Manuscript Details

Manuscript number	JAPG_2018_1107_R3
Title	Assessing the impacts of various street-level characteristics on the burden of urban burglary in Kaduna, Nigeria
Article type	Full Length Article

Abstract

Evidence suggests that crimes committed in urban environments are geographically concentrated across a range of scales, and that the variation in rates of crime within an urban space is significantly dependent on the physical environment as well as the situation in which the crime takes place. However, these assertions are typically drawn from environmental criminological studies that have focussed on Euro-American cities and western intellectual perspectives. We seek to move beyond these by focussing on a second-tier city in sub-Saharan Africa (Kaduna, Nigeria), a context for which very little literature exists. This paper therefore examines the association between a range of street characteristics and the risk of residential burglary in Kaduna for the first time. It describes a methodology for conducting a household crime victimisation survey in Nigeria, and then aggregating the information to a street-level to perform a population-based ecological study. It integrates street network analysis and statistical modelling techniques in order to provide novel estimates for factors that may increase the risk of burglary such as street accessibility metrics (e.g. connectivity, betweenness and closeness centrality), segment length, socioeconomic status and business activities. Finally, the article provides a discussion on the plausibility and implication of findings within the sub-Saharan African context.

Keywords	Sub-Saharan Africa; Nigeria; Urban residence; Street networks; Street characteristics; Burglary; Negative binomial regression modelling;

Corresponding Author	Anwar Musah
Corresponding Author's Institution	University College London
Order of Authors	Anwar Musah, Faisal Umar, Khadijat Nda Yakubu, Muktar Ahmad, Babagana Abdullah, Adamu Ahmed, Tatiana Thieme, James Cheshire

Submission Files Included in this PDF

File Name [File Type]

Cover_letter_09112019.docx [Cover Letter]

Response_to_Reviewers_091119.docx [Response to Reviewers (without Author Details)]

Manuscript_RevisedVersion3_HighlightedChanges_09112019.docx [Highlights]

Title_page_09112019.docx [Title Page (with Author Details)]

Manuscript_RevisedVersion3_09112019.docx [Manuscript (without Author Details)]

List_of_figure_legends_09112019.docx [Figure]

Figure_1ab.jpg [Figure]

Figure_2ab.jpg [Figure]

Figure_3ab.jpg [Figure]

Figure_4.jpg [Figure]

List_of_table_09112019.docx [Table]

Assessing the impacts of various street-level characteristics on the burden of urban burglary in Kaduna, Nigeria

Anwar Musah*[1], Faisal Umar[2,3], Khadijat N. Yakubu[2], Muktar Ahmad[3], Abdullah Babagana[3], Adamu Ahmed[2,3], Tatiana A. Thieme[4], James A. Cheshire[4]

*__Email address__: Anwar Musah – a.musah@ucl.ac.uk

[1] Institute of Risk and Disaster Reduction, University College London, London WC1E 6BT, United Kingdom
[2] Department of Urban and Regional Planning, Ahmadu Bello University, Samaru Main Campus, Zaria, Nigeria
[3] Centre for Spatial Information Science, Ahmadu Bello University, Zaria, Nigeria
[4] Department of Geography, University College London, London WC1E 6BT, United Kingdom

1 Introduction

It is widely accepted that urban crime is spatially concentrated (Johnson, 2010; Umar, Johnson & Cheshire, 2019; Weisburd, 2015; Weisburd, Bushway, Lum, & Yang, 2004) and that the variation in rates of crime across urban space is influenced by the immediate physical environment and the situation in which a crime event takes place (Bernasco, Block, & Ruiter, 2013; Bernasco & Luykx, 2003; Bernasco & Nieuwbeerta, 2005; Brantingham & Brantingham, 1981; Perkins, Wandersman, Rich, & Taylor, 1993). However, the theoretical development of this perspective - known as environmental criminology (Wortley & Mazerolle, 2009) - is based on a body of work that has almost exclusively focused on cities in the Global North. In response, this paper seeks to explore (and where relevant, challenge) the relevance of such theories in the context of sub-Saharan Africa and in particular for the city of Kaduna, Nigeria.

We seek to determine whether measures of street accessibility (such as connectivity, closeness and betweenness) as well as street-level factors such as socioeconomic status (SES) and business activities create situational opportunities that play a significant role in the occurrence of property crime (burglary) in Nigeria's urban settings. We use a population-based ecological study design to quantify the burden of residential burglary by providing contemporary crime rates for the city of Kaduna. In addition, a multivariable regression model was implemented to establish the characteristics most associated with increased levels of burglary at the street-level, whilst considering the major contextual differences between the conditions, infrastructure, and development pathways of cities in the Global North, and sub-Saharan African cities that have urbanized in vastly different ways. We believe that the results facilitate a deeper understanding of the environmental influence on the distribution of urban crime in this context, and raise important questions for future research on urban crime in the global South.

1.1 Background

Though sub-Saharan African urbanism is highly diverse and embedded in particular localized histories of pre-colonial, colonial and post-colonial development, cities in this region share certain commonalities, namely rapid, unplanned or unregulated urbanization giving way to a paradoxically divided urbanism: state of the art commercial centers and residential estates on the one hand, and makeshift 'slum' urbanism on the other.

Consider the example of road infrastructure. The conditions of roads in Euro-American urban settings usually feature tarred roads or paved sidewalks. The orientation, width, and mapping of roads are rendered what Scott (1998) has called "legible": a process of simplification and organization for planners and state officials for centralized monitoring, control, and policing. By contrast, sections of cities in sub-Saharan Africa may not have achieved full coverage of tarred roads or paved sidewalks, and there are neighborhoods that are in part officially unmapped, or off the grid of CCTV surveillance technologies. These areas may therefore be "illegible" to those who do not have local knowledge and understanding of key landmarks, access points, and social mechanisms of surveillance. Furthermore, the everyday strategies for deterring property crime and safeguards against other forms of crime generally are not the same in New York as they are in Lagos, for instance. To compensate for the paucity of street-level infrastructure, households of various income levels in sub-Saharan African cities and their residents may deliberately install various forms of access control or target hardening systems for home protection, including the use of fences, gates and locks with various degrees of efficacy (Perkins et al., 1993). Therefore, the impacts of certain street characteristics on crimes in urbanized areas in sub-Saharan Africa are under-documented and merit further investigation to better understand how individuals and communities address the risks associated with urban crime.

These considerations lend themselves to the environmental criminology perspective (Wortley & Mazerolle, 2009), which has changed the criminological research paradigm in the last four decades in two key ways. Firstly, it has shifted the attention away from investigating the people that commit crimes to understanding the wider social and physical environment that facilitates opportunities and situations for crime. Secondly, the attention to environmental factors focuses on smaller geographic units of analysis such as addresses (e.g. Sherman, Gartin & Buerger, 1989) and street segments (Davis & Johnson, 2015; Weisburd, Bushway, Lum & Yang, 2004) rather than larger urban districts or neighborhoods (Gill, Wooditch, & Weisburd, 2017).

Routine activity theory (Cohen & Felson, 1979) has become influential in this context and posits that for crime to occur a motivated offender and a suitable target must converge in the absence of capable guardianship. Crime pattern theory (Brantingham & Brantingham, 1981) indicates the likely locations where a motivated offender, and suitable target are most likely to converge. Specifically, the theory considers how the crime opportunity structure is shaped through the routine activities of people, as offenders encounter crime opportunities in their particular "awareness spaces" – that is those places they become familiar with in their normal "non–criminal" daily life. These awareness spaces are formed around major routine "activity nodes" – those places where people stay or visit frequently such as homes, workplaces and shopping areas – and along "paths", which are the links they follow to get to those places. In theory, it is suggested that offenders are more likely to select targets around those activity nodes and along paths that fall within their awareness space, likewise people are more likely to experience crime near routine activity nodes or pathways that they share with motivated offenders (see: Bernasco et al., 2013; Feeney, 1986; Gabor et al., 1987; Rengert & Wasilchick, 1985). Notably, the configuration of the street network is fundamental in shaping the awareness space of an offender in that it connects the activity nodes of people and also influences their movement patterns (Davies & Johnson, 2015).

These theories have been widely applied in conjunction with street network analysis and graph theory to determine the impacts of street characteristics on crime in Euro-American urban settings (for example: Birks & Davies, 2017; Davies & Bishop, 2013; Davies & Johnson, 2015; Frith, Johnson, & Fry, 2017; Johnson & Bowers, 2010; Summers & Johnson, 2017). Most of these studies demonstrate that more accessible streets with higher footfall are more likely to be frequented by offenders in their day-to-day lives (Block & Bernasco, 2009; Cromwell et al. 1991; Johnson et al., 2007; Townsley and Sidebottom, 2010) and therefore suffer increased exposure to potential opportunities for crime (Armitage, 2006; Johnson & Bowers, 2010). Paradoxically, while some studies show that homes located on more accessible streets have an elevated risk of victimization, other urban scholars studying the streets of inner-city neighborhoods have argued that more passers-by offer a mediating influence since they provide natural surveillance and "eyes on the street" (Jacob's, 1961). That said, street-based community surveillance does not necessarily equate to willingness or ability to stop crimes (Reynald, 2010).[1]

[1] This is a topic we pick up on in another forthcoming publication related to this research, focusing on qualitative interviews with community-based security providers in Kaduna.

Considering that the focus of this study is on Kaduna, Northern Nigeria, we begin with the following contentions:

1. Dominant theories of environmental criminology have tended to draw on studies conducted in European, American and Australian settings. Therefore, we argue that there is a need to question the extent to which these predominantly Euro-American perspectives are useful in examining empirical data from Sub-Saharan African cities.

2. Environmental criminology or spatial analysis of crime studies that are focused on Sub-Saharan Africa are very rare, and where they exist, the approach taken uses larger geographic units of analyses such as countries, states, regions or large urban districts instead of micro units such as street segments or homes (e.g. Adzande, Gyuse & Atser, 2018; Appiahene–Gyamfi, 1999; Appiahene–Gyamfi, 2003; Owusu et al., 2015; Sidebottom, 2013).

3. Additionally, these sub-Saharan Africa studies have not benefitted from the extensive data collection adopted in this present study.

It is important, therefore, to test the established environmental criminology framework to address key research questions about the potential impacts of key street characteristics on criminality in the context of Northern Nigeria, but we do so with the critical awareness of the major contextual differences between the conditions, infrastructure, and development pathways of sub-Saharan African cities that have urbanized in vastly different ways. As such, our research seeks to challenge both the predominantly Euro-American bias in environmental criminological theories, and the tendency to classify African cities in homogenizing and pejorative terms associated with crisis (Myers 2011). Uneven development in African cities is inextricably linked to colonial legacies of urban planning, a large informal economy, and a growing youthful population (Pieterse & Parnell, 2014). The contribution of this research is to situate questions regarding urban crime in Sub-Saharan Africa within the context of a secondary African city that does not often get mainstream attention, but sheds important light on “global understandings of urbanism” and factors influencing patterns of urban crime (Myers, 2011).

2 Materials and Methods

2.1 Study area

The study was conducted in three neighboring urban districts in the city of Kaduna, Nigeria: Badawara, Malali and (parts of) Kawo. These districts lie between latitudes 10° 32' 57.01"N & 10° 35' 14.8"N and longitudes 7° 26' 7.07"E and 7° 29' 39"E, and cover an area of 13.12km^2 with an estimated total population of 137,540. This population represents about 12% of the city of Kaduna or about 13% of all households. The average household size in the study area is about 9.91 which is also similar to the city’s average of 9.88. The study areas were selected firstly because some of the authors have prior knowledge of the area both in terms of its social and physical characteristics, based on recent research experience and regular access to the study sites. Crucially, this has facilitated direct contact with diverse research participants including various community leaders, local residents and the local police (see: Umar, 2017). Secondly, as discussed below, there is a considerable variation in physical settings and socio-demographic characteristics between residential neighborhoods.

The study area is sub-divided into 35 residential neighborhoods, as shown in Figure 1, each can be broadly characterized as high, medium and low–density. The high–density residential areas, where the most under-resourced communities reside, account for about half of the total residential land-use and have no formal physical planning. These areas are typified by irregular plot layouts with mostly unpaved and narrow streets. In contrast, the medium and low–density residential areas, where the more affluent population reside, exhibit formal physical planning and have mostly paved and wide streets with regular sized plots that are well arranged on large city blocks. No other districts within Kaduna provide this combination and proximity between planned and unplanned urbanization, making the area ideal for studying the patterns of crime in the city.

In a recent study regarding crime concentration, Umar, Johnson & Cheshire (2019) confirms the uneven distribution of crime in the city of Kaduna, which is consistent with the observations in prior studies in Euro-American urban settings.

2.2 Data sources

Reliable crime victimization records in the form of digital police registries in Nigeria and across sub-Saharan Africa more widely are difficult to acquire. This contrasts with countries such as the UK or USA where police reports (or incident crime data) are electronically recorded, georeferenced, anonymized, and then made publicly available (for example see https://data.police.uk/). In the case of Nigeria, such data gathering efforts are hampered by the poor address system that prevents crime events from being properly geocoded. In addition, the standard practice is for police stations to record incident events manually into crime diaries (essentially school exercise books that are often incomplete). It is therefore impossible to accurately quantify the rates of crime in Nigeria from official records and for policy makers to use these as a basis to address the challenges associated with urban (in)security. We suggest that the development and subsequent analysis of a crime victimization survey allied to a block environmental inventory offers a viable and cost-effective option for conducting evidence based criminological research in this context.

The data for this research originated from a comprehensive crime survey that took place between March and June of 2014 within our study area. In brief, this cross-sectional dataset was compiled through three phases: Field mapping, a Block Environmental Inventory (BEI) survey (Perkins et al., 1992, 1993) and an area-based Household Crime Victimization survey. The dataset includes a BEI survey of 13,687 properties that have been extensively mapped (Figure 2). It also contains spatial information on 1,195 street segments on which the properties were located. The BEI survey has 26 different attributes that describe the physical and environmental characteristics of each individual property, as well as a description of the road condition of each individual street segment which was recorded as a binary measure as ‘Paved’ or ‘Unpaved’ road. From the 13,687 properties surveyed for the BEI, a sub-sample of 3,294 properties were selected for a more detailed household crime victimization survey. This gathered 46 different attributes in total to capture the social and demographic characteristics of each household, of which 14 attributes describe how respondents perceive crime and safety in their area including 4 criminality outcomes on victimization experience (residential burglary, theft, automobile vandalism and car theft). The full description of the processes behind the field work and data collection is detailed in Umar (2017).

2.3 Study design

All BEI and household survey information were aggregated to a street segment to determine whether certain street characteristics such as street accessibility metrics, street segment length (in meters), business activities and SES were associated with an increased risk of burglary. The main outcome of focus is the total number of residential households to have reported being burgled (at least once) within the last year on a street segment.

2.4 Street-level risk factors that may influence crime

2.4.1 Street network variables (connectivity, closeness and betweenness)

Three network metrics were used as proxy measurements for street accessibility and permeability. These were connectivity (the number of streets connected to a given street), closeness centrality (the average length of the shortest path between one street and all other street segments in a network) and betweenness centrality (the frequency of a street segment being traversed by the shortest paths connecting other segments). Street segments with higher estimates for closeness centrality indicate greater levels of accessibility. Lastly, betweenness centrality measures how often a given street segment serves as a bridge to other streets within the network. Street segments with higher values for betweenness therefore represent greater permeability.

Before deriving each of the three metrics for each street segment, it was necessary to transform the spatial street segment to a graph network (Figure 3a). The first step in the generation of an undirected street network is to convert every single street segment to a node. The next step is to generate an adjacency matrix in a long format. Here, we first determined all end-points and intersections on a street to create a dataset of vertices. A buffer distance with a radius as small as 0.5m was drawn around the center of each vertex of a street to capture the unique identifiers of all overlapping streets that connected to a street segment. The adjacency matrix data was formatted extensively and converted to an edge dataset. An undirected street network represented as a dual connectivity graph using the nodes and edge datasets were generated with the Kamada-Kawai algorithm using the '*igraph*' package (Csardi & Nepusz, 2006). All estimates for street connectivity, betweenness and closeness centrality were extracted from the graph shown in Figure 3b. The betweenness and closeness centrality values were normalized and split into quartiles.

2.4.2 Socioeconomic status & other environmental street variables

The business activity variable was constructed from our sample using four measurements relating to the number of shops (i.e. the number of shops owned and attached to property of household head), kiosks (i.e. the number of kiosks, a non-permanent structure, owned and inside or in front of household head's property), in-door trading (i.e. number of petty trading activities within the owner's home) and outdoor trading (i.e. number of petty trading activities in-front of the owner's home). For each construct – i.e. shops, kiosks, indoor and outdoor trading – their street-level prevalence was calculated before computing z-scores via simple averaging (Song, Lin, Ward, & Fine, 2013). If the prevalence of a variable was skewed, we applied a log-transformation for normalization using the formula $ln\ (x + 1)$. The composite index for business activities was computed by summing the z-scores across these four constructs, and then categorized them accordingly using quintiles. The roads with the lowest quintile have the least amount of street-level business activity.

Finally, it should be noted that, due to concerns regarding non-response to questions about earnings and wealth, collecting data about average household income is difficult and rarely approached directly in many developing countries (Lindelov and Yazbeck 2004). The variable for SES, therefore, was calculated using five proxy measures concerned with household characteristics. These include property ownership, non-overcrowded households (i.e. single person or single family), developed properties (i.e. properties made out of concrete), properties with drive-in facilities (i.e. gated home with private car parking garages) and adult employment. The z-score was computed using simple averaging for each construct – log-transformation using $ln\ (x + 1)$ was applied to any construct if the distribution was skewed (Song et al., 2013). The composite index for SES was derived by summing the z-scores across five constructs, and then categorized using quintiles whereby roads with the lowest quintile are socioeconomically under-resourced.

2.5 Statistical analysis

2.5.1 Determination of crime rates for residential burglaries

The primary outcome measures for our descriptive analysis are the crime incident rates for residential burglaries in Kaduna. The results also provide a breakdown of burglary crime rates according to risk factor group for each street characteristic.

The estimates derived were standardized (street-adjusted) crime rates for burglaries. These were calculated using the direct standardization approach (Naing, 2000). We first determined the street-specific crime rates for burglary for each street segment by taking the number of households on a street segment to have reported being victimized within the past twelve months prior to the time of data collection (March to June, 2014), and dividing this quantity by the overall number of sampled households on a street segment at risk of being victimized in 2014. Through collection of the BEI indicators and the digitization of every household in the study area – we determined the actual number of households on a street segment and deemed it as the reference population at risk in 2014. Here, we calculated the expected number of burglaries to have occurred on a street segment simply by multiplying the street-specific crime rates for burglaries with the reference population at risk on a street segment. The expected numbers and the reference population were aggregated accordingly for the whole area, as well as by street-level risk categories whereby the latter values were treated as denominators. The expected counts for the study area (or per risk category) were divided by their corresponding denominators to derive directly standardized (street-adjusted) crime rates. All standardized (street-adjusted) rates per-capita were expressed as per 100 households. The purpose for using standardized estimates in the analysis is to allow for future comparisons between other urban areas in Nigeria, or in other African countries.

2.5.2 Negative binomial Poisson regression model

The negative binomial multivariable Poisson regression was used to assess the effects of street-level characteristics on the reported number of burglaries on a street segment. The models were mutually adjusted for all street-level covariates such as street accessibility measurements (i.e. connectivity, closeness and betweenness), segment length, business activities and SES. The implementation of a negative binomial model is an appropriate approach for this study since we aim to fit counts of victimization whose distribution is over-dispersed (Osgood, 2000; Zeileis, Kleiber, & Jackman, 2008). The mathematical formula for modelling the relationship between the outcome and street covariates is given as follows:

$$\mu_i = exp\left\{ln(\boldsymbol{\delta}_i) + \sum_i \boldsymbol{x}_i \boldsymbol{\beta}_i\right\}$$

The model parameter μ_i is the conditional mean incidence rate which typically represents the occurrence rate for burglaries on a street segment. Here, we are assuming that the offset variable is the street-level reference population at risk of victimization during 2014 which is represented as $\boldsymbol{\delta}_i$. The street-level risk factors (or covariates) are represented as $\boldsymbol{x}_i$. It should be noted that covariates such as closeness, betweenness, business activities and SES were fitted categorically into the model, whereby the lowest categories were treated as the reference groups for comparing the risk of occurrence among higher categories. The two variables, connectivity and length of street segment, were fitted as continuous measures into the model. The regression coefficients are represented as $\boldsymbol{\beta}_i$ – these estimated parameters are reported as crime rate ratios (CRRs) with their corresponding 95% confidence intervals (CIs), whereby statistical significance was deemed if the 95% CI excluded the null value of 1 between its lower and upper limits. The model predictions for victimization for street segments were derived from the above multivariable model and geographically plotted as a street map to show the predicted distribution of counts for burglaries for the study area.

We first checked for the presence of multi-collinearity among the independent variables using a series of multivariable linear regression models by using them as a continuous outcome and fitting it against all other remaining variables to calculate its variance inflation factor (VIF). All variables satisfied the criteria (VIF < 4) (Table 2) (Fox, 1991; Neter, Kutner, Nachtsheim, & Wasserman, 1996; O'Brien, 2007). After parameter estimation for risk factors in relation to burglary, we tested the appropriateness of using a negative binomial model over a standard Poisson regression by comparing the difference between their log-likelihood estimates using a log-likelihood ratio test (LLRT). This means that we fitted a standard Poisson model to the data to compare its log-likelihood estimate with the original model. Our justification for this approach is that a negative binomial model assumes that its conditional mean is unequal to its conditional variance, and that these estimates can be compared with a standard Poisson regression because the latter model holds the same assumptions regarding its conditional mean being unequal to its conditional variance. It should also be noted that the latter model is nested within a negative binomial model, thus enabling comparison (Osgood, 2000; Zeileis, Kleiber, & Jackman, 2008). A violation of this assumption occurs when the p-value of this test is above 0.05 indicating that a negative binomial regression is an inappropriate choice for the analysis. Estimates from our LLRT shows no evidence of violation of the model assumptions indicating that a negative binomial model was appropriate for this analysis (i.e. for burglary: χ^2-statistic = 2531.44 [degrees of freedom: 18] and $p < 0.001$).

3 Results

3.1 Exploratory analysis of crime rates in the study area

The overall number of residential burglaries to have been reported during the study period was 869. The overall standardized (street-adjusted) crime rates for burglary was 29.6 per 100 households.

In terms of the street characteristics, we found that burglaries appear to be more pronounced on streets with the lowest quartile for closeness (i.e. streets that have the lowest levels of accessibility in the network) with a standardized rate of 38.6 per 100 households, however, the standardized rates for burglaries on streets decrease as the quartiles for closeness increase. The patterns for burglaries in relation to business activities appear to be somewhat U-shaped indicating that it is more pronounced on streets with the lowest (1st quintile: standardized rate – 31.9 per 100 households) and highest (5th quintile: standardized rate – 44.3 per 100 households) levels of business activities. We observed that the crime rates for burglaries are higher on streets with the lowest SES (1st quintile: standardized rate – 38.2 per 100 households) and these rates tend to diminish as levels of SES increase. For betweenness, while burglaries appear to be more pronounced among the middle risk category (standardized rates: 2nd quartile – 34.9 per 100 households; 3rd quartile – 32.5 per 100 households), nevertheless, the patterns seem unclear as the relationships resemble an inverted J-shaped distribution. A summary of the above results, as well as an overall breakdown of the standardized rates are provided in Table 1.

3.2 Interpretation of results from negative binomial multivariable Poisson regression

Our model indicates an overall reduction in the rates for burglary by 31% (Model Intercept: CRR 0.69, 95% CI: 0.50 – 0.95) when all other risk factors show no influence. For street connectivity, we found that a unit increase in the number of connections on a street segment significantly increases the rate of burglaries by 5% (CRR 1.05, 95% CI: 1.03 – 1.08). We found that the length of a street segment has a modest and positive relationship with burglary, however, this estimate was statistically non-significant (CRR 1.01, 95% CI: 0.99 – 1.02). The betweenness network measure was strongly associated with an increased risk of victimization. It shows the risk of burglary is at least 55% higher for residential properties located on street segments whose betweenness value falls in the 3rd (CRR: 1.55, 95% CI: 1.20 – 2.02) and 4th quartile (CRR: 1.64, 95% CI: 1.19 – 2.29). For the closeness network measure, it shows an overall reduction in the risk of burglary regardless of the quartile categories for closeness. The relationship for closeness appears unclear as the pattern for risk is akin to an inverted v-shape (Table 2).

The risk patterns for residential burglaries in relation to the street-level business activity index has a somewhat J-shaped association showing that the risks are more pronounced for residential properties located on a street where business activity index is in the 4th (CRR: 1.47, 95% CI: 1.15 – 1.86) and 5th (CRR: 1.31, 95% CI: 1.01 – 1.68) quintile. For SES, we observed that it has an inverse relationship with the risk of victimization, while the patterns of risk appeared to decrease with increasing risk categories for SES – nevertheless, the risk estimates remain statistically non-significant (Table 2). The predicted counts for burglaries on street segments have been determined from the above model and plotted for the streets in the study area (Figure 4).

4 Discussion and conclusion

To our knowledge, this is the first study in Nigeria (and in sub-Saharan Africa) to use an extensive area-based crime victimization database to explore the relationships between risk factors related to various street characteristics and urban crime. This research adopts an ecological study approach using street segments as the unit of observation and is the first to combine techniques from street network and statistical modelling to quantify the potential impacts of three different street accessibility measurements, street-level SES and business activities on urban crime in a Nigerian setting.

This study benefits from an extensive area-based crime victimization survey conducted at the household-level. Households were interviewed directly, and data relating to BEI indicators were rigorously collected on site by a team of enumerators (see Umar, 2017). This provides the basis for a reliable approach to calculate contemporary per-capita standardized rates for an entire urban area enabling comparability among cities within Nigeria. Here we used a robust approach to account for the over-dispersed nature in the frequency of the reported counts of burglaries when quantifying the risk for our street-level risk groups. Before and after checks were performed to ensure the quality and validity in our risk estimates, as well as non-violation of the model assumptions.

We must, however, acknowledge that our aggregation of demographic and BEI variables to the street-level renders any risk inferences prone to ecological fallacy. A further limitation is that the study participants were asked to provide past information about the number of times they were burgled within the last twelve months prior to March – June 2014. Therefore, the results are prone to potential recall bias, which is an issue that cannot be quantified without validation or corroboration with police records. However, as previously discussed, the paucity of police registries in Kaduna makes it all but impossible to do this. While we did take precautionary steps to include only meaningful risk factors in our models, we do acknowledge our inability to incorporate important adjustments in our analysis of urban crime such as the inability to account for information related to the decision-making process of offenders (Frith et al., 2017), street type (Wu et al., 2015; Yue, Zhu, Ye, Hu, & Kudva, 2018), deterrents such as street lighting, surveillance & active guardianship (Reynald, 2009, 2010) and suitable target opportunities (Breetzke, 2012). The lack of these adjustments may have led to some residual confounding in our analysis. These limitations have subsequently become integral questions folded into the research design of the next phase of data collection and analysis.

With the above limitations in mind, this study asserts that street connectivity plays a modest role in the burden of urban crimes in Kaduna. Streets with more connections to other road segments have a modest effect on the number of reported burglaries. One plausible explanation for such findings is that street segments in Kaduna with more connections indirectly provide a much larger activity space, or area in which motivated offenders can operate. A higher level of connectivity on a street also facilitates the increased “space awareness” enabling an offender to scout for potential households that are susceptible for burglary. In this regard, our results are consistent with previous research undertaken in the UK and North America where risk assessments have shown that highly connected streets were associated with an increased risk of urban crime (e.g. Johnson & Bowers, 2010; Nubani & Wineman, 2005; Yang, 2006).

In terms of closeness, while the patterns appear unclear, it should be noted that there is a broad reduction in the levels of residential burglaries across risk categories. This can be attributed to a motivated offender’s awareness of the space within which s/he is operating – in the sense that a motivated offender perceives that the risks of being identified by a capable guardian (or being caught by one) are minimized if they target residential properties located on minor roads that are less integrated to the street network. The most likely explanation is that the result may be an anomaly in the structure of the road network for the study area and therefore further research in Nigeria is warranted to examine whether similar patterns will emerge in future studies in other urban contexts.

Nevertheless, our results contrast notably with those found in previous studies that have shown highly integrated (i.e. high closeness centrality values) streets in London (UK), Ypsilanti (Michigan, USA) and Wuhan (China) to be significantly associated with other forms of crimes (i.e. outdoor violence, larceny, burglaries and robberies) (Nubani & Wineman, 2005; Summers & Johnson, 2017; Wu et al., 2015).

However, when it comes to betweenness, our study showed that roads with high-betweenness values were significantly associated with increased burglaries. One possible explanation is that potential offenders scouting for vulnerable targets may inadvertently take into consideration the degree of street permeability and how easy (or difficult) it is for one to navigate through such streets within close proximity to the targeted home (Frith et al., 2017). This result is similar to previous studies that indicated high-betweenness streets in London (UK) and Toulouse (France) which were positively linked to increased burglary risk (e.g. Davies & Bishop, 2013; Summers & Johnson, 2017).

In terms of street-level business activity, this measure in our analysis was treated as a proxy by the degree of commerce practiced by residents on a street segment. As expected, street segments with a high density of business activities experience an increased risk of burglary. One of the components for opportunity theory postulates that opportunities that are physically present in the environment play a role in causing crime (Clarke, 2012; Felson & Clarke, 1998). It should be noted that small retail shops and businesses in low income urban settings in Nigeria (as in other African countries) are most often establishments attached or in close proximity to the owner's main property (household or compound), which means that customers may have access to the business owner's dwelling (Umar, 2017). It is plausible that potential offenders who have access to properties where commerce is practiced are opportunistically able to access both the business and the household. Street segments with a high concentration of stores within properties are likely to attract motivated offenders who identify a greater concentration of potential opportunities to commit burglary. This result is corroborated by somewhat similar studies who have explored the impacts of different types of urban land-use and reported that areas with the highest density of commercial land use have an increased risk of victimization (e.g. Browning et al., 2010; Kinney, Brantingham, Wuschke, Kirk, & Brantingham, 2008; Stucky & Ottensmann, 2009).

For SES, we hypothesized that the most affluent street segments were at the greatest risk of victimization since the households along them were likely to contain the items of highest value to motivated offenders. Instead, we found that the risk of victimization fell as streets became more affluent, with the caveat that the results were not statistically significant. While untested, an explanation of such a result could be that burglaries are concentrated on streets that are most socioeconomically deprived. Nevertheless, further research is needed to explain why burglaries are concentrated on streets from lower income neighborhoods, and to determine whether similar patterns for SES might emerge elsewhere in Nigerian studies.

Since this is a novel study – we cannot concisely affirm that there is external validity. While the relationships between risk factors and urban crime have been established in this study, we call for further studies of a similar design in order to generate wider and even comparative analysis of street characteristics in a different urban context of Nigeria in order to confirm whether there are similar risk patterns to those found in our present study. Corroboration of results would allow us to determine whether such studies are externally valid and are therefore representative of other urban areas in Nigeria. However, we argue that our study is internally valid as extensive attempts were made to minimize any forms of systematic error that can occur at the various stages of fieldwork including when conducting household interviews, when surveying properties for BEI data, when digitizing all households and streets, and correctly matching the former to the latter. Furthermore, we tried to extensively minimize any systematic errors that may have arisen from our analytical models for crime by taking precautionary steps to ensure that the correct models were implemented for this problem, that a restricted set of meaningful risk factors were included in the models to avoid over-fitting, and that before and after model diagnostics were made to prevent multi-collinearity and violation of model assumptions. As for our argument of internal validity – this study relies on a database which provides a large population size for determining crime rates, and a large statistical power for establishing causal relationships between street characteristics and urban crime.

In conclusion, our study demonstrates the value of street network analysis to quantify the burden of urban crime at the street-level in an African context. This study presents contemporary standardized crime rates for Kaduna from a large-scale area-based victimization survey that can be emulated elsewhere in Nigeria and beyond. It demonstrates that street segments having a greater degree of connectivity to other areas, and segments with high-betweenness values must be considered in urban crime prevention, as they are the key activity space that a potential offender operates within (or must navigate through) for opportunistic crime. Our study also highlights that properties closely tied to commercial enterprises, or street segments concentrated with retail outlets, are especially vulnerable to burglaries, since they are situated within locations where commercial and residential, public and private spaces converge and become potentially accessible opportunities (and "awareness spaces") for potential offenders. Finally, and in addition to its empirical findings, we hope that this study contributes to a broader perspective for criminological research beyond that of Euro-American cities and offers a template for further research in sub-Saharan Africa.

Abbreviations

Block Environmental Inventory (BEI); Local Government Area (LGA); Unique Reference Number (URN); Systematic random sampling (SRS); Socioeconomic status (SES); Interquartile range (IQR); crime rate ratios (CRR); 95% confidence intervals (CI); Variance Inflation Factor (VIF); Log-likelihood Ratio test (LLRT)

Funding

This research was conducted under the project Development frontiers in crime, livelihoods and urban poverty in Nigeria (FCLP) which is jointly supported by the Economic and Social Research Council, and the UK Department for International Development (ESRC-DFID), grant reference ES/R001596/1.

References

Appiahene–Gyamfi, J. (1999) An Exploration of the Spatial and Temporal Patterning and Distribution of Crime in Ghana with Emphasis on Accra. (PhD thesis), Simon Fraser University.

Appiahene–Gyamfi, J. (2003) Urban crime trends and patterns in Ghana: The case of Accra, *Journal of Criminal Justice*, 31(1): 13–23.

Armitage, R. (2006). Predicting and preventing: Developing a risk assessment mechanism for residential housing. *Crime Prevention and Community Safety*, *8*(3), 137–149. https://doi.org/10.1057/palgrave.cpcs.8150024

Adzande, P., Gyuse, T.T. and Atser, J. (2018) Correlates of Crime in Urban Makurdi, Nigeria, *African Journal of Built Environment Research*, 2(1), p.21-40.

Bernasco, W., Block, R., & Ruiter, S. (2013). Go where the money is: Modeling street robbers' location betweennesss. *Journal of Economic Geography*, *13*(1), 119–143. https://doi.org/10.1093/jeg/lbs005

Bernasco, W., & Luykx, F. (2003). Effects of attractiveness, opportunity and accessibility to burglars on residential burglary rates of urban neighbourhoods. *Criminology*, *41*(3), 981–1002. https://doi.org/10.1111/j.1745-9125.2003.tb01011.x

Bernasco, W., & Nieuwbeerta, P. (2005). How do residential burglars select target areas? A new approach to the analysis of criminal location betweenness. *The British Journal of Criminology*, *45*(3), 296–315. https://doi.org/10.1093/bjc/azh070

Bernasco, W., Block, R., & Ruiter, S., (2013) Go where the money is: modelling street robbers' location choices. *Economic Geography*, 13(1): 119 – 43.

Birks, D., & Davies, T. (2017). Street network structure and crime risk: An agent-based investigation of the encounter and enclosure hypotheses. *Criminology*, *55*(4), 900–937. https://doi.org/10.1111/1745-9125.12163

Block, R. & Bernasco, W. (2009) Finding a serial burglar's home using distance decay and conditional origin–destination patterns: a test of empirical Bayes journey to crime estimation in The Hague. Journal of Investigative Psychology and Offender Profiling, 6: 189–211.

Brantingham, P. J., & Brantingham, P. L. (1981). *Environmental criminology*. Beverly Hills, CA: Sage Publications.

Breetzke, G. D. (2012). The effect of altitude and slope on the spatial patterning of burglary. *Applied Geography*, *34*, 66–75. https://doi.org/10.1016/j.apgeog.2011.10.017

Browning, C. R., Byron, R. A., Calder, C. A., Krivo, L. J., Kwan, M.-P., Lee, J.-Y., & Peterson, R. D. (2010). Commercial density, residential concentration, and crime: Land use patterns and violence in neighbourhood context. *Journal of Research in Crime and Delinquency*, *47*(3), 329–357. https://doi.org/10.1177/0022427810365906

Clarke, R. V. (2012). Opportunity makes the thief. Really? And so what? *Crime Science*, *1*(1), 3.

Cohen, L. E., & Felson, M. (1979). Social change and crime rate trends: A routine activity approach. *American Sociological Review*, *44*(4), 588–608. https://doi.org/10.2307/2094589

Comaroff, J., & Comaroff, J. L. (2012). Theory from the South: Or, how Euro-America is evolving toward Africa. *Anthropological Forum*, *22*(2), 113–131. https://doi.org/10.1080/00664677.2012.694169

Cromwell, P. R., Olson, J. N. & Avary, D. A. W. (1991) How residential burglars choose targets: an ethnographic analysis. *Security Journal*, 2: 195–9.

Csardi, G., & Nepusz, T. (2006). The igraph software package for complex network research. *InterJournal, Complex Systems*, *1695*(5), 1–9.

Davies, T. P., & Bishop, S. R. (2013). Modelling patterns of burglary on street networks. *Crime Science*, *2*(1), 10. https://doi.org/10.1186/2193-7680-2-10

Davies, T. and Johnson, S. D. (2015) Examining the relationship between road structure and burglary risk via quantitative network analysis. *Journal of Quantitative Criminology*, 31: 481–507.

Feeney, F. (1986) R*obbers as decision makers*. In D. Cornish, and R. Clarke (eds), The Reasoning Criminal, New York, NY: Springer–Verlag.

Felson, M. and Clarke R. V. (1998) *Opportunity makes the thief: practical theory for crime prevention*. Police Research Series Paper 98, London: Policing and Reducing Crime Unit, Home Office Research, Development and Statistics Directorate.

Fox, J. (1991). *Regression diagnostics: An introduction* (Vol. 79). Newbury Park, California: Sage Publications.

Frith, M. J., Johnson, S. D., & Fry, H. M. (2017). Role of the street network in burglars' spatial decision-making. *Criminology*, *55*(2), 344–376. https://doi.org/10.1111/1745-9125.12133

Gabor, T., Baril, M., Cusson, M., Elie, D., LeBlanc, M., & Normandeau, A. (1987) *Armed robbery: cops, robbers, and victims*. Springfield, IL: Charles C. Thomas Publisher.

Gill, C., Wooditch, A., & Weisburd, D. (2017). Testing the "law of crime concentration at place" in a suburban setting: Implications for research and practice. *Journal of Quantitative Criminology*, *33*(3), 519–545. https://doi.org/10.1007/s10940-016-9304-y

Jacobs, J. (1961) T*he death and life of great American cities*. New York: Random House.

Johnson, S. D., Bernasco, W., Bowers, K. J., Elffers, H., Ratcliffe, J., Rengert, G. & Townsley, M. (2007) Space–time patterns of risk: a cross national assessment of residential burglary victimization. Journal of Quantitative Criminology, 23: 201–219.

Johnson, S. D. (2010). A brief history of the analysis of crime concentration. *European Journal of Applied Mathematics*, *21*(4–5), 349–370. https://doi.org/10.1017/S0956792510000082

Johnson, S. D., & Bowers, K. J. (2010). Permeability and burglary risk: Are cul-de-sacs safer? *Journal of Quantitative Criminology*, *26*(1), 89–111. https://doi.org/10.1007/s10940-009-9084-8

Kinney, J. B., Brantingham, P. L., Wuschke, K., Kirk, M. G., & Brantingham, P. J. (2008). Crime attractors, generators and detractors: Land use and urban crime opportunities. *Built Environment*, *34*(1), 62–74.

Lindelov, Magnus, and Abdo Yazbeck. 2004. Measuring Socioeconomic Status. Presentation on "Reaching the Poor". World Bank HQ, Washington DC: February 18–20. Retrieved (13/07/2019) from: https://slideplayer.com/slide/4509481/

Myers, G. (2011). *African cities: alternative visions of urban theory and practice*. New York (USA): Published by Zed Books Ltd.

Naing, N. N. (2000). Easy way to learn standardization: Direct and indirect methods. *The Malaysian Journal of Medical Sciences: MJMS*, *7*(1), 10–15.

Neter, J., Kutner, M. H., Nachtsheim, C. J., & Wasserman, W. (1996). *Applied linear statistical models* (4th Edition). WCB McGraw-Hill, Publisher (Chicago: Irwin)

Nubani, L., & Wineman, J. (2005). The role of space syntax in identifying the relationship between space and crime. In *Proceedings of the 5th Space Syntax Symposium on Space Syntax, Delft, Holland*.

O'Brien, R. M. (2007). A caution regarding rules of thumb for variance inflation factors. *Quality & Quantity*, *41*(5), 673–690.

Osgood, D. W. (2000). Poisson-based regression analysis of aggregate crime rates. *Journal of Quantitative Criminology*, *16*(1), 21–43. https://doi.org/10.1023/A:1007521427059

Owusu, G., Wrigley–Asante, C., Oteng–Ababio, M., & Owusu, A.Y. (2015) Crime prevention through environmental design (CPTED) and built-environmental manifestations in Accra and Kumasi, Ghana, Crime Prevention and Community Safety, 17(4): 249–269.

Perkins, D. D., Meeks, J. W., & Taylor, R. B. (1992). The physical environment of street blocks and resident perceptions of crime and disorder: Implications for theory and measurement. *Journal of Environmental Psychology*, *12*(1), 21–34. https://doi.org/10.1016/S0272-4944(05)80294-4

Perkins, D. D., Wandersman, A., Rich, R. C., & Taylor, R. B. (1993). The physical environment of street crime: Defensible space, territoriality and incivilities. *Journal of Environmental Psychology*, *13*(1), 29–49. https://doi.org/10.1016/S0272-4944(05)80213-0

Pieterse, D. E., & Parnell, S. (2014). *Africa's Urban Revolution*. New York, NY (USA): Published by Zed Books Ltd.

Rengert, G. F. & Wasilchick, J. (1985) Suburban burglary: a time and place for everything, Springfield, IL: C.C. Thomas Publishing.

Reynald, D. M. (2009). Guardianship in action: Developing a new tool for measurement. *Crime Prevention and Community Safety*, *11*(1), 1–20. https://doi.org/10.1057/cpcs.2008.19

Reynald, D. M. (2010). Guardians on guardianship: Factors affecting the willingness to supervise, the ability to detect potential offenders, and the willingness to intervene. *Journal of Research in Crime and Delinquency*, *47*(3), 358–390. https://doi.org/10.1177/0022427810365904

Scott, J.C. (1998) Seeing like a state: How certain schemes to improve the human condition have failed. New Haven, Connecticut (USA): Published by Yale University Press

Sidebottom, A. (2013) *Understanding and Preventing Crime in Malawi: An Opportunity Perspective*. (PhD thesis), University College London (UCL).

Sherman, L. W., Gartin, P. R. & Buerger, M. E., (1989) Hot spots of predatory crime: routine activities and the criminology of place. *Criminology*, 27: 27–55.

Song, M.-K., Lin, F.-C., Ward, S. E., & Fine, J. P. (2013). Composite variables: When and how. *Nursing Research*, *62*(1), 45–49. https://doi.org/10.1097/NNR.0b013e3182741948

Stucky, T. D., & Ottensmann, J. R. (2009). Land use and violent crime. *Criminology*, *47*(4), 1223–1264. https://doi.org/10.1111/j.1745-9125.2009.00174.x

Summers, L., & Johnson, S. D. (2017). Does the configuration of the street network influence where outdoor serious violence takes place? Using space syntax to test crime pattern theory. *Journal of Quantitative Criminology*, *33*(2), 397–420. https://doi.org/10.1007/s10940-016-9306-9

Townsley, M. & Sidebottom, A. (2010) All offenders are equal, but some are more equal than others: variation in journeys to crime between offenders. Criminology, 48(3): 897 – 917.

Umar, F., Johnson, S.D., & Cheshire J. A. (2019). Assessing the spatial distribution of urban crime in a developing country. *Journal of Quantitative Criminology*. DOI: 10.1007/s10940-019-09432-x

Umar, F. (2017). *Understanding spatial patterns of urban crime in developing country* (PhD Thesis). University College London (UCL), Department of Geography. Retrieved from http://discovery.ucl.ac.uk/1553240/9/FUmar_PostViva_PhDThesis.pdf

Weisburd, D. (2015). The law of crime concentration and the criminology of place. *Criminology*, *53*(2), 133–157. https://doi.org/10.1111/1745-9125.12070

Weisburd, D., & Amram, S. (2014). The law of concentrations of crime at place: The case of Tel Aviv-Jaffa. *Police Practice and Research*, *15*(2), 101–114. https://doi.org/10.1080/15614263.2013.874169

Weisburd, D., Bushway, S., Lum, C., & Yang, S.-M. (2004). Trajectories of crime at places: A longitudinal study of street segments in the city of Seattle. *Criminology*, *42*(2), 283–322. https://doi.org/10.1111/j.1745-9125.2004.tb00521.x

Worldpop. (2013). *Nigeria 100m Population* [Data set]. University of Southampton. https://doi.org/10.5258/SOTON/WP00196

Wortley, R., & Mazerolle, L. (2009). Environmental criminology and crime analysis: Situating the theory, analytic approach and application. *Crime Prevention and Community Safety*, 11(2):1–32.

Wu, L., Liu, X., Ye, X., Leipnik, M., Lee, J., & Zhu, X. (2015). Permeability, space syntax, and the patterning of residential burglaries in urban China. *Applied Geography*, *60*, 261–265. https://doi.org/10.1016/j.apgeog.2014.12.001

Yang, X. (2006). *Exploring the influence of environmental features on residential burglary using spatial-temporal pattern analysis* (PhD Thesis). University of Florida Gainesville.

Yue, H., Zhu, X., Ye, X., Hu, T., & Kudva, S. (2018). Modelling the effects of street permeability on burglary in Wuhan, China. *Applied Geography*, *98*, 177–183. https://doi.org/10.1016/j.apgeog.2018.06.005

Zeileis, A., Kleiber, C., & Jackman, S. (2008). Regression models for count data in R. *Journal of Statistical Software*, *27*, 1–25. https://doi.org/info:doi/10.18637/jss.v027.i08

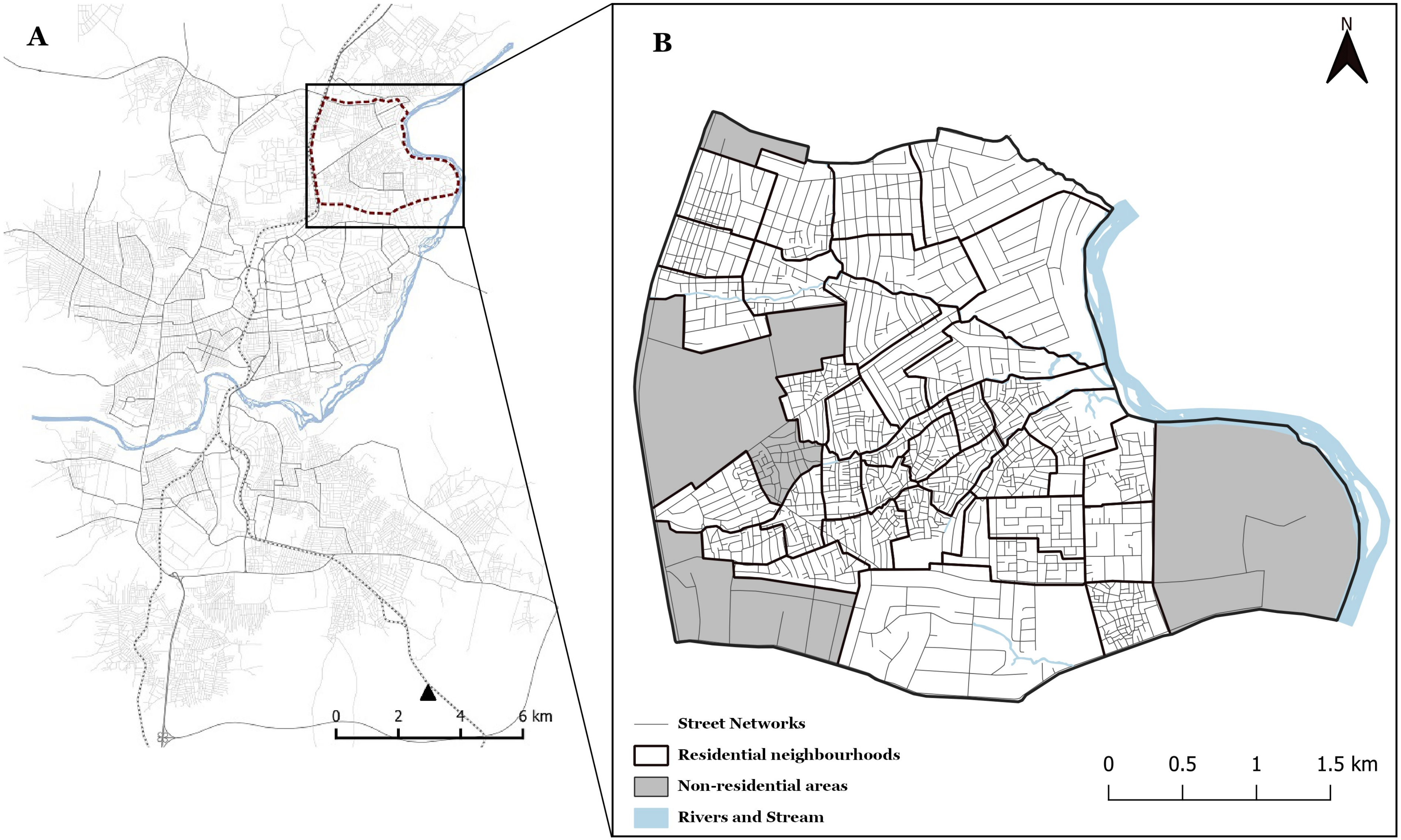
List of figure legends

Figure 1: Panel A shows where the study area is situated in Kaduna, Nigeria; Panel B shows a close-up image of the study area (Badawara, Malali and Kawo) under observation.

Figure 2: Panel A shows an overview of all the residential households in Badawara, Malali and Kawo. This data was used as denominators in the calculation of expected counts and standardised rates of burglary; Panel B is the sampled households interviewed in the crime victimisation survey.

Figure 3: Map shows the overview of the street network within the study area. Panel A illustrates the black polylines represented as street segments. The black points represent the endpoint and/or intersection of a street; Panel B shows a connectivity graph (i.e. the image in Panel A transformed to nodes and edges). The street segments are represented as the black dots which are called 'nodes'. The lines that are joined between nodes are termed 'edges' to show connectivity between street segments.

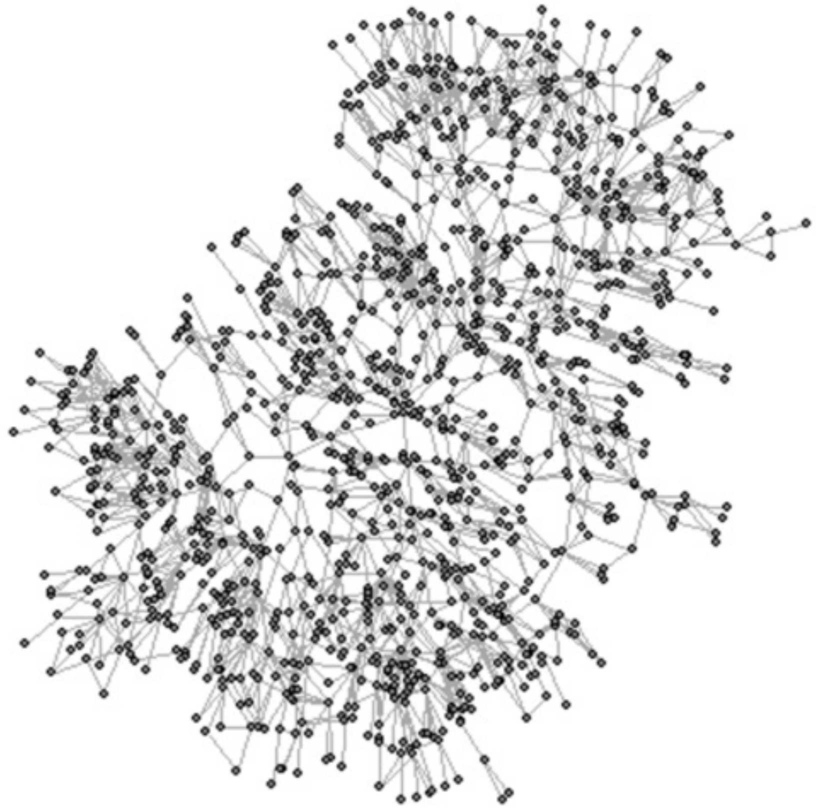
Figure 4: A street map showing the predicted cases of residential burglaries in study area after street accessibility measurements, segment length, business activities and socioeconomic status have been included in our negative binomial Poisson regression model.

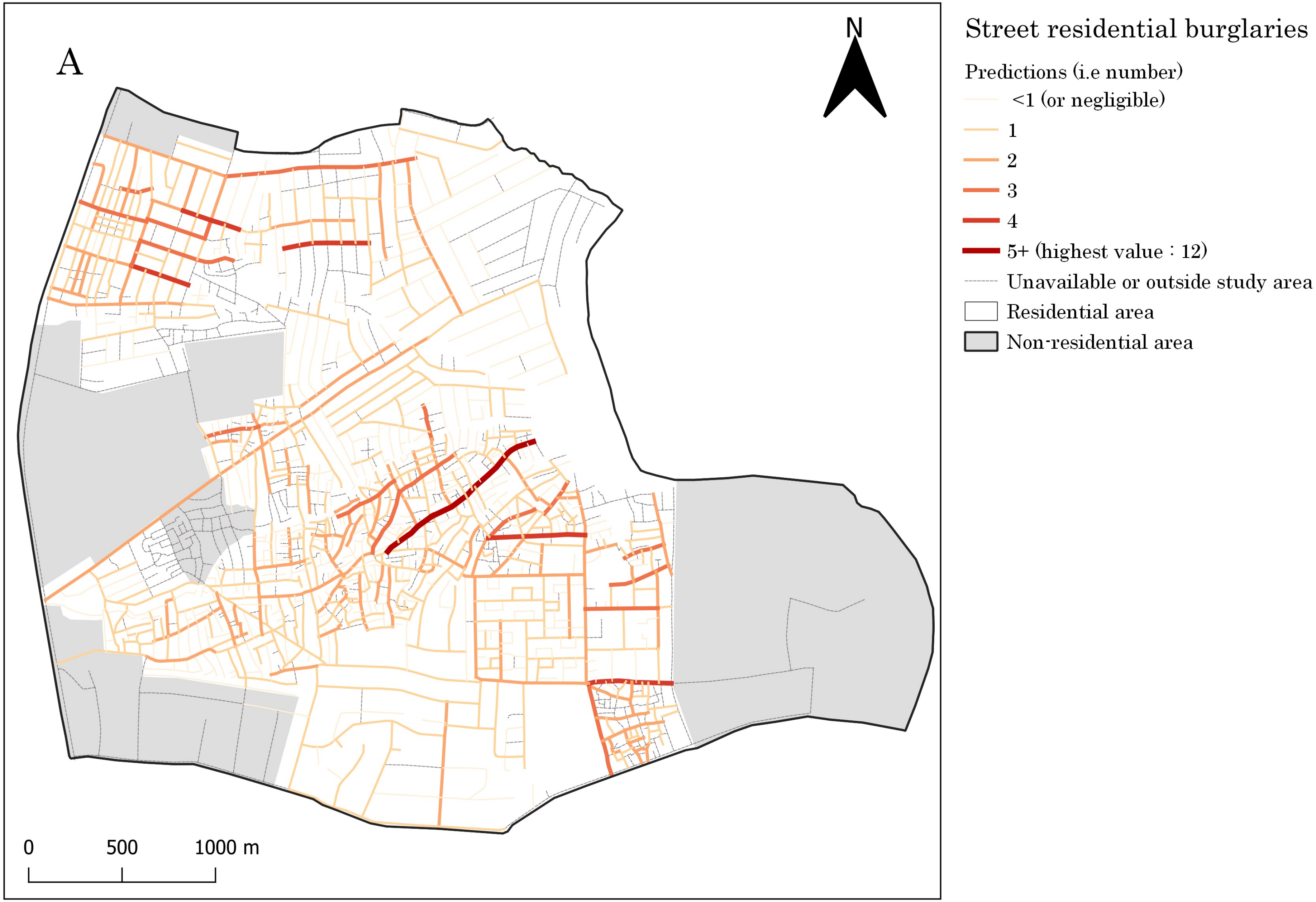

A
0
2
4
6 km
B
N
Street Networks
Residential neighbourhoods
Non-residential areas
Rivers and Stream
0
0.5
1
1.5 km


A
N
0
500
1000 m
B
N
0
500
1000 m

A

B




A
N
0
500
1000 m
Street residential burglaries
Predictions (i.e number)
<1 (or negligible)
1
2
3
4
5+ (highest value : 12)
Unavailable or outside study area
Residential area
Non-residential area

List of tables

Table 1: A breakdown of street-level characteristics showing the standardised (i.e. street-adjusted) crime rates (per 100 households) for residential burglaries that occurred on residential premises in Kaduna, Nigeria.

Street characteristics	Streets	Households		Residential burglary	
	N (743)	Sampled (2,911)	Reference (10,401)	*n* (869)	Standardised rate
Betweeness (normalised index) (quartiles)					
1st Quartile (lowest)	186	458	1,544	108	21.46
2nd Quartile	185	562	1,948	183	34.92
3rd Quartile	185	722	2,674	229	32.55
4th Quartile (highest)	187	1,169	4,235	349	28.47
Closeness (normalised index) (quartiles)					
1st Quartile (lowest)	184	526	1,989	215	38.66
2nd Quartile	186	631	2,493	177	29.79
3rd Quartile	186	747	2,736	236	29.50
4th Quartile (highest)	187	1,007	3,183	241	24.15
Business activity index (z-scores) (quintiles)					
1st Quintile (lowest)	149	398	1,445	131	31.99
2nd Quintile	149	414	1,384	113	27.79
3rd Quintile	148	616	2,445	115	16.46
4th Quintile	149	928	2,966	270	29.66
5th Quintile (highest)	148	555	2,161	240	44.36
Socioeconomic status (z-scores) (quintiles)					
1st Quintile (lowest)	150	443	1,533	168	38.29
2nd Quintile	148	577	2,004	200	33.36
3rd Quintile	149	637	2,229	164	29.11
4th Quintile	148	589	2,166	154	25.16
5th Quintile (highest)	148	665	2,469	183	25.85

Table 2: Using a negative binomial Poisson regression model to report multivariable associations between street-level exposures and residential burglaries in Kaduna, Nigeria

Street exposure variables	Residential Burglary	
	CRR (95% CI)	**VIF**
Intercept	0.69 (0.50 – 0.95)*	-
Length of street segment (m)	1.01 (0.99 – 1.02)	1.83
Connectivity	1.05 (1.03 – 1.08)*	2.62
Betweeness (normalised index) (quartiles)		2.33
1st Quartile (lowest)	1.00 (referent)	
2nd Quartile	1.29 (0.99 – 1.66)	
3rd Quartile	1.55 (1.20 – 2.02)*	
4th Quartile (highest)	1.64 (1.19 – 2.29)*	
Closeness (normalised index) (quartiles)		1.12
1st Quartile (lowest)	1.00 (referent)	
2nd Quartile	0.62 (0.49 – 0.78)*	
3rd Quartile	0.78 (0.61 – 0.99)*	
4th Quartile (highest)	0.62 (0.48 – 0.81)*	
Business activity index (z-scores) (quintiles)		1.18
1st Quintile (lowest)	1.00 (referent)	
2nd Quintile	0.96 (0.72 – 1.29)	
3rd Quintile	0.71 (0.57 – 1.03)	
4th Quintile	1.47 (1.15 – 1.86)*	
5th Quintile (highest)	1.31 (1.01 – 1.68)*	
Socioeconomic status (z-scores) (quintiles)		1.15
1st Quintile (lowest)	1.00 (referent)	
2nd Quintile	1.28 (1.00 – 1.63)	
3rd Quintile	0.95 (0.74 – 1.21)	
4th Quintile	0.79 (0.61 – 1.02)	
5th Quintile (highest)	0.81 (0.63 – 1.05)	

*Significant with p-value < 0.05; Crime Rate Ratios (CRR); 95% Confidence Intervals (95% CI); Variance Inflation Factor (VIF)