Transport Mode Choice across Road Corridors and Residential Density Zones in Kano Metropolis

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ABSTRACT

Transport planning requires evidence on differences in mode use within cities. This study examined transport mode choice across three road corridors and residential density strata in Kano metropolis, Nigeria. A cross-sectional survey provided an analytical sample of 1,183 commuters. Spatial distributions were examined using cross-tabulations, Pearson chi-square tests and Cramer's V. A multinomial logistic model adjusted for gender, age group, income category and household size, with Keke Napep as the reference mode. Mode distributions differed across corridors, χ^2 (8) = 52.85, and density strata, χ^2 (8) = 94.06 (both $p < .001$); corresponding Cramer's V values were .149 and .199. Corridor and density remained associated with the five-mode outcome after adjustment, LR χ^2 (8) = 48.91 and 53.58, respectively (both $p < .001$). Relative to Zoo Road, Katsina Road had higher Motorcycle-to-Keke Napep and Taxi-to-Keke Napep ratios: adjusted relative risk ratios were 2.03 (95% CI: 1.29–3.18) and 9.87 (3.46–28.14). High-density strata had a lower Car-to-Keke Napep ratio than low-density strata, 0.36 (0.22–0.58). Expanded penalised specifications and an all-record sensitivity analysis retained the directions of these three contrasts. The findings support corridor-specific service assessment and attention to residential context. Disproportionate allocation, recruitment at selected locations and broad density classifications limit metropolitan generalisation and causal interpretation.

KEYWORDS

Transport mode choice, Road corridors, Residential density, Multinomial logistic regression, Kano metropolis

I. INTRODUCTION

Transportation connects residences with employment, markets, education and essential services. Within a city, the combination of routes, services and access conditions can differ between road corridors and settlement settings. Metropolitan mode shares can conceal these differences. Transport geography therefore places movement within the organisation of urban space and its networks.

Kano's commuting alternatives include Keke Napep, Public Bus, Taxi, Private Motorcycle and Private Car. Research documents urban expansion, spatial patterns of tricycle emissions in Kano and the institutional conditions shaping informal mobility in Nigeria. These findings establish context but do not quantify differences in the composition of five commuter modes across selected Kano corridors and density strata.

Corridor and residential density capture distinct aspects of the survey setting. Corridor identifies the road environment of recruitment; density distinguishes the low-, medium- and high-density areas represented in the sampling frame. Neither directly measures network connectivity, route frequency or accessibility. Simultaneous analysis can distinguish their conditional associations while accounting for differences in commuter characteristics.

This study compares five-mode distributions across Zoo Road, Hadejia Road and Katsina Road and across residential density strata. It then estimates spatial associations adjusted for gender, age, income and household size. Its statistical contribution is the integrated use of distributional tests, effect sizes, likelihood-based inference, confidence intervals, regularised sensitivity analysis and marginally standardised predicted probabilities. The resulting evidence identifies spatial contrasts for targeted service assessment without treating a cross-sectional association as a policy effect.

A. Urban form accessibility and mode choice

Cervero and Kockelman (1997) organised built-environment analysis around density, diversity and design. Their framework distinguishes residential concentration from the mix of activities and the arrangement of streets. Ewing and Cervero's (2010) meta-analysis found that travel outcomes related to different environmental dimensions; density alone had relatively weak associations after other dimensions were considered. Aston et al. (2021) likewise found variation across indicators, settings and methodological controls. Together, these studies support analysing density as one element of spatial context, rather than a complete explanation of mode choice.

Geurs and van Wee (2004) showed that accessibility measures differ in theoretical basis and data requirements. Recording a mode does not measure the opportunities reachable by that mode. Næss (2012) further emphasised that metropolitan structure and local neighbourhood conditions operate at different spatial scales. For Kano, corridor and density classifications provide broad comparisons, while the absence of geocoded destinations, network measures and service frequencies prevents direct estimation of accessibility. A greater Car share cannot therefore be equated with better access to employment or essential services.

Cao et al. (2009) reviewed evidence on residential self-selection, distinguishing environmental associations from the tendency of households to select places consistent with their resources and preferences. Associations can remain after such adjustment, but their practical magnitude and causal interpretation require care. The present design adjusts for measured commuter characteristics without observing residential preferences or changes after relocation. Its spatial coefficients consequently describe conditional relationships within the survey sample.

B. Evidence from African and Nigerian cities

Nuuyandja et al. (2024) reviewed 22 African studies and linked mode choice with urban form, infrastructure, socioeconomic conditions and institutions. Their synthesis supports local analysis because transport relationships established elsewhere may not transfer directly to African cities. Acheampong (2020), using land-use information and a survey of 1,158 workers in Kumasi, connected commuting with the organisation of residences and employment. This regional evidence motivates within-city comparison, while differing journey definitions and spatial measures limit direct transfer of numerical estimates to Kano. Campbell et al. (2019) compared accessibility across transport modes and residential developments in Nairobi and showed that higher-income settings did not automatically offer the greatest place-based access. Salon and Gulyani (2010), studying 4,375 informal-settlement residents, identified affordability and gender-related constraints on mobility. Lucas (2012) placed such constraints within transport-related social exclusion. These studies distinguish observed mode use from unrestricted preference: frequent use can reflect practical convenience, limited alternatives or both. A survey of active commuters also omits people prevented from making journeys.

Birago et al. (2017) studied Metro Mass Transit non-preference among 134 commuters in Accra. Concerns involving waiting, reliability, comfort and accessibility helped explain service perceptions. Venter et al. (2018), reviewing bus rapid transit in the Global South, showed that spatial coverage and fares shape the distribution of benefits. These findings justify service assessment alongside spatial comparison. However, low Bus shares in Kano cannot establish that the same service deficiencies apply, quantify unmet demand or determine the appropriate scale of a new service.

Nigerian evidence also qualifies simple density-based explanations. Nkeki and Asikhia (2023), using 1,735 valid responses and a nested logit model in Benin, found weaker built-environment associations than individual demographic and socioeconomic associations. Ayila et al. (2014) documented Kano's urban growth through remote sensing, while Uwais et al. (2026) modelled spatial and temporal variation in tricycle emissions in Sabon Gari, Kano. These studies concern land-cover change and emissions rather than individual five-mode choice. Lenshie et al. (2022) additionally highlighted institutional conditions surrounding commercial motorcycles and tricycles; these should not be conflated with the present Private Motorcycle category.

C. Statistical gap and analytical framework

The literature supports considering spatial setting and commuter resources jointly, retaining distinctions between formal transit, par transit and private modes. A remaining empirical question concerns how the five recorded modes differ across Kano's selected corridors and density strata after adjustment. Separate marginal tables cannot resolve this question because the composition of respondents may differ between settings. A multinomial model retains the five-category outcome and estimates conditional spatial contrasts, with Keke Napep providing a substantively relevant reference.

The analytical framework therefore links corridor, density and core demographic

characteristics with reported mode use. Education, occupation and trip context enter an expanded sensitivity specification. Chosen-mode fare, journey time, waiting time, safety and comfort are excluded because they can be attributes or consequences of the reported choice. Sparse categories require confidence intervals and stability checks. The study combines these components to distinguish observed percentages, conditional relative ratios and standardised probabilities, rather than treating them as interchangeable measures.

II. MATERIALS AND METHODS

A. Study design and sampling

A cross-sectional survey was conducted in April 2026 among adults aged at least 18 years making regular journeys in Kano metropolis. Journeys included work, business, education, shopping and family-related travel. Zoo Road, Hadejia Road and Katsina Road were selected to cover major commuter movements and contrasting transport settings. One most frequently used motorised mode was recorded per respondent.

A stratified multistage procedure allocated 417 completed questionnaires to each corridor, totalling 1,251. Within each corridor, targets were 209 respondents in high-density, 125 in medium-density and 83 in low-density strata. Equal corridor allocation and the approximate 50:30:20 density allocation broadened coverage for comparisons; they were not proportional metropolitan population allocations. Six assistants worked in corridor-based pairs, approaching every tenth eligible commuter at selected terminals and boarding points. Private-mode users were approached when parked at these locations. Declining participants were replaced by the next eligible commuter while maintaining the interval.

Interviews were administered in English or Hausa over ten working days during 07:00–09:00, 12:00–14:00 and 16:00–19:00. Data cleaning in R excluded 68 respondents (5.4%) with incomplete responses from the 1,251 records, leaving N = 1,183 for the principal analysis. This cohort comprised 390 respondents on Zoo Road, 388 on Hadejia Road and 405 on Katsina Road; density totals were 225 low, 340 medium and 618 high. Completed targets do not provide a response rate among all people approached. Estimates are unweighted and conditional on recruitment at the selected locations.

B. Variable coding and statistical notation

Let Y_i take five values: 0 for Keke Napep, 1 for Public Bus, 2 for Private Motorcycle, 3 for Taxi and 4 for Private Car. This notation is a recoding for model presentation. Corridor contrasts compare Hadejia and Katsina Roads with Zoo Road; density contrasts compare medium and high with low. Density denotes a field-defined area stratum. Kurna Asabe, Fagge and Nasarawa GRA were documented examples of high-, medium- and low-density settings. Numerical density thresholds and geocoded boundaries were unavailable, so density is not interpreted as a measured value at each respondent’s home.

The principal model includes corridor and density with gender, age group, monthly household income category and household size. Gender is coded 1 = male (reference) and 2 = female. Age codes 1–5 denote the recorded groups 15–24, 25–34, 35–44, 45–54 and 55–64 years, respectively; eligibility restricted the first group to ages 18–24, which is the reference. Monthly household income codes 1–5 retain the questionnaire brackets: below

₦50,000; ₦51,000–100,000; ₦101,000–200,000; ₦201,000–500,000; and above ₦500,000. Income enters as an ordered score, imposing equal log-ratio increments across category steps rather than per naira. Household size is the number of persons in the household.

Education codes 1–6 denote no formal education (reference), primary, secondary, NCE/ND, HND/Bachelor's degree and postgraduate education. Occupation codes 1–5 denote student (reference), unemployed, self-employed, government employee and private-sector employee. Trip-purpose codes 1–6 denote school/university, work/office (reference), market/shopping, visiting family/friends, business and other journeys. These categorical variables enter as indicators. Access time to the nearest stop, labelled DistanceToStop in the data, is measured in minutes rather than geographical distance. Traffic congestion enters as its recorded ordered score from 1 to 5; it is not treated as a measured road-quality index.

For numerical optimisation, numerical covariates were centred using their analytical-cohort means and scaled using standard deviations calculated with divisor N. Category indicators remained on the zero–one scale. Screening checked respondent-ID uniqueness, mode coding and agreement between records and tabulated frequencies. The same cleaned cohort was retained across the principal and expanded specifications to keep their sample composition constant.

C. Descriptive distributions and association tests

For mode j in spatial group g, let $n_{j}g$ denote its count, $n_{+}g$ the group total and n_{j+} the mode total across all groups. N = 1,183 is the principal sample size, with respondent index i ranging from one to N. There are J = 5 modes and G = 3 groups in each spatial comparison. Within-group percentages were calculated by dividing a mode count by its group total and multiplying by 100. Corridor and density distributions were examined separately.

Under independence, expected frequencies equal the product of the marginal totals divided by N. Pearson's statistic in Equation (1) was compared with a chi-square distribution with $(J - 1)(G - 1) = 8$ degrees of freedom. Expected frequencies were checked because the Bus and Taxi categories were small.

$$\chi^2 = \sum_{g=1}^{G} \sum_{j=0}^{J-1} \frac{(n_{jg} - E_{jg})^2}{E_{jg}}, \quad E_{jg} = \frac{n_{j+} n_{+g}}{N} \tag{1}$$

Cramér's V in Equation (2) reports association magnitude alongside p-values. For these five-by-three tables, the minimum dimension is two. Both measures describe the sample distribution; neither corrects unequal recruitment probabilities or identifies a causal effect.

$$V = \sqrt{\frac{\chi^2}{N \min(J - 1, G - 1)}} \tag{2}$$

D. Multinomial model and likelihood estimation

For non-reference modes j = 1, 4, let p_{ij} denote the probability that respondent i reports mode j, conditional on the measured covariates. Equation (3) models the log probability ratio relative to Keke Napep (Train, 2009). C_1 and C_2 indicate Hadejia and Katsina Roads; D_1 and D_2 indicate medium and high density. The γ coefficients describe corridor contrasts and the δ coefficients describe density contrasts. Z_i contains gender and age indicators and

standardised income and household size; θ_j is their mode-specific coefficient vector. Each α_j is a mode-specific intercept.

$$\eta_{ij} = \log\left(\frac{p_{ij}}{p_{i0}}\right) = \alpha_j + \gamma_{1j}C_{1i} + \gamma_{2j}C_{2i} + \delta_{1j}D_{1i} + \delta_{2j}D_{2i} + \theta_j{}^T Z_i \quad (3)$$

The baseline-category probabilities follow Equation (4), with $\eta_{i0} = 0$. They are positive and sum to one for each respondent. The denominator includes the baseline contribution of one and all four alternative-mode contributions.

$$p_{ij} = \frac{\exp(\eta_{ij})}{1 + \sum_{h=1}^{4}\exp(\eta_{ih})}, \quad p_{i0} = \frac{1}{1 + \sum_{h=1}^{4}\exp(\eta_{ih})} \quad (4)$$

Let y_{ij} equal one when respondent i reports mode j and zero otherwise. The individual contributions from the log-likelihood in Equation (5). Parameters were estimated by maximising it under the assumption of independent observations. Summing, rather than averaging, the log-likelihood also fixes the scale of the sensitivity penalties described below.

$$\ell(\beta) = \sum_{i=1}^{N}\sum_{j=0}^{4} y_{ij}\log p_{ij}\,; \quad \hat{\beta} = \arg\max_{\beta}\ell(\beta) \quad (5)$$

The coefficient vector β stacks the four non-reference mode coefficient vectors. Each uses the same 12-element design vector x_i: an intercept, four spatial indicators, one gender indicator, four age indicators and two numerical terms. The principal model therefore estimates K = 48 parameters, without interactions. Numerical maximisation used Python, NumPy and SciPy with an analytical gradient. Convergence was assessed using finite estimates, the gradient and information-matrix eigenvalues. A second optimiser and finite-difference derivatives checked numerical agreement. The information-matrix specification is provided in Supplementary Methods, Equation (S1).

The Keke Napep coefficient vector is fixed to zero for identification. Finite maximum-likelihood estimates require a full-rank design and sufficient information in category combinations. Because sparse combinations can destabilise estimates, numerical convergence was assessed alongside information-matrix eigenvalues and confidence-limit precision. These checks do not eliminate unmeasured confounding.

E. Uncertainty inference and model fit

Model-based standard errors were calculated from the square roots of the diagonal entries of the inverse information matrix evaluated at the fitted coefficients. Supplementary Methods, Equation (S2), documents this calculation. These standard errors assume independent respondents; no location-cluster correction was possible from the available identifiers.

For a one-unit spatial indicator contrast, exponentiation its estimated coefficient gives the adjusted relative risk ratio in Equation (6). Here a indexes the scalar coefficient, $\hat{\beta}_a$ is its estimate and SE ($\hat{\beta}_a$) is its standard error. The lower and upper limits of its 95% Wald confidence interval are L_a and U_a, respectively. Two-sided Wald p-values compare the estimated coefficient divided by its standard error with a standard normal distribution. All 16 spatial contrasts are presented, including those whose intervals contain one; these exploratory contrasts have no multiplicity adjustment.

$$\begin{aligned} RRR_a &= \exp(\hat{\beta}_a) \\ L_a &= \exp\left(\hat{\beta}_a - 1.96\,\mathrm{SE}(\hat{\beta}_a)\right) \\ U_a &= \exp\left(\hat{\beta}_a + 1.96\,\mathrm{SE}(\hat{\beta}_a)\right) \end{aligned} \tag{6}$$

Each RRR compares a non-reference mode with Keke Napep and a focal spatial category with its reference category. It is not an absolute probability ratio for that mode alone. Joint tests assess each entire spatial term using Equation (7), with full and reduced models estimated on the same cohort. Omitting either spatial term removes two indicators from each of four logits, giving d = 8; the overall comparison with intercepts alone has d = 44. Under the null hypothesis, the likelihood-ratio statistic is asymptotically chi-square.

$$LR = 2(\ell_F - \ell_R) \sim \chi^2_d, \quad d = K_F - K_R \tag{7}$$

The corridor null sets both corridor coefficients to zero in each non-reference logit; density is tested analogously. Each reduced model retains the other spatial term and all four demographic covariates. These joint tests differ from the individual Wald tests in Tables 5 and 6: a significant joint result does not imply significance for every mode-specific contrast.

Akaike's information criterion was calculated from twice the parameter count minus twice the fitted log-likelihood. McFadden's pseudo-R^2 was calculated as one minus the ratio of fitted-model to intercept-only log-likelihood. In the principal model, K = 48 includes all intercepts and slopes. These standard likelihood-based fit summaries are interpreted following Train (2009): pseudo-R^2 describes improvement relative to the null likelihood rather than explained outcome variance. Statistical tests use a two-sided .05 threshold. IIA remains an unverified assumption; numerical convergence cannot establish it.

F. Regularisation and standardised probability summaries

An expanded sensitivity model adds education, occupation and trip purpose as categorical terms, together with numerical access time to a stop and the ordered traffic-congestion score. Numerical covariates are standardised. Equation (8) applies an L_2 penalty to every non-intercept coefficient in the four baseline-parameterised logits, extending the regularisation principle described by Friedman et al. (2010). The r index runs over q non-intercept design columns, with q = 27 in this expanded specification. Each of its four logits also has an unpenalised intercept. B_{rj} is a non-intercept coefficient, λ is the penalty strength, and $\hat{\beta}\lambda$ is the minimiser of the penalised objective.

$$\hat{\beta}_\lambda = \arg\min_{\beta}\left(-\ell(\beta) + \tfrac{\lambda}{2}\textstyle\sum_{j=1}^{4}\sum_{r=1}^{q}{\beta_{rj}}^2\right) \tag{8}$$

Penalties λ = 0.1, 1 and 10 form a sensitivity grid on the summed negative log-likelihood scale. They were not selected by cross-validation; conventional unpenalised Wald intervals are not attached to these estimates. Direction and magnitude were compared across penalties. A further unpenalised fit used all 1,251 records, which had complete values for the variables required by the principal demographic specification. This check assessed sensitivity to restricting analysis to the cleaned cohort. Neither specification includes chosen-mode fare, travel time, waiting time, safety or comfort.

The penalty depends on coefficient scale and the baseline parameterisation. Category references were held fixed across fits, numerical variables were standardised, and indicators retained their zero–one scale. Larger penalties shrink coefficients towards zero. The grid

checks sensitivity to specification; it does not identify an optimal prediction penalty or an unbiased spatial effect.

Marginally standardised predicted probabilities translate relative contrasts into absolute mode composition. In Equation (9), x_i (g) sets one focal spatial variable to category g for every respondent while retaining their other covariates. The principal-model probabilities are averaged over N = 1,183 respondents. Corridor and density are standardised separately. These are conditional sample summaries, without population weights or causal interpretation; 95% confidence intervals were calculated using the delta method and the principal-model coefficient covariance matrix. Intervals were formed on the logit scale and back-transformed to remain between zero and one. They quantify coefficient uncertainty conditional on the observed covariate distribution and assume independent respondents.

$$\bar{\hat{p}}_j(g) = \frac{1}{N}\sum_{i=1}^{N} \hat{p}_j\left(x_i(g); \hat{\beta}\right) \quad (9)$$

Standardisation uses a common observed covariate distribution across displayed settings, rather than comparing groups with different demographic compositions. It assumes the fitted specification describes those profiles at each assigned setting. Because individual choice sets were not recorded, these estimates are not forecasts under relocation or altered service availability.

G. Ethical considerations

The research design and questionnaire were reviewed by the research supervisor. Participation was voluntary, verbal informed consent preceded each interview, and respondents could decline without consequence. Interviews were conducted in the participant's preferred language. No personal identifying information was collected.

III. RESULTS AND DISCUSSION

A. Spatial distribution of the sample

Table 1. Respondents by road corridor and residential density zone

Characteristic	Category	n	%
Corridor	Zoo Road	390	33.0
	Hadejia Road	388	32.8
	Katsina Road	405	34.2
Density zone	Low	225	19.0
	Medium	340	28.7
	High	618	52.2

Note. N = 1,183. Corridor and density are separate classifications of the same respondents. Percentages may not sum to 100 because of rounding.

The corridor sample was approximately balanced, while high-density strata contributed 52.2%, reflecting the design allocation (Table 1). Overall counts were 576 Keke Napep

(48.7%), 299 Private Car (25.3%), 219 Private Motorcycle (18.5%), 46 Public Bus (3.9%) and 43 Taxi (3.6%). These are sample proportions rather than metropolitan population shares.

B. Transport mode differences across road corridors

Table 2. Transport mode within each road corridor

Mode	Zoo Road n (%)	Hadejia Road n (%)	Katsina Road n (%)
Keke Napep	212 (54.4)	201 (51.8)	163 (40.2)
Public Bus	12 (3.1)	19 (4.9)	15 (3.7)
Private Motorcycle	63 (16.2)	69 (17.8)	87 (21.5)
Taxi	5 (1.3)	4 (1.0)	34 (8.4)
Private Car	98 (25.1)	95 (24.5)	106 (26.2)
Total	390 (100.0)	388 (100.0)	405 (100.0)

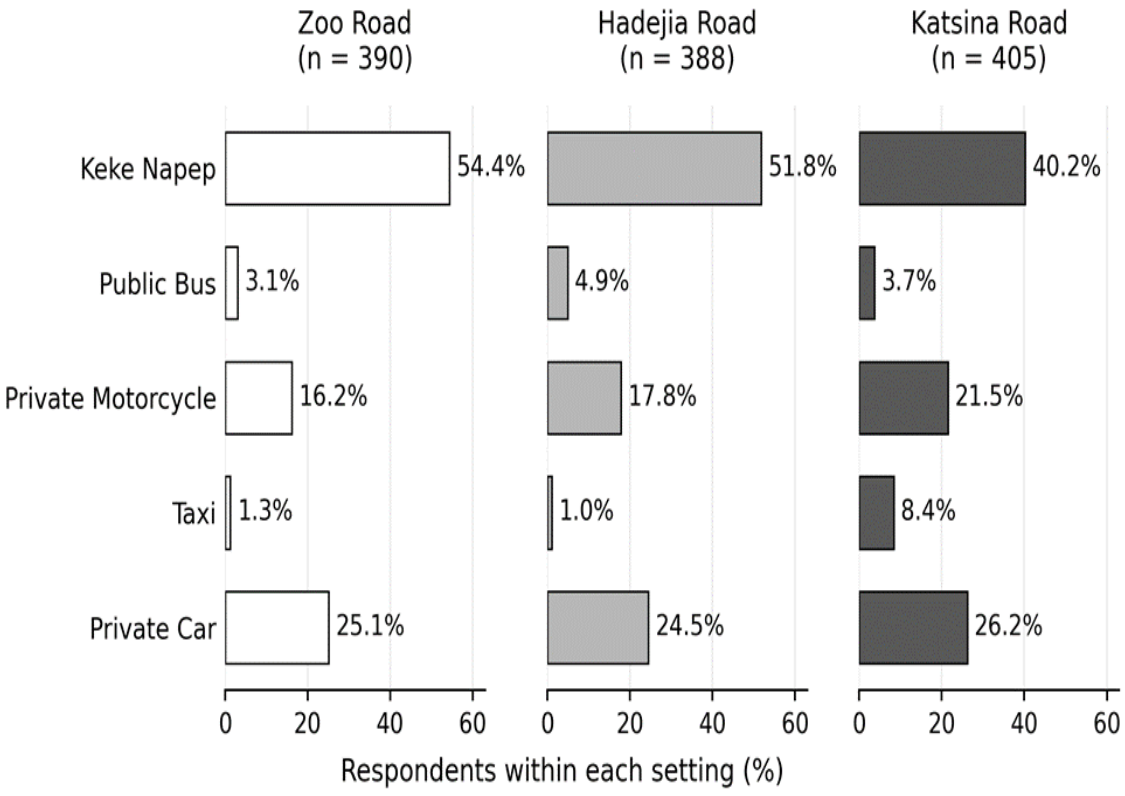

Figure 1. Transport mode composition across the three road corridors

Source: Kano Metropolis commuter survey. Percentages are within each corridor (Zoo Road, n = 390; Hadejia Road, n = 388; Katsina Road, n = 405).

Keke Napep was the largest category on every corridor, with a lower share on Katsina Road (Figure 1). Katsina Road had the highest Motorcycle and Taxi shares; 34 of the 43 Taxi respondents were recruited there, compared with five on Zoo Road and four on Hadejia Road.

Car shares ranged from 24.5% to 26.2%, and Bus shares were below 5%. The corridor table gave Cramér's V = .149 and a minimum expected frequency of 14.10. The significant Pearson test concerns the full distribution, rather than every mode or corridor pair.

C. Transport mode differences across residential density zones

Table 3. Transport mode within each residential density zone

Mode	Low density n (%)	Medium density n (%)	High density n (%)
Keke Napep	72 (32.0)	177 (52.1)	327 (52.9)
Public Bus	3 (1.3)	2 (0.6)	41 (6.6)
Private Motorcycle	42 (18.7)	57 (16.8)	120 (19.4)
Taxi	9 (4.0)	8 (2.4)	26 (4.2)
Private Car	99 (44.0)	96 (28.2)	104 (16.8)

Note. Column denominators are 225, 340 and 618 for low-, medium- and high-density zones. Percentages may not sum to 100 because of rounding. Pearson χ^2 (8) = 94.06, $p < .001$

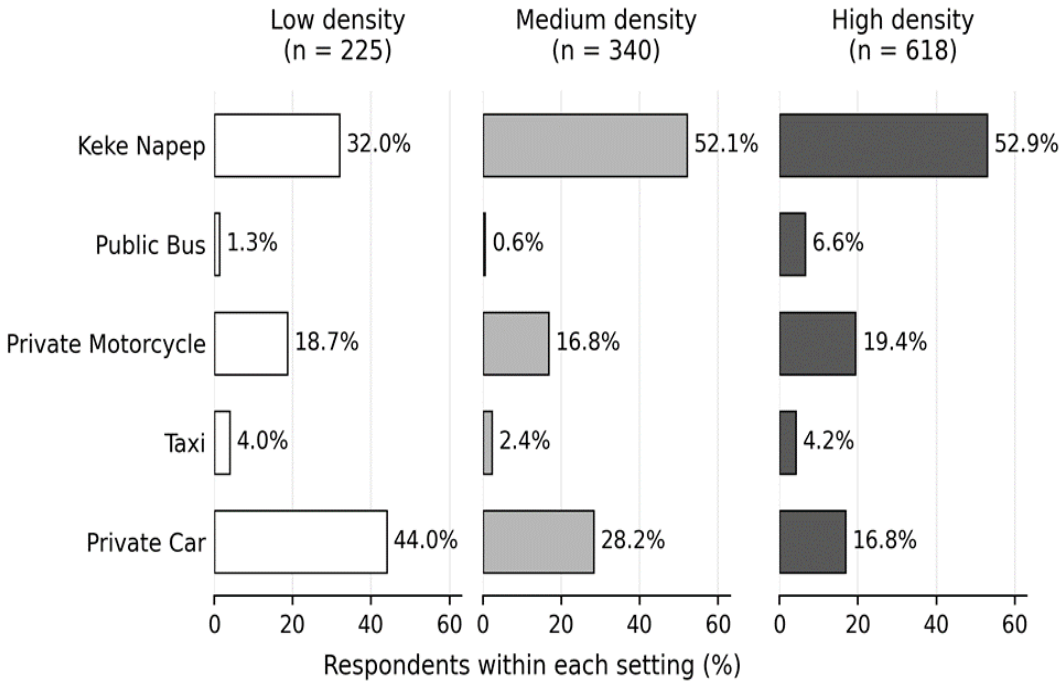

Figure 2. Transport mode composition across residential density zones

Source: Kano Metropolis commuter survey. Percentages are within each density category (low, n = 225; medium, n = 340; high, n = 618).

Private Car predominated in low-density strata (44.0%) but accounted for 16.8% in high-density strata (Figure 2). Keke Napep showed the opposite pattern, increasing from 32.0% to 52.9%; the medium-density share was 52.1%. The density table gave Cramér's V = .199, with a minimum expected frequency of 8.18.

Bus use was highest in the high-density stratum, although the total Bus count was small. Motorcycle shares varied less than Car or Keke Napep shares. Marginal tables do not establish whether the density gradient is the same within every corridor.

D. Adjusted spatial associations

Table 4. Omnibus adjusted tests for the spatial predictors

Predictor	LR χ^2	df	p
Corridor	48.91	8	< .001
Residential density zone	53.58	8	< .001

Note. N = 1,183. Each likelihood-ratio test compares the principal demographic-adjusted model with an otherwise identical model omitting the indicated spatial predictor.

Both spatial terms contributed to the adjusted five-mode model (Table 4). The corridor likelihood-ratio statistic was 48.91 and the density statistic was 53.58, each with eight degrees of freedom and $p < .001$. The model log-likelihood was −1,153.26, compared with −1,487.08 for the intercept-only model: overall LR χ^2 (44) = 667.63, $p < .001$. McFadden's pseudo-R^2 was .224 and AIC was 2,402.52. These likelihood-based measures describe relative fit; pseudo-R^2 is not the proportion of outcome variance explained.

Table 5. Adjusted corridor contrasts relative to Keke Napep

Corridor contrast	Mode vs Keke Napep	RRR	95% CI	p
Hadejia vs Zoo	Public Bus	2.10	0.94–4.70	0.071
Hadejia vs Zoo	Private Motorcycle	1.14	0.74–1.75	0.563
Hadejia vs Zoo	Taxi	0.96	0.25–3.76	0.958
Hadejia vs Zoo	Private Car	0.90	0.58–1.39	0.635
Katsina vs Zoo	Public Bus	2.26	0.95–5.38	0.066
Katsina vs Zoo	Private Motorcycle	2.03	1.29–3.18	0.002
Katsina vs Zoo	Taxi	9.87	3.46–28.14	< .001
Katsina vs Zoo	Private Car	1.29	0.83–2.01	0.259

Note. RRR = adjusted relative risk ratio; CI = 95% Wald confidence interval. Spatial reference: Zoo Road. Outcome reference: Keke Napep. All estimates adjust for density, gender, age group, income category score and household size. P-values are two-sided Wald tests.

Katsina Road had higher Motorcycle-to-Keke Napep and Taxi-to-Keke Napep ratios than Zoo Road (Table 5). The Motorcycle RRR was 2.03 (95% CI: 1.29–3.18), and the Taxi RRR was 9.87 (3.46–28.14). The latter interval is wide, consistent with the small Taxi counts on Zoo Road and Hadejia Road. The Car contrast was not statistically clear, with an RRR of 1.29 (0.83–2.01). All Hadejia Road corridor intervals included one. The omnibus corridor association therefore reflects selected contrasts rather than a uniform difference across all four alternatives.

Table 6. Adjusted density contrasts relative to Keke Napep

Density contrast	Mode vs Keke Napep	RRR	95% CI	p
Medium vs low	Public Bus	0.27	0.04–1.67	0.158
Medium vs low	Private Motorcycle	0.66	0.39–1.13	0.128
Medium vs low	Taxi	0.43	0.15–1.22	0.111
Medium vs low	Private Car	0.65	0.39–1.06	0.085
High vs low	Public Bus	3.15	0.92–10.79	0.067
High vs low	Private Motorcycle	0.75	0.46–1.21	0.234
High vs low	Taxi	0.73	0.31–1.73	0.470
High vs low	Private Car	0.36	0.22–0.58	< .001

Note. Spatial reference: low-density stratum. Outcome reference: Keke Napep. Estimates adjust for corridor, gender, age group, income category score and household size. CI = 95% Wald confidence interval; p-values are two-sided Wald tests.

The high-density Car-to-Keke Napep ratio was lower than the low-density ratio after demographic adjustment: RRR = 0.36 (95% CI: 0.22–0.58; Table 6). The corresponding medium-density estimate was 0.65 (0.39–1.06). Other density-specific confidence intervals included one, including the Bus contrasts, for which relatively few low- and medium-density users produced wide intervals. These results distinguish the strong overall density association from uncertainty concerning several individual modes. They also show that the observed Car gradient retains a high-versus-low density contrast under this adjustment set.

E. Numerical checks and sensitivity results

The principal model converged with a positive-definite information matrix (minimum eigenvalue 0.732; condition number 538.2). A second optimizer matched the log-likelihood within 10^{-8}, and finite differences agreed with the analytical matrix. All confidence limits were finite. These checks establish numerical agreement, not freedom from sampling or specification uncertainty.

Table 7. Sensitivity of three principal spatial contrasts

Spatial contrast and mode	Expanded λ = 0.1	Expanded λ = 1	Expanded λ = 10	All records N = 1,251

Katsina vs. Zoo: Motorcycle	2.21	1.99	1.43	1.63
Katsina vs. Zoo: Taxi	15.47	8.54	2.46	9.63
High vs. low density: Car	0.26	0.33	0.52	0.35

Note. Entries are RRRs relative to Keke Napep. Expanded models (N = 1,183) add education, occupation, trip purpose, access time to a stop and traffic congestion, with L_2 penalties on non-intercept coefficients. The unrealized all-record model uses the principal adjustment set. These are sensitivity estimates, not additional significance tests.

The three highlighted contrasts retained their directions across penalties and in the all-record model (Table 7). Magnitudes varied, particularly for Taxi. These checks support directional consistency across the specified models, rather than an exact effect size.

F. Marginally standardized predicted probabilities

Table 8. Marginally standardized predicted probabilities and 95% confidence intervals (%)

Spatial setting	**Keke Napep**	**Public Bus**	**Private Motorcycle**	**Taxi**	**Private Car**
Zoo Road	54.1 (49.5–58.6)	2.6 (1.5–4.6)	15.9 (12.6–19.8)	1.2 (0.5–2.9)	26.3 (22.9–29.9)
Hadejia Road	52.3 (47.8–56.8)	5.2 (3.3–8.0)	17.3 (14.0–21.0)	1.1 (0.4–2.9)	24.1 (20.8–27.8)
Katsina Road	39.8 (35.2–44.5)	4.2 (2.5–6.9)	22.4 (18.7–26.6)	8.5 (5.9–12.0)	25.2 (22.0–28.8)
Low density	41.4 (35.2–47.8)	1.6 (0.5–5.0)	20.0 (15.3–25.7)	4.5 (2.4–8.4)	32.5 (27.7–37.7)
Medium density	50.9 (46.2–55.5)	0.6 (0.1–2.2)	17.2 (13.7–21.3)	2.5 (1.2–4.8)	29.0 (25.3–33.0)
High density	50.4 (46.8–54.1)	6.6 (4.9–8.9)	19.2 (16.4–22.3)	4.0 (2.8–5.8)	19.9 (17.2–22.8)

Note. Percentages are followed by 95% confidence intervals. Each spatial category was assigned to all 1,183 respondents, retaining other observed covariates. Principal-model predictions were averaged. Delta-method intervals use the coefficient covariance and logit transformation, conditional on observed covariates. Estimates are unweighting; rounding affects row totals.

The standardized summaries provide an absolute-probability counterpart to the relative ratios (Table 8). At a common covariate distribution, fitted Taxi probability was 8.5% for Katsina Road and 1.2% for Zoo Road, while Motorcycle probability was 22.4% and 15.9%, respectively. Fitted Car probability was 32.5% for low-density and 19.9% for high-density strata. The descriptive low-density Car share was 44.0%, illustrating how demographic standardization can attenuate an observed percentage difference without eliminating it. These fitted contrasts remain conditional model summaries.

IV. DISCUSSION OF SPATIAL ASSOCIATIONS

The corridor and density associations describe different dimensions of motorised mode composition. Similar raw Car shares across corridors coexist with greater Taxi and Motorcycle representation on Katsina Road, whereas density shows a pronounced Car–Keke Napep contrast. Joint modelling retains both spatial terms after demographic adjustment. This is compatible with the regional evidence that place and commuter resources jointly relate to travel (Acheampong, 2020; Nuuyandja et al., 2024), while providing no basis for assuming the same urban structure or mechanism across cities.

The high-density Car RRR of 0.36 remains below one after adjustment, but the standardised Car contrast is smaller than the raw difference: 32.5% versus 19.9%, compared with observed shares of 44.0% versus 16.8%. This attenuation shows why marginal percentages and conditional model summaries should be distinguished. Remaining differences may involve service supply, household resources or residential selection. They do not isolate density from the other built-environment dimensions emphasised by Cervero and Kockelman (1997) and Ewing and Cervero (2010). The Taxi corridor interval is wide despite a strong point estimate. Few Taxi respondents on Zoo and Hadejia Roads limit precision, and the expanded model's coefficient magnitude varies with shrinkage. Agreement in the directions of the three highlighted contrasts across specifications is useful sensitivity evidence, but it does not establish their exact magnitudes. The unadjusted association sizes, V = .149 and .199, similarly complement significant tests without implying that location alone strongly determines individual choices.

Keke Napep's prominence supports including tricycle users and operators in service assessments. Research on tricycle emissions in Kano also illustrates the value of examining variation across urban locations (Uwais et al., 2026). Low Bus shares warrant investigation of route coverage and operating conditions, informed by the service-quality concerns identified in Accra (Birago et al., 2017). The present survey does not establish specific deficiencies. Following Geurs and van Wee (2004) and Campbell et al. (2019), subsequent planning should measure destinations and reachable opportunities alongside mode shares. Such evidence is needed before selecting routes, fleet sizes or infrastructure investments.

A. Limitations and further research

Cross-sectional measurement prevents separation of spatial associations from residential self-selection and unmeasured confounding. Density thresholds and geocoded boundaries were unavailable; corridor and density remain broad classifications. Neither spatial dependence nor corridor-by-density interaction was estimated. The five-mode outcome excludes walking, cycling, non-travellers and multimodal chains, so it cannot describe total metropolitan mobility or transport exclusion. Disproportionate allocation, selected boarding locations and recruitment of parked private-mode users limit representativeness. Selection probabilities and location clusters were unavailable for weighted or cluster-adjusted inference. Reported confidence intervals and p-values therefore depend on an independent-observation model. Small Bus and Taxi groups limit precision; IIA is unverified, and individual choice sets were not recorded. Income-category scoring imposes a linearity assumption. Sensitivity checks address specified model changes, rather than every source of uncertainty.

B. Planning and statistical recommendations

Service assessments should represent Katsina Road's Taxi and Motorcycle users and the substantial Keke Napep populations on Zoo and Hadejia Roads. Within density strata, they should examine affordability, service hours and links to activity destinations. These are priorities for investigation, not evidence for a fixed allocation of investment. Equity appraisal should include people unable to make journeys, following the concerns raised by Lucas (2012) and Venter et al. (2018). Future surveys should record geocoded origins and destinations, measured settlement characteristics, available alternatives, residential preferences and recruitment-location identifiers. These additions would support clearer density definitions, interaction tests, assessment of spatial dependence and appropriate survey variance estimation. More observations in small modes would improve precision. Repeated or longitudinal measurement would permit stronger evaluation of transport changes than interpreting the current spatial coefficients as intervention effects.

V. CONCLUSION

Motorized mode composition differed across the three surveyed road corridors and residential density strata in Kano. After adjustment for core commuter characteristics, Katsina Road retained higher Motorcycle-to-Keke Napep and Taxi-to-Keke Napep ratios than Zoo Road, while high-density settings retained a lower Car-to-Keke Napep ratio than low-density settings. These three directions persisted in expanded penalized models and the all-record sensitivity analysis. The findings support targeted assessment of the services and users represented in each setting. Broad density classifications and the sampling design require interpretation as associations in the surveyed commuter population, rather than causal effects or metropolitan modal-share estimates.

DECLARATIONS

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