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URBAN FORM INFLUENCE ON TERRORIST ATTACKS IN MAIDUGURI, NIGERIA: A STREET TOPOLOGY ANALYSIS

Abstract: This study examined the impact of street characteristics on terrorist attack incidences in Maiduguri, Nigeria. Terrorist attack data from the Global Terrorism Database (GTD) was analysed using network analysis and Axwman 6.3. Regression models identified spatial predictors of attacks. Results indicated that global integration and connectivity significantly increased bomb and armed attacks by 933.66% and 3.32%, respectively. Armed assault mitigation was associated with a 6.97% increase in edge betweenness. Betweenness centrality increased bomb attacks by 6.42%, while straightness centrality reduced them by 9.47%. The study underscores the role of urban form in city safety and resilience.

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Key words: Maiduguri, natural street, space syntax, terrorist attacks, urban form

INTRODUCTION

Terrorist attacks have evolved, ranging from armed assaults to suicide bomb attacks. The Taliban's rise led to a shift in attack styles, which the Euskadi ta Askatasuna (ETA) terrorist group in Spain categorised into control, contagious diffusion, attrition attack, and hierarchical diffusion (Lafree et al. 2012). The transportation network has been identified as a key factor in successful attacks (Jordán 2008; Sharifi 2019b). P. Lehr (2019b) identified three categories of attacks: conventional low-impact, conventional high-impact, and unconventional high-impact. The first type sends a message, the second causes destruction, and the last uses sophisticated means like nuclear weapons. Attacks can occur at any time, on special occasions, or in specific locations, depending on the terrorist group's operations.

Studies have demonstrated that components of the urban form have a great tendency to influence the occurrence and distribution of crime in urban areas (Babagana 2025; Babagana et al. 2025, 2026; Dempsey et al. 2010; Glaeser, Shapiro 2001; Lynch, Rodwin 2007; Musah et al. 2020; Onyeneke, Onu 2019; Pinho, Oliveira 2009; Sharifi 2019a, 2019b; Sharma 2014; Wuschke et al. 2021). As described by J.B. Kinney et al. (2008), land use is a critical component that tends to concentrate crime and create hotspots. Also, the street network has been described as the salient component on which other elements depend to shape activities in urban places (Jiang 1998; Jiang, Yin 2008; Lynch 1960).

The transportation network is a crucial element in shaping a city, ensuring circulation and flow to activity places and establishing mobility patterns. It is a foundation for identity, structure, and meaning and provides a linkage between various urban spaces. However, the design of streets can lock urban systems into positive or negative trajectories, making them attractive for suicide terrorism (Sharifi 2018). Street networks are also essential for crime prevention through environmental design, as they help prevent crime through aggregations around land uses (Kliot, Charney 2006).

The street network is a living system that shapes, determines, and predicts urban activities through its interrelation, interdependence, and interactions with different street types. Graph theory, a tool for understanding these relationships, has been developed to calculate the mathematical relationships of spaces around street networks (Campedelli et al. 2022; Wuschke et al. 2021). Space syntax, a tool for this theory, uses metrics such as global integration, local integration, mean depth, and connectivity to calculate the mathematical relationships among spaces around street networks (Hillier 2004). Centrality measures, such as gravity centrality, betweenness centrality, straightness centrality, and information centrality, are used to define the importance and significance of individual networks (Jiang, Liu 2007; van Nes, Yamu 2021).

Different street types influence crime differently (Wuschke et al. 2021). Some streets (based on their types) are traversed more often than others. A more permeable street should expect greater pedestrian and vehicular traffic, while a less permeable one (such as a sinuous cul-de-sac) should expect the opposite. Since terrorists take advantage of ambient populations, permeable streets will be more attractive, especially for bomb attacks (Sharifi 2018, 2019b). Also, the activities around the streets are contributory factors. Land uses such as markets, motor parks, and bus stops, among others, have been described as crime generators and attractors in spatial space (Amoako 2021; Brantingham, Brantingham 1995; Groff, Lockwood 2014; Klakla et al. 2021; Loukaitou-Sideris et al. 2002; Steinman et al. 2020; Tillyer, Walter 2019; Yu, Fang 2022).

This study investigates the impact of the street as an important urban form parameter on terrorist attacks in Maiduguri, a major northeastern city in West Africa, using space syntax and node centrality metrics. The study aims to understand the spatial factors that influence these attacks, as the situation in northeastern Nigeria, particularly in Maiduguri, is unprecedented. The research is organised into sections on topological metrics, methods, results, and discussion.

LITERATURE REVIEW

Streets are the foundation of human settlements and activity, shaping their form, structure, and pattern. Urban planners and designers shape the built environment through street patterns, which, in turn, shape human activities. A well-arranged street network system is crucial for circulation, ventilation, and aesthetics. Streets are essential for crime prevention and achieving a secure and resilient urban environment (Obateru 2003; Sharma 2014). A study by J. Wang (2015) found that well-laid grids in Beijing are more reliable, robust, and resilient than dendritic networks in London. The London Bombings occurred in stations connected to major streets, highlighting the importance of network disruptions in affecting street and city activities (Lieberman, Cheloukhine 2009). Therefore, streets are not only fundamental to city growth but can also influence the design and pattern of urban systems.

This work acknowledges that streets, being the skeletal structure of the urban area, play a vital role in understanding the urban form and how it can be used to achieve resilience against crime and terrorist attacks. Space syntax parameters have been utilised in previous studies to demonstrate the importance of nodes and edges (Jiang 1998; Jiang et al. 1999; Wang 2015) and how they influence traffic events (Jiang, Yin 2008). This study examined the influence of streets on terrorist attacks.

Graph theory has been used to understand the dynamism of urban forms and how urban areas function as systems (van Nes, Yamu 2021; Zivkovic 2019). It involves nodes and vertices connected by edges that represent the relationships between elements. Network analysis is a mathematical method for understanding the significance of specific streets or nodes within a network, using tools and space syntax to determine their centrality. B. Hillier and K. Tzortzi (2006) developed space syntax, with specific parameters, to explain city structure. Spatial phenomena shape human activities, and the importance and configuration of every node and edge are crucial for easy mobility (Jiang, Liu 2007). This study used centrality metrics and space syntax parameters to understand the influences of street networks on terrorist attacks.

Closeness centrality: this metric indicates the ability to reach a destination from other network paths at a reasonable distance within a stipulated time. A. Sharifi (2018) opined that emergency services such as fire, Police, and ambulance services, among others, should be located in streets with high closeness centrality to improve service efficiency and effectiveness. The deactivation of a link towards a node with a high closeness centrality measure will cause a disruption. Offenders can take advantage of such to wreak havoc. Mathematically, closeness centrality is calculated as

$$C_i^c = \frac{N - 1}{\sum_{j=1; j \neq i}^N d_{ij}} \quad (1)$$

where: C_i^c is closeness centrality of node i

N is the number of nodes

d is the distance between one node and other nodes

j is every other node

Betweenness centrality is a crucial metric that measures the importance of a node or edge within a network, ensuring the effective and efficient flow of information. It translates the relevance of every path or node within a network in terms of vehicular and pedestrian movements (Bröhl, Lehnertz 2022; Gómez et al. 2021; Pung et al. 2022). Studies have used betweenness centrality as a fundamental metric to ascertain street permeability, such as the 2005 London terrorist attacks (Jordán 2008). High edge betweenness centrality is more vulnerable to burglary, and street network permeability can influence crime through heterogeneity and place characteristics. Linear streets have a lower risk of burglary than sinuous ones. Street permeability also influences the spatial distribution of burglary in Jiangnan District, Wuhan City, China. Understanding betweenness centrality metrics helps inform decisions for safer neighborhoods by planners and criminologists. Betweenness centrality for nodes is expressed mathematically as:

$$C_B(v) = \sum_{s \neq v \neq t \in V} \frac{d(s, \frac{t}{v})}{d(s, t)} \quad (2)$$

where: $d(s, t/v)$ is the number of shortest paths between s and t passing through vertex v and $d(s, t)$ total number of shortest paths between s and t

While for edges is:

$$C_B(e) = \sum_{s, t \in V} \frac{d(s, \frac{t}{e})}{d(s, t)} \quad (3)$$

where: $d(s, t/e)$ is the number of shortest paths between s and t passing through edge e and $d(s, t)$ total number of shortest paths between s and t

Straightness centrality: This metric measures the deviation of the shortest paths between two nodes in a network. The distance between the two nodes used to calculate this metric is the Euclidean distance between them – the higher the straightness centrality, the greater the interaction between the nodes. A. Sharifi (2018) argued that it means increased interaction between nodes, which will serve as an avenue for increased resilience in the entire network. It is mathematically expressed as:

$$C_i^E = \sum_{i \neq j \in d(i, j) \leq r_i} \frac{d^{Eu}(i, j)}{d(i, j)} \quad (4)$$

where: d^{Eu} is the Euclidean distance or linearity between i and j along a straight path

$d(i, j)$ is the shortest path between i and j , where node j lies within the range r_i from node i

Global and local integration: Streets relate in a spatial system, either local or global, within a neighbourhood, village, town, or city. Local integration refers to the degree of accessibility between streets within a small, locally connected street and between one street and all other streets within the network. Local integration is a useful space syntax parameter for examining pedestrian and vehicular movements in urban systems, as greater integration attracts more movement. Global integration measures the robustness of the road system, calculated as the level to which streets or nodes are spatially integrated into a network (Hillier, Hanson 1984; van Nes, Yamu 2021).

Connectivity: It enhances economic activities by attracting large pedestrian and vehicular traffic (Chuku et al. 2017; Vogelbacher et al. 2016). Well-connected streets are producers of the ambient population and have higher connectivity values. Studies have shown that street connectivity is influenced by the axial line representation, which is widely used to understand street functions in cities. Natural streets, which combine named streets, street segments, and axial lines, provide a better representation of streets and are suitable for aggregating units of analysis.

METHODOLOGY

The Study Location and Terrorism

Maiduguri, a key city in northeastern Nigeria, became an administrative hub in 1907 when the Kanem-Borno Empire relocated there (Hiribarren 2017). It serves as a vital economic link between Nigeria and neighbouring countries like Cameroon, Chad, and Niger (Fig. 1) (Iweze 2020). However, the city suffered from the Boko Haram crisis, which escalated in 2009 and led to a state of emergency in 2013 (Omenma et al. 2020; Tar, Ayegba 2021). Although the group was pushed out of Maiduguri, attacks continued until 2015. Covering approximately 18 km by 15 km, Maiduguri's population was estimated at 1,217,432 in 2021 (Daura 2001; International Office of Migration 2021).

The city of Maiduguri serves as a central hub for Islamist terrorism in Nigeria, primarily because of the Boko Haram insurgency founded in 2002 by Mohammed Yusuf (Tar, Ayegba 2021). Initially

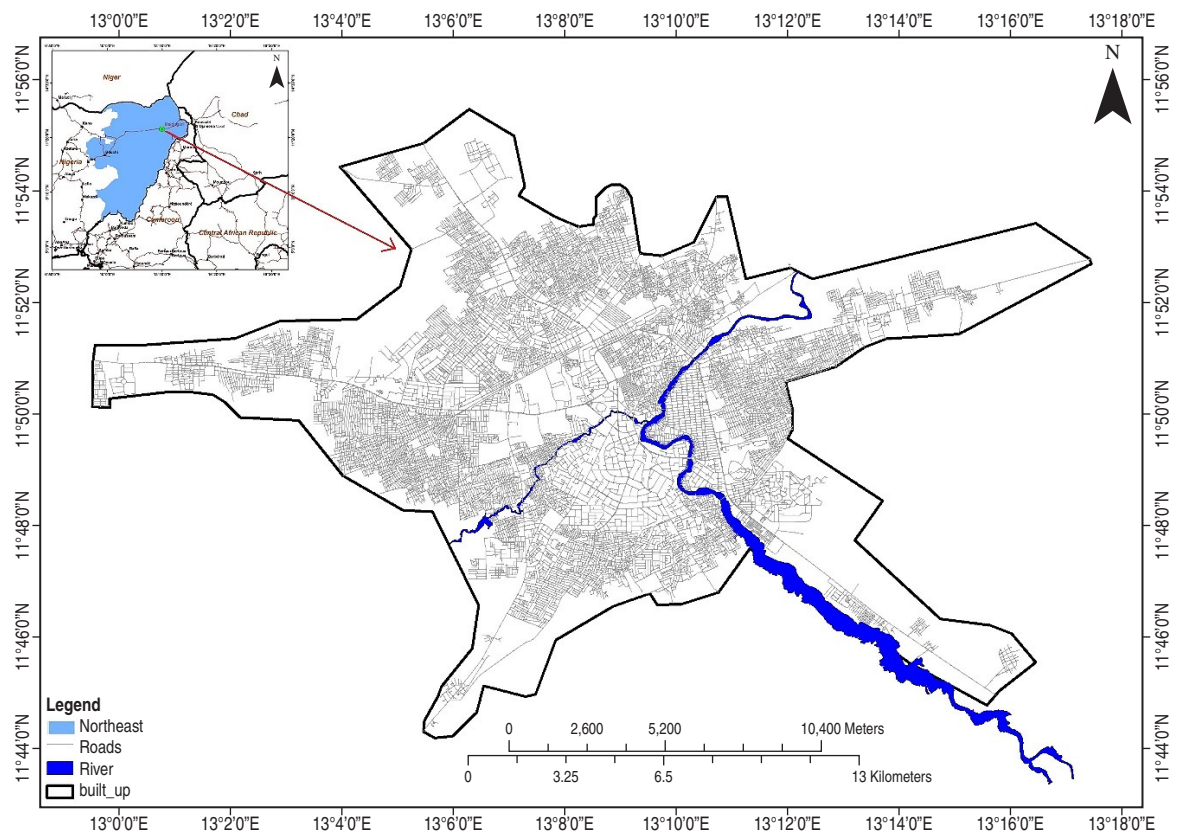


Fig. 1. The Study Area

Source: own elaboration.

a radical Islamic movement against Western education and governance, Boko Haram evolved into an armed insurgent group post-2009, with 69% of its attacks concentrated in Borno State (Fondapol 2024). Maiduguri, the movement's birthplace, has endured repeated violence, including bombings, armed assaults, and kidnappings targeting markets, mosques, schools, and other civilian and military sites, creating significant fear and humanitarian crises (Ezeugo 2016; Fondapol 2024; Tar, Ayegba 2021). Since 2009, Boko Haram has been responsible for over 3,500 attacks and more than 26,000 deaths across the Lake Chad region, primarily in Nigeria (Fondapol 2024). The peak of their activities occurred between 2014 and 2015, marked by large-scale massacres and coordinated suicide bombings mostly emanating from Maiduguri. Civilians represented over 64% of those targeted, illustrating a deliberate strategy of terror against local communities. As such, Maiduguri epitomizes the urban insecurity and resilience in northeastern Nigeria's battle against terrorism (Fondapol 2024; Iweze 2020).

Data requirements

The study analysed the extent of terrorist attacks in Maiduguri, Nigeria, using data from the Global Terrorism Database (GTD) for 2010 to 2020. The data included information on the point of attack, casualty, assailants, weapon type, and type of attack. However, some coordinates were incorrect, leading to the correction of 402 (80%) attacks. The Borno State Urban Development Law 1992 determined the city's extent based on factors such as population, urbanisation, economies of scale, and agglomeration. A high-resolution satellite image of Maiduguri was obtained from Google

Earth, and natural streets were processed using Axwman 6.3. Only 219 (3%) streets accounted for attacks, and the Zero-Inflated Negative Binomial Regression model was used to fit the smaller area (Fig. 2).

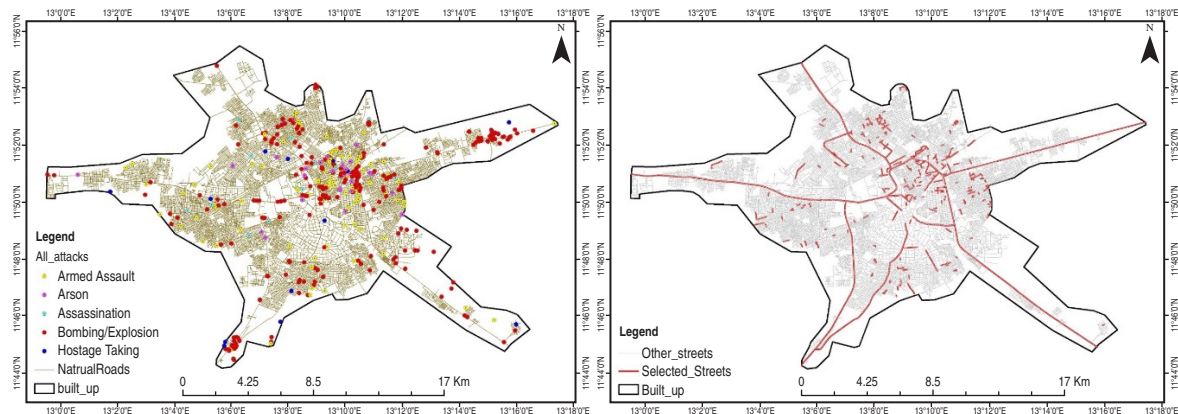


Fig. 2. Distribution of Terrorist Attacks and Spatial Units of Attacks
Source: own elaboration.

Data Analysis

The study used the Urban Network Analysis Toolbox and Axwman 6.3 to compute centrality and space syntax metrics for the street network. The data was extracted from the network and counted independently along streets. A buffer was created for each street category, with buffering at 200 meters, 100 meters, 50 meters, and 20 meters. The data was then exported to Microsoft Excel and filtered by attack type and street. A 1000-square-meter grid was generated using the Create Fishnet tool in ArcGIS 10.3.1, and the Spatial Join tool was used to extract the number of attacks and average centrality metrics. The selected grid system for analysis provides a standardised, spatially neutral method that minimises the Modifiable Aerial Unit Problem, unlike administrative boundaries (Andresen 2021; Openshaw 1984; Wong 2009). It balances spatial precision and manageability, aiding in identifying localised terrorism hotspots and their connections to urban environments as demonstrated by previous studies (Mitrović 2024; Zhao et al. 2021). Terrorist attacks were entered as the dependent variable, and descriptive statistics were run to understand the best-fit model for the analysis. The analysis revealed that all attack types were under-dispersed except for bomb attacks, which had an over-dispersed distribution. The Poisson regression model was used for bomb attack analysis, while truncated negative binomial regression was employed for other over-dispersed attack types (Harris et al. 2012).

RESULTS

Influence of Street Segments (Geometry)

Connectivity and edge betweenness (a measure of permeability) were positively and negatively associated with armed assault, respectively. Mathematical form connectivity increases armed assault by 3.32% ($IRR = 1.0332$), while permeability (edge betweenness) decreases armed assault by 6.97% ($IRR = 0.9303$) (Fig. 3 and Table 1). In essence, well-connected streets have a 1.03 times higher

Table 1. Results for the negative binomial model for bomb attacks and the generalised Poisson model for other attack typologies and space syntax parameters on natural streets

Attack type	Urban form Parameter (spaces syntax metrics)				
		Connectivity	Edge betweenness	Global integration	Local integration
Arson	β	-0.0661	0.1544	3.2148	0.2184
	IRR	0.936	1.1671	24.8991	1.2441
	Sig.	0.202	0.281	0.202	0.103
Assassination	β	-0.0015	-0.0044	-0.0327	-0.0606
	IRR	0.9985	0.9956	0.9679	0.9411
	Sig.	0.994	0.993	0.995	0.997
Armed assault	β	0.0327	-0.0722	0.4202	0.0443
	IRR	1.0332	0.9303	1.5222	1.0454
	Sig.	0.004	0.003	0.431	0.584
Bomb	β	-0.0109	0.0713	2.3357	0.2511
	IRR	0.9892	1.0739	10.3366	1.2854
	Sig.	0.643	0.186	0.004	0.187
Hostage-taking	β	0.054	-0.0758	2.8456	-0.3712
	IRR	1.0555	0.927	17.2118	0.69
	Sig.	0.393	0.431	0.677	0.699

IRR: incident rate ratio. The likelihood ratio test of $\alpha=0$ for bomb attacks and $\delta=0$ for other attacks indicates that the negative binomial model is appropriate for bomb attacks and the generalised Poisson model is appropriate for other attack types.

Source: own elaboration.

likelihood of experiencing armed assaults. Well-connected streets facilitate easy pedestrian and vehicular mobility, including offenders, at a local scale, providing an advantage for armed assault as they don't support the ambient population. Edge betweenness measures the permeability of a street, influencing its importance beyond connectedness. High edge betweenness reflects the ambient population, making it unsuitable for armed assaults. Global integration was also positively significant with bomb attacks. It increases bomb attacks by 933.66% (IRR = 10.3366). Globally integrated streets have a 10.3-times likelihood of experiencing bomb attacks. Bomb attacks are associated with densely populated areas.

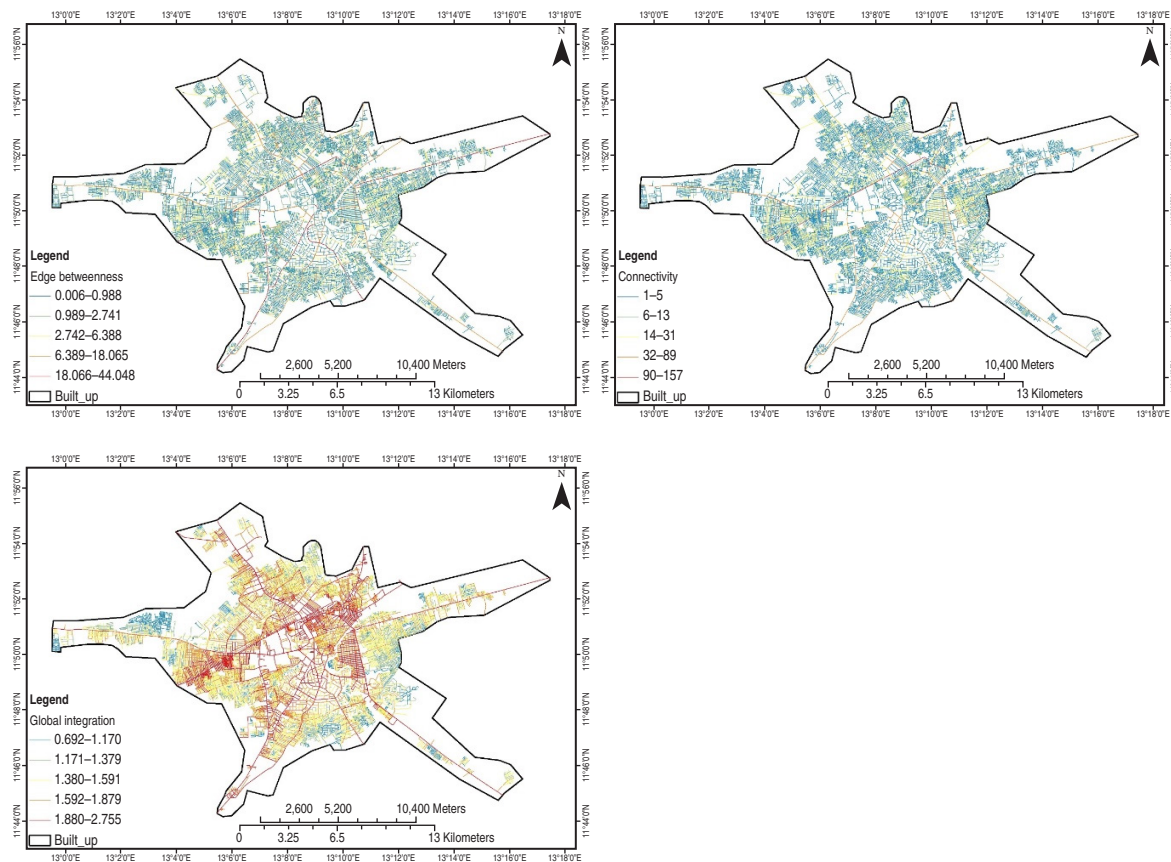


Fig. 3. Distribution of Space Syntax Metrics of Street Segments

Source: own elaboration.

Influence of Street Intersections (Nodes)

Betweenness and straightness centralities showed significant positive and negative correlations with bomb attacks. Betweenness centrality increased bomb attacks by 6.42% (IRR = 1.0642), while straightness centrality of nodes decreased bomb attacks by 9.94% (IRR = 0.9006). Therefore, the number of shortest paths to a node attracts bomb attacks. There is a 1.06 times greater likelihood that such a node will experience bomb attacks. Also, the centrality of nodes (that is, increased interaction between nodes) tends to reduce the number of bomb attacks. Straightness centrality is, therefore, a good metric for ensuring network resilience (Sharifi 2018) (Fig. 4 and Table 2).

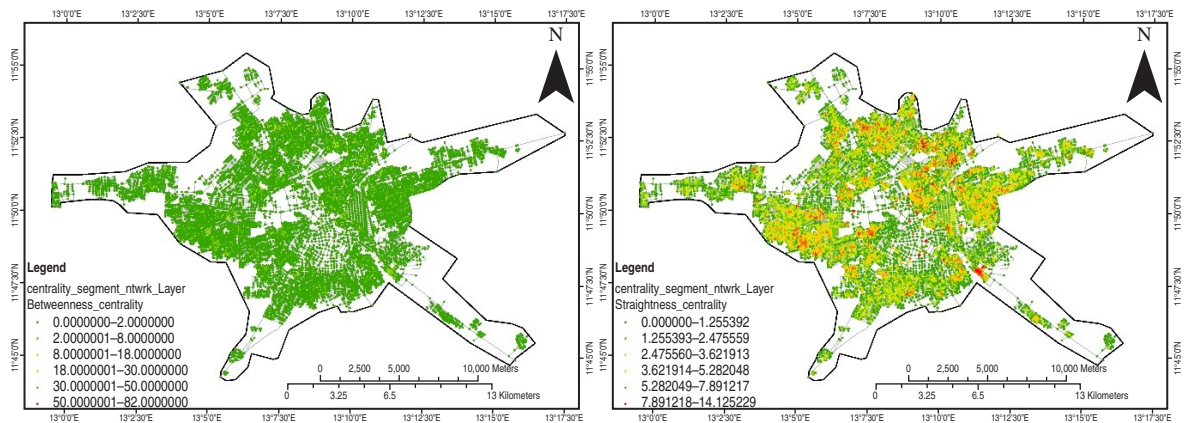


Fig. 4. Distribution of Street Intersection Metrics

Source: own elaboration.

Table 2. Results for the negative binomial model for bomb attacks and the generalised Poisson model for other attack typologies and space syntax parameters on natural streets

Attack type		Urban form parameter (centrality metrics)		
		Betweenness centrality	Closeness centrality	Straightness centrality
Arson	β	0.0062	4.0399	0.0496
	IRR	1.0062	56.8184	1.0508
	Sig.	0.79	0.639	0.717
Assassination	β	-0.029	-4.9659	0.4307
	IRR	0.9724	0.007	1.5382
	Sig.	0.78	0.908	0.429
Armed assault	β	0.1061	12.4734	0.0422
	IRR	1.112	261260.3	1.0431
	Sig.	0.459	0.592	0.937
Bomb	β	0.0622	-0.59	-0.1047
	IRR	1.0642	0.5545	0.9006
	Sig.	0.000	0.76	0.047
Hostage-taking	β	0.0092	5.296	-0.2206
	IRR	1.0092	199.53	0.8021
	Sig.	0.858	0.805	0.48

IRR: incident rate ratio. The likelihood ratio test of $\alpha = 0$ for armed assaults, $\delta = 0$ for arson, assassination and hostage-taking, and likelihood ratio $\chi^2 = 0.000$ for bomb attacks, signifying that the truncated negative binomial model is fit for armed assault, the generalised Poisson model is fit for arson, assassination and hostage-taking, and the Poisson regression model is fit for bomb attacks.

Source: own elaboration.

DISCUSSION

An essential aspect of terrorist operations is the ability to navigate and manoeuvre through built-up areas, taking advantage of specific spatial features. There is no dichotomy between the routine activities of non-offenders and offenders as they are shaped by experiences and understandings of the spatial characteristics of the built environment (Cohen, Felson 1979; Cozens 2011; Kim et al. 2022; Kinney et al. 2008; Silke 2011; Yue, Zhu 2019). This study demonstrated the role of an important aspect of urban form that determines its structure. Street characteristics are essential determinants of city resilience (Sharifi 2019b). In this study's findings, well-connected streets increase the likelihood of armed assault, whereas the reverse is true for permeable streets. Armed assaults are primarily carried out on motorcycles or on foot (Global Terrorism Index 2019). Such a situation requires a less crowded area with many escape routes. Well-connected streets provide a conducive platform for such operations. Edge betweenness, which measures a street's permeability, tends to mitigate the likelihood of armed assaults. Streets with high permeability and having a global influence in the network support heavy pedestrian and vehicular mobility. As a result, they support establishing an ambient population that is unsuitable for armed assaults. This finding corroborates that of S. Favarin (2018), which demonstrated how streets with limited access mitigate burglary but aggravate armed robbery. Armed assault has many similarities with armed robbery in the sense that they are not restricted to households (in the case of burglary in several studies) and have an offensive *modus operandi*. They require fewer crowds and access for manoeuvrability.

The road network of Maiduguri town is essentially a product of spontaneous development. Recently, urban planning interventions and traditional development have gone hand in hand, strongly influencing the city's growth and the distribution of activities. The influence of permeability (a measure of edge betweenness) and straightness centrality tends to make the city resilient against armed assault and bomb attacks. In contrast, global integration and betweenness centrality make the city much less resilient to bomb attacks. Based on A. Sharifi's (2018) findings, Maiduguri is supposed to be resilient even though the study does not attribute any crime type to it. The nature by which bomb attacks are carried out is quite different from armed assault, which doesn't require the Place to be crowded. Bomb attacks require the ambient population to send a message or register significant impacts (Lehr 2019a). As a result, a city's resilience varies depending on the attack type. To achieve city-wide resilience, the types of attacks and the threats they pose must be considered.

Making the city safe is big business. If urban planners are to guarantee this, the take-off point for any form of urban development (transportation network) needs to receive all attention. Whether the development is planned, spontaneous, or a combination, planners must take appropriate steps to ensure it is safe. This study has shown that siting activities are a product of the network pattern. A. Loukaitou-Sideris (1999) and A. Loukaitou-Sideris et al. (2002) described the Los Angeles Green Line light rail system as a determinant of siting rail stations and bus stops throughout the city. They are characterised by high connectivity and global integration, making them attractive to offenders. In this regard, it will be essential to avoid the concentration of major crime attractors and generators on streets with such characteristics. A proliferation of these activities in terms of distribution should be encouraged. Such will be easy for planned cities but very challenging for spontaneous cities. Urban planners, therefore, need to look beyond gated communities and conventional e-policing to ensure safer and sustainable cities.

Other parameters (apart from those discussed earlier in this section) were insignificant in the models used to test relationships with attack typologies. The result might be due to characteristics or situations in the attack data, as well as to this study's aggregating unit of analysis. Firstly, the attack types differ in terms of the number of occurrences and their spatial distribution. Bomb attacks and armed assaults are the most common. The other typologies have just a few. Such a situation can affect the results obtained, as shown in previous studies (Favarin 2018; Yu, Fang 2022; Yue,

Zhu 2019), even after units are removed without incident occurrences. Secondly, the attack data underwent a re-geocoding exercise using ground truthing to ensure the authenticity of individual attack locations and the reliability of the study. The raw GTD data was a massive dataset with several items. The incident description (a component of the dataset) was critical for the study. Unfortunately, most of the geocoding (80%) was incorrect, but it was corrected based on the descriptions in the raw dataset. A considerable number (20%) were removed from the dataset because their location could not be determined. Such can affect the data's tendency to populate the spatial space, contributing to inadequate data for the three other attack types. This situation is considered a significant limitation associated with this study.

The availability of crime data for studies of Asian cities is subject to greater restrictions than in their Western counterparts (Yue et al. 2018; Yue, Zhu 2019). In sub-Saharan African cities, data for crime studies are difficult to access. They are either unavailable or, when available, are incredibly inadequate and unreliable for studies (Umar 2017; Umar et al. 2020b, 2020a). This situation affects the number of crimes recorded over time and space. Another implication is the difficulty in fulfilling the criteria for the appropriate analysis model.

CONCLUSION

This study demonstrated how space syntax and centrality metrics influence a high-profile crime, such as terrorist attacks. To the best of our knowledge, only a few studies have employed these metrics for low-profile crimes. They instead dwelt on urban design issues and mobility. It is imperative and warrants further research to investigate the sociodemographic factors shaping the network of cities. In this regard, insights into how human factors align with network nature can be better understood.

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