Spatial Inequalities in Urban Environmental Infrastructure: A GIS-Based Environmental Justice Assessment of Neighbourhoods in Minna, Nigeria

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ABSTRACT

Rapid urban growth can deepen environmental inequality when essential services are unevenly distributed, poorly maintained, or concentrated in already advantaged neighbourhoods. This study examines the distribution and spatial pattern of six urban environmental infrastructure indicators across the 66 neighbourhoods of Minna, Nigeria: water supply, security facilities, schools, playgrounds/green areas, primary healthcare facilities, and tarred roads. The analysis draws on field-survey and spatial data assembled for a city-wide environmental justice assessment. Facility functionality was summarised descriptively, neighbourhood conditions were mapped in ArcGIS 10.8, and Global Moran's I was used to test whether similar infrastructure conditions were clustered, dispersed, or randomly distributed. Of 364 water-supply facilities identified, only 180 (49.45%) were in use, compared with 100% of schools, 98.21% of security facilities, 97.50% of playgrounds/green areas, and 97.50% of primary healthcare facilities. All 454.37 km of identified tarred roads were functional. Spatial autocorrelation was insignificant for water supply ($I = -0.0125$, $p = .962$), security ($I = -0.0014$, $p = .815$), schools ($I = -0.0676$, $p = .381$), and playgrounds/green areas ($I = 0.0261$, $p = .486$). Primary healthcare showed weak evidence of dispersion ($I = -0.1196$, $p = .081$), whereas tarred roads were significantly clustered ($I = 0.2459$, $p < .001$). The findings show that environmental injustice in Minna is not captured by facility counts alone. Functionality, neighbourhood-level condition, and spatial concentration reveal different forms of disadvantage. Water infrastructure presents the clearest functionality deficit, while road provision displays a geographically concentrated pattern. The study argues for neighbourhood-sensitive infrastructure planning that prioritises service functionality and underserved areas rather than relying on city-wide provision totals.

Keywords: Environmental justice; Spatial inequality; Urban infrastructure; GIS; Moran's I; Neighbourhoods

INTRODUCTION

Urbanisation has intensified the challenge of distributing environmental benefits and burdens fairly across cities. There is a growing concern on the global urban transition in which growing populations place increasing pressure on land, housing, infrastructure and environmental services. Environmental justice provides a useful lens because it asks not only whether urban services exist, but also who benefits from them, where they are located, and whether environmental burdens and amenities are shared fairly (Agyeman et al., 2016; Hussaini et al., 2023). In planning terms, this is fundamentally a spatial question: the location and condition of infrastructure can reproduce advantage in some neighbourhoods while leaving others with weaker access or lower-quality services (Ntiwane & Coetzee, 2018). The distributional dimension of environmental justice is especially relevant in rapidly growing cities where public investment does not necessarily keep pace with settlement expansion. Environmental inequality may appear through unequal access to water, roads, schools, healthcare, security, recreational space and other everyday services. Such inequalities matter because

infrastructure is not simply a technical system. It structures daily opportunities, mobility, exposure to environmental risks and the practical quality of neighbourhood life. The wider environmental justice literature has therefore moved beyond pollution alone to consider the unequal distribution of urban amenities and public goods (Banzhaf et al., 2019; Israel & Frenkel, 2018).

In Nigeria, environmental justice research has documented disparities in environmental quality and service provision, but much of the evidence remains place-specific. In Minna, Mohammed et al. (2019) reported marked environmental injustice between Dutsen Kura Hausa and Dutsen Kura Gwari, two neighbouring communities separated by a road. Mohammed et al. (2021) similarly linked urban management and neighbourhood conditions to environmental justice. Elsewhere, Olowoporoku et al. (2023) showed that residents' experiences of environmental justice in Ile-Ife vary across residential zones, while Aliu et al. (2021) demonstrated that water deprivation forms an important part of socio-spatial disadvantage in Lagos informal settlements. Together, these studies suggest that urban environmental inequality is visible at scales below the city as a whole. A remaining problem is that the presence of infrastructure is often treated as equivalent to access or benefit. A neighbourhood may contain a water point, school or health facility without receiving an adequate service if the facility is non-functional, poorly maintained or difficult to reach. A second problem is that descriptive differences between neighbourhoods do not establish whether disadvantage forms a systematic spatial pattern. Geographic Information Systems (GIS) and spatial statistics provide a way to distinguish these issues by combining facility condition, neighbourhood mapping and tests of spatial autocorrelation.

This paper therefore examines urban environmental infrastructure through a distributional environmental justice framework across all 66 neighbourhoods of Minna. It focuses on: (1) what environmental justice infrastructure indicators are present and functional across Minna; and (2) what spatial patterns characterise their neighbourhood-level conditions? By combining a city-wide inventory with Global Moran's I, the paper contributes neighbourhood-scale evidence from a Nigerian secondary city and demonstrates why infrastructure functionality and spatial pattern should be assessed together.

Environmental Justice, Infrastructure and Spatial Inequality

Environmental justice as a distributional planning concern

Environmental justice is concerned with fair treatment in the distribution of environmental benefits and burdens and with meaningful participation in decisions that shape environmental conditions (Figueroa, 2022). Although the concept includes distributive, procedural and recognition dimensions, the present paper concentrates on distributional justice because the empirical focus is the spatial condition of urban infrastructure (Mark et al., 2025). Ntiwane and Coetzee (2018) describe distributional justice in planning as the spatial fairness of environmental benefits and burdens. This framing is useful for infrastructure because roads, water systems, schools, healthcare and green spaces are territorially fixed investments whose benefits depend on both location and operational condition (World Health Organization, 2020).

Spatial justice strengthens this interpretation by treating space as an active expression of social and planning processes rather than a neutral container (Madanipour et al., 2022). The research adopts Spatial Justice Theory to explain how uneven arrangements of services, resources and burdens can reproduce inequality. Applied to infrastructure, the key question is not simply how many facilities a city possesses, but whether neighbourhoods receive comparable opportunities to use functioning services. This makes neighbourhood-scale analysis particularly important: city-wide totals can conceal substantial local deficits.

Urban infrastructure as an environmental justice indicator

This paper emphasis is on benefit and access indicators that can be observed in the urban landscape. Water supply, educational facilities, security facilities, playgrounds and green areas, primary healthcare and tarred roads represent everyday infrastructure through which residents encounter the city. Their relevance is consistent with work linking environmental justice to access to water and sanitation, green space, mobility and public services (Aliu et al., 2021; Ranganathan & Balazs, 2015). Infrastructure justice also requires

attention to functionality. A nominal facility count may overstate actual provision when installations are abandoned or out of use. This is particularly important in contexts where infrastructure maintenance is uneven (Ramakrishnan et al., 2021). The distinction between presence and functionality is therefore analytically significant: it separates physical availability from the practical capacity of infrastructure to deliver an environmental benefit (Uddin, 2022).

GIS and spatial autocorrelation in environmental justice assessment

GIS allows environmental and social information to be linked to location, mapped at neighbourhood scale and analysed for spatial pattern (Otero Peña et al., 2022). The spatial analysis is beyond visual description by applying Global Moran's I. Moran's I evaluates whether neighbouring spatial units have similar values more often than would be expected under spatial randomness (Amissah et al., 2026). Positive values indicate a tendency toward clustering, negative values indicate dispersion, and values near zero indicate randomness (Chen 2021). In environmental justice research, this distinction matters because a city can contain substantial inequality even when disadvantaged neighbourhoods do not form one continuous cluster. Conversely, significant clustering can identify geographically concentrated patterns of advantage or deprivation that warrant targeted planning (Viteri et al., 2026).

METHODOLOGY

Study area

Minna is the capital of Niger State in north-central Nigeria. Niger State lies between latitudes 8°20′N and 11°30′N and longitudes 3°30′E and 7°20′E. The study covers the 66 neighbourhoods that make up the urban study area. The study projected the study-area population to 496,009 in 2025 from the 2006 population base. Minna provides a useful setting for neighbourhood-scale environmental justice analysis because earlier local studies already identified disparities in environmental conditions and infrastructure between communities (Mohammed et al., 2019, 2021).

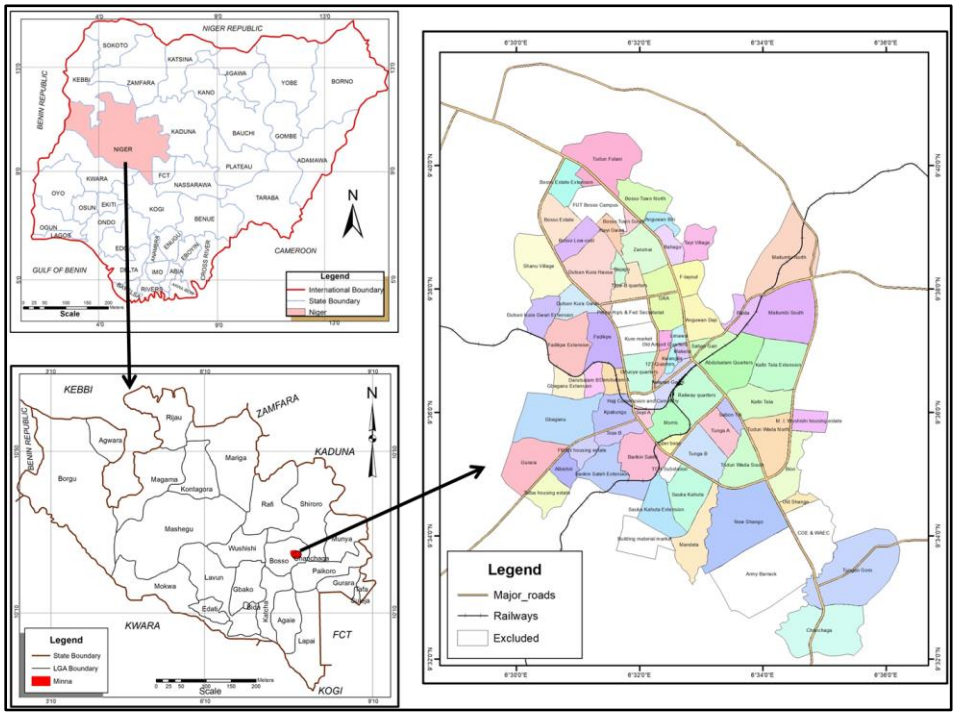


Figure 1: Locational Map of the Study Area

Source: Niger State Ministry of Lands and Housing, 2025

Research design, data and sampling

The study employed quantitative, descriptive, inferential and spatial analytical methods. Primary information was collected through a field survey, questionnaires and personal interviews, while secondary materials included population statistics, past research, satellite imagery, topographical information and street-guide maps. A total of 771 households were selected across the 66 neighbourhood clusters using stratified simple random sampling. The sample size was derived using the Salant and Dillman (1997) approach at a 95% confidence level and an acceptable sampling error of ±3.5%. Respondents were allocated proportionally across neighbourhoods.

For the two objectives reported in this paper, the central dataset consists of the identified environmental justice facilities and their neighbourhood-level condition. Six indicators were analysed: water supply, schools, security facilities, playgrounds/green areas, primary healthcare facilities and tarred roads. Facility status was recorded as in use or unused, while neighbourhood condition scores were used for mapping and spatial analysis.

Analysis

Descriptive statistics were first used to summarise the number and operational status of facilities. Neighbourhood-level mean scores were then computed and mapped in ArcGIS 10.8 to visualise variation across the 66 neighbourhoods. The study classified mean scores below 3.0 as low, scores from 3.0 to 3.99 as moderate, and scores of 4.0 or above as high, adapted from Nassar et al. (2023).

Global Moran's I was used to test spatial autocorrelation in the condition of each indicator. The analysis used inverse-distance conceptualisation, Euclidean distance and a distance threshold of 2,026.2848 m. The null hypothesis was that the spatial pattern did not differ from randomness. Moran's I values close to zero were interpreted as random, positive values as clustered and negative values as dispersed. Statistical significance was assessed using the associated z scores and p values.

RESULTS

Availability and functionality of environmental justice infrastructure

The inventory in Table 1 reveals a sharp contrast between water infrastructure and the other indicators. Out of the 364 water-supply facilities identified, 180 (49.45%) were in use and 184 (50.55%) were unused. Water was therefore the only infrastructure category in which non-functional facilities outnumbered functioning ones. By comparison, all 61 schools were in use. Fifty-five of 56 security facilities (98.21%) were functional, as were 39 of 40 playgrounds/green areas (97.50%) and 39 of 40 primary healthcare facilities (97.50%). The study identified 454.37 km of tarred roads, all recorded as functional.

Table 1: Environmental Justice Indicators in the Study Area

Indicator	In Use		Unused		Total
	Freq	%	Freq	%	
Water supply	180	49.45	184	50.55	364
Schools	61	100.00	0	0.00	61
Security	55	98.21	1	1.79	56
Playground/green area	39	97.50	1	2.50	40

Primary healthcare facilities	39	97.50	1	2.50	40
Tarred roads	454.37km	100.00	0	0.00	454.37km

Figure 2 revealed the location of infrastructural facilities in the study area. The locational pattern further shows that the large number of water points should not be interpreted as evidence of adequate water service. Water facilities were widely distributed across the city, but more than half were not operational. Schools, security facilities, primary healthcare facilities and playgrounds/green areas were fewer and were visually more concentrated around central and more developed neighbourhoods and major road corridors. Peripheral neighbourhoods generally contained fewer of these facilities.

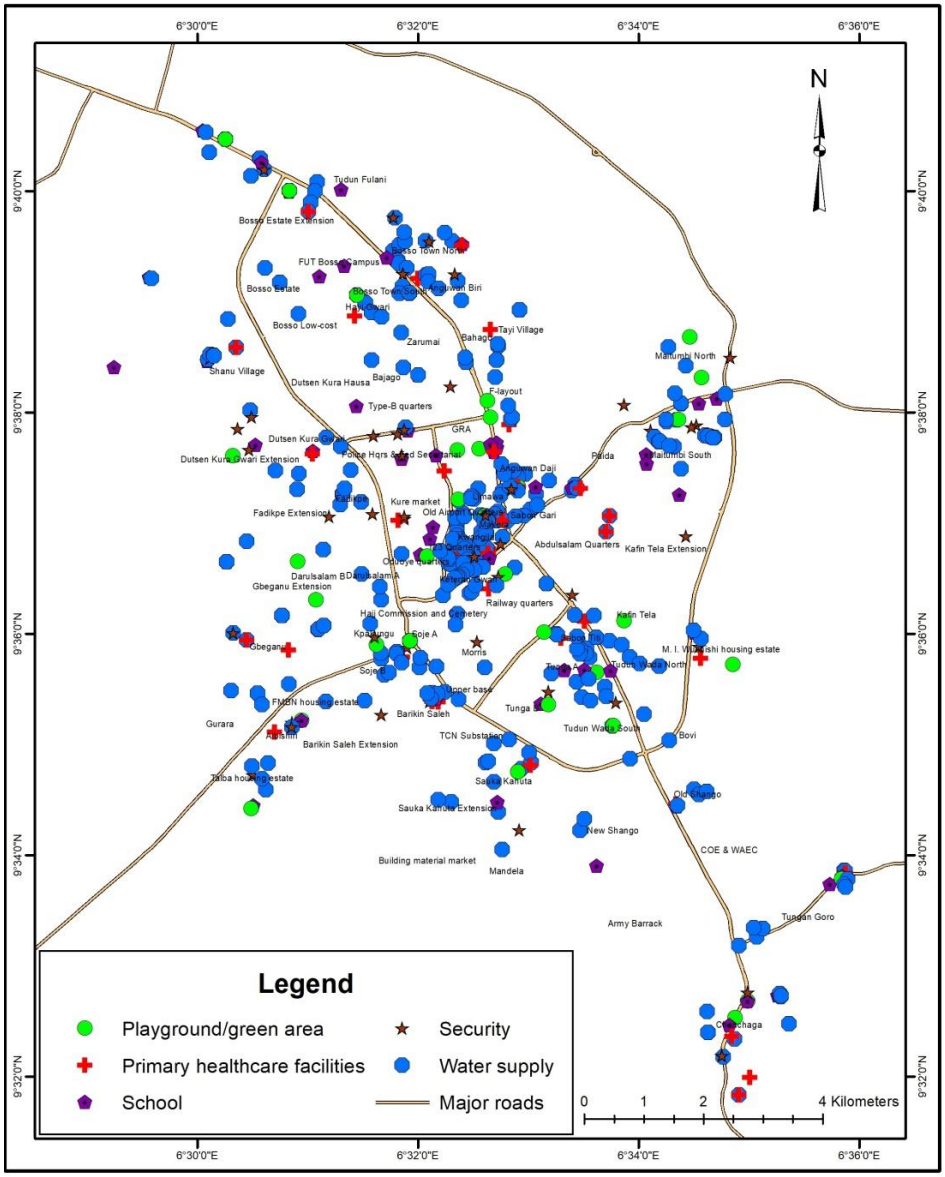


Figure 2. Locational distribution of environmental justice indicators in Minna.

Source: Field survey, 2026.

Neighbourhood Variation in Environmental Justice Indicators

The mean condition scores in Figures 3 to 8 demonstrate that infrastructure quality is uneven within Minna. Water supply illustrates this clearly. Relatively poor water conditions occurred in Bahago, Barikin Saleh Extension, Anguwan Biri, Zarumai, Kpakungu, Sabon Titi and Sauka Kahuta, among other neighbourhoods.

Moderate conditions were reported in Chanchaga, Bosso Town South, Fadikpe, Makera, Talba Housing Estate and Tungan Goro. Better conditions were confined to a smaller set of neighbourhoods, including Paida, Albishiri, Bosso Low-cost, FMBN Housing Estate and Upper Base.

Security facilities also varied. Low-condition areas included Keteran Gwari, Kwangila, M. I. Wushishi Housing Estate, Railway Quarters, Shanu Village and Kpakungu. Moderate conditions occurred in neighbourhoods such as Anguwan Daji, Chanchaga, Fadikpe, Fadikpe Extension, Gurara, Maitumbi South, Mandela, Talba Housing Estate and Tungan Goro, while high-condition security facilities were limited to a few locations including Abdulsalam Quarters, Morris and Tunga B. These patterns reinforce the distinction between a city possessing a service and all neighbourhoods experiencing that service under comparable conditions.

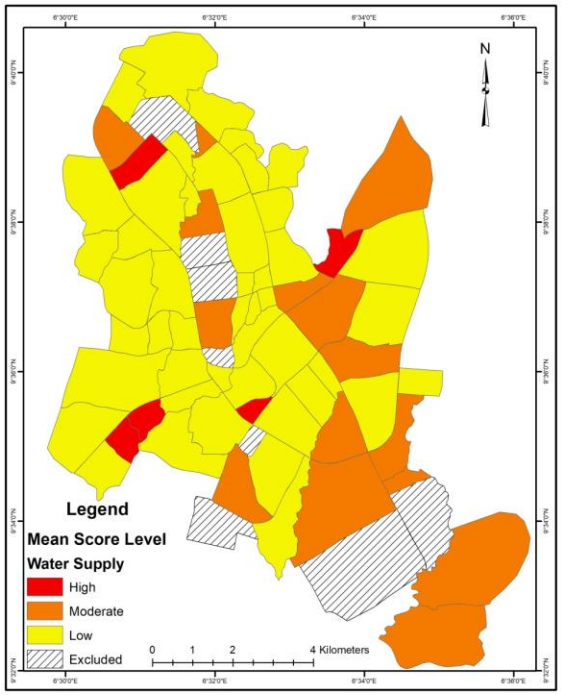


Figure 3: Mean Condition of Water Supply Facilities

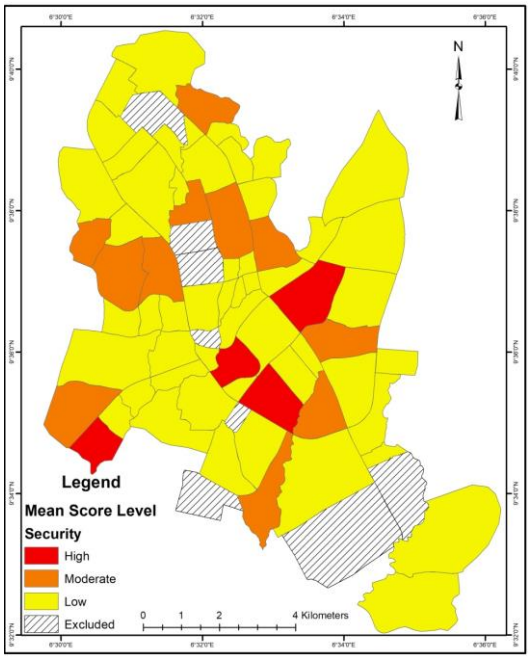


Figure 4: Mean Condition of Security Facilities

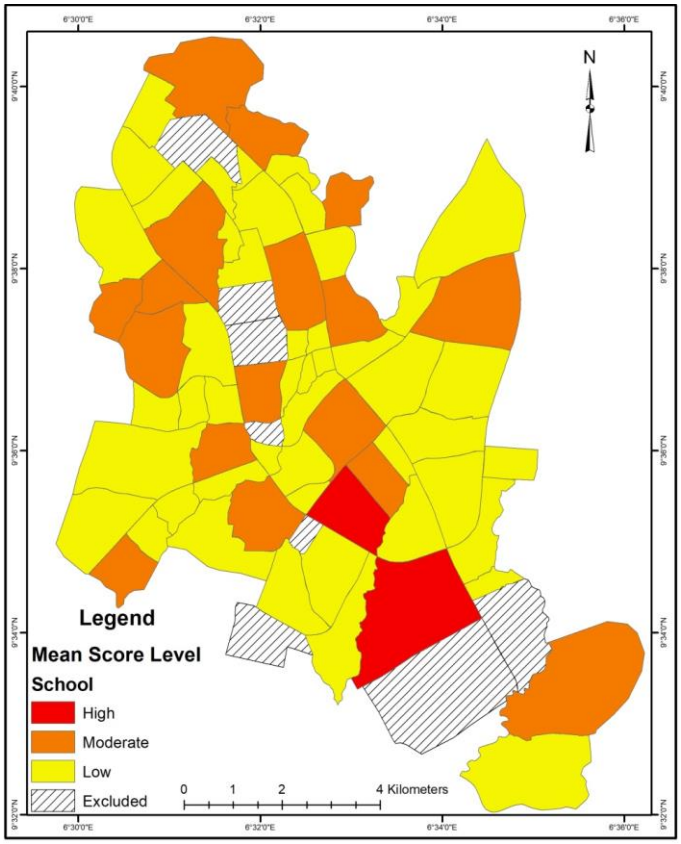


Figure 5: Mean Condition of School Facilities

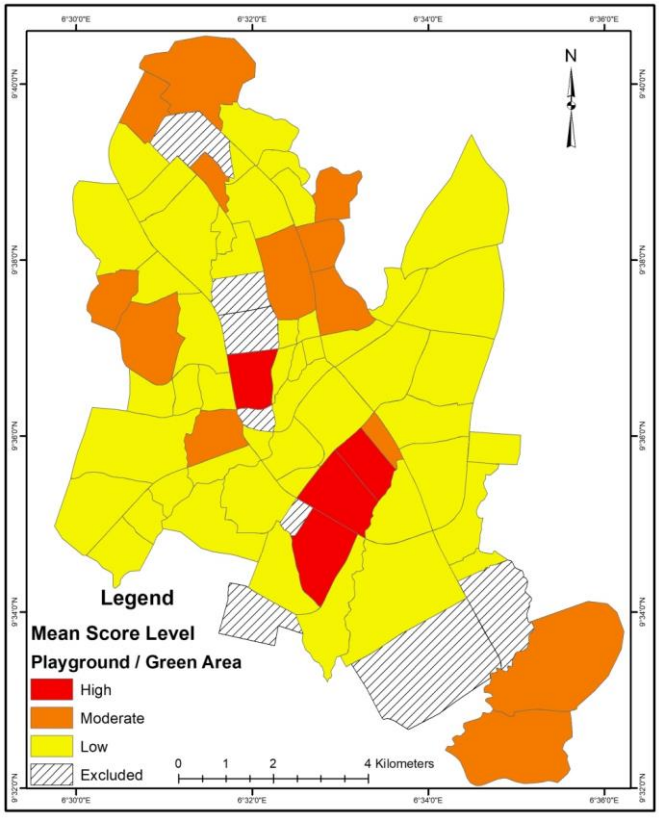


Figure 6: Mean Condition of Playground/Green Area Facilities

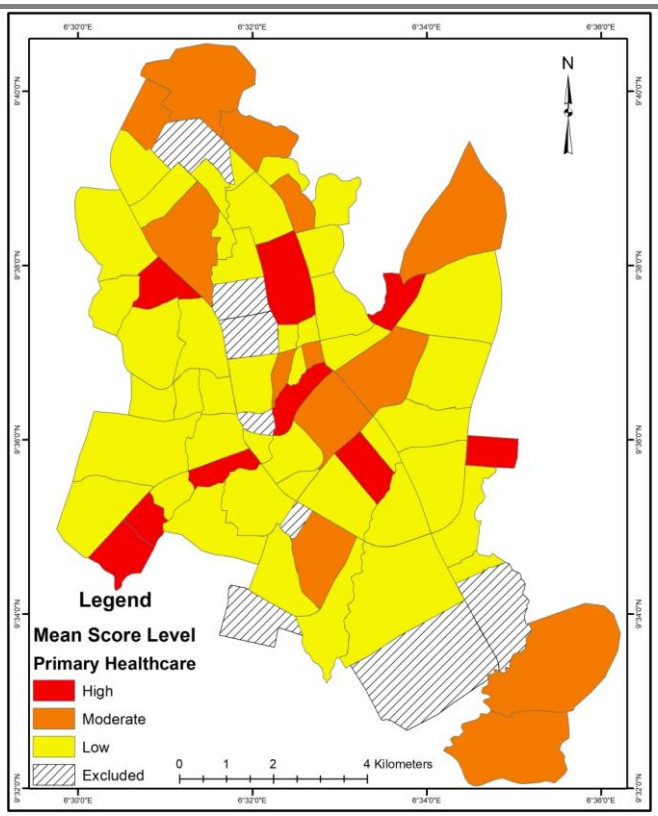


Figure 7: Mean Condition of Primary Healthcare Facilities

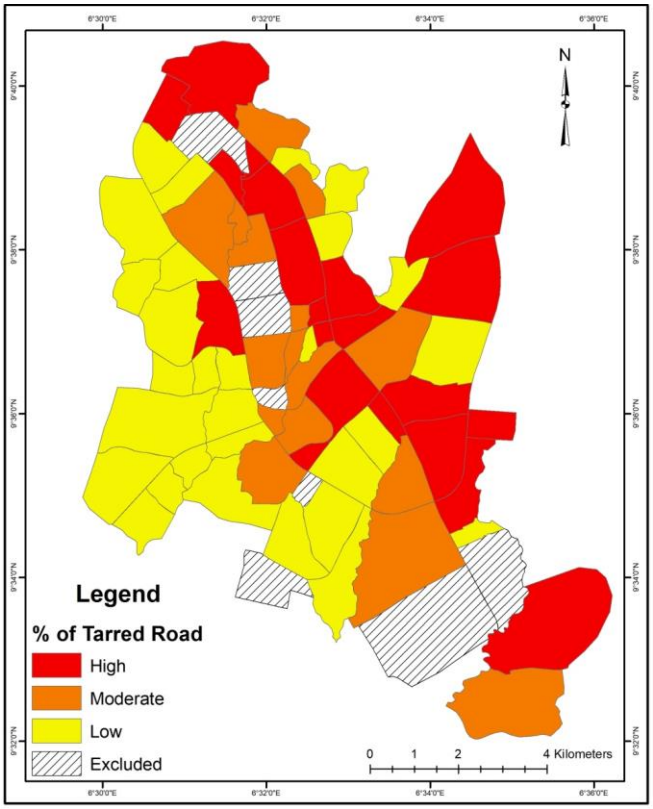


Figure 8: Percentage of Tarred Road Infrastructure

Under alternative classification thresholds, some neighbourhoods, particularly those with mean scores close to the category boundaries, could shift from low to moderate or from moderate to high conditions. However, neighbourhoods with relatively poor conditions, such as Bahago, Barikin Saleh Extension, AnguwanBiri, Zarumai, Kpakungu, SabonTiti and SaukaKahuta in terms of water supply, and KeteranGwari, Kwangila, M.

I. Wushishi Housing Estate, Railway Quarters, Shanu Village and Kpakungu in terms of security facilities, may retain their classifications where their mean scores are sufficiently below the alternative thresholds. Similarly, neighbourhoods with consistently better conditions may retain their high classifications. This suggests that although the classification of some neighbourhoods may be sensitive to the choice of cut-off points, the broader pattern of uneven infrastructure provision across Minna remains an important consideration. Nevertheless, confirmation of the extent of this robustness requires reclassifying the actual neighbourhood mean scores under alternative thresholds.

Spatial autocorrelation of infrastructure condition

Global Moran's I in Table 2and Figures 9 to 14 produced different spatial signatures across the six indicators. Water supply had an index of -0.0125 (z = 0.048, p = .962), security -0.0014 (z = 0.234, p = .815), schools -0.0676 (z = -0.876, p = .381), and playgrounds/green areas 0.0261 (z = 0.696, p = .486). None differed significantly from spatial randomness. Primary healthcare recorded I = -0.1196 (z = -1.745, p = .081), indicating weak evidence of dispersion at the 10% level but not at the conventional 5% level. Tarred roads were the clear exception: I = 0.2459, z = 4.368, p = .000013, demonstrating statistically significant positive spatial clustering.

Table 2: Global Moran's I Summary for Condition of Environmental Justice Indicators

Indicator	Moran's I	z score	p value	Interpretation
Water supply	-0.012536	0.048220	.961541	Random
Security	-0.001387	0.234425	.814655	Random
Schools	-0.067617	-0.875674	.381207	Random
Playground/green area	0.026110	0.696223	.486289	Random
Primary healthcare	-0.119574	-1.745083	.080970	Weak tendency to dispersion
Tarred roads	0.245861	4.368369	.000013	Significantly clustered

Note. Inverse-distance spatial weights; Euclidean distance; threshold = 2,026.2848 m. Source: Field survey, 2026.

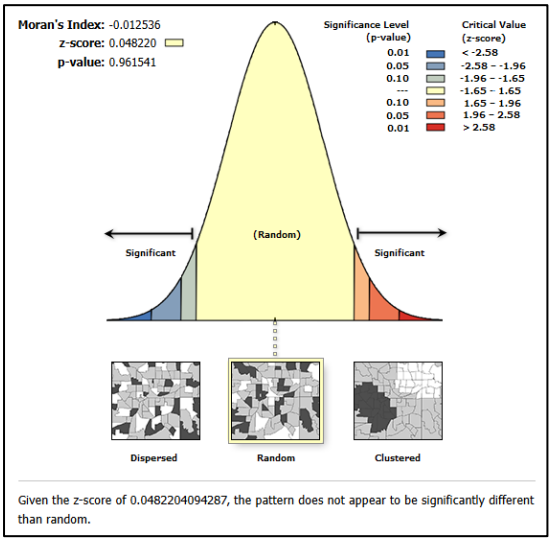


Figure 9: Spatial distribution pattern of water-supply condition.

Source: Field survey, 2026.

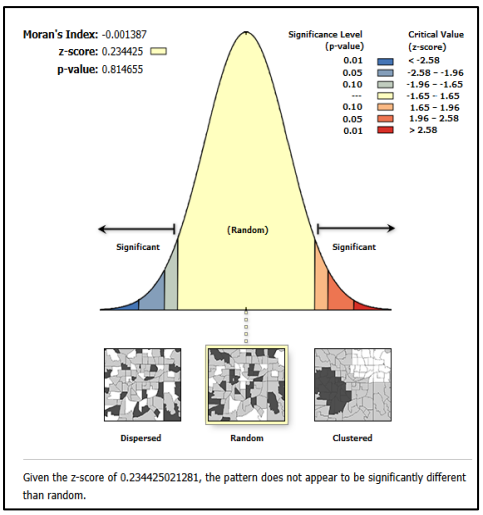


Figure 10: Spatial distribution pattern of security-facility condition.

Source: Field survey, 2026.

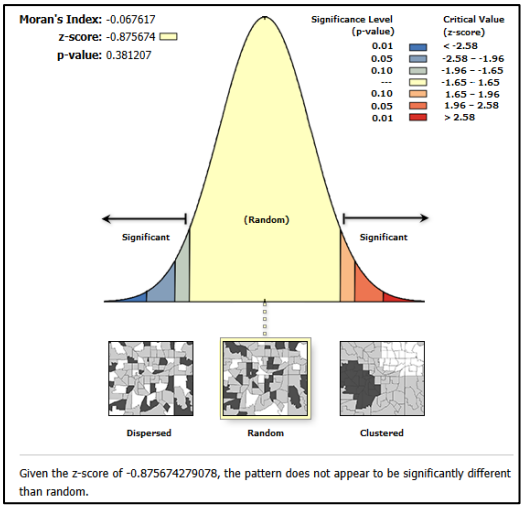


Figure 11. Spatial distribution pattern of school-facility condition.

Source: Field survey, 2026.

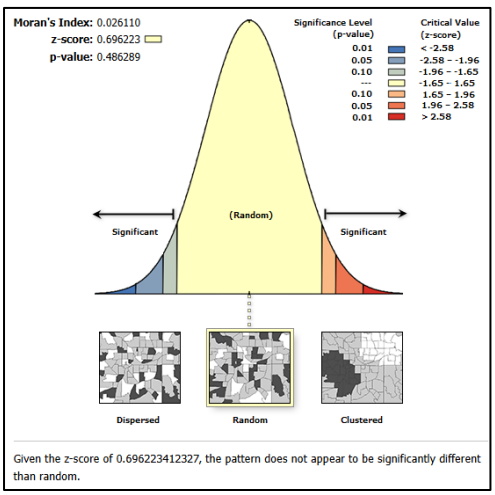


Figure 12: Spatial distribution pattern of playground/green-area condition.

Source: Field survey, 2026.

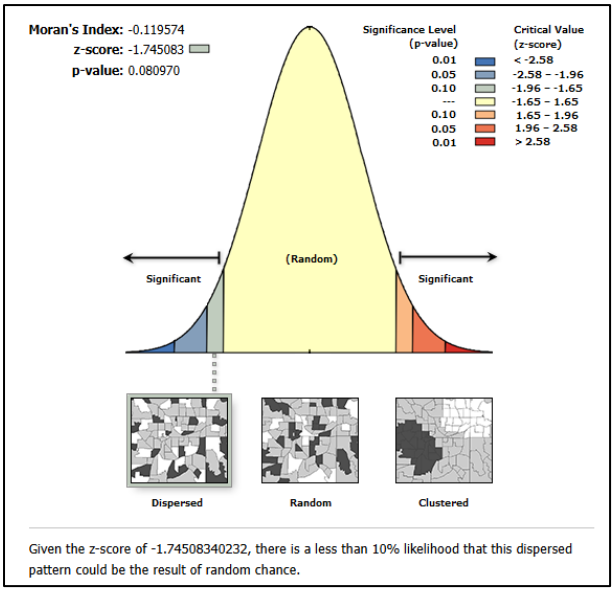


Figure 13: Spatial distribution pattern of primary-healthcare condition.

Source: Field survey, 2026.

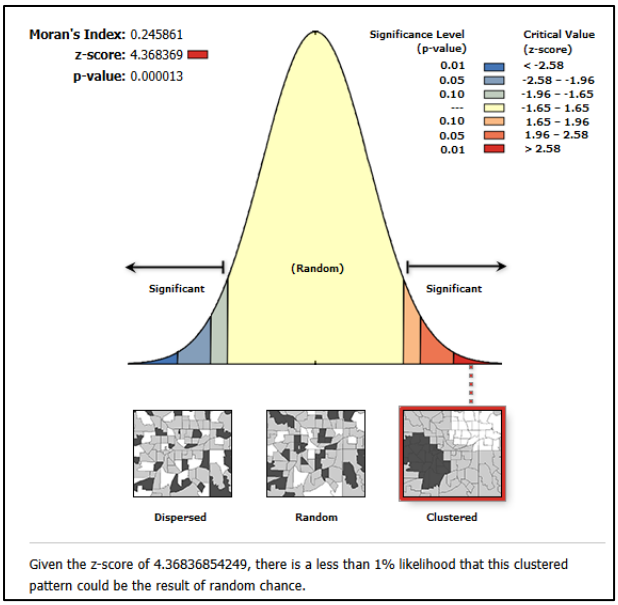


Figure 14. Spatial distribution pattern of tarred-road infrastructure.

Source: Field survey, 2026.

DISCUSSION

The most important empirical distinction in the results is between infrastructure presence and infrastructure functionality. Water supply had by far the largest facility count, yet only 49.45% of the identified facilities were operational. A simple inventory would therefore create an overly favourable picture of water provision. From an environmental justice perspective, non-functional infrastructure represents a lost environmental benefit: residents may live near a facility without receiving the service that justified its provision.

This finding is consistent with the broader concern identified by Aliu et al. (2021), who linked water deprivation in Lagos informal settlements to wider residential disadvantage. The Minna evidence extends that

concern beyond a study of highly deprived informal settlements because the present analysis covers different neighbourhood types across the city. It therefore suggests that unreliable water infrastructure can operate as a city-wide justice issue, although its severity differs from one neighbourhood to another.

The contrast with schools, security, healthcare and recreational/green facilities is also instructive. Their high functionality rates indicate that operational failure is not equally distributed across infrastructure sectors. Environmental justice assessments should therefore avoid collapsing different services into a single undifferentiated infrastructure measure. The mechanisms producing water disadvantage may differ from those shaping access to schools, security or green space.

A second important result is that most infrastructure conditions were statistically random at the city scale. This should not be interpreted as evidence of equality. The neighbourhood maps show meaningful differences in condition, but Moran's I indicates that good and poor conditions for water, security, schools and playgrounds/green areas do not consistently form large contiguous clusters. In other words, inequality is present without a strong city-wide autocorrelation structure.

This distinction is important for environmental justice practice. If planners rely only on hotspot logic, scattered disadvantaged neighbourhoods may be overlooked because they do not belong to a statistically significant cluster. The findings support a two-stage reading of spatial justice: first assess actual neighbourhood condition and functionality; then test whether those conditions form spatial concentrations. Both questions matter, but they answer different planning problems.

The result broadly agrees with Olowoporoku et al. (2023), who found that environmental justice experiences vary across residential zones in Ile-Ife. It also extends the earlier Minna studies by Mohammed et al. (2019, 2021), which demonstrated neighbourhood disparities but did not provide the same city-wide test of spatial autocorrelation across six infrastructure dimensions. The present analysis therefore adds a spatial-statistical layer to existing evidence of intra-urban inequality.

Tarred roads followed a different pattern from every other indicator. Their significant positive Moran's I means that neighbourhoods with relatively similar road conditions tend to be located near one another. Better-served areas are spatially associated with other better-served areas, while poorer road provision tends to occur near poorer provision. This is a stronger geographical structure than was observed for the other infrastructure categories.

The finding is compatible with the broader concern that rapid urban growth can produce uneven planning and infrastructure outcomes in Nigerian cities. Bayode and Siegmund (2024), working in Akure, emphasised the interrelationship between urban planning, city growth and sustainable development. In Minna, the clustering of tarred-road infrastructure provides neighbourhood-level statistical evidence that one important component of urban investment is geographically patterned rather than randomly distributed.

Road clustering has practical implications because roads influence accessibility to other services and can shape subsequent development. The present analysis does not establish why the clusters formed, and causal claims would go beyond the data. Nevertheless, the pattern is sufficiently strong to justify planning attention to neighbourhoods that remain within poorly served road clusters.

Three planning implications follow. First, infrastructure monitoring should report operational status alongside facility counts. This is especially urgent for water supply, where the numerical presence of facilities masks a severe functionality deficit. Second, investment decisions should be based on neighbourhood-scale evidence. The city-wide existence of schools, health facilities or green spaces does not demonstrate equitable neighbourhood conditions. Third, spatial statistics should complement, rather than replace, mapped condition assessments. A non-significant Moran's I does not mean that every neighbourhood is adequately served.

These implications fit the planning understanding of environmental justice advanced by Ntiwane and Coetzee (2018): fairness is expressed spatially through the distribution of environmental benefits and burdens. In

Minna, the relevant environmental benefits are not abstract. They include a working water point, a usable school or clinic, a functioning security facility, an accessible recreational space and a road network that does not systematically favour already well-served areas.

The discussion of findings demonstrates that infrastructure disparities across urban neighborhoods in Minna are structurally rooted in systemic governance deficits, acute socioeconomic stratification, and severe institutional lags (Zakari et al., 2025). Empirical evidence shows that an outdated Minna Master Plan, coupled with a critical lack of funding, technical capacity, and poor budgeting, prevents the Niger State urban planning agencies from proactively coordinating infrastructure with the city's rapid population growth (Kuma et al., 2026). This institutional failure has led to a stark socio-spatial dichotomy where low-income inner-city neighborhoods and spontaneous peri-urban settlements suffer from extreme infrastructure deficits. While high-income enclaves command functional service networks or self-fund upgrades, low-income areas score exceptionally poorly on structural drainage, access roads, and public water supply networks, yielding notably low user satisfaction indices. This disparity is further aggravated by an uncoordinated influx of informal economic activities that encroach onto road corridors. Additionally, because the state has partially withdrawn from routine public utility maintenance, infrastructure quality relies heavily on a neighborhood's internal capacity to mobilize community-based organizations (CBOs) and local funding.

CONCLUSION AND RECOMMENDATIONS

This paper assessed spatial inequalities in urban environmental infrastructure across the 66 neighbourhoods of Minna using six environmental justice indicators. The evidence shows that infrastructure inequality has more than one form. Water supply presents a functionality problem: despite 364 identified facilities, 50.55% were unused. Schools, security facilities, playgrounds/green areas and primary healthcare facilities were overwhelmingly functional, but their conditions varied between neighbourhoods. Tarred roads, totalling 454.37 km in the survey, were operational but displayed a statistically significant clustered spatial pattern.

The spatial analysis further demonstrates that inequality and clustering are not synonymous. Water supply, security, schools and playgrounds/green areas were largely random in Global Moran's I terms, while primary healthcare showed only weak evidence of dispersion. Yet the neighbourhood maps still reveal uneven conditions. The main methodological lesson is therefore that environmental justice assessment should combine facility functionality, neighbourhood-level condition and spatial autocorrelation rather than relying on any one measure. For urban policy, priority should be given to restoring non-functional water infrastructure and identifying the neighbourhood-specific reasons for poor service conditions. Infrastructure audits should be institutionalised at neighbourhood scale and should record whether facilities are usable, not merely whether they exist. Road investment should also be reviewed spatially so that existing clusters of poor provision are not reinforced by future allocations. Finally, planning agencies should use GIS-based neighbourhood monitoring to direct resources toward areas with demonstrably weak conditions, including isolated disadvantaged neighbourhoods that may not appear within statistically significant clusters.

The study is limited by its cross-sectional design and by its focus on facility condition and spatial pattern rather than causal mechanisms. The analysis identifies where inequalities occur and whether they are spatially structured, but it does not establish the historical, fiscal or political processes that produced them. Future research can build on these findings by tracking infrastructure condition over time and linking spatial patterns to investment decisions, maintenance histories and residents' effective access.Future research should consider longitudinal analysis to assess how infrastructure inequalities evolve over time

Acknowledgements

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Conflicts of Interest

The Authors declare no conflict of interest

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