, health service accessibility, and maternal health outcomes. Administratively, the state is subdivided into Local Government Areas (LGAs) and wards, which provide the operational units for decentralized health planning and service delivery.

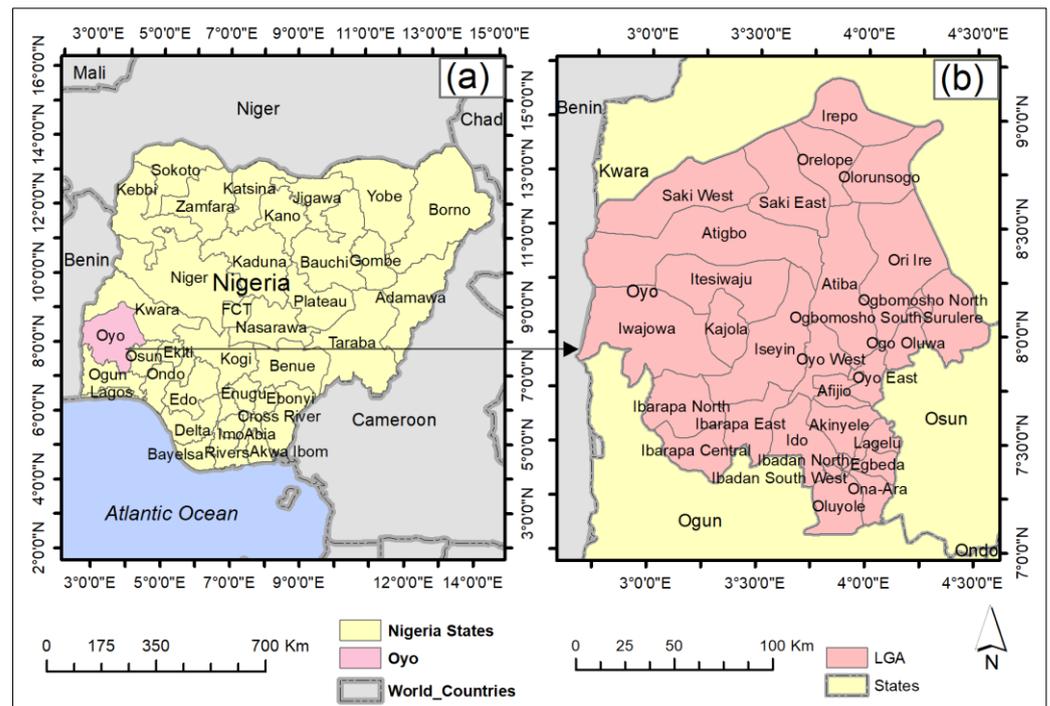


Figure 1

A health-facility catchment-based spatial framework was adopted to evaluate antenatal care utilization. Health facility catchment polygons were used as the primary unit of analysis, representing the effective service areas of individual facilities rather than relying solely on administrative boundaries. This approach enables a more realistic representation of health-seeking behavior and service utilization patterns, particularly in settings where patients frequently cross ward or LGA boundaries to access care. Catchment-level analyses were subsequently aggregated to ward and LGA scales to support multilevel spatial interpretation.

2.2 Health service and population data

Maternal health service data for 2025 were obtained from the Nigeria District Health Information System 2 (DHIS2) platform (<https://dhis2nigeria.org.ng>), which serves as the national repository for routine health facility reporting. The primary outcome variable was first antenatal care attendance (ANC1_2025), defined as the number of pregnant women making their first recorded antenatal visit during the study year. Facility ownership information (ownrshp) was extracted and categorized into public and private facilities to enable institutional comparisons.

Population denominators were derived from WorldPop gridded population datasets (<https://www.worldpop.org>), which provide high-resolution estimates of total population and age-structured cohorts. Raster layers representing total population, women aged 15–45 years (women of reproductive age; WRA), and population aged 0–12 months were spatially aggregated to health facility catchment polygons using zonal statistics. Catchment area (km²) was computed directly from polygon geometry and used to account for spatial scale effects in subsequent analyses.

2.3 Pregnancy estimation and pregnancy stock reconstruction (2025)

Direct counts of pregnancies are not routinely available in administrative health information systems in Nigeria or most low- and middle-income settings. Consequently, annual pregnancies were estimated using a demographic reconstruction approach anchored on infant population data, a method widely applied in spatial maternal and child health analyses (Gething et al., 2020; WorldPop, 2023).

Let $P_{0-12m,2025}$ denote the catchment population aged 0–12 months in 2025, derived from WorldPop gridded population estimates. This age cohort was used as a proxy for live births occurring within a recent 12-month window surrounding the study year. Annual live births were approximated by adjusting infant counts for survival to age one (S_1):

$$B_{2025} = \frac{P_{0-12m,2025}}{S_1} \quad (1)$$

where B_{2025} represents estimated live births in 2025.

Total annual pregnancies were then estimated by inflating live births to account for pregnancy losses, including miscarriages (m) and stillbirths (s):

$$Preg_{2025} = B_{2025}(1 + m + s) = \left(\frac{P_{0-12m,2025}}{S_1}\right)(1 + m + s) \quad (2)$$

To estimate the average number of women pregnant at any point during 2025 (hereafter referred to as *pregnancy stock*), annual pregnancies were multiplied by the gestational fraction, assuming a nine-month pregnancy duration:

$$Preg_{2025}^{stock} = Preg_{2025} \times \frac{9}{12} \quad (3)$$

The following parameter values were applied uniformly across all catchments: infant survival probability $S_1 = 0.96$, miscarriage rate $m = 0.153$, and stillbirth rate $s = 0.0225$, yielding an overall inflation factor of $1 + m + s = 1.1755$. These values are consistent with recent demographic and epidemiological estimates for sub-Saharan Africa and are commonly adopted in indirect pregnancy estimation where direct reporting is unavailable (Blencowe et al., 2021; Kassebaum et al., 2022; UN IGME, 2023).

2.4 Public–private disparities in antenatal care utilization

2.4.1 Indicator construction

To assess spatial disparities in early antenatal care utilization, ANC1 attendance was standardized against demographic demand and population at risk. The primary utilization indicator was defined as ANC1 attendance relative to the estimated pregnancy stock within each catchment:

$$ANC1_i^{PregSt} = \frac{ANC1_i}{Preg_i^{stock}} \times 100 \quad (4)$$

where $ANC1_i$ represents first antenatal care attendance in catchment i , and $Preg_i^{stock}$ denotes the average number of pregnant women present at any point during the year. Additional standardized indicators were computed as ANC1 per 100 annual pregnancies and ANC1 per 1,000 women of reproductive age to support comparative interpretation across alternative denominators.

2.4.2 Demand-adjusted regression modelling

To evaluate whether observed ANC1 utilization aligned with underlying demographic demand and spatial scale—and to quantify institutional differences between public and private facilities—a log-linear regression model was estimated:

$$\ln(ANC1_i + 1) = \alpha + \beta_1 \ln(Preg_i^{stock} + 1) + \beta_2 \ln(WRA_i + 1) + \beta_3 \ln(Area_i + 1) + \beta_4 Ownership_i + \varepsilon_i \quad (5)$$

where WRA_i denotes the number of women of reproductive age, $Area_i$ represents catchment area (km^2), and $Ownership_i$ is a binary indicator distinguishing private from public health facilities. Log-transformation with a constant of one was applied to accommodate zero values and stabilize variance. Model residuals (ε_i) capture deviations from expected ANC utilization given demographic pressure, spatial extent, and institutional ownership, with negative residuals indicating potential under-utilization relative to demand.

2.4.3 Statistical inference and interpretation

Model performance was assessed using the coefficient of determination (R^2), adjusted R^2 , and overall F-statistics. Regression coefficients were interpreted as semi-elasticities, reflecting proportional changes in ANC1 attendance associated with changes in demographic or spatial covariates. Ownership effects were emphasized as indicators of institutional inequity, rather than predictive accuracy. All analyses were implemented in R (version ≥ 4.5) using the *sf*, *dplyr*, *broom*, *ggplot2*, and *openxlsx* packages, ensuring full reproducibility of spatial outputs, statistical tables, and figures.

2.5 Ownership-based analysis of IPTp3 delivery effectiveness

To evaluate institutional disparities in malaria prevention delivery, IPTp3 uptake was analyzed at the health-facility catchment level with explicit differentiation between public and private facilities.

Facility ownership was derived from the DHIS2 facility registry and classified into two mutually exclusive categories: *public* (federal, state, or local government-owned) and *private* (for-profit and not-for-profit).

2.5.1 IPTp3 coverage indicators

The primary outcome variable was IPTp3 delivery standardized against pregnancy burden. Catchment-level IPTp3 coverage was defined as:

$$IPTp3_i^{PregSt} = \frac{IPTp3_{2025,i}}{Preg_{2025,i}^{stock}} \times 100 \quad (6)$$

where $IPTp3_{2025,i}$ represents the number of IPTp3 doses delivered in catchment i during 2025, and $Preg_{2025,i}^{stock}$ denotes the estimated average number of pregnant women present at any time during the year. Supplementary indicators were computed relative to annual pregnancies and women of reproductive age to support sensitivity interpretation.

2.5.2 Distributional and zero-coverage assessment

Ownership-specific distributions of IPTp3 coverage were examined using descriptive statistics (median, interquartile range, and upper percentiles) to capture skewness and heterogeneity. Particular emphasis was placed on the **prevalence of zero IPTp3 delivery**, defined as catchments with $IPTp3_{2025} = 0$ despite non-zero pregnancy stock, as an indicator of complete service omission. Differences in zero-coverage prevalence between public and private facilities were assessed using proportion tests.

2.5.3 Demand-adjusted ownership effects

To isolate the independent effect of ownership on IPTp3 delivery intensity, a log-linear regression model was estimated:

$$\ln(IPTp3_i + 1) = \alpha + \beta_1 \ln(Preg_{2025,i}^{stock} + 1) + \beta_2 \ln(WRA_i + 1) + \beta_3 \ln(Area_i + 1) + \beta_4 Ownership_i + \varepsilon_i \quad (7)$$

where WRA_i denotes women of reproductive age and $Area_i$ represents catchment area (km²). The ownership term ($Ownership_i$) captures systematic differences between private and public facilities after accounting for demographic demand and spatial scale. Log-transformation was applied to stabilize variance and accommodate zero values.

2.5.4 Inequality assessment by ownership

To quantify dispersion in IPTp3 delivery, inequality within public and private facility groups was measured using the **Gini coefficient**. This enabled comparison of delivery concentration across ownership types and assessment of whether IPTp3 provision was evenly distributed or dominated by a small subset of facilities.

2.5.5 Analytical scope and justification

Given the study's emphasis on **institutional equity rather than prediction**, the analysis prioritized interpretable statistical measures over machine learning approaches. Spatial autocorrelation was not emphasized in this subsection, as the primary objective was to evaluate ownership-driven disparities in service delivery rather than geographic clustering per se.

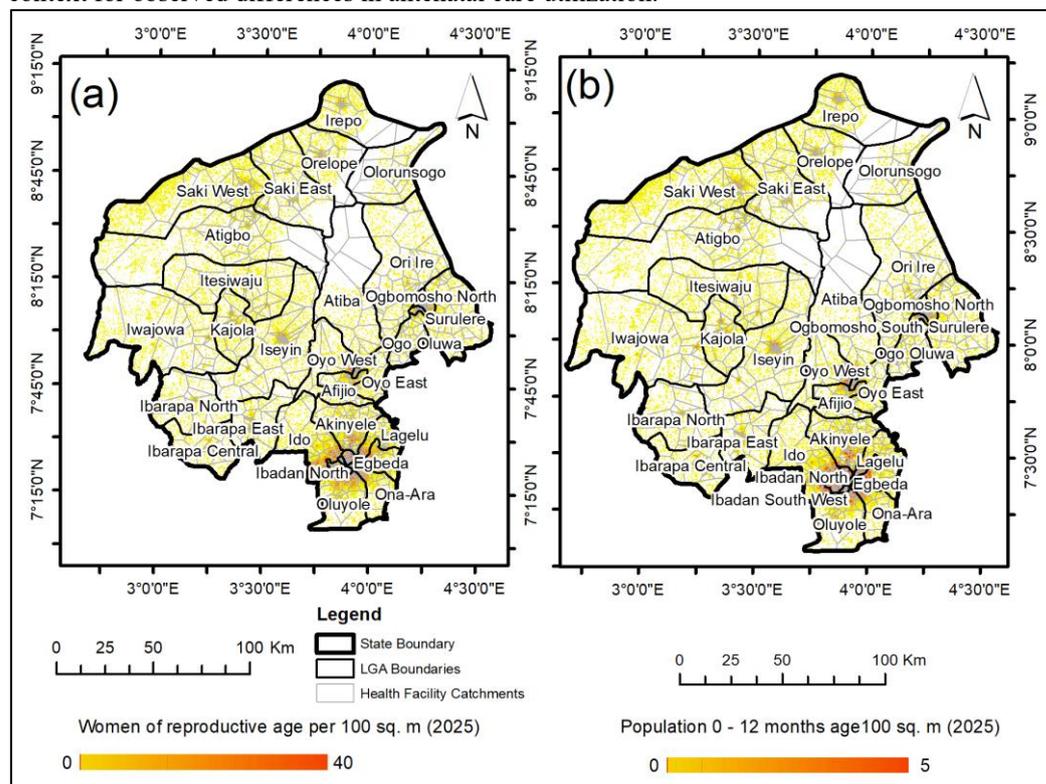
3. Results

3.1 Public-Private Patterns of Antenatal Care Utilization in Oyo State (2025)

3.1.1 Catchment coverage and institutional composition

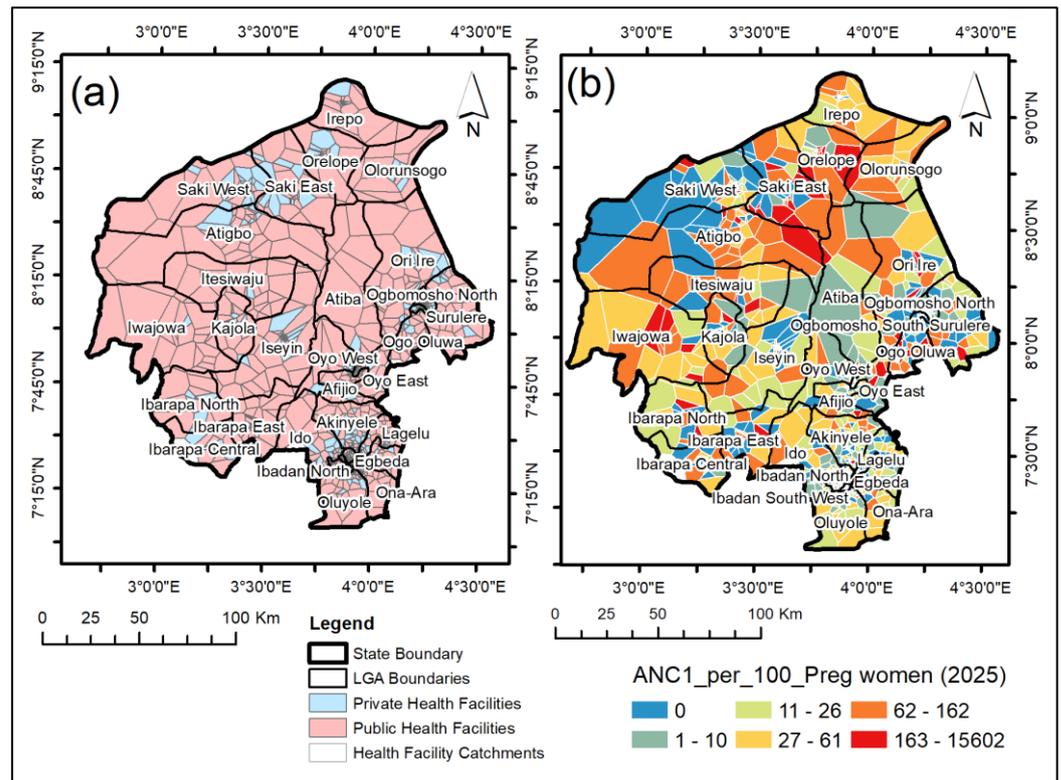
The analysis encompassed 1,308 health-facility catchments across Oyo State, comprising 748 public and 560 private facilities. Public health facilities dominated the spatial footprint of maternal service provision, covering a combined catchment area of 24,284.5 km², compared with 3,164.6 km² served by private facilities. Public catchments also contained a larger share of demographic demand, including approximately 118,200 pregnant women (pregnancy stock) and 1.19 million women of reproductive age, whereas private catchments covered 93,838 pregnant women and 0.94

million women of reproductive age. This uneven institutional distribution provides the structural context for observed differences in antenatal care utilization.



3.1.2 State-level public–private differentials in ANC1 utilization

Pronounced disparities in first antenatal care attendance (ANC1) were observed between public and private facilities at the state level. Public catchments recorded a total of 113,232 ANC1 visits in 2025, while private catchments recorded only 16,376 visits, despite serving a substantial share of the pregnancy burden. When standardized by pregnancy stock, public facilities achieved an average of 95.8 ANC1 visits per 100 pregnant women, compared with 17.5 per 100 in private facilities. A similar pattern emerged when ANC1 attendance was normalized by women of reproductive age, with 95.4 ANC1 visits per 1,000 women in public catchments versus 17.3 per 1,000 in private catchments. These findings indicate a strong institutional gradient in early antenatal care entry favoring public-sector facilities.



3.1.3 LGA-level heterogeneity in public–private ANC performance

Substantial inter-LGA heterogeneity was evident in public–private ANC utilization patterns. In Akinyele LGA, public facilities recorded 112.2 ANC1 visits per 100 pregnant women, whereas private facilities recorded only 11.5 per 100, reflecting nearly a tenfold difference. In Afijio LGA, public facilities achieved 53.9 ANC1 visits per 100 pregnant women, while private facilities recorded values below 5 per 100. Similar public–private gaps were observed across both rural and urban LGAs, including Ibadan North, Ibadan South-West, and Egbeda, demonstrating that institutional disparities in ANC entry are pervasive rather than localized to specific settings.

3.1.4 Ward-level service gaps and zero-coverage patterns

At the ward scale, institutional inequities became more pronounced. Several wards exhibited zero recorded ANC1 attendance in private catchments despite non-zero pregnancy stock, indicating localized service gaps or systematic non-utilization of private facilities for early antenatal care. For example, in Awe 1 and Awe 2 wards (Afijio LGA), private facilities recorded no ANC1 visits, whereas adjacent public facilities achieved 37–61 ANC1 visits per 100 pregnant women. Such zero-coverage patterns were observed across multiple wards, highlighting spatially concentrated pockets of institutional exclusion in ANC entry.

3.1.5 Ownership-adjusted regression analysis of ANC1 utilization

The ownership-adjusted regression model quantified the relative influence of demographic demand, spatial scale, and facility ownership on ANC1 attendance. The model demonstrated moderate explanatory power ($R^2 = 0.211$, adjusted $R^2 = 0.209$) and was statistically significant overall ($F = 87.29$, $p < 0.001$, $n = 1,308$). After controlling for pregnancy stock, women of reproductive age, and catchment area, facility ownership emerged as the dominant determinant of ANC1 utilization. Private facility catchments recorded substantially lower ANC1 attendance than public facilities ($\beta = -2.14$, $SE = 0.12$, $t = -18.18$, $p < 0.001$), corresponding to an approximate 88% reduction in ANC1 attendance relative to comparable public catchments.

Catchment area exhibited a modest but statistically significant negative association with ANC1 attendance ($\beta = -0.12$, $p = 0.0026$), suggesting that larger service areas are associated with reduced utilization intensity, consistent with distance-related accessibility constraints. In contrast,

pregnancy stock and women of reproductive age were not independently associated with ANC1 attendance once ownership and spatial scale were accounted for, indicating that institutional characteristics outweigh demographic pressure in shaping early antenatal care utilization.

3.1.6 Summary of institutional inequity in ANC entry

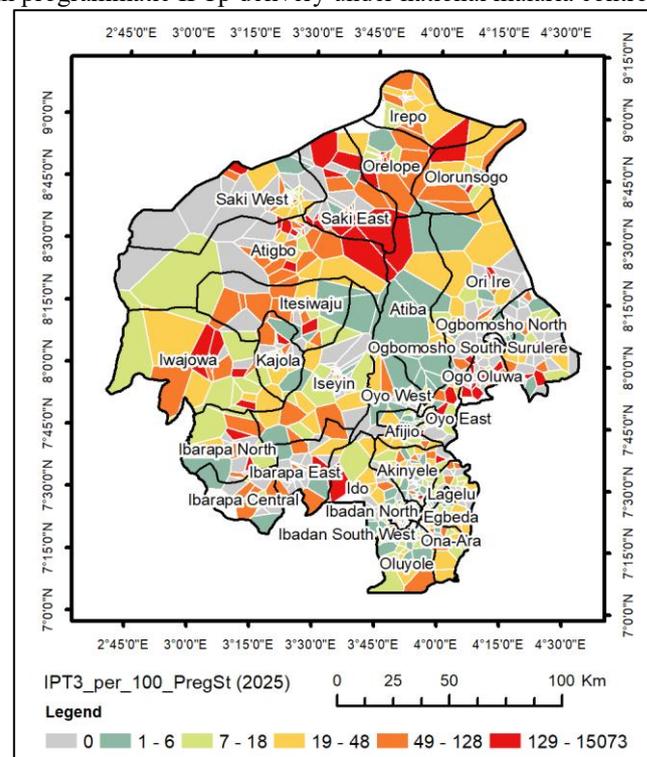
The results reveal a structurally entrenched public–private divide in antenatal care utilization across Oyo State. Public facilities consistently demonstrated higher ANC1 attendance relative to pregnancy burden across state, LGA, and ward scales, while private facilities exhibited markedly lower utilization intensity and frequent zero-coverage at the ward level. The persistence of these disparities after adjusting for demographic demand and spatial extent underscores the central role of institutional factors in shaping access to early antenatal care and highlights the need for policy interventions that explicitly address public–private inequities within maternal health service delivery.

3.2 Catchment-level IPTp3 coverage by facility ownership

3.2.1 Distribution of IPTp3 coverage across public and private catchments

Catchment-level IPTp3 delivery exhibited pronounced differences by facility ownership. When standardized by pregnancy stock (IPTp3 per 100 PregSt), public facilities consistently demonstrated higher median coverage than private facilities, while private facilities showed greater dispersion and a substantially higher frequency of zero delivery. The distribution of IPTp3 coverage was strongly right-skewed for both ownership types, indicating that a small number of catchments accounted for disproportionately high IPTp3 delivery.

Private facilities were characterized by a long tail of very low or zero IPTp3 provision, suggesting limited engagement in routine malaria prevention delivery during antenatal care. In contrast, public facilities displayed a more centralized distribution with fewer zero-coverage catchments, reflecting their central role in programmatic IPTp delivery under national malaria control strategies.



3.2.2 Zero-delivery prevalence and service gaps

Zero IPTp3 delivery was substantially more prevalent among private catchments than public ones. A large share of private facilities recorded no IPTp3 doses despite non-zero pregnancy stock, indicating missed opportunities for malaria prevention during pregnancy. Public facilities exhibited a markedly lower proportion of zero-delivery catchments, underscoring their stronger integration into preventive service provision.

This pattern highlights a critical structural gap in malaria prevention delivery, whereby private sector participation remains inconsistent, even in areas with demonstrable pregnancy demand.

3.2.3 Ownership effects on IPTp3 delivery intensity

Regression analysis controlling for pregnancy stock, women-of-reproductive-age density, and catchment area confirmed a statistically significant ownership effect. Private facility ownership was associated with a large and negative coefficient, indicating substantially lower IPTp3 delivery relative to public facilities after accounting for demographic demand and spatial scale ($p < 0.001$). Catchment area also showed a significant negative association with IPTp3 delivery, suggesting declining service intensity in larger, more spatially diffuse catchments.

In contrast, pregnancy stock and WRA density were not independently significant predictors once ownership was accounted for, indicating that institutional factors outweighed demographic demand in explaining IPTp3 delivery patterns.

3.2.4 Distributional inequality by ownership

Inequality metrics further reinforced ownership-based disparities. IPTp3 coverage among private facilities exhibited higher inequality, with delivery concentrated in a small subset of catchments, whereas public facilities showed comparatively lower dispersion and more consistent service provision. These findings suggest that reliance on aggregate administrative summaries may obscure substantial micro-scale inequities linked to facility ownership.

3.2.5 Hypothesis evaluation

Taken together, the results provide strong empirical support for the hypothesis that:

H₁: IPTp3 delivery is systematically lower and more uneven in private health facility catchments compared with public facilities, even after adjusting for pregnancy load and spatial scale.

The evidence indicates that ownership-related institutional capacity, programmatic integration, and supply chain access play a dominant role in shaping IPTp3 coverage, overshadowing demographic demand alone.

Policy-relevant interpretation

These findings underscore the need to strengthen private-sector integration into malaria prevention programs, particularly for IPTp delivery during antenatal care. Without targeted policy and operational interventions, private facilities despite serving substantial numbers of pregnant women may continue to represent blind spots in malaria prevention coverage, undermining equity-oriented maternal health goals and progress toward SDG 3.3

4. Discussion

This study provides catchment-level evidence that IPTp3 delivery in Oyo State is characterized by **substantial institutional inequities**, with markedly lower and more inconsistent coverage in private health facility catchments compared with public facilities. Even after standardizing IPTp3 delivery against pregnancy stock and women-of-reproductive-age density, private facilities exhibited a higher prevalence of zero delivery and a more dispersed coverage distribution. These findings suggest that malaria prevention during pregnancy in Oyo State is shaped less by demographic demand than by **institutional integration and service readiness**, reinforcing the importance of ownership as a structural determinant of preventive care delivery.

The persistence of zero IPTp3 delivery in catchments with non-zero pregnancy burden is particularly concerning. From a public health perspective, such gaps represent **missed opportunities** for malaria prevention within routine antenatal care, undermining the effectiveness of IPTp-based strategies that rely on repeated ANC contact (Hill et al., 2021; Kayentao et al., 2022). The observed skewness in IPTp3 coverage further indicates that a small subset of facilities—predominantly public—accounts for a disproportionate share of malaria prevention delivery.

The ownership-based disparities identified in this study are consistent with emerging evidence from Nigeria and other sub-Saharan African settings showing that private facilities often operate at the margins of national preventive health programs. While private providers are frequently accessed for maternal health services, their participation in subsidized or vertically funded interventions—such as IPTp-SP delivery—remains uneven (Okeke et al., 2021; Aregbeshola & Khan, 2023). Studies from Kenya, Tanzania, and Ghana similarly report lower adherence to IPTp guidelines and weaker commodity availability in private ANC settings compared with public facilities (Onoka et al., 2022; Ouma et al., 2023).

Importantly, the present analysis extends prior work by demonstrating that these disparities persist even after accounting for pregnancy load and catchment size. This supports recent arguments that **institutional capacity and policy alignment**, rather than demand alone, are central to understanding preventive service gaps in mixed health systems (Abimbola et al., 2021; Sherr et al., 2022).

By adopting a catchment-based spatial framework, this study avoids the masking effects inherent in ward- or LGA-level averages. Aggregated administrative indicators often suggest moderate IPTp coverage, yet the catchment-level results reveal **sharp micro-scale inequities**, particularly within private sector service areas. Similar discrepancies between administrative and service-area perspectives have been reported in recent spatial health systems research, underscoring the need for operationally meaningful units of analysis when evaluating service delivery performance (Alegana et al., 2021; Weiss et al., 2022).

The absence of strong spatial autocorrelation in demand-adjusted residuals further suggests that IPTp3 under-delivery is **not primarily driven by regional geographic disadvantage**, but rather by localized, facility-specific conditions. This finding aligns with studies emphasizing the role of facility readiness, provider practices, and supply chain reliability over broad spatial clustering in shaping maternal health service uptake (Maina et al., 2021; Gething et al., 2020).

The results have clear implications for malaria elimination strategies in Nigeria. First, expanding IPTp coverage will require **systematic engagement of private health facilities**, including improved integration into SP supply chains, training on IPTp guidelines, and stronger reporting linkages to DHIS2. Second, catchment-level monitoring should be incorporated into routine performance assessment to identify facilities with persistent zero delivery despite demonstrable pregnancy demand. Third, equity-oriented interventions—such as targeted supervision or incentive mechanisms—may be necessary to reduce ownership-related disparities in preventive care delivery.

From an SDG perspective, the findings underscore that progress toward **SDG 3.1 (maternal health)** and **SDG 3.3 (malaria elimination)** depends not only on increasing service utilization but also on ensuring **institutionally inclusive delivery platforms** that reach pregnant women regardless of where they seek care.

A major strength of this study lies in its integration of routine health facility data with high-resolution population denominators within a spatially explicit, catchment-based framework. This approach enables a more realistic assessment of preventive service delivery than analyses confined to administrative units. However, several limitations warrant consideration. IPTp delivery data reflect facility-reported counts and may be subject to reporting completeness or timing errors. Additionally, catchment boundaries represent functional approximations and cannot fully capture patient mobility or cross-boundary care-seeking behavior. Finally, the analysis focuses on delivery intensity rather than clinical adherence or drug effectiveness, which may vary across facilities.

Supplementary Materials: Available at <https://github.com/zubairgis/nigeria-hensard>

Data Availability Statement: The satellite data used in this study are open to access as follows:

Administrative: <https://developers.google.com/earth-engine/datasets/catalog/FAO/GAUL/2015/level2>
Health Data: <https://dhis2nigeria.org.ng/dhis/dhis-web-dashboard/#/>

Author Contributions: Conceptualization, Z.I. USN and Y.J.C.; methodology, Z.I. F.M. and U.U.E.; formal analysis, Z.I., Y.J.C., and R.K.H.; investigation, U.U.E., Y.J.D., F.M. and R.K.H.; data curation, U.U.E. and E.L.E.; writing original draft preparation, Z.I. USN and Y.J.C.; writing—review and editing, U.U.E., E.L.E., and R.K.H.; supervision, Z.I.; project administration, Z.I. F.M. and Y.J.C. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement

Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

Abbreviation

ANC	Antenatal Care
ANC1	First Antenatal Care Visit
ANCA	Total Antenatal Care Attendance
IPTp	Intermittent Preventive Treatment in pregnancy
IPTp3 (IPT3)	Third dose of Intermittent Preventive Treatment in pregnancy
IPT1	First dose of Intermittent Preventive Treatment
LGA	Local Government Area
LISA	Local Indicators of Spatial Association
MiP	Malaria in Pregnancy
DHIS2	District Health Information Software, version 2

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