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Deciphering the stroke–built environment nexus in transitional cities: conceptual framework, empirical evidence, and implications for proactive planning intervention

Abstract

Adverse lifestyle-associated health outcomes, and stroke in particular, have been aggravated in transitional countries under high-speed urbanisation. Against this backdrop, deciphering the nexus between built environments (BEs) and lifestyle-associated health outcomes is of importance for crafting proactive interventions. The existing literature on this topic, however, fails to sufficiently capture the multiplicity of health-related BEs and, in turn, the complexity of such a nexus, largely challenging the applicability of established frameworks and the reliability of relevant findings.

Looking at the case of stroke in Wuhan, China, this research aims to flesh out the understanding of the nexus between multidimensional BEs and lifestyle-associated health outcomes in transitional cities, with regards to conceptual framework and empirical evidence. To this end, we clarified stroke-related BE elements and integrated them into one conceptual framework. We then visualised stroke risk and examined its BE determinants using the Bayesian conditional autoregressive model. The visualisation results showed that stroke risks exhibited significant clustering in the high-density urban core. The statistical analysis found that, after the data were controlled for sociodemographic characteristics, net population density and building density were positively associated with stroke risk. In contrast, an abundance of public parks and institutional land use and access to medical care facilities have presented negative correlations with stroke risk, regardless of urban density. Our research reveals that compact urban developments might not be a silver bullet for health promotion in transitional cities, calling for an urgent need to scrutinise their applicability. Moreover, providing better access to these identified salubrious resources is crucial for offsetting the adverse effects of increasingly dense urban environments. Furthermore, we argue that the establishment of comprehensive conceptual frameworks that connect BEs and lifestyle-associated health outcomes deserves to be highlighted in further research, planning intervention schemes, and health impact assessment projects.

Keywords: Built environment; Stroke; Lifestyle-associated health outcome; Transitional city; China

1. Introduction

Since 1978 and the establishment of the free market in China, the country has been experiencing rapid urbanisation (Gu, Kesteloot, and Cook 2015). Similar to the most transitional countries (see Eckert and Kohler (2014) and Cyril, Oldroyd, and Renzaho (2013) for reviews), the accelerating urbanisation in post-reform China has dismayingly created numerous representative health problems. During this period, major changes to demographic structures and lifestyles have been catalysed, which in turn raise nonnegligible health challenges. The ageing population has disproportionally grown due to decades of sub-replacement fertility and the escalation of life expectancy (Xie et al. 2018). In the context of increasing prosperity, people (urban residents in particular) have been living more sedentary lifestyles (Monda et al. 2007); the transition of nutrition dietary patterns, characterised by the increased consumption of processed food, has also become prevalent (Wilkinson 2004).

In addition, built environments (BEs), which are defined as manmade elements of the physical environment, e.g., land-use patterns, transport routes, open spaces, and buildings (World Health Organization 2009), have been radically reshaped. The considerable transformation to BEs in China, e.g., the explosive growth in density (Shi et al. 2017), the shrinkage of urban green space (Ren et al. 2011), and the homogenisation of land use, has largely contributed to the deteriorated air quality (Yuan, Ng, and Norford 2014), aggravated automobile dependency (Jiang et al. 2016), and limited leisure-time environments (Zhang et al. 2014).

Against this backdrop, China has seen a remarkable epidemiological transition from a predominance of infectious diseases to one of adverse lifestyle-associated health outcomes, such as obesity, cancers, and cardiovascular diseases (Su et al. 2016, Zhu et al. 2011). Of the various diseases, stroke — a type of acute cardiovascular disease — has become China’s biggest killer. More than 1.5 million Chinese residents die from stroke each year (Liu et al. 2011), and its prevalence is growing rapidly at an annual rate of 8% (NCCD. 2017).

It should be noted that these alarming figures represent, to a large extent, the epitome of the exacerbated burden of stroke and of adverse lifestyle-associated health outcomes in transitional countries over recent decades. Stroke is the second leading cause of death worldwide, and three out of four stroke deaths occur in developing countries (Feigin et al. 2015). From 1990 to 2010, the stroke incidence increased by 12% in low- and middle-income countries, whilst this figure exhibited a significant downward trend in their higher income counterparts (Feigin et al. 2014). Within this context, scholars have speculated that the aggravated stroke burden in transitional countries is potentially associated with urbanisation (e.g., Matenga (1997); Lin et al. (2007); Truelsen and Bonita (2008)). However, based on the existing epidemiological evidence, they predominately attributed this association to lifestyle transitions, and the role of BE transformations — an essential step of urbanisation — is overlooked.

Insights into risk factors for stroke can be drawn from early epidemiological studies on demographic characteristics (NCCD. 2017), lifestyles (e.g., Larsson, Virtamo, and Wolk (2011); Bhat et al. (2008); Patra et al. (2010)), and physiological factors (e.g., Bi et al. (2010); Hu and Sun (2008); O'Donnell et al. (2016)). In recent years, there has also been a surge of interest in the association between stroke (and its precursors) and toxic environmental exposure (e.g., Yin et al. (2015)). However, to the best of our knowledge, there is no research explicitly examining the association between stroke and manmade (built) environments. Considering the effects of BEs on the aforementioned risk factors (e.g., Wang et al. (2016); Ouyang et al. (2018)), it is reasonable to hypothesise the stroke-BE nexus. Additionally, whilst previous studies conducted at the similar lifestyle-associated health outcome level (e.g., cardiovascular diseases, diabetes, and cancers) provide a basic empirical basis for deciphering such a nexus (e.g., Su et al. (2016); Chum and O’Campo (2015); Ouyang et al. (2018); Malambo et al. (2016); Xie et al. (2018); Kan et al. (2008)), only limited BE elements and exclusive/relatively narrow BE dimensions have been considered in each study. To wit, the *multiplicity* of health-related BEs and the *complexity* of relationships between BEs and lifestyle-associated health outcomes have not been sufficiently captured in these studies, which challenges the applicability of established conceptual frameworks and the reliability of relevant findings.

This study aims to better understand the relationship between lifestyle-associated health outcomes and multidimensional BEs in transitional cities by looking at the representative case of stroke in Wuhan, central China. To this end, we narrow our focus to the following questions:

- Where do strokes occur in transitional cities, and what are the BE characteristics of these areas?

- To what extent is stroke risk affected by BEs in transitional cities?

Our research addresses the above issues in the following ways: (1) it clarifies stroke-associated multidimensional BE elements and integrates them into one conceptual framework; (2) it visualises stroke risk in Wuhan using the Bayesian conditional autoregressive (CAR) method; and (3) it examines the BE determinants of stroke risk in the focal area. The approach and conceptual framework are applicable to other cities. The framework and results will contribute to a more comprehensive understanding of the effects of BE in transitional cities on lifestyle-associated health outcomes and on stroke in particular.

2. Literature review

This section elaborates on two aspects: studies on the nexus between BEs and lifestyle-associated health outcomes and the mechanism by which stroke is potentially affected by BEs. The focus of the current research lies within the latter, but a review of the broader context of the topic helps provide a critical overview of the established frameworks, elucidate the multiplicity of stroke-related BEs, and discuss the complexities of the relationship between BEs and lifestyle-associated health outcomes through the case of stroke.

2.1. BEs and lifestyle-associated health outcomes

Along with the increasing interest in healthy urban planning in recent decades, a growing body of evidence endorses the effects of BEs on lifestyle-associated health outcomes. One overwhelming stream of such studies has focused on the obesity-BE nexus (See Sallis et al. (2012) and Durand et al. (2011) for reviews). Given the relatively self-evident behavioural causes of obesity, this set of studies is primarily inspired by the accessibility/presence of (1) (in)salubrious food choices in food environments (e.g., Ford and Dzewaltowski (2008); Morland, Roux, and Wing (2006); Anderson et al. (2011)) and (2) environments that support physical activity (PA) (e.g., Zhang, Liu, and Liu (2015); Rundle et al. (2007); Wen and Kowaleski-Jones (2012)), which are generally built upon classic travel theories, such as the 3 Ds (Cervero and Kockelman 1997) and 6 Ds frameworks (Ewing and Cervero 2010).

Despite the extensive literature on the obesity-BE nexus, the literature on health outcomes that involve more complex pathogenesis, e.g., cardiovascular diseases, metabolic syndrome, and cancers, remains relatively sparse. **Table 1** compares the international literature on this topic. In summary, both the findings and conceptual frameworks support the need for future works on the effects of BE on lifestyle-associated health outcomes. However, the insufficient consideration of BEs in terms of their dimensions and elements has challenged the contributions of these studies. For example, research by Ouyang et al. (2018), Xie et al. (2018), and McLafferty and Wang (2009) has focused on the effects of exclusive BE domains (i.e., land uses, open spaces, and healthcare facilities, respectively). Although several studies have incorporated multiple BE dimensions into integrated conceptual frameworks, few domains constituted by exclusive/limited BE elements have been considered (e.g., Sundquist et al. (2015); Su et al. (2014); Chum and Patricia (2013); Chum and O'Campo (2015); Kan et al. (2008)). Given the multiple pathways between BEs and health-related determinants and the (geographical) correlations among health-related BEs (Moeller 2013), methodologically, omitting BE elements/dimensions linked to modifiable health factors might contribute to the endogeneity problem and, in turn, biased results. More importantly, due to incomprehensiveness, the established frameworks might not effectively capture the complexity of relationships between BEs and lifestyle-associated health outcomes, raising questions of their applicability in further studies, intervention schemes, and health impact assessment projects.

Table 1 Literature of BEs and lifestyle-associated health outcomes.

Study area and sample	Methods	Health outcomes	BE variables	Main findings
700 older adults in Wuhan, China (Xie et al. 2018)	Logistic regressions	Cardio-cerebral vascular diseases; joint diseases; digestive diseases; endocrine diseases; urological diseases; nervous system diseases; respiratory diseases	Open spaces: accessibility to parks	Negative correlation: accessibility to parks and risks of cardio-cerebral vascular diseases, joint diseases, and endocrine diseases
121 samples of cancer registry areas in the Pan-Yangtze River Delta, China (Ouyang et al. 2018)	Structural equation modelling (SEM)	Total adjusted cancer; lung cancer; stomach cancer; mammary cancer; liver cancer; colorectal cancer; oesophageal cancer; pancreatic cancer; renal and urinary cancer	Land-use mix: Shannon's Diversity Index (SHDI); landscape shape index (LSI) Land-use type: proportion of built-up area; proportion of open spaces	Positive correlation: LSI and colorectal cancer, lung cancer, mammary cancer, renal and urinary cancer
57 districts in Shenzhen, China (Su et al. 2016)	Spatial regressions; SEM	Cardiopathy; obesity; hypertension; type 2 diabetes; chronic pneumonia; chronic hepatitis; chronic nephritis; physical fitness; liver cancer; new cancers; thyroid diseases	Land-use abundance; land use; land use; morphology, land-use proximity; land use mix Land-use type: residential; industrial; commercial; institutional; transportation; green; blue; forest; agricultural land; public facilities Walkability: integrated index measured by distances to POIs Street connectivity: intersection density	Negative correlation: proximity to institutional land use and public facilities and cardiopathy, chronic hepatitis, chronic nephritis, chronic pneumonia, liver cancer, new cancers; green land abundance and hypertension, obesity, new cancers, type 2 diabetes, chronic pneumonia; land-use mix and hypertension, physical fitness, obesity, type 2 diabetes, chronic hepatitis; walkability and cardiopathy, obesity, type 2 diabetes, physical fitness, chronic pneumonia; street connectivity and hypertension, physical fitness, liver cancer Positive correlation: industrial land-use morphology and cardiopathy; proximity to industrial land use

				and chronic pneumonia
2,411 adults in Toronto, Canada (Chum and O'Campo 2015)	Multilevel logistic regressions	Cardiovascular diseases	Open spaces: proportion of parkland Food environments: fast food/food store density	Positive correlation: fast food/food store density and myocardial infarction (MI)/any cardiovascular diseases; proportion of parkland and MI
1,626 adults in Toronto Canada (Chum and Patricia 2013)	Unweighted analysis; time-weighted analysis	Cardiovascular diseases	Open spaces: proportion of parkland Food environments: food store density; presence of fast-food restaurant Exposure to traffics: whether lives/works within 100-metre buffer of high traffic	Positive correlation: cardiovascular diseases and fast-food density, presence of fast-food restaurant, lives/works within 100-metre buffer of high traffic
512,061 adults in Stockholm, Sweden (Sundquist et al. 2015)	Multilevel logistic regressions	Type 2 diabetes	Neighbourhood walkability (characterised by residential density, land-use mix, and street connectivity)	Negative correlation: walkability and type 2 diabetes
13,309 middle-age adults in the U.S. (Kan et al. 2008)	Cox proportional hazards regressions	Coronary heart disease	Traffic exposure: traffic density; distance to major roads	Positive correlation: traffic density and coronary heart disease
671 adults in Cape Town and Mount Frere, South Africa (Malambo et al. 2016)	Logistic regressions	Hypertension	Perceived land-use mix; perceived land-use access Perceived street connectivity; perceived infrastructure for walking/cycling	Positive correlation: perceived land-use mix and self-reported hypertension
166,289 cases of cancers in Illinois, the U.S. (McLafferty and Wang 2009)	Multilevel logistic regressions	Breast cancer; colorectal cancer; lung cancer; prostate cancer	Accessibility to healthcare	Negative correlation: accessibility to healthcare and late-stage cancer risk for breast and lung

2.2. Potential stroke-BE nexus

2.2.1. Stroke risk factors

Epidemiological research on stroke risk factors has primarily focused on the demographic, physiological, and lifestyle (behavioural) domains. It is widely accepted that one of the most important demographic determinants of stroke is age (NCCD. 2017); Liapis et al. (2009) estimated that the risk of stroke increases with each decade of life.

Four physiological determinants (i.e., precursors) of stroke have been identified: hypertension, cardiac disease, diabetes, and obesity. Approximately half of all strokes occur in individuals with a history of hypertension (Bi et al. 2010), and lower hypertension awareness contributes to greater stroke mortality (Joffres et al. 2013). The risk of stroke is also significantly higher among individuals with cardiac disease, especially atrial fibrillation (Hu and Sun 2008). Additionally, a global case study of 32 countries has suggested that the occurrence of stroke in people with diabetes and the highest tertile of the waist-to-hip ratio were 1.36 and 1.44 times higher than in the control group, respectively (O'Donnell et al. 2016).

Various lifestyles have been connected to stroke in either direct or indirect (i.e., via the modification of physiological determinants) ways. Evidence has supported the independently protective effect of moderate-vigorous PA on strokes and its physiological determinants (Lee, Folsom, and Blair 2003, Sallis et al. 2012). Additionally, higher risks of stroke and its precursors are more prevalent among individuals with unbalanced diets, e.g., diets high in fat, cholesterol, salt, and processed food (Larsson, Virtamo, and Wolk 2011, Larsson et al. 2009, Feng, Pomborodrigues, and Macgregor 2014). Additional studies have demonstrated that cigarette smoking and alcohol consumption are closely linked with ischaemic and haemorrhagic strokes, respectively, with a strong dose-response relationship (Bhat et al. 2008, J et al. 2010).

In recent years, researchers have begun to investigate the role of environmental toxins, especially of air pollution, in the induction of stroke (Yin et al. 2015, Cevik et al. 2015, Shah et al. 2015, Lipsett et al. 2011). Evidence has shown that both short-term and long-term exposure to air contaminants, including gaseous pollutants and particulate matter, were significantly associated with stroke prevalence and mortality, *ceteris paribus* (Shah et al. 2015, Lipsett et al. 2011). Exposure to ambient air pollution has also been found to be an important contributor to the risk of cardiac diseases and deteriorating vascular function (Lundback et al. 2009, Shah et al. 2013). Recent research by Roberts, Voss, and Knight (2014) revealed that physical inactivity is more prevalent in communities with poor air quality; the authors suggested that such findings might be attributed to physiological (e.g., difficulty breathing) and psychosocial (e.g., antipathy to smoke) effects. Even if these negative effects are overcome, exercising in polluted communities contributes to adverse lifestyle-associated health outcomes (Li et al. 2015).

2.2.2. BE elements related to stroke

Despite the lack of research explicitly connecting BEs with stroke risk, evidence has broadly connected BEs with three identified modifiable risk factors of stroke, namely, lifestyle, physiological factors, and environmental toxins. Therefore, it is reasonable to hypothesise the indirect stroke-BE nexus. To this end, the following section elaborates on the potential mechanism by which stroke is affected by BEs as it relates to multidimensional elements — land use, transport system, open space, facilities, and architectural characteristics — followed by the classic definition proposed by the World Health Organization (2009).

Several studies have examined the correlations between stroke-related risks and land use. Recent research by Su et al. (2016) proposed a theoretical framework to illustrate how land use delivers health benefits against the worsening public health in China via the promotion of active lifestyles and the control of air pollution. Specifically, the authors employed SEMs to construct the association between land use pattern and typical chronic disease incidences. Mediated by increased PA and decreased $PM_{2.5}$ concentrations, an abundance of institutional land (e.g., schools, community centres, and universities) is found to be associated with a lower risk of type 2 diabetes, hypertension, and cardiopathy. Additionally, the role of mixed land use in supporting active travel behaviour has been highlighted over the decades (Cervero and Kockelman 1997); correspondingly, a higher level of PA and a lower likelihood of obesity and hypertension have been observed in districts with mixed land use (Malambo et al. 2016, Zhang, Liu, and Liu 2015). In contrast, previous studies have revealed that increased industrial and residential areas tend to exacerbate ambient air pollution (Bertazzon et al. 2015, Henderson et al. 2007), in turn potentially increasing stroke risk.

The effects of transport on PA and thus on stroke risk have been examined in previous studies. Better street connectivity could facilitate walking and moderate-intensity PA (Frank et al. 2005, Moeller 2013). Moreover, an increased number of sidewalks and paved streets has been correlated with increased walking as a mode of transport (Zhang et al. 2014). Additionally, Lachapelle and Frank (2009) found that public transit users were more likely to meet the recommendation for daily PA than automobile users. Rundle et al. (2007) also observed that the densities of bus and subway stops were negatively associated with body mass index (BMI). Therefore, BE elements that encourage the ability to choose a mode of active transport might counteract the risk of stroke.

Sufficient access to both green space and public space delivers health benefits against stroke risks, such as better general health status (Mowen et al. 2007) and a lower risk of cardiovascular disease and diabetes (Chum and O'Campo 2015, Xie et al. 2018). Open space is regarded as the "third place", after the home and the workplace, in individual social lives since it provides opportunities for social interaction and access to social network-based resources (Mowen and Rung 2016). Accordingly, it largely supports the accumulation of social capital, promoting better self-management in terms of health (Xie et al. 2018). Moreover, a plethora of studies has shown that better access to open space, e.g., greater proximity, higher abundance, and a better landscape, is positively associated with various types of PA (Kaczynski et al. 2009, Schipperijn et al. 2017, Lu, Sarkar, and Xiao 2018). Public open space could therefore play an important role in reducing the risk of stroke by facilitating PA and promoting social capital.

It has also been postulated in the literature that access to a variety of facilities plays a critical role in shaping individual lifestyles, which might impact stroke risk. A recent study on urban China suggested that having more destinations within walking distance is positively correlated with more PA (Zhou, Grady, and Chen 2017). In contrast, a higher density of catering facilities could lead to an increased risk of cardiovascular disease and obesity, which can be attributed to excessive fat and calorie intake (Chum and O'Campo 2015, Ford and Dzewaltowski 2008). Moreover, prior research has also emphasised the importance of medical care facilities to disease prevention and health information dissemination (Anasi 2012); easy access to medical facilities might help reduce stroke risk.

The architectural characteristics of BEs have been closely linked with air pollution and PA. Recent research (in the context of high-density urban China) has shown that the $PM_{2.5}$ concentration was strongly associated with building volume density and building coverage ratio (Shi et al. 2017). Dense urban environments and high-intensity urban development not only play important roles in the generation of air pollutants but also contribute to the urban heat island effect (Sharifi 2019), which impacts urban airflow dynamics and thereby influences the movement and concentration of pollutants (Agarwal and Tandon 2010, Edussuriya and Chan 2015). Additionally, building compactness was associated with PA. For example, by separating density indicators into seven subtypes, Forsyth et al. (2007) found that both housing and total building density were positively correlated with walking for travel purposes but negatively associated with walking for work and leisure purposes.

As such, given the multiplicity of stroke-associated BEs, we put forward a conceptual framework to capture the potential impact of multidimensional BEs on stroke risk (**Fig. 1**). The goal of the current research is to understand the complexity of the stroke-BE nexus, thereby fleshing out the current picture on the nexus between BEs and lifestyle-associated health outcomes with regards to conceptual frameworks and empirical evidence.

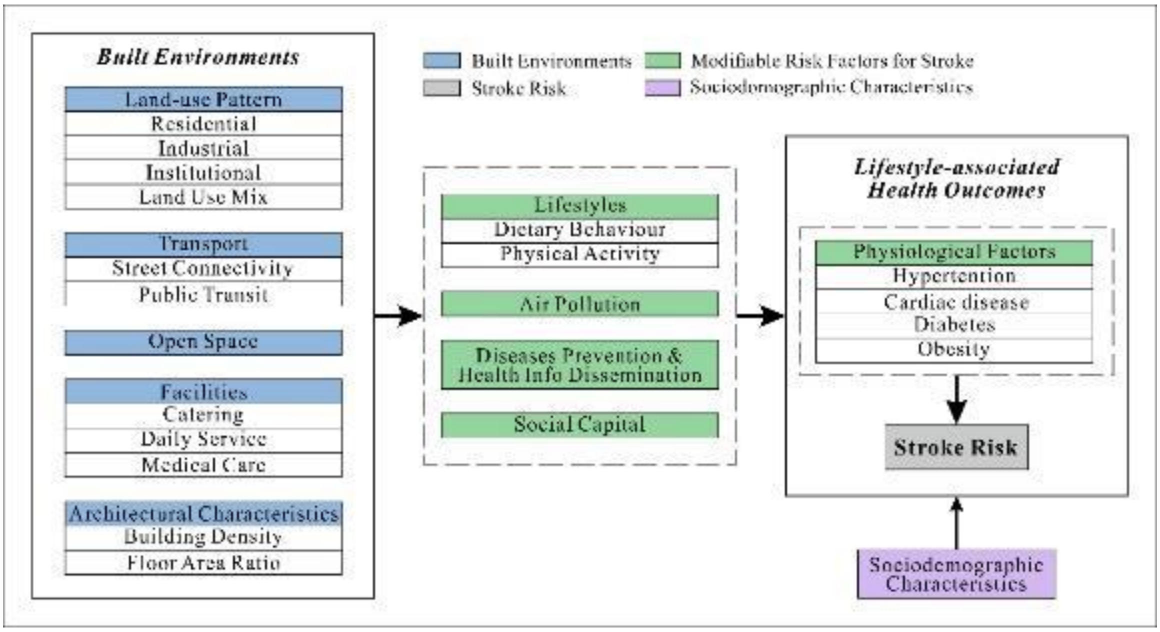

Figure 1. Conceptual framework of the stroke-BE nexus.

3. Research design

3.1. Study area

This study focuses on the urbanised area in Wuhan, China (**Fig. 2**). Wuhan has a population of 10.7 million (as of 2015) and a total area of 8,494.4 km^2. It is the most populated city and the economic and political centre of central China. Similar to other Chinese metropolises (Gu, Kesteloot, and Cook 2015), Wuhan has witnessed remarkable urban expansion, with prosperous industrialisation and rapid economic development. During this period, lifestyle-associated diseases, especially stroke and its precursors, have gradually become substantial burdens on public health (Xie et al. 2018).

The geographical distribution of the population in Wuhan is highly centralised (Xie et al. 2019). The area of the urban core (i.e., the urbanised area within the boundaries of the second ring road) and the urban fringe (i.e., the urbanised area outside the boundaries of the second ring road) is approximately 2% and 8% of that of the rural district, respectively, but both of these areas cover approximately 30% of the total population of Wuhan. Our precise focal area covers an area of 734.8 km^2 and has a population of approximately 6.4 million. The area is characterised by high density, a rapidly ageing population, and poor air quality, all of which are potentially associated with stroke risk. In 2015, the gross population density was 8,711 people per km^2 in this area. This population density is approximately 10 and 5 times that of Toronto, Canada (954 people per km^2) and Portland, U.S. (1,684 people per km^2), respectively, where prior BE-cardiovascular disease studies have been conducted (Chum and O'Campo 2015, Li et al. 2009). Additionally, the ageing population has rapidly grown and now exceeds 20% of the total population, and the air quality in Wuhan is low; according to the 2015 Wuhan Environmental Status Bulletin, hazardous pollution days comprised nearly half the year, and such issues are much more severe in built-up areas.

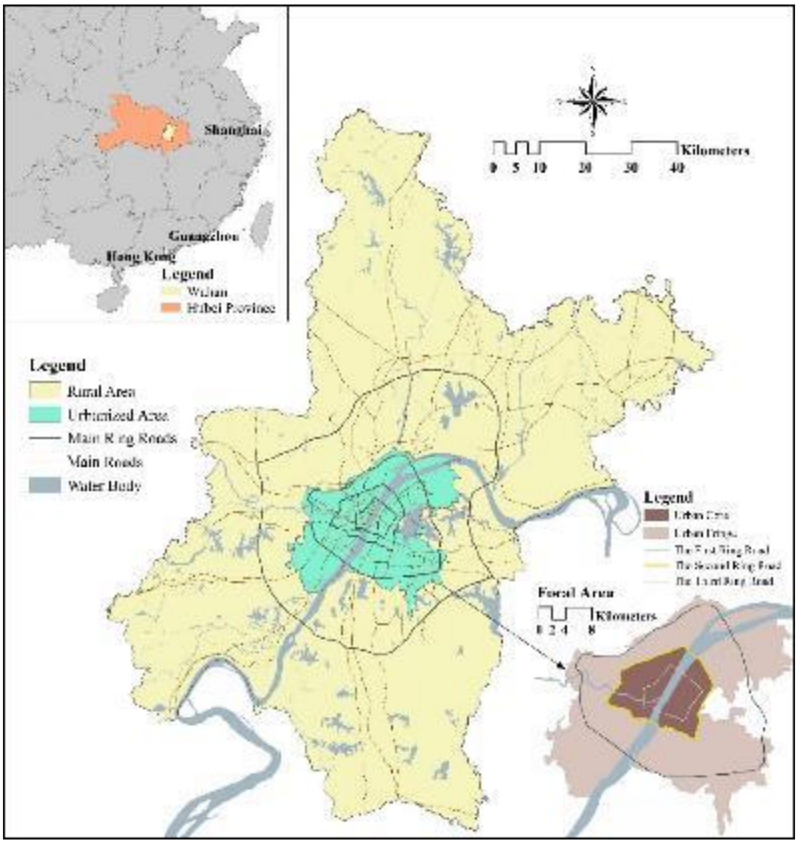

Figure 2. Map of Wuhan.

3.2. *Data source*

This study used three types of data: medical data, BE data, and community-level sociodemographic data. Medical data on stroke cases in Wuhan from 2015 were collected from the Wuhan Emergency Medical Centre (Wuhan EMMC). Each medical case included the patient's age, gender, disease type, onset time, and geocoded home address. The disease types were diagnosed by professional doctors, and the home addresses were geocoded by an independent commercial company under the supervision of Wuhan EMMC. We successfully extracted 10,971 stroke cases from the dataset according to the International Classification of Diseases (ICD-10: I60-I69). The crude stroke incidence in our focal area was calculated to be 170.1/100,000, which is slightly lower than the average stroke incidence in urban China (203.6/100,000) (NCCD. 2017). Moreover, recent nationwide research has suggested that the stroke incidence in China exhibits a considerably geographical dependency at the province level (Wang et al. 2017). The stroke incidence in Changsha — a twin city with Wuhan in central China — is therefore employed to be compared with our data. As estimated by Sun et al. (2014), based on a self-sampled stroke surveillance network, the stroke incidence in Changsha was comparable, at

168.5/100,000 in 2011, although this figure exhibited an upward trend over time. These figures showed the relatively high representativeness of our dataset in depicting stroke prevalence in urban China.

We obtained the BE data and community-level sociodemographic data, including land use, facilities, housing, transport (except sidewalks), buildings, and community-level population, employment, age structure, and gender ratio, from the Wuhan Land Resources and Planning Information Centre for 2015 (**Table 2**). Due to the data restrictions on public institutions, sidewalk data were obtained from an open-access and volunteered GIS platform, namely, OpenStreetMap.org.

3.3. BE measurements

The unit of analysis for this study is the individual community (n=1,237). The community, namely, the *juweihui*, is the smallest administrative unit and the basic official unit for conducting population statistics and managing public services for residents in urban China. As previously stated, we adapted the framework from the World Health Organization (2009) to capture and measure the multidimensional stroke-related BEs of these communities. The five categories measured were (1) land-use patterns, (2) transport, (3) open spaces, (4) facilities, and (5) architecture. Variables for spatial variations in population and employment were also included in this research due to their roles in shaping urban form. The community-level sociodemographic characteristics were served as controlled variables in the analysis. **Table 2** shows the descriptive statistics and descriptions of the variables that were included in this study.

Two metrics were employed to measure land-use patterns: land-use mix and land-use proportion. The former indicator emphasises the diversity of land use. Given the development of communities, especially those in urban cores that were dominated by an exclusive residential pattern, the indicator was measured by Shannon’s diversity index for an all-land-use mix (SAM) and Shannon’s diversity index for a residential-use-excluded mix (SREM). The proportions of variables were used to reflect the abundance of the specified land-use classes. Based on previous research, three land-use classes (residential, industrial, and institutional) were eventually included.

With regard to transport, intersection density, as suggested by Moeller (2013), was used to characterise street connectivity. Sidewalk provisioning was measured by the density of the sidewalks. We also considered the accessibility of public transit. To do this, catchment-based accessibility metrics were employed due to the significant variation in community sizes and the uneven distribution of residents. **Fig. 3(a-b)** shows a comparison of the catchment-based and container-based metrics for facility access. With the container-based metric, facilities within a specified community were considered accessible. However, this measure did not consider the facilities outside the community boundaries or the facilities far from residents; thus, this metric might either underestimate or overestimate the mobility of residents and lead to a modifiable area unit problem (MAUP) (Xie et al. 2018). Specifically, we geocoded all residential building addresses within communities and then measured the number of transit facilities within a catchment area (i.e., road network distance) of 600 metres (an approximate 10-minute walking distance) around each residential building. Finally, we calculated the number of accessible facilities for every residential building in each community. The median value of the facilities was used to represent accessibility to public transit within each community, as the standard deviations were higher than the mean values in most communities.

The interaction between facilities and residents was indicated by the accessibility of catering (i.e., restaurants, fast-food stores, groceries, and markets), daily services (i.e., ATMs, banks, telecommunication businesses, and laundromats) and medical care (i.e., clinics and polyclinics). The measurement of accessibility to these facilities was consistent with the metrics for public transit accessibility.

Open space was measured using the proportion of area devoted to public parks and squares. Urban omnibus parks (UOPs), community parks (CPs), and public squares/plazas are three of the main public open spaces in Wuhan. The UOPs and CPs are mainly built for social interactions, recreational activities and daily entertainment activities. These two types of parks are associated with a relatively adequate presence of green space but have great disparities in terms of scale, amenities, management and maintenance. Because squares/plazas are mainly established for commemorative functions, they are poorer in terms of auxiliary facilities and greenery than parks.

We employed two types of spatial indicators to reflect architectural characteristics: intensity and density. The intensity indicator was measured by the average floor area ratio (FAR) within communities, and the density features were indicated by building density.

Population density and employment density are historically intertwined with zonal economic development, urban form (e.g., compactness versus sprawling), and BEs (Cervero and Kockelman 1997, Wu and Gopinath 2010); correspondingly, such measurements were also included in the current research. Gross population density and net population density were initially considered, but given the high correlation between these variables, the former variable was excluded, as net population density can capture the concentration and compactness of the population more appropriately.

With respect to sociodemographic characteristics, age structure, percentage of males, and average housing price were included in the current research. The percentages of adults (residents between 19 and 59 years of age) and older adults (residents over 60) were used to reflect the age structure. Considering the potential correlations among socioeconomic status, stroke risk, and BEs within communities, the average housing prices within communities were employed as a proxy for the wealth values of residents to reduce endogeneity. Moudon et al. (2011) aggregated the values of land parcels and individual-level wealth metrics to measure neighbourhood wealth and property values and found that the housing-price indicator was more predictive of health status than the individual socioeconomic status (SES). Moreover, several studies have indicated that area-level housing prices strongly affect the wealth and debt of households and have significant implications for stroke and related health outcomes (Fichera and Gathergood 2013); thus, area-level housing prices could be used as a proxy for area-level SES in health studies (Sohn 2013). Additionally, the inclusion of the housing price variable could help reduce potential residential self-selection bias, i.e., individuals deliberately opt for where to live according to their sociodemographic traits and preferences (Cao, Mokhtarian, and Handy 2009), since housing affordability plays a key role in choosing residential locations and, in turn, the community BEs in urban China (Xiao et al. 2017).

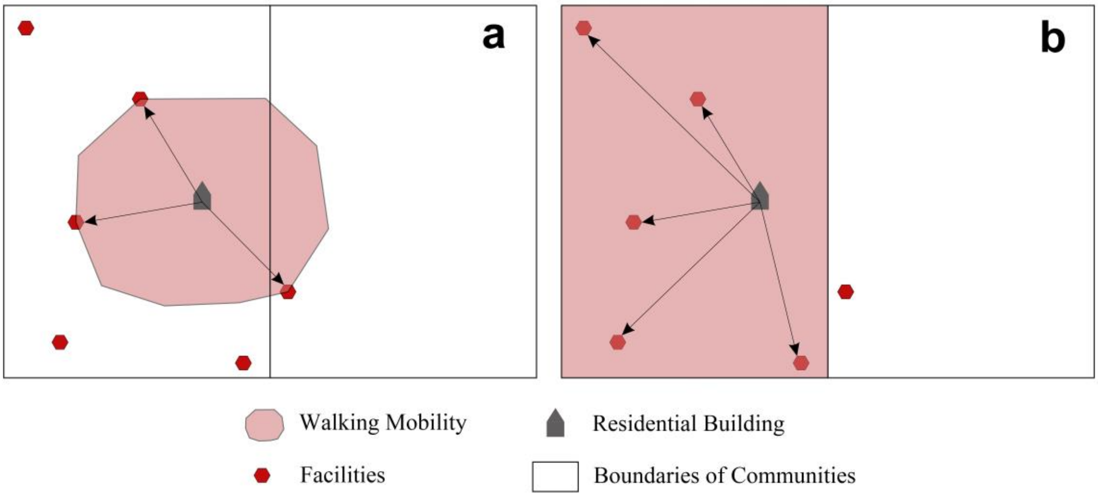

Figure 3. Comparison of (a) catchment-based and (b) container-based metrics for facility access.

Table 2 Summary and definition of variables.

Domains	Variables	Min	Max	Mean	Std.	Definition
Sociodemographic Characteristics	Male	0.447	0.982	0.516	0.062	Male population/community population. (%)
	Older Adult	0.017	0.658	0.193	0.075	Population older than 60/community population. (n)
	Adult	0.332	0.919	0.722	0.078	Population aged between 19 and 59/community population. (n)
	Housing Price	1162.000	41080.000	11654.275	2395.757	Average housing price within communities. (yuan)
Land-use Pattern	SAM	0.010	2.111	1.009	0.419	Shannon's diversity index for all land-use mix.
	SREM	0.004	1.523	0.878	0.366	Shannon's diversity index for residential-use-excluded mix.
	Residential Land Use	0.089	0.962	0.367	0.133	Proportion of urban residential land use. (%)
	Institutional Land Use	0.000	0.790	0.096	0.235	Proportion of governmental land use, including areas with education and social welfare uses. (%)
	Industrial Land Use	0.000	0.954	0.046	0.187	Proportion of industrial land use, including areas with research, manufacturing, and assembling uses. (%)
Transport	Intersection	0.023	7.594	0.347	0.563	Number of intersections/community land area. (1/ha)
	Sidewalk	0.002	0.313	0.022	0.089	Total sidewalk length/community land area. (km/ha)
	Bus Stop	0.000	11.000	1.283	1.825	Accessibility to bus stops. (n)
	Metro Station	0.000	7.000	0.424	1.398	Accessibility to metro stations. (n)
Open Space	CP	0.000	0.431	0.006	0.018	Proportion of areas devoted to community parks. (%)
	UOP	0.000	0.641	0.017	0.037	Proportion of areas devoted to urban omnibus parks. (%)
	Square	0.000	0.146	0.000	0.000	Proportion of areas devoted to public squares and plazas. (%)
Facilities	Catering	1.000	319.500	122.786	129.883	Accessibility of catering facilities. (n)
	Daily Service	11.500	245.000	57.491	44.891	Accessibility of daily service facilities. (n)
	Medical Care	0.000	32.000	8.554	6.484	Accessibility of medical care facilities. (n)
Architectural Characteristics	Building Density	0.001	0.846	0.138	0.268	Area of building footprint/community land area (%)
	FAR	0.041	7.485	1.830	0.989	Gross floor area/area of the plots within communities. (ratio)
Population Density	Net Population Density	17.028	6373.448	446.860	1095.459	Population/residential land area of the community. (1/ha)
Employment Density	Employment Density	1.050	3398.238	40.281	165.235	Employment population/land area of the community. (1/ha)

3.4. Bayesian CAR model

The Bayesian CAR model was employed to (1) smooth and visualise stroke risk and (2) examine the association of BE elements with stroke risk.

3.4.1. Smoothed and standardised risk of stroke

In previous studies, two major indicators were employed to quantify the epidemic circumstances in a specific area: (1) crude incidence (Su et al. 2016) and (2) standardised incidence ratios (SIRs) (Maheswaran et al. 2012). Crude incidence represents the number of new cases per population at risk while neglecting the significant impact of the demographic characteristics of the study area on diseases. As an alternative indicator, SIRs measure the ratio of observed cases to expected cases, which is standardised by age and gender and could thus offset the statistical bias caused by demographic characteristics. However, SIRs are subject to large variation, especially in areas with small populations, as the number of expected cases can be small, and a very small change in the number of observed cases might exaggerate epidemic fluctuations (Wu et al. 2004). To avoid this problem, a smoothed SIR (SSIR) measure was used to visualise the risk of stroke in this study.

The Bayesian CAR model is a new approach for modelling spatial data with limited observations. This model incorporates spatially structured heterogeneity with hierarchical parameters into the estimation of SSIRs, thereby eliminating the dependence of variance on population size (Ebrahimipour et al. 2016, Wu et al. 2004). Recently, the Bayesian CAR model has been increasingly used to explore the geographical variation in diseases (Yin et al. 2014, Alegana et al. 2013).

Following Hegarty, Carsin, and Comber (2010), a Poisson CAR model (**Eqs. (1)–(3)**) was applied to the estimation of SSIRs using the Markov chain Monte Carlo (MCMC) method.

$$O_i \sim Poisson(E_i R_i) \tag{1}$$

$$E_i = \sum\sum N_{ijk} \frac{O_{jk}}{N_{jk}} \tag{2}$$

$$log(R_i) = \alpha + v_i + u_i \tag{3}$$

Here, the fitted value of R_i represents the final SSIR within community i. E_i and O_i represent the expected and observed number of cases within community i, respectively. Specifically, E_i is defined as the number of age-sex-specific cases. N_{ijk}

represents the total population in community i for age group j and sex k; O_{jk} represents the observed number of cases for age group j and sex k, and N_{jk} represents the total population for age group j and sex k. α represents the intercept; v_i and u_i represent the unstructured and structured spatial correlations, and their prior distributions were assigned according to **Eqs. (4)–(5)**, respectively, with τ_h^2 and τ_e^2 controlling the variance and equalling the prior Gamma distributions (0.5 and 0.0005, respectively), as suggested by Aguero-Valverde and Jovanis (2006). In this study, the first-order adjacent neighbourhood was used to represent spatial dependency, and n_{δ_i} denoted the total number of adjacent communities for area i.

$$v_i \sim N(0, \tau_h^2) \tag{4}$$

$$\left[u_i \middle| u_{j,i \neq j}\right] \sim N\left(\sum_{j \in \delta_i} \frac{u_{j,}}{n_{\delta_i}}, \frac{\tau_e^2}{n_{\delta_i}}\right) \tag{5}$$

3.4.2. Stroke-BE association

The following Bayesian-Poisson CAR model was employed to examine the predictors of stroke risk under the domains of BEs and sociodemographic characteristics:

$$O_i \sim Poisson(E_i R_i) \tag{6}$$

$$E_i = N_i \frac{O}{N} \tag{7}$$

$$log(R_i) = \alpha + \sum \beta_{ij} x_{ij} + v_i + u_i \tag{8}$$

where R_i represents the stroke risk within a given area i. E_i and O_i denote the expected and observed number of cases, respectively, within area i. More specifically, given the introduction of demographic characteristics (e.g., age structure variables), E_i was different from that in **Eq. (2).** In this model, E_i is defined as the population-weighted average number of cases. N_i represents the total population in community i; O and N denote the total number of observed cases and the total population of the focal area, respectively. x_{ij} represents the predictor, and β_{ij} represents the corresponding coefficient. The settings of the other variables and the prior distributions of the parameters were assigned according to **Eqs. (1)–(5)**.

Additionally, given the richness of our dataset, multicollinearity issues potentially emerge, which might contribute to biased estimations. The classic variance inflation factors (VIFs) were therefore implemented for classic Poisson regressions (instead of the Bayesian-Poisson CAR model due to computing limitations) to determine the input variables. In each round of VIF calculation, a variable with a VIF greater than 10 was excluded from the Bayesian CAR model. Ultimately, three variables — the residential land-use proportion, bus stop accessibility, and daily services accessibility — were excluded from the estimation model.

3.5. Hot spot analysis

The hot spot analysis was performed to identify the geographical cluster of SSIRs based on the Getis-Ord Gi* statistic (Ord and Getis 1995). The resultant z-score indicates the spatial aggregation of stroke risks. Communities with a high z-score (i.e., $z>1.96$) and a low p-score (i.e., $p< 0.05$) have statistically significant hot spots. The model was implemented using the fixed distance band tool in ArcGIS 10.3.

4. Results

4.1. Distribution of stroke risk

Fig. 4-a depicts the distribution of SSIRs in Wuhan. Strong geographical variation in the SSIRs of stroke was observed in the city. Residents living in the urban core appeared to have a higher risk of stroke, whereas residents living along the urban fringe were less likely to have strokes. **Table 3** shows the comparison of SSIRs between the two urban regions. Specifically, high-risk communities (i.e., communities with a stroke risk greater than 2) were broadly concentrated in the urban core. Within this area, the percentage of high-risk communities was noticeably higher than that in the urban fringe (23.82% versus 10.09%).

The geographical clusters of high SSIRs were identified using hot spot analysis (**Fig. 4-b**). All three distinct hot spots included many high-density and overcrowded neighbourhoods compared to the average development level in the city (**Table 4**). Specifically, two hot spots were located exactly over the city centre. Hot Spot A was located to the south of the Han River (**Fig. 5-a**). The communities within Hot Spot A were mainly composed of old state-owned enterprises with a high concentration of established enterprise workers, and the majority of residents were retired with a low income. Housing in the area tends to forgo necessary maintenance due to the bankruptcy of these state-owned enterprises. Hot Spot B was located in a traditional and historic commercial district north of the Han River (**Fig. 5-b**). In this area, the living and commercial spaces were highly mixed, the building density was extremely high, and the public space was scarce, accounting for only 1.4% of the total area. Hot Spot C was located along the edge of the city centre and was surrounded by main arterial roads (**Fig. 5-c**). This area included both old and new communities, with high building and population concentrations. Our results implied that residents living in the compact urban core tended to have a higher risk of stroke, whereas residents who lived in the urban fringe were less likely to be diagnosed with stroke.

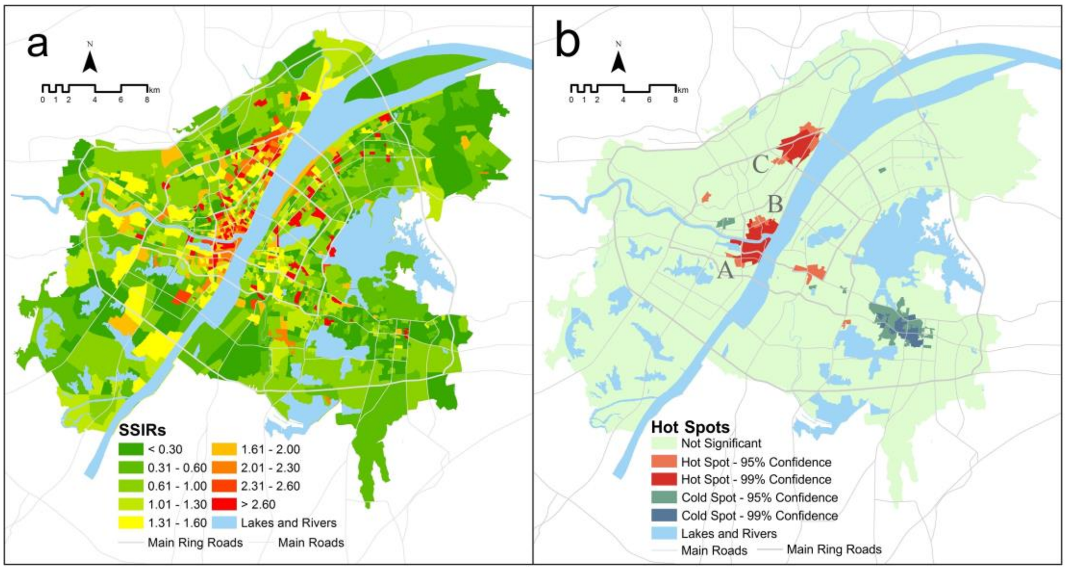

Figure 4. Distribution and high-risk clusters of stroke risks.

Table 3 Comparison of stroke risks between the urban core and the urban fringe.

SSIRs	<1.0	1.0-2.0	2.0-3.0	>3.0
Proportion of communities within urban core (%)	37.25	38.93	15.42	8.40
Proportion of communities within urban fringe (%)	59.79	30.12	5.90	4.19

Table 4 Comparison of the hot spots and the overall study area in terms of density.

Area	PD	NPD	BD	FAR
Study Area	87.735	446.860	0.138	1.83
Hot Spot A	210.179	459.089	0.362	2.31
Hot Spot B	886.891	1257.958	0.671	2.63
Hot Spot C	176.361	551.419	0.198	1.74

Abbreviations: population density (PD), net population density (NPD), building density (BD), floor area ratio (FAR)

Figure 5. Typical cityscapes in the high-risk clusters for stroke: (a) Hot Spot A; (b) Hot Spot B; (c) Hot Spot C.

4.2. Impact of BEs on stroke

Using the Bayesian CAR analysis, we identified an association between stroke risk and BE variables (**Table 5**). With regard to the sociodemographic characteristics of communities, we found that the percentage of older adults was positively correlated with stroke risk, which implied that a higher risk of stroke was observed in ageing communities. Land-use patterns were also closely associated with stroke. The proportion of institutional land use was negatively associated with stroke risk, indicating that people were less prone to strokes in communities with larger amounts of institutional land use. However, there was no significant correlation between the land-use mix variables and stroke risk. The association between stroke risk and the transport system also remained unclear in our research. Regarding access to open spaces, both CPs and UOPs were negatively related to stroke risk, suggesting communities with greater area devoted to parks were potentially beneficial for stroke prevention. Regarding facilities, only medical care facilities acted as negative predictors of stroke risk, which indicated that better access to medical care facilities could benefit stroke prevention. Additionally, the results showed that building density was positively related to stroke, and such findings were similar to another density indicator: net population density. FAR was not significantly related to stroke risk, which indicated that residents living in crowded communities rather than high-FAR communities were more prone to stroke. In other words, high-rise buildings alone were not correlated with stroke risk in Wuhan, China.

Table 5 BE-stroke association.

Domains	Variables[a]	Mean	2.5% CI[b]	97.5% CI [b]
Sociodemographic Characteristics	Male	0.0271	-0.0612	0.1217
	Older Adult *	0.2502	0.1153	0.3965
	Adult	0.0096	-0.0430	0.0686
	Housing Price	0.1026	-0.0419	0.2090
Land-use Pattern	SAM	-0.0663	-0.1932	0.0525
	SREM	-0.0483	-0.1647	0.0608
	Institutional Land Use *	-0.1422	-0.2592	-0.0177
	Industrial Land Use	-0.0535	-0.2048	0.0804
Transport	Intersection	-0.0901	-0.2118	0.0393
	Sidewalk	-0.0694	-0.1972	0.0612
	Metro Station	0.0333	-0.0612	0.1261
Open Space	CP *	-0.1714	-0.3265	-0.0099
	UOP *	-0.1573	-0.2787	-0.0471
	Square	-0.0208	-0.1209	0.0813
Facilities	Catering	0.0344	-0.0583	0.1313
	Medical Care *	-0.1785	-0.3122	-0.0403
Architectural Characteristics	Building Density *	0.2857	0.1256	0.4516
	FAR	0.0110	-0.0604	0.0704
Population Density	Net Population Density *	0.1988	0.0583	0.3347
Employment Density	Employment Density	0.0584	-0.1059	0.2326
Model Fit (DIC)	4870.805			

[a] Independent variables have been standardised.
[b] CI denotes the credible interval.
* Significant at $p<0.05$

5. Discussion

5.1. Health benefits for stroke prevention related to BEs

Our research has identified several community-BE elements that could deliver health benefits for stroke prevention after controlling for sociodemographic characteristics. First, a lower stroke risk was observed in communities with greater area devoted to institutional land use, which might be attributed to the increase in PA (Su et al. 2016). Similar findings can be found in research by Su et al. (2016) who revealed that the abundance of institutional land use is negatively correlated with risks of cardiopathy and hypertension in Shenzhen, China. In contrast, land-use mix measures were not significantly correlated with stroke risk, which was inconsistent with previous findings that showed positive health benefits from mixed land use in urban China, such as lower risk of hypertension, from mixed land use in urban China (Su et al. 2016) and more PA (Gao, Ahern, and Koshland 2016). Second, residents in communities with sufficient park areas were less likely to suffer from strokes because parks offer valuable opportunities for interpersonal socialisation and participation in modest daily PA (Mowen and Rung 2016, Kaczynski et al. 2009). This finding is consistent with the research by Chum and Patricia (2013) and Chum and O'Campo (2015) on cardiovascular diseases in Toronto, Canada. Although CPs were of lower quality in terms of size, management and amenities than UOPs, our results suggested that both types of parks were conducive to reducing stroke risk. In contrast, the association between stroke risk and squares remained unclear. Third, communities with closer medical care facilities tended to have lower stroke risk, further emphasising the role of both public primary and tertiary medical care facilities in stroke prevention. This finding might be attributed to the crucial role of these health services in disease prevention and health information dissemination (Anasi 2012). Despite the difference in subject matter, this finding is partly consistent with the research by McLafferty and Wang (2009) conducted at a similar lifestyle-associated health outcome level (i.e., late-stage cancer risk) in Illinois, U.S.

Moreover, these elements were identified under the consideration of the multiplicity of potential stroke-associated BEs. Given the multiple pathways linking BEs and stroke, the identification is of relatively high robustness. It should also be noted that these salubrious elements lie within various BE dimensions. These issues, to a large extent, imply that incomprehensive conceptual frameworks focusing on exclusive/narrow BE domains might not sufficiently capture the intricate BE-stroke nexus.

5.2. High-density urban context correlates to stroke

The current research also yielded insight into the association between high-density development and increased stroke risk. The geographical examination showed that residents living in dense and compact urban cores tended to have a higher risk of stroke than residents living in the urban fringe. The statistical analyses revealed that net population density and building density are positively correlated with stroke risk. One reasonable explanation is that air pollution and decreased PA might act as mediators of these associations. Many studies have concluded that high-density development, especially in the central areas of cities, is positively associated with ambient air pollution (Frank and Engelke 2005, Shi et al. 2017). Several major air pollution sources, e.g., use of personal vehicles, discharge of domestic refuse, and fuel/gas consumption, are remarkably more prevalent in populated and dense areas (Hixson et al. 2012). Increased human activities and building construction in these areas also contribute to the exacerbation of the urban heat island (Sharifi 2019), in turn potentially obstructing the air flow condition and diffusion of pollutants (Agarwal and Tandon 2010). Moreover, exercising and walking in polluted environments can expose residents to combustion-related airborne pollutants and amplify the deleterious effects of harmful air pollution (Li et al. 2015). Li et al. (2015) argued that such situations can be severe in urban China due to the worsening air pollution crisis and the prevalence of outdoor-oriented activities.

Although prior studies have found that high-density and compact communities do provide residents with opportunities to engage in PA in developed countries (e.g., Frank et al. (2005); Rundle et al. (2007)), several findings supporting the opposite conclusion have been observed regarding high-density developing countries (e.g., Salvo et al. (2014); Reis et al. (2013)). A recent study of ultra-dense Zhongshan, China, found that, after the data were controlled for sociodemographic characteristics and other BE elements, an increase in population density would hinder both the total walking frequency and the total walking duration of older adults, who are particularly vulnerable to stroke (Zhang et al. 2014). Lu, Xiao, and Ye (2016) argued that there might be a threshold effect of density on walking, and hence, the excessive high-density urban context might obstruct participation in PA, at least to some extent.

In addition, density is considered to be a primary factor in planning practices and inevitably has an impact on the layout and formation of various BE elements; naturally, factors that support stroke prevention might be involved. To wit, the effects of urban density on stroke might be *inherently* underestimated in our results from the perspective of practices. Thus, Spearman's correlation coefficient was employed to examine the associations between density and stroke-related indicators (**Table 6**).

As shown in **Table 6**, building density is strongly and negatively correlated with the proportion of area devoted to public parks within communities (i.e., CPs and UOPs, with correlation coefficients less than −0.3). Similar but weaker trends are also observed between building density and the proportion of institutional land use and between net population density and park variables. Higher densities, especially building density, might decrease the areas devoted to institutional land use and parks, which potentially hinders recreational activities. Within this context, decreased leisure-time PA has been generally associated with high building density in urban China (Su et al. 2014, Xu et al. 2010). For example, a cross-sectional study in Hong Kong, where the population density is comparable to that of our study area, found that, compared with medium-density areas, less leisure-time walking was observed in high-density neighbourhoods (Lu, Xiao, and Ye 2016). Moreover, Day (2016) argued that excessive density in Chinese megacities might lead to perceived overcrowding, thereby reducing recreational PA. The crowding barrier reflects, to a large extent, an imbalanced supply-demand relationship between local residents and space/facilities for PA; correspondingly, the local population density might have negative implications for the individual availability of open spaces/facilities due to the barriers presented by crowds (Ekkel and de Vries 2017). In this vein, recent research by Xie et al. (2018) on urban China highlighted the role of crowding in inducing chronic health conditions, particularly cardiovascular diseases, by obstructing participation in park-based PA. Therefore, even considering the relatively weak association between population density and the proportion of areas devoted to institutional land use and open space, highly dense communities potentially hinder leisure-time PA due to the exacerbation of perceived overcrowding and the supply-demand imbalance.

Table 6 Summary of Spearman's correlation coefficients.

Variables	Older Adult	Institutional Land Use	CP[a]	UOP[b]	MCF
Net Population Density	0.198 **	-0.052	-0.267 **	-0.209 **	0.166 **
Building Density	0.320 **	-0.151 *	-0.373 **	-0.380 **	0.109 **

Abbreviations: community park (NP), urban omnibus park (UOP), floor area ratio (FAR), medical care facilities (MCF)
* denotes that the correlation reaches statistical significance at the 0.05 level.
** denotes that the correlation reaches statistical significance at the 0.01 level.

5.3. *Planning as a tool for proactive health intervention*

Planning intervention has emerged as a crucial need for a healthy urban agenda, since it is deemed a more proactive, fundamental, far-reaching, and longstanding strategy for health promotion than programmes that solely focus on changing the behaviours of small groups (Barton and Grant 2013). Some planning implications can be drawn from the current research. First, our research indicates that high-density development could be a potential public health concern, at least for stroke, which calls for the need to scrutinise and reconsider the applicability of the prevailing compact urban developments in transitional cities. Historically, compactness has been extensively acknowledged as an effective urban form that supports healthy urban living in developed countries (Ewing and Hamidi 2015). However, in many transitional countries such as China, population growth has continuously accelerated due to rapid economic growth and large population size (Wen and Goodman 2013). Meanwhile, to pursue economic benefits and meet surging residential requirements, urban housing provisions are generally dominated by market-oriented programmes that are largely based on low-mixed/exclusive residential use (Shin 2014). Consequently, in recent decades and in the immediate future, the population and building density in transitional cities has and will continue to overload. Therefore, the applicability of compact urban development in these ultra-dense cities should be examined via systematic health impact assessments. Additionally, if such developments are identified as insalubrious, planners might need to consider de-densifying crowded urban cores and alleviating the extremely unbalanced distribution of population across urban areas. A rational way to achieve these goals is to promote the 'new suburbanisation' that aims at developing multifunctional centres to coordinate residential settlements, commercial areas, and workspaces (Shen and Wu 2017).

Second, as indicated by statistical analyses, several BE elements, i.e., the abundance of parks and institutional land and access to medical care facilities, still provide residents with the benefits of stroke prevention regardless of urban density. Therefore, the guarantee of sufficient opportunities for residents to access these salubrious resources could be seen as a crucial goal of planning practices for health promotion, especially considering that urban densities in transitional cities will inevitably increase in the future. Under such a scenario, planning practitioners should try to provide adequate urban therapeutic landscapes within communities (e.g., institutional land and parks). Medical facilities at various levels should also be delicately configured to ensure residents can access health care services, at least primary health care services, that are within walking distance.

Third, intervention scheme planning for health promotion and the reliability of the corresponding assessment projects of the schemes largely relies on systematic and comprehensive frameworks (Ross et al. 2012). By looking at the BE-stroke relation, our research highlighted the necessity of considering the multiplicity of health-related BEs in the development of these frameworks. Although the intricate nexus between BEs and lifestyle-associated health outcomes might vary with changes in focal cities, comprehensive conceptual frameworks allow planners to identify relevant BE elements accurately and to change them in a targeted manner.

6. Conclusion

Deciphering the nexus between BEs and lifestyle-associated health outcomes is of capital importance for crafting planning interventions. To this end, this article presented a conceptual framework of BE-stroke relation. Using Bayesian CAR methods, the research team was able to visualise the spatial distribution of stroke risk and identify BE correlates of stroke in the study area. The results revealed that BE variables were significantly associated with stroke risk at the community level after controlling for sociodemographic characteristics. The following determinants were identified: net population density, building density, an abundance of parks and institutional land, and access to medical facilities.

The current research has made new achievements as follows: (1) it elucidated the multiplicity of stroke-related BE elements and established a conceptual framework for capturing the intricate BE-stroke nexus; (2) inconsistent with prior studies conducted in developed countries, it indicated that compact urban developments might not be a panacea for public health promotion, at least not for stroke prevention; and (3) it identified several salubrious BE elements that act against the prevalence of stroke. As such, we argue that, given the multiple pathways connecting BEs and lifestyle-associated health outcomes, the establishment of comprehensive conceptual frameworks that sufficiently consider the multiplicity of health-related BEs deserves to be highlighted in further research, intervention schemes, and assessment projects. Policy makers and planning practitioners should scrutinise the applicability of prevalent compact urban developments in transitional cities. Additionally, more efforts should be made to guarantee access to the identified salubrious BE resources, especially considering that the urban densities in transitional countries will inevitably increase.

We end by acknowledging the limitations of our research. First, only one-year stroke records are included, while the distribution of stroke risks might vary over time. Second, detailed information about community-level air pollution and diseases that are precursors to stroke is not taken into consideration due to data availability and privacy protections in China. Excluding these variables might exaggerate the influence of BEs on stroke. Third, this study reveals only the stroke-BE correlations rather than causal relationships. Future studies could employ longitudinal datasets to eliminate temporal variation in stroke. The mediators of the association between the BE and stroke risk could be quantified. Additionally, a more sophisticated research design (e.g., a quasi-experimental design) could be implemented to better understand the causal relationship between BEs and stroke.

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