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Spatial Structure of Mobile Broadband Performance in Nigeria: Regional Differences and Latency Clustering

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Abstract
State-level broadband rankings identify weak-performing areas but do not establish whether similar conditions occur in neighboring states. This study examines the spatial structure of mobile broadband performance across Nigeria's 36 states and the Federal Capital Territory using Ookla Open Data from Q2 2025 to Q1 2026. Device-weighted estimates of download throughput, upload throughput, and latency were compared across six geopolitical zones and evaluated using Global and Local Moran statistics under first-order Queen contiguity. Test weighting assessed aggregation sensitivity. Download and upload varied across states without significant pooled regional differences or global spatial autocorrelation. Latency showed regional differentiation ($H = 21.45$, $p = 0.000667$, $\varepsilon^2 = 0.530$) and positive spatial autocorrelation ($I = 0.400$, permutation $p < 0.001$). Quarterly regional differences remained significant after Holm correction across four tests. Local analysis with false-discovery-rate adjustment identified high-high latency relationships in Sokoto and Zamfara and low-low relationships in Ogun, Osun, and Oyo. Ogun, Osun, Sokoto, and Zamfara remained significant under test weighting. These findings support separate monitoring of throughput and latency and identify locations for coordinated engineering investigation. The observed clusters do not establish a particular infrastructure fault or the experiences of all users within a state.
Keywords: mobile broadband; latency; spatial autocorrelation; Nigeria; crowdsourced measurement

1.0 Introduction

Broadband inequality is increasingly a question of service quality as well as access. National coverage or subscription indicators can show whether connectivity is available, but they do not establish whether realized service quality is geographically even. Download throughput, upload throughput, and latency describe different aspects of network performance, and the same location can occupy different positions depending on the metric being examined (Stocker and Whalley, 2018; Jembre et al., 2022; Frias et al., 2025; Reed et al., 2026). For mobile networks, these dimensions are shaped by a combination of radio conditions, congestion, backhaul, routing, device context, server selection, and the location of network resources.

Coverage and measured service quality answer different questions. A radio signal may be available even where users experience low throughput or long delays. Stocker and Whalley (2018) show that access speed alone does not describe broadband experience, while Jembre et al. (2022) assess mobile broadband using several performance measures. Studies using granular speed-test data also find substantial differences within countries and across settlement and socioeconomic contexts (Caldas et al., 2023; Gallardo and Whitacre, 2024; Melchiorri et al., 2024). These findings support examining observed performance directly rather than inferring it from coverage or subscription counts.

A second issue is that broadband quality is multidimensional. Download throughput, upload throughput, and latency are produced by overlapping but not identical parts of the end-to-end system. Throughput is shaped by factors such as radio conditions, available capacity, congestion, scheduling, device capability, and backhaul, while latency additionally reflects path length, routing, peering, server location, transport infrastructure, and protocol behavior. Feamster and Livingood (2020) emphasize that Internet speed measurements capture an end-to-end service outcome rather than a single network subsystem. Stocker and Whalley (2018) similarly show that access speed alone is insufficient to characterize broadband experience, while more recent longitudinal and mobile-network studies retain throughput and latency as complementary indicators because they can evolve differently across technologies and places (Loh et al., 2025; Reed et al., 2026; Schnitzer et al., 2024). Frias et al. (2025) likewise argue that the usefulness of a broadband metric depends on the policy or engineering question being asked. A geographic pattern observed for download speed should therefore not be assumed to recur for latency,

and a spatial analysis that keeps these dimensions separate can reveal structure that a single composite score would obscure.

Crowdsourced speed-test data provide an unusually broad basis for such analysis because they make repeated measurement across many geographic areas possible without requiring a researcher-operated national drive-test campaign. At the same time, these observations are user initiated and spatially uneven. The devices, subscriptions, locations, testing motivations, access conditions, and servers represented in the data are not selected through a probability-sampling design. Paul et al. (2022) show why crowdsourced measurements require contextualization, while MacMillan et al. (2023) demonstrate that platform design and measurement method can affect observed results. Other studies document geographic sampling imbalance, selection effects, and the difficulty of treating voluntary speed tests as population-representative observations (Mangla et al., 2022; Saxon and Black, 2022; Lee et al., 2023; Stuyvesant et al., 2025). Ookla's own server deployment and user-server assignment can also vary geographically and over time, introducing another layer of measurement context (Zhang et al., 2024). For that reason, the present study treats Ookla observations as evidence of measured end-to-end performance among participating devices, not as a census of every connection in a state. The purpose of the spatial analysis is to ask whether the observed state-level performance surface contains geographic structure after consistent aggregation, not to claim that every resident experiences the state mean.

Spatial analysis contributes something different from conventional ranking. A ranking identifies which states have relatively high or low values, but it does not establish whether high values tend to occur beside other high values, whether low values form contiguous clusters, or whether apparent regional differences exceed what would be expected from the national distribution. The scale of observation also matters: a state average can conceal local contrasts that become visible in finer geographic data (Caldas et al., 2023; Melchiorri et al., 2024). Work using speed tests and other granular connectivity data finds substantial regional, urban-rural, and neighborhood-scale structure in Internet quality (Caldas et al., 2023; Gallardo and Whitacre, 2024; Melchiorri et al., 2024). Janc et al. (2022) demonstrated that Internet performance can display local spatial regularities, and Gozzi et al. (2024) showed that connectivity inequality can remain geographically patterned even when average conditions improve. Sharma et al. (2024) further argue that latency observations benefit from regional interpretation because individual measurements are embedded in larger network and geographic contexts. These findings motivate the use of both predefined geopolitical regions and contiguity-based spatial statistics in the present analysis.

Previous Nigerian studies provide useful technical detail but cover different spatial scales and measurement designs. Dahunsi and Akinlabi (2019) used a smartphone application to examine 2G and 3G performance in Akure and Ibadan over three months. Their observations resolve user-side and time-of-day variation within two cities, but cannot establish nationwide state-level clustering. Yusuf et al. (2024) used drive tests in Abuja, Lafia, and Makurdi to compare 4G/LTE operators. This design offers information about operator and signal conditions that the public tiles used here do not retain, although its selected routes and short measurement window limit nationwide inference. Odo and Ezeonye (2022) evaluated 4G handoff performance using call setup and handover success rates against Nigerian Communications Commission indicators.

Akinlabi et al. (2026) extended application-based monitoring to 500 volunteers across the six South-West states over nine months. That study provides a stronger regional and repeated-measurement basis, including additional service metrics, but does not cover all Nigerian states. Adeleke (2021) examined Internet use across the 36 states and the Federal Capital Territory and applied Global Moran's I. Its nationwide spatial scope is directly relevant, while its outcome is Internet use rather than measured throughput or delay. The present study combines nationwide administrative coverage with repeated performance measurements. Its contribution is the comparison of regional and neighboring-state structure across three technical metrics; it does not replace the operator-specific or within-city detail of the earlier measurement studies.

Latency deserves particular attention because its geography can differ from throughput. Download speed is often the dominant headline indicator, yet latency affects interactive applications and may reflect routing, peering, backhaul, transport distance, and the location of network exchange resources in addition to radio access. African measurement studies have shown that circuitous routing and weak local peering can substantially increase end-to-end delay, while country-level latency patterns can align with regional interconnection structure (Chavula et al., 2015, 2017). Longitudinal broadband measurement work also shows that latency deserves separate treatment from throughput because changes in one metric do not necessarily imply equivalent changes in the other (Schnitzer et al., 2024; Reed et al., 2026). Sharma et al. (2024) similarly show that crowdsourced latency observations should be interpreted regionally rather than as independent points. A broadband assessment based only on throughput can therefore miss geographically structured delay conditions.

The Nigerian National Broadband Plan 2020-2025 identifies coverage and speed as national priorities (Federal Ministry of Communications and Digital Economy, 2020). This provides a policy context for examining

differences in realized service quality. The present measurements span the final three quarters of 2025 and the first quarter of 2026, but are not used as a formal compliance audit of the plan.

The study has three objectives: to compare download throughput, upload throughput, and latency across Nigeria's six geopolitical zones; to identify global spatial association and local clusters under a common state-neighbor definition; and to assess whether regional latency differences recur across four quarters and whether pooled latency clusters remain under alternative aggregation weights.

The novelty of this study lies in its combined assessment of regional differences and neighboring-state relationships across three mobile-broadband metrics, using the same national geography and observation window. It brings together full state estimates, measurement-support counts, quarterly regional comparisons, and local latency classifications checked under two weighting rules. This design makes it possible to distinguish a low-performing state from a spatial cluster and a recurring regional difference from a pooled local classification. The innovative aspect is the integrated empirical comparison across all 36 states and the FCT; the statistical procedures themselves are established methods.

The literature reviewed above leaves a specific gap. Nigerian user-side studies describe performance in selected cities or regions, while nationwide spatial work examines Internet use rather than measured throughput and latency (Dahunsi and Akinlabi, 2019; Adeleke, 2021; Yusuf et al., 2024; Akinlabi et al., 2026). These studies do not establish whether the three performance dimensions share the same regional and neighboring-state structure across Nigeria during a common four-quarter period. This study addresses that gap by combining national state coverage with separate spatial tests for each metric and temporal and weighting checks for latency. Its contribution is to locate and characterize observed performance differences; identifying their network causes requires additional evidence.

2.0 Materials and methods

2.1 Data sources and processing

The analysis used the public Ookla Open Data mobile performance tile products for Q2 2025, Q3 2025, Q4 2025, and Q1 2026 (Ookla, n.d.). Each quarterly product summarizes measurements within zoom-level 16 tiles. The retained variables were average download throughput, average upload throughput, average latency, test count, device count, tile identifier, and tile coordinates. Download and upload values were converted from kilobits per second to megabits per second (Mbps); latency was retained in milliseconds (ms). The archived Nigerian extract contains 50,781 quarter-tile records, with 292,446 reported tests and a sum of 99,770 reported device counts. These are counts supporting the retained records, not a probability sample of the national subscriber population (Feamster and Livingood, 2020; Paul et al., 2022; MacMillan et al., 2023).

Nigeria's first-level administrative boundaries were obtained from geoBoundaries gbOpen, using boundary ID NGA-ADM1-27671186, representing 2022 boundaries (Runfola et al., 2020). A rectangular geographic prefilter reduced the global files read into memory. Final inclusion used the Nigerian polygons: each tile coordinate was treated as a point and assigned to one state or the Federal Capital Territory (FCT). The same boundaries were used in all four quarters and in the spatial-neighbor analysis. Aggregation produced 37 pooled state/FCT estimates and 148 state-quarter estimates. The FCT label was standardized across the measurement and boundary files before joining them.

The use of one administrative geography throughout the study is important for spatial inference. Changing boundaries or mixing incompatible geographic units can produce artificial differences in adjacency and regional composition. geoBoundaries provides a reproducible open boundary source, and the same ADM1 polygons were used both to assign observations and to construct the spatial-neighbor structure. The centroid/point assignment rule necessarily simplifies tiles that lie near boundaries, but it avoids ambiguous multi-state membership and applies the same rule nationally.

The retained extract contains one record per tile and quarter. Duplicate tile-quarter keys, missing analytical fields, non-finite values, and nonpositive test or device counts were checked before reconstruction of the reporting tables. Five records with zero reported latency were retained to preserve the submitted analytical sample; their presence is not evidence of a physically zero end-to-end delay. The reconstructed state estimates agreed with the archived state summaries to floating-point precision. This agreement verifies the aggregation of the retained extract, rather than independently validating the underlying speed tests.

2.2 State-level performance estimation

Performance was summarized separately for download throughput, upload throughput, and latency. For state s and metric x, the pooled device-weighted estimate was calculated as the sum of $d(t,q)x(t,q)$ divided by the sum of

d(t,q), over all retained tiles t and quarters q assigned to s, where d(t,q) is the reported device count. Thus, the input to the calculation is a tile mean weighted by its reported device count, rather than an individual device measurement. The test-weighted alternative replaced d(t,q) with the reported test count. Quarterly estimates used the same calculation within one quarter. Table 1 reports the pooled primary estimates and both supporting counts for every state/FCT.

Device weighting assigns greater influence to tile records supported by more reported devices and reduces the direct influence of repeated testing relative to test weighting. Nevertheless, the public tile means are not device-level means, and weighting them cannot reconstruct an exact mean across unique people or devices. Device counts can recur across tiles or quarters, and no device identifiers are available to deduplicate them nationally. The reported device total is therefore the sum of tile-quarter device counts. The reported test total is the sum of tile-quarter tests. Neither count is a count of residents served, and neither weighting rule establishes population representativeness.

2.3 Regional and spatial analysis

States were grouped into six geopolitical zones, with the FCT included in North Central. North Central and North West each contained seven administrative units; North East, South South, and South West each contained six; and South East contained five. Each state/FCT contributed one value to a regional comparison. Kruskal-Wallis tests compared the six distributions for each pooled metric. The statistic H was evaluated against the chi-square reference distribution with five degrees of freedom. The effect-size estimate was calculated as

$$\varepsilon^2 = max[0, (H - k + 1)/(n - k)] \quad (1)$$

where k = 6 and n = 37. These rank-based comparisons do not require normality, but their p-values retain the usual independent-observation assumption. Medians describe the direction of the regional contrasts; a significant test is not interpreted as proving a pure location shift when distribution shapes differ.

For each significant regional latency comparison, all 15 zone pairs were evaluated using two-sided exact Mann-Whitney U tests. The state estimates contained no ties within these pairwise samples. Holm's sequential adjustment was applied across the 15 comparisons separately for the pooled period and for each quarter (Chen et al., 2017). The pooled pairwise results include sample sizes, U statistics, unadjusted p-values, and adjusted p-values. Quarterly pairwise results are also reported, including comparisons that did not remain significant. No post hoc throughput comparisons were interpreted because neither pooled throughput omnibus test was significant.

For temporal reporting, the latency omnibus test was repeated in each quarter and a separate Holm adjustment was applied across the four quarterly omnibus p-values. This four-test family is distinct from the 15 pairwise tests within a period and from the 37 local spatial tests. Both raw and adjusted quarterly values are reported to six decimal places, with full-precision results retained in the analysis files. The four-test correction was added for this revision to address the request for adjusted quarterly p-values. Repeated-quarter comparisons assess recurrence during the study window, not the independence of successive observations.

The zone analysis and the contiguity analysis answer different questions. Geopolitical zones are predefined regions; a significant zone effect indicates that distributions differ among those groups. Moran statistics instead evaluate whether similar values occur near one another under an explicit neighbor definition. A performance surface can therefore show no statistically significant zone difference while still containing local clusters, or it can show a zone difference without strong global spatial autocorrelation. Using both approaches reduces the risk of interpreting one regional partition as the only meaningful geography.

Spatial autocorrelation was assessed using a row-standardized first-order Queen-contiguity matrix derived from the same ADM1 polygons. Two administrative units were neighbors if their polygons shared at least one boundary point. The matrix contained 86 undirected neighbor links, and all 37 units had at least one neighbor. Global Moran's I was calculated for each pooled metric; its permutation inference used 9,999 random reallocations of state values over the fixed geography. Local Moran's I examined the latency pattern using 9,999 conditional permutations, following the treatment in Anselin (2024). Benjamini-Hochberg false-discovery-rate (FDR) adjustment was applied across the 37 local tests, with adjusted $p < 0.05$ used for the reported local classifications (Chen et al., 2017).

Queen contiguity represents administrative contact, not a measured connection between telecommunications networks. Row standardization divides each nonzero neighbor weight by that state's neighbor count. Global Moran's I consequently summarizes the association between deviations from the national state mean and the average deviation among neighboring states. Its randomization expectation is -1/(n - 1), or approximately -0.0278 for 37 units. A positive observed value is interpreted relative to this reference and the permutation distribution; it is not a percentage of delay attributable to geography or a measure of infrastructure failure.

Local Moran analysis distinguished high-high and low-low relationships from high-low and low-high spatial outliers. High and low refer to positions relative to the national mean of the pooled state estimates, not to an engineering service threshold. A high-high classification therefore identifies a relatively high-latency state surrounded by relatively high-latency neighbors, conditional on the specified weights and significance procedure. FDR adjustment limits the number of local findings interpreted from the 37 simultaneous tests; it does not remove selection bias from the underlying speed tests. The local analysis was used here to describe the significant pooled latency pattern. The absence of significant global throughput autocorrelation does not rule out every possible local throughput pattern.

Robustness was assessed by repeating the pooled latency spatial analysis with test-weighted rather than device-weighted state estimates. This check was used to determine whether the identified latency clusters depended on the aggregation weighting convention.

3.0 Results and discussion

3.1 State performance has different geographic signatures

Table 1 provides the full state-level results and their observation support. Pooled download throughput ranged from 18.03 Mbps in Yobe to 68.29 Mbps in the FCT, while upload throughput ranged from 12.10 Mbps in Benue to 21.92 Mbps in Kano. Latency ranged from 38.70 ms in Oyo to 158.04 ms in Kebbi. These ranges demonstrate substantial interstate variation, but a range alone does not show whether neighboring states have similar values. Fig. 1 displays the three performance surfaces on a common administrative geography before the regional and contiguity-based tests are considered.

The state support counts are uneven. Lagos contributes 77,464 tests and a sum of 25,763 device counts, whereas Zamfara contributes 479 tests and a sum of 161 device counts. The FCT and Ogun also account for substantial observation volumes. Reporting these counts alongside performance makes the empirical support visible, particularly for a state such as Zamfara that appears in the local latency results. A large count does not remove voluntary-testing bias, and a small count does not establish that a state has few subscribers. The counts describe the retained measurements and should be considered when selecting locations for independent follow-up.

For this reason, the maps should be read as complementary performance surfaces rather than competing attempts to identify a single 'best' state. A state with relatively strong throughput but higher latency may support large transfers well while still imposing delay on interactive applications. Conversely, a state with moderate throughput and comparatively low latency can occupy a different position depending on the use case. The analytical value of Fig. 1 lies in showing that these technical dimensions have different geographic signatures before any formal spatial statistic is applied.

The maps and Table 1 should be read together. Fig. 1 makes broad geographic contrasts visible, while the table supplies the numerical scale and supporting counts for each administrative unit. Neither display identifies variation within a state or separates operators. In particular, a state-level latency mean cannot be used as a prediction for every location, subscriber, or application in that state. The unit of inference in the comparisons that follow remains the state/FCT estimate.

Table 1: Pooled device-weighted state performance and observation support, Q2 2025-Q1 2026

State/FCT	Download (Mbps)	Upload (Mbps)	Latency (ms)	Device count sum	Test count	Quarter-tile records
Abia	25.03	12.82	80.31	1,014	2,942	741
Adamawa	24.95	18.54	73.78	489	1,981	377
Akwa Ibom	26.59	13.62	50.21	1,475	3,549	1,037
Anambra	37.11	17.83	62.43	2,532	7,142	1,548
Bauchi	26.76	16.00	55.99	571	1,789	457
Bayelsa	33.47	13.72	55.99	655	1,481	449
Benue	21.57	12.10	82.39	741	1,655	591
Borno	31.83	18.50	85.94	489	1,163	387
Cross River	24.78	15.57	62.81	759	2,229	490
Delta	38.25	16.37	67.29	4,764	12,779	2,760
Ebonyi	23.79	12.97	77.82	610	1,913	401

State/FCT	Download (Mbps)	Upload (Mbps)	Latency (ms)	Device count sum	Test count	Quarter-tile records
Edo	45.85	15.76	49.55	3,788	10,364	2,320
Ekiti	31.52	15.95	49.03	1,013	2,935	638
Enugu	50.16	16.09	60.28	2,518	7,493	1,309
FCT	68.29	19.41	56.05	12,277	39,096	4,846
Gombe	34.85	17.68	72.17	331	873	253
Imo	35.59	18.12	72.31	1,767	5,415	1,114
Jigawa	24.97	16.01	95.31	629	1,182	525
Kaduna	43.14	18.34	59.26	2,147	5,769	1,323
Kano	43.76	21.92	71.19	2,972	9,070	1,588
Katsina	24.68	17.62	131.40	719	2,009	508
Kebbi	22.34	15.87	158.04	264	760	214
Kogi	20.07	13.29	57.14	536	1,491	440
Kwara	31.31	15.55	43.56	1,943	4,682	1,145
Lagos	65.75	17.37	39.34	25,763	77,464	8,128
Nasarawa	23.50	15.23	95.38	1,001	4,239	673
Niger	20.25	13.13	69.23	1,331	4,052	906
Ogun	37.26	13.28	49.36	7,324	22,310	4,561
Ondo	24.09	13.52	55.73	2,594	7,459	1,507
Osun	25.62	13.90	52.02	3,117	9,172	1,792
Oyo	42.24	16.79	38.70	5,592	14,425	3,090
Plateau	25.67	17.51	61.42	1,615	5,381	1,018
Rivers	53.29	15.17	58.13	5,118	13,260	2,594
Sokoto	25.01	17.86	85.87	671	2,369	492
Taraba	21.40	13.72	80.27	257	1,444	231
Yobe	18.03	15.91	92.50	223	630	198
Zamfara	21.70	12.41	105.67	161	479	130

Notes: FCT = Federal Capital Territory. Device counts are summed over tile-quarter records and are not unique devices or users over the study period. Test counts are sums of the reported tile-quarter tests. Performance values are weighted means of tile means. Totals: 99,770 reported device counts, 292,446 tests, and 50,781 quarter-tile records. Source: authors' calculations from the archived Ookla extract.

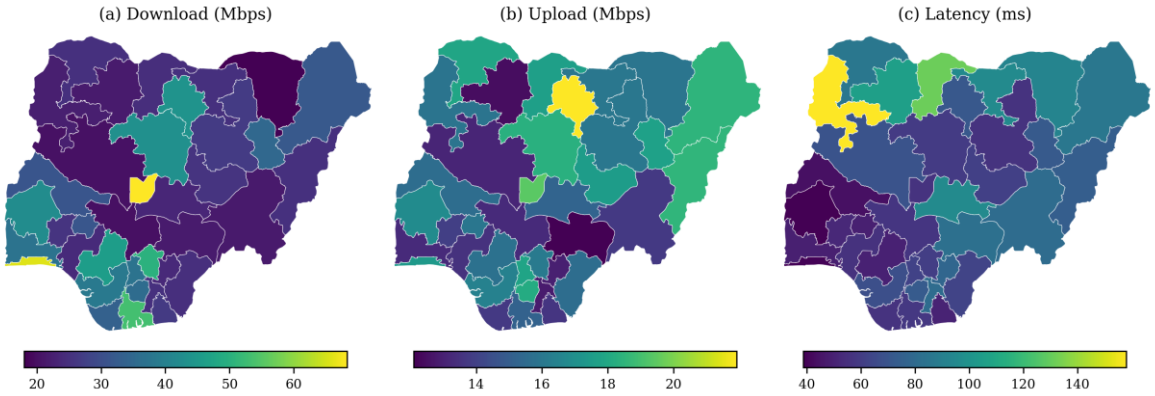

Figure 1: Pooled device-weighted mobile broadband performance across Nigeria's 36 states and the FCT, Q2 2025-Q1 2026: download throughput, upload throughput, and latency. Source: authors' calculations from Ookla Open Data (Ookla, n.d.); boundaries from geoBoundaries gbOpen, NGA-ADM1-27671186 (Runfola et al., 2020). The maps are original analytical figures. Color scales differ by metric.

3.2 Geopolitical-zone differences are strongest for latency

The pooled zone comparisons in Table 2 show no statistically significant regional difference for download throughput ($H = 7.07$, $p = 0.215795$, $\varepsilon^2 = 0.067$) or upload throughput ($H = 5.77$, $p = 0.328777$, $\varepsilon^2 = 0.025$). Latency differs across zones ($H = 21.45$, $p = 0.000667$), with an effect-size estimate of 0.530. The regional comparison uses 37 state/FCT estimates, not the underlying tests as independent observations. The result describes the separation among these observed state distributions under the rank-test assumptions.

Table 2: Pooled regional differences and global spatial autocorrelation

Metric	H	Regional p	Epsilon-squared	Moran's I	Permutation p
Download	7.07	0.215795	0.067	0.060	0.188
Upload	5.77	0.328777	0.025	0.122	0.087
Latency	21.45	0.000667	0.530	0.400	<0.001

Notes: Regional comparisons use 37 state/FCT values in six zones (five degrees of freedom). The regional p-values are unadjusted omnibus values. Moran inference uses 9,999 permutations under row-standardized Queen contiguity. Source: authors' analysis.

The pooled zone medians show the direction of the latency contrast: 49.2 ms in South West, 57.1 ms in South South, 61.4 ms in North Central, 72.3 ms in South East, 77.0 ms in North East, and 95.3 ms in North West. Table 3 reports all 15 pooled pairwise comparisons. After Holm correction, North West versus South West remains significant (adjusted $p = 0.017483$), as does North East versus South West (adjusted $p = 0.030303$). The remaining pooled pairwise comparisons do not reach the 0.05 threshold.

Table 3: Complete pooled pairwise comparisons of regional latency

Zone comparison	n1/n2	U1	Raw p	Holm p
North Central vs North East	7/6	14	0.365967	1.000000
North Central vs North West	7/7	8	0.037879	0.303030
North Central vs South East	7/5	13	0.530303	1.000000
North Central vs South South	7/6	28	0.365967	1.000000
North Central vs South West	7/6	38	0.013986	0.153846
North East vs North West	6/7	12	0.234266	1.000000
North East vs South East	6/5	19	0.536797	1.000000
North East vs South South	6/6	33	0.015152	0.153846
North East vs South West	6/6	36	0.002165	0.030303
North West vs South East	7/5	27	0.148990	0.893939
North West vs South South	7/6	40	0.004662	0.056277
North West vs South West	7/6	42	0.001166	0.017483
South East vs South South	5/6	26	0.051948	0.363636
South East vs South West	5/6	30	0.004329	0.056277
South South vs South West	6/6	32	0.025974	0.233766

Notes: Two-sided exact Mann-Whitney tests; U1 corresponds to the first listed zone. Holm adjustment covers all 15 pooled comparisons. Values below 0.05 identify the North East-South West and North West-South West contrasts. Source: authors' calculations.

The North West and South West medians differ by 46.1 ms, with the North West median about 1.94 times the South West median. This is a difference between medians of state-level pooled estimates, not a matched comparison of individual users or applications. Its engineering relevance is the need to investigate why the observed delay environment differs across these regions. The pairwise results support specific contrasts with South West and do not justify treating all northern states as equivalent or all north-south differences as significant. African interconnection research provides plausible mechanisms for geographic delay contrasts, but those mechanisms require separate evidence in the Nigerian locations identified here (Chavula et al., 2015, 2017).

Table 4 reports the four quarterly latency tests. Holm adjustment across these four omnibus tests gives $p = 0.016236$ for Q2 2025, 0.016236 for Q3 2025, 0.010591 for Q4 2025, and 0.001797 for Q1 2026. The regional

difference therefore recurs throughout the observation window after this correction. The associated effect-size estimates range from 0.291 to 0.560. These tests describe four repeated snapshots of the same states and should not be interpreted as four independent replications of the study.

Table 5 shows all quarterly pairwise adjusted p-values. In Q2 2025, no individual zone pair remained significant after adjustment across the 15 comparisons, despite the significant omnibus result. In Q3 2025 and Q1 2026, North East versus South West and North West versus South West remained significant. In Q4 2025, North West differed from both South South and South West (adjusted p = 0.034965 for each). The recurrence is thus an overall regional finding, with some variation in the pairwise contrasts. It should not be described as an identical set of significant zone differences in all four quarters.

Table 4: Quarterly regional latency tests with correction across four periods

Quarter	H	Epsilon-squared	Raw p	Holm p
2025Q2	14.012680	0.291	0.015529	0.016236
2025Q3	15.589921	0.342	0.008118	0.016236
2025Q4	17.574070	0.406	0.003530	0.010591
2026Q1	22.349035	0.560	0.000449	0.001797

Notes: Each test compares six zones using 37 state/FCT estimates and five degrees of freedom. Holm adjustment is across the four quarterly omnibus tests. All four adjusted p-values are below 0.05. Values are displayed to six decimal places. Source: authors' calculations.

Table 5: All quarterly pairwise latency comparisons

Zone comparison	2025Q2	2025Q3	2025Q4	2026Q1
North Central vs North East	1.000000	1.000000	1.000000	0.440559
North Central vs North West	1.000000	1.000000	1.000000	0.174825
North Central vs South East	1.000000	1.000000	1.000000	1.000000
North Central vs South South	1.000000	1.000000	0.912587	1.000000
North Central vs South West	1.000000	0.419580	0.384615	0.153846
North East vs North West	1.000000	1.000000	1.000000	1.000000
North East vs South East	1.000000	1.000000	1.000000	1.000000
North East vs South South	1.000000	1.000000	0.181818	0.207792
North East vs South West	0.337662	0.030303	0.112554	0.030303
North West vs South East	1.000000	1.000000	1.000000	0.174825
North West vs South South	1.000000	0.734266	0.034965	0.056277
North West vs South West	0.114219	0.017483	0.034965	0.017483
South East vs South South	1.000000	1.000000	1.000000	1.000000
South East vs South West	0.064935	0.056277	0.519481	0.056277
South South vs South West	0.779221	0.452381	1.000000	0.207792

Notes: Cells contain Holm-adjusted p-values from two-sided exact Mann-Whitney tests. The 15 pairs form a separate adjustment family within each quarter. No pair remains significant in Q2 2025. North East-South West and North West-South West remain significant in Q3 2025 and Q1 2026; North West-South South and North West-South West remain significant in Q4 2025. Source: authors' calculations. Full-precision U statistics and raw p-values are retained in the accompanying analysis tables.

3.3 Latency, but not throughput, is spatially autocorrelated

The contiguity-based analysis produced the same distinction. Global Moran's I was 0.060 for download (permutation p = 0.188) and 0.122 for upload (p = 0.087), providing no statistically significant evidence that neighboring states had similar throughput values under the specified Queen-contiguity model. Latency produced Moran's I = 0.400 with permutation p < 0.001. High and low latency values were therefore more geographically clustered than expected under spatial randomness.

Interstate variation and spatial autocorrelation describe different properties. The first concerns the spread of state values; the second concerns how those values are arranged among neighbors. States can differ substantially in throughput while high and low values are geographically interspersed, so that positive and negative neighboring deviations partly offset one another. State averages also combine different operators, technologies, urban concentrations, and testing conditions. These features could weaken association with administrative adjacency, although their separate contributions cannot be estimated from the public tiles. The non-significant throughput results therefore indicate insufficient evidence of global association under this particular model, not equal service across states or proof that throughput lacks geographic influences.

For latency, Moran's I = 0.400 is well above the randomization expectation of approximately -0.0278. Together with permutation $p < 0.001$, this indicates positive association between a state's latency deviation and the average deviation of its neighbors. The statistic does not mean that 40% of latency is caused by location, that service is 40% worse, or that 40% of states have failed infrastructure. Its practical value is to show that individual high-delay observations form part of a wider geographic pattern. Neighboring states can therefore be examined together when planning diagnostic measurements, while the cause of the association remains an open engineering question.

After FDR correction, Local Moran analysis identified Sokoto and Zamfara as high-high states and Ogun, Osun, and Oyo as low-low states in the device-weighted analysis. These are relative spatial classifications. Kebbi has the largest pooled latency estimate, but it is not among the FDR-significant high-high classifications. This illustrates why a high value alone is insufficient for a local-cluster finding: the surrounding values and the local randomization result also matter. Fig. 2 presents the regional latency distributions and the pooled local classifications.

Under test weighting, Ogun, Osun, Sokoto, and Zamfara remain significant after FDR adjustment; Oyo does not meet the adjusted 0.05 threshold. The conclusion is therefore stable for these four core states, while Oyo's classification depends on the weighting convention. This check changes the contribution of heavily tested tile records without changing the spatial boundaries or measurement source. It tests sensitivity to aggregation weights only and cannot exclude bias shared by both estimators. In particular, the pooled local-cluster results do not establish that the same states form significant local clusters in every individual quarter.

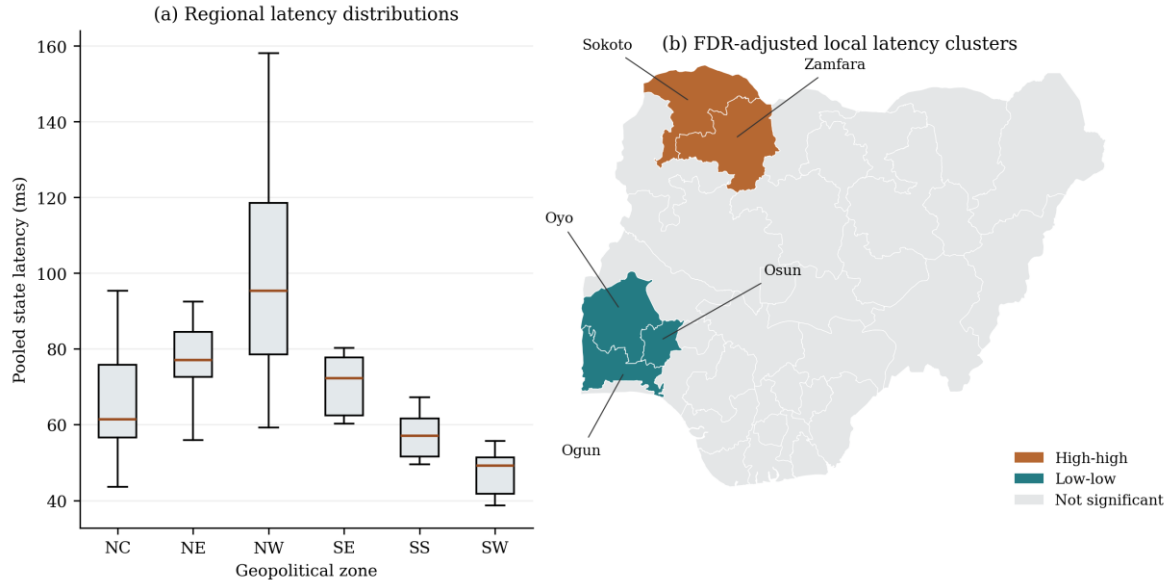

Figure 2: Latency distributions and local spatial classifications: (a) pooled device-weighted state latency by geopolitical zone; (b) Local Moran classifications after FDR adjustment across 37 state/FCT tests. High-high and low-low are relative to the national state mean; unclassified states do not meet adjusted $p < 0.05$. Source: authors' analysis of Ookla Open Data (Ookla, n.d.) and geoBoundaries gbOpen NGA-ADM1-27671186 (Runfola et al., 2020). The figure is original to this study. Zone abbreviations: NC = North Central; NE = North East; NW = North West; SE = South East; SS = South South; SW = South West.

3.4 Engineering interpretation

The principal finding is that broadband performance disparities in Nigeria do not share one spatial structure. Throughput varies across states, but the specified contiguity model does not identify statistically significant global clustering for download or upload. Latency differs both across geopolitical zones and among neighboring states.

This metric-specific geography is consistent with work showing that broadband quality can vary sharply across regions while different performance dimensions reveal different aspects of network disadvantage (Caldas et al., 2023; Gallardo and Whitacre, 2024; Loh et al., 2025). A performance map that reports only download speed would therefore miss an important geography of delay.

Comparison with Nigerian evidence shows both overlap and differences. Adeleke (2021) identified concentrations of high Internet use in Lagos, Oyo, Ogun, Kaduna, Kano, and Abuja. Ogun and Oyo also occur in the present device-weighted low-low latency group, but the other four locations do not. Thus, the geography of Internet use and the geography of delay overlap only partly. The studies measure different outcomes in different periods, so this comparison does not establish that higher use produces lower latency. It does show why penetration patterns alone are insufficient to identify the neighboring-state relationships found here.

The comparatively low South West latency also requires care. Akinlabi et al. (2026) reported that all three operators they tested across the six South-West states fell short of their latency benchmark. Here, the South West has the lowest pooled zone median, 49.2 ms, and contains the low-low states. These findings answer different questions: one assesses operator performance against a benchmark, while the other compares state estimates within Nigeria. A region can perform better than other regions and still fail an application or service requirement. Differences in endpoints, participating devices, observation periods, and aggregation further prevent treating the two estimates as interchangeable.

Dahunsi and Akinlabi (2019) found substantial time-of-day variation in Akure and Ibadan, with better performance in the early morning and deterioration during busy periods. The present results add a different scale of variation: all four quarterly regional latency tests remain significant after correction, although the significant zone pairs vary by quarter. Quarterly state estimates cannot resolve the intraday fluctuations captured by their application. Conversely, measurements in two cities cannot establish nationwide adjacency patterns. Together, the findings support monitoring both when performance changes and where similar conditions occur, with temporal resolution matched to the engineering question.

Several technical mechanisms could plausibly contribute to the latency pattern, but the present data cannot distinguish among them. End-to-end latency can be influenced by backhaul paths, routing, peering, transport distance, server location, congestion, and access to exchange infrastructure in addition to local radio conditions. Previous African measurement work shows that circuitous routes and limited local peering can more than double latency for intra-African traffic, and that regional interconnection conditions can leave recognizable geographic signatures in measured delay (Chavula et al., 2015, 2017). Broader longitudinal measurement studies also show that latency is shaped by network technology and path conditions in ways that are not reducible to headline throughput (Schnitzer et al., 2024; Reed et al., 2026). The present result should therefore be interpreted as a screening signal: the high-latency cluster in north-western Nigeria and the low-latency cluster in the South West identify regions where network-topology and infrastructure evidence would be especially useful.

Routing, peering, backhaul, and server location are hypotheses for follow-up rather than measured explanations of these clusters. Two neighboring states may share transport infrastructure or interconnection arrangements, but they may also contain different operator networks and testing populations. Chavula et al. (2017) show the relevance of interconnection context to African country-level delay, while Sharma et al. (2024) examine the value of regional interpretation of crowdsourced latency. These studies justify investigating network paths in the identified regions. They do not establish that a specific route, exchange, or backhaul link is responsible for the present state-level pattern.

For Nigerian mobile-network engineering, a practical first step is a coordinated measurement campaign in Sokoto and Zamfara and their neighboring states, with Ogun and Osun providing lower-latency comparison areas under both weighting rules. Measurements should record operator, radio technology, signal conditions, time of day, and test endpoint. Traceroutes and operator transport information could then be used to examine path length, interconnection, and shared backhaul. Comparisons made under consistent conditions would help distinguish a recurring network-path issue from differences in who tested, where they tested, and which servers handled the tests. This is a proposal for diagnosis, not a finding that any particular network component has failed.

The 46.1 ms contrast between North West and South West state medians offers a more direct description of the observed delay difference than Moran's I alone. It could matter for applications that depend on responsive interactions, but the study does not observe application performance or establish an acceptable-delay threshold. Diagnostic work should combine the relative spatial pattern with absolute latency, observation support, and the application's requirements. This prevents a statistically significant cluster from being treated as an automatic service-level violation and keeps the choice of remediation tied to measured network conditions.

From a monitoring perspective, the result argues against reporting download speed as the sole subnational quality indicator. A download-only map would reveal substantial interstate variation but would miss the statistically significant regional structure found in latency. Broadband-quality research similarly cautions that speed alone does not capture the full consumer or network experience (Stocker and Whalley, 2018), and longitudinal benchmarking shows that throughput and latency can follow different trajectories and policy interpretations (Reed et al., 2026). Likewise, a single composite index could conceal the fact that one component carries a much stronger spatial signature than the others. Retaining component measures allows regulators and network planners to distinguish a capacity-oriented problem from a delay-oriented problem and to decide what additional engineering evidence is needed.

Regional medians, global autocorrelation, and local classifications provide complementary summaries. The first describes differences among six predefined groups, the second summarizes association under adjacency, and the third locates statistically identified relative clusters. These summaries are calculated from the same state values, so agreement among them should not be treated as independent confirmation. Their combined use makes the spatial finding easier to interpret and helps specify what further engineering evidence is needed. It also shows why state ranking remains useful: an extreme such as Kebbi merits attention even when its local test does not survive FDR correction.

The study remains subject to the limitations of crowdsourced measurement. Ookla observations are self-selected, state estimates conceal within-state heterogeneity, and administrative contiguity is not equivalent to telecommunications topology. Studies of public speed-test data document selection effects, regional sampling imbalance, and differences in who is represented in voluntary measurement platforms (Mangla et al., 2022; Saxon and Black, 2022; Lee et al., 2023; Stuyvesant et al., 2025). Platform architecture also matters: server deployment and user-server assignment can vary geographically and over time (Zhang et al., 2024). These issues mean that large observation counts do not make the state estimates probability-sampled measures of every user experience. The spatial weights matrix represents shared borders rather than fiber routes, exchange-point relationships, operator networks, or backhaul architecture. The analysis therefore identifies spatial organization in observed performance but does not establish its engineering cause.

A second limitation is scale. State/FCT aggregation provides a nationally consistent administrative framework, but it can conceal differences among cities, rural areas, operators, network generations, and neighborhoods. Studies using finer geographic data identify broadband disparities at regional, urban, and neighborhood scales (Caldas et al., 2023; Melchiorri et al., 2024). The modifiable areal unit problem is therefore relevant here: changing the spatial units can change the association being measured (Anselin, 2024). The present state-level findings should guide where to investigate; they do not resolve local network conditions.

Third, the neighbor structure is administrative rather than topological in the telecommunications sense. Queen contiguity captures geographic adjacency, but mobile traffic does not necessarily follow state borders or shortest geographic paths. Two neighboring states may depend on different operator backbones, while non-neighboring states may be closely connected through national transport infrastructure. Future work could compare administrative contiguity with weights based on fiber connectivity, travel distance, Internet exchange access, or measured routing paths. Such extensions would test whether the latency clusters identified here align with the actual topology through which traffic is carried.

The quarterly results support recurrence of regional differentiation within the one-year study window. They do not establish long-term permanence or quarterly persistence of every pooled local classification. Infrastructure upgrades, server deployment, routing changes, spectrum use, and changes in the participating measurement population can alter the observed surface (Schnitzer et al., 2024; Reed et al., 2026; Zhang et al., 2024). Continued measurement should therefore distinguish changes in observed performance from changes in observation support. The independence assumption of the regional rank tests is a further limitation because the latency values are spatially associated. Holm correction addresses multiplicity, not this dependence between state observations; the regional p-values are interpreted as exploratory summaries alongside the spatial diagnostics.

4.0 Conclusion

This study examined the spatial structure of mobile broadband performance across Nigeria using four quarters of state-level measurements. Its central finding is that the geographic pattern depends on the performance metric, so throughput alone cannot describe the spatial distribution of service quality. Download and upload varied across states without statistically significant global spatial autocorrelation under first-order Queen contiguity. Latency showed regional differentiation and positive association among neighboring states, with Global Moran's I = 0.400. The regional latency differences remained significant in each quarter after adjustment across the four tests.

The pooled local analysis identified Sokoto and Zamfara as high-high latency states and Ogun, Osun, and Oyo as low-low states under device weighting. Ogun, Osun, Sokoto, and Zamfara retained their significant classifications under test weighting, whereas Oyo did not. These four states form the part of the pooled local result that is stable across the two weighting rules. Quarterly regional recurrence does not establish that every pooled local cluster persists in each quarter, and the spatial associations do not identify the cause of delay.

The contribution is a nationwide comparison that separates state performance levels, regional contrasts, and relationships among neighboring states. Reporting these results alongside device and test counts makes their measurement support visible. For Nigerian broadband monitoring, the findings support retaining latency as a distinct indicator and using the identified locations to plan coordinated network investigations. The results indicate where additional evidence is needed before selecting an intervention.

Future studies should test whether the state-level patterns remain at finer geographic scales and over longer observation periods. Operator-specific measurements, common test endpoints, and routing or backhaul information would help distinguish network mechanisms from differences in who tested and where. Comparing administrative adjacency with measured network connections would also show whether the clusters align with telecommunications topology. These extensions would build on the present descriptive findings while addressing the limits of crowdsourced sampling and state-level aggregation.

5.0 Recommendation

Broadband monitoring in Nigeria should report latency as a core subnational performance indicator rather than treating it as a secondary supplement to download speed. State-level maps and regional comparisons should be updated over repeated periods so that persistent delay patterns can be separated from short-lived fluctuations. This recommendation is consistent with national and international measurement research that treats latency alongside throughput as a core component of service quality and longitudinal benchmarking (Jembre et al., 2022; Loh et al., 2025; Reed et al., 2026).

Routine monitoring should also preserve the distinction between regional summaries and local spatial clusters. Geopolitical-zone medians are useful for communication and broad planning, but they should not replace state-level diagnostics because local high-high or low-low concentrations can occur within larger regions. Reporting both levels would make it easier to identify whether an apparent regional disadvantage is widespread or anchored by a smaller set of neighboring states.

Where resources permit, future analyses should move below the state level and integrate crowdsourced measurements with independent network evidence. Tile- or local-government-level analyses could test whether the state clusters remain visible at finer scale, while operator-specific data could distinguish whether the pattern is shared across networks or concentrated within particular providers. Similar work using granular speed-test and population or socioeconomic data shows the analytical value of moving below broad administrative averages when studying digital inequality (Caldas et al., 2023; Gallardo and Whitacre, 2024; Melchiorri et al., 2024). Combining end-user speed tests with routing traces, exchange-point information, backhaul maps, or regulator measurements would also help identify the mechanisms behind the observed latency geography.

Observation support should be published with future monitoring results. Changes in a state mean can arise from improved network performance, a different mix of participating locations, or a change in the number of reported devices and tests. Keeping quarterly counts and geographic inclusion rules visible would make these possibilities easier to examine. For sparsely observed states, additional measurements should seek broader geographic and operator coverage; simply accumulating more tests from existing locations would not necessarily resolve the representation problem.

Operational follow-up should use the state estimates as a screening baseline. For high-delay areas, the Nigerian Communications Commission and participating operators could compare measurements to common endpoints and inspect route and transport information before deciding whether remediation should target radio capacity, backhaul, peering, or another component. Low-latency comparison areas should be assessed with the same protocol. Where network changes are implemented, repeated measurements with comparable observation support can evaluate whether delay improves. The current analysis supplies locations and measurable outcomes for such work; it does not supply an intervention cost model or evidence that a particular investment will reduce latency.

Data availability

The measurement products are available through Ookla Open Data at https://github.com/teamookla/ookla-open-data (mobile products for Q2 2025, Q3 2025, Q4 2025, and Q1 2026). The boundary product is geoBoundaries gbOpen Nigeria ADM1, boundary ID NGA-ADM1-27671186, representing 2022 boundaries: https://www.geoboundaries.org/api/current/gbOpen/NGA/ADM1/. State estimates and regional reporting tables

were reconstructed from the retained Nigerian quarter-tile extract without refreshing the observation window. The revision analysis files contain the numerical tables, correction procedures, and verification records. No individual-level Speedtest histories or personally identifiable information were used.

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Nomenclature

ADM1 - first-order administrative division
FCT - Federal Capital Territory
FDR - false discovery rate
LISA - local indicators of spatial association
Mbps - megabits per second
ms - milliseconds

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