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Suburban neighborhood environments and depression: A case study of Guangzhou, China

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A B S T R A C T

Background: Research on neighbourhood environments and depression has concentrated on public health in developed countries. This study aims to enrich the discourse on geographic characteristics and depression by providing new evidence of direct and indirect associations between suburban neighbourhood environments and depression in urban China.

Methods: Panyu in Guangzhou, a suburban district restructured by the speedy expansion of private housing, was selected as the case study area. Given the wide variety of influential factors of neighbourhood environments on depression, multivariate statistical analysis was performed using a two-stage model: 1) Binary Logistic Regression to evaluate the direct associations between neighbourhood environmental factors and depression; 2) Path Analysis to assess the indirect relationships between neighbourhood environmental attributes, physical activity and depression.

Results: We found that population density, sufficiency of public space, land use mix level and street connectivity had direct impacts on depressive symptoms. Land use mix, street connectivity and destination accessibility had indirect effects on depressive symptoms through influencing time spent on public transport and driving time. However, no significant effect of social capital on depression was found.

Conclusion: Environmental factors and mechanisms negatively affecting depressive symptoms in the specific suburban context of Guangzhou, China, are found to be the unsatisfactory public space and community facility provision, and land use mix. This study particularly identifies the mediation effect of time spent on public transit and driving time on depressive symptoms, enriching the debates in the extant literature on mediating effects of utilitarian physical activity in suburban China. It was also ascertained that interventions that create comfortable, convenient, appropriate, and active built environment can reduce depression symptoms.

1. Introduction

Depression among Chinese urban adults has become more prevalent, increasing from 1.7% in 2001 to 6% in 2012, more so in highly populated cities (Yang et al., 2018; Gupta et al., 2016). The major residential developments in China's suburbs are expected to have tremendous mental health implications, both positive and negative (Frumkin, 2002). Transiting from a government-led mode to a market-led mode and ensued by the land-based government revenue policy, housing and land reforms in China have ushered in a suburbanization process led by private housing development. The consequences of such a suburbanization process are high-density and mixed land-use development, engendering rapid spatial and social transformations (Yang et al., 2018; Tana et al., 2016; Feng et al., 2008). These newly risen Chinese suburban residential developments mainly take the form of gated communities, differing significantly from the former work unit residential compounds commonly found in the urban areas. They are featured by specific design styles and forms to suit the tastes and lifestyles of the growing urban middle class, such as exclusivity through gating, high-rise building form, market-oriented communal service provision, enclosed green and public space, and private property management (Wu, 2010; Breitung, 2012). Within the Chinese context, the influence of these proliferating suburban neighbourhoods on residents' mental health, specifically depression, which is the most common form of mental health problem, needs urban researchers' urgent attention (Gong et al., 2012).

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There has been a recent spree in urban research on the connections between neighbourhood environments and mental health, focusing on the implications of physical and social environmental factors such as walkability, green space, air pollution, social cohesion, and social capital (Clark et al., 2006; Dong and Qin, 2017; Miles et al., 2012). Suburbs, as residential units within commuting distance of cities and specific units for analysis, are expected to have impacted on the mental health of the local population (Butterworth et al., 2012). Nonetheless, the thrust of the extant literature on this topic mainly concerns the more developed countries (e.g. Frumkin, 2002; Oliver, 2003; Sturm and Cohen, 2004; Ewing et al., 2008), while that on the less developed areas has been slow coming. To help fill the research gap, a population-based study based on a theoretical framework was developed to examine the direct and indirect associations between neighbourhood environments and depression in China's suburbs, which have been proliferating fast since the 1990's.

2. Theoretical contexts: suburbs, neighbourhood environments and depression

Locality and geographical area matter in the associations between neighbourhood environments and mental health. To decipher mental health implications of neighbourhood environments, voluminous literature draws on "residents' percpetions of their environment and geographical area variations or contextual assessments of the quality of the built environment" (Araya et al., 2006, p.3074; Wainwright and Surtees, 2004; Weich et al., 2002; Weich et al., 2003). Evidence for environmental influence in mental health outcomes remains erratic across different local contexts (Propper et al., 2005). The extant literature proved several attributes of suburbs to be associated with mental health: automobile reliance, land use decisions, social capital, and environmental justice (Frumkin, 2002; Weich et al., 2002, 2003). Thus, this study, though contextualized in the suburban areas, does not deal with geographical differences among the chosen suburban neighbourhoods, but the impact of the living environment of housing estates as discrete neighbourhoods on the mental health of their residents.

Regarding the relationships between neighbourhood environments and depression, many plausible theoretical mechanisms have been put forward to explain their putative associations, incorporating two groups of influential factors: neighbourhood environment factors and individual factors (Weich et al., 2003; Guite et al., 2006; Kim, 2008; O'Campo et al., 2009; Sarkar et al., 2014; Frank et al., 2019). The neighbourhood factors are broadly categorized into the built and social environments: the former category mainly includes land use morphometric, transportation, public amenities, and design features; the latter category mainly involves social capital, sense of community and social disorder (Frank et al., 2003; Kim, 2008; Sarkar et al., 2014). The individual factors are composed of socio-demographic characteristics, physiologic and psychosocial factors, and health-related behaviors. Thus, examining the impact of neighbourhood environments on depression is complex, because many of the above factors may be interrelated and may also influence each other (Diez-Roux, 2001), suggesting both direct and indirect pathways linking neighbourhoods and depression.

Numerous extant studies posit behavioral pathways which link up the built environment and depression, emphasizing the mediation of physical activity (e.g. Frumkin, 2002; Sturm and Cohen, 2004; Frank and Engelke, 2001; Vojnovic et al., 2006; Frank et al., 2019). Regular physical activity can contribute to the development of higher tolerance levels and increase individual's ability to cope with stress, relieving the symptoms of depression and anxiety and improving peoples' mood (Ewing et al., 2008; Frank et al., 2003). Physical activity is shaped by the built environment, particularly the urban form characteristics, indicated by, for example, density, land use mix, walkability, connectivity, building design and configuration, transportation infrastructure and streetscapes (Frank and Engelke, 2001; Vojnovic et al., 2006; Frank et al., 2019). However, the underlying mechanisms between the built environments and residents' physical activity and its consequential impacts on depression are under-studied, due to the overwhelming attention given to physical health (Pfeiffer and Cloutier, 2016). Within the suburban context, the uniqueness of suburban urban form may exact a depression toll, such as its location necessitating automobile commuting that was found to be linked with self-reported stress (Frank and Engelke, 2001). More empirical research on the influence of suburban environments on physical activity effecting mental health is thus called for.

Neighbourhood social environment is mostly evaluated by social capital, whose direct effects on depression are acknowledged (Dong and Qin, 2017; Cao et al., 2015; Kim, 2008). Two components of social capital are usually distinguished on the links between social capital and depression (Forsman et al., 2012; Almedom, 2005): cognitive social capital (trust and reciprocity) and structural social capital (social relationships and social participation) (Cao et al., 2015; Forsman et al., 2012; De Silva et al., 2005; Araya et al., 2006). More evidence is found in the connections between depression and cognitive social capital (Cohen-Cline et al., 2018; De Silva et al., 2005). Overall, research on the associations of social capital with depression often give mixed findings (Cao et al., 2015; Araya et al., 2006). There are studies which demonstrate that social capital is weak in suburbs because of over-long driving time reducing opportunities for face-to-face interactions, while some found null associations (Sturm and Cohen, 2004; Frank and Engelke, 2001). Arguably, the mixed findings owe to the complex and compound nature of social capital (Almedom, 2005; Araya et al., 2006). Additionally, the associations between social capital and depression may be confounded by built environmental variables and individual factors (Cohen-Cline et al., 2018), indicating the indirect effects of social capital on depression.

Regarding the local context of Chinese rapid suburbanization, built and social environments of suburban neighbourhoods could potentially affect depression, mediated or confounded by residents' individual factors. Therefore, both direct and indirect associations between suburban neighbourhood environments and depression, with the mediations of physical activity, should be examined comprehensively.

3. Methods

3.1. Selection of "area of interest"

Guangzhou was selected as the area of interest due to its pioneering role in China's residential suburbanization (Wu et al., 2006), in particular, the speedy expansion of commodity residential enclaves in Panyu District over the past three decades (He and Jia, 2007). To represent various neighbourhood environments, three typical housing estates developed in different stages of Guangzhou's suburbanization were chosen (Fig. 2). They were: *Luoxi New Town* (LNT) (developed in the 1990s), developed by market-government cooperation and characterized by high-density and mixed land uses; 2) Agile Garden (AG) (constructed from 2000 to 2010), mainly produced by developers. It is a large-scale gated community with single land use and provides self-dependent public service facilities; 3) Asian Game Village (GV) (from 2007 to 2010), a transportation-oriented development built under government's enhanced regulation of land leasing. It is a gated community of single land use, and comprised of high-rise buildings.

3.2. Data collection

Focusing on mental conditions and perceived neighbourhood environment of each individual, this population-based study collected all information through a long-form questionnaire between June 15 and September 5, 2015. This long-form questionnaire included the following dimensions of information: 1) prevalence of depression; 2) perceived built and social environment; 3) physical activity; and 4) demographic characteristics.

Due to the gated nature of commodity housing estates in China and the difficulties of household survey, convenience sampling was employed at the entrances and public spaces of each housing estate. Participants were adult residents aged from 20 to 90 who had been living in the neighbourhoods for at least half a year. Strategies to improve sample randomness while balancing the sample representatives were also implemented, including 1) sampling at different public place including parks, squares and public service facilities; 2) sampling at different time periods, including 9:00am to 12:00pm or 3:00pm to 8:00pm on both weekdays and weekends; and 3) sampling local residents of different age groups. A total of 596 adults participated, including 98 participants with invalid responses such as the participant giving exactly the same responses for each single item that he or she was asked, or more than 20% incomplete responses. Excluding the invalid information, there were 498 valid participants in this study.

3.3. Measures of depressive symptoms

Prevalence of depression was measured based on the Center for Epidemiological Studies-Depression (CES-D) scale, an instrument for measuring contemporary depressive symptomology in a community setting (Miles et al., 2012). The reliability and validity of CES-D scale in general population have been proved in the extant literature (Radloff, 1977; Miles et al., 2012; Chen et al., 2013; Chen et al., 2014). Furthermore, CES-D scale has good psychometric properties across cultures (Zhang and Norvilitis, 2002), and in particular it has been validated in Chinese population by many scholars, demonstrating good reliability (Lu et al., 2012; Pan et al., 2009; Wu et al., 2010). Specifically, depression was measured by the occurrence frequency of twenty depressive symptoms within a week (Wu et al., 2010) (Table 1). Four response categories, scored from 0 to 3, were provided for evaluating each item, with an optimal cutoff point of 16 adopted to decide the "cases" of depression, following the studies of Cho and Kim (1998), Radloff (1977), and Weich et al. (2002). The Cronbach's α is 0.81 for the participants in this study.

3.4. Measures of neighbourhood social environment: social capital

Neighbourhood social environment was diagnosed with the concept of social capital. Four measures of social capital associated with both cognitive and structural social capital were used, including 1) trust, 2) reciprocity, 3) sense of belonging, and 4) social relationship. Respondents were asked to indicate how strongly they agreed or disagreed with the following four items: *1) I can trust my neighbors; 2) Residents here are willing to help each other; 3) I could feel a strong sense of belonging living in this neighbourhood; 4) overall, we have a harmonious social relationship in this neighbourhood.* A five-point response scale was used, ranging from strongly disagree (score 1) to strongly agree (score 5). The Cronbach's alpha for the four items in these data was 0.826. Sum score (SC) were computed, with higher score indicating higher level of social capital.

3.5. Measures of neighbourhood built environment: perceived environment

Neighbourhood built environment was measured by perceived environment, paying particular attention to the salient characteristics of Chinese suburban neighbourhood form. An environment-behavior approach was adopted for assessing residents' perception of the built environment and urban form attributes. Accordingly, respondents were asked about their daily living experience and post-occupancy evaluation on the built environment. Six measures related to perceived environment were used, including 1) perceived comfort level of population density (PE1) based on a 5-point scale (1-very discomfort, 2-discomfort, 3-neutral, 4-comfort, 5-very comfort); 2) destination accessibility (PE2) based on an average of five scores with 5-point scales for the perception of the high or low accessibility to following types of destinations: commercial facilities, recreational destinations, schools or kindergartens, health care facilities, and public service center; 3) land use mix level (PE3) based on an average of three scores with 5-point scales for perceived sufficiency of commercial, educational and health care facilities; 4) street connectivity (PE4) based on the average of three scores with 5-point scales for perceived connections from home to public services, transit stops and subway station; 5) public space (PE5) based on a score with 5-point scales for perceived sufficiency of public space for social interaction between neighbors and community activity; and 6) green space (PE6) based on a score with 5-point scales for perceived sufficiency of green space. Specifically, the 5-point scales for the measures of 2) to 6) were ratings of agreement, with "1" as strongly disagree and "5" as strongly agree.

Table 1
Center for epidemiologic studies depression scale (CES-D).

	During the past week			
	less than 1 day	1–2days	3–4days	5–7days
1. I was bothered by things that usually don't bother me.				
2. I did not feel like eating; my appetite was poor.				
3. I felt that I could not shake off the blues even with help from my family or friends.				
4. I felt I was just as good as other people.				
5. I had trouble keeping my mind on what I was doing.				
6. I felt depressed.				
7. I felt that everything I did was an effort.				
8. I felt hopeful about the future.				
9. I thought my life had been a failure.				
10. I felt fearful.				
11. My sleep was restless.				
12. I was happy.				
13. I talked less than usual.				
14. I felt lonely.				
15. People were unfriendly.				
16. I enjoyed life.				
17. I had crying spells.				
18. I felt sad.				
19. I felt that people dislike me.				
20. I could not get “going.“				

3.6. Measures of activity: transportation and recreational related physical activity

Referring to the purpose of activity, physical activity can be either recreational or utilitarian in nature (Frank et al., 2003). Recreational physical activity is undertaken for discretionary reasons during one's leisure time, while utilitarian physical activity is undertaken to accomplish specific purposes, such as walking or cycling to work, school or shop (Frank et al., 2003). This study investigated residents' physical activity from both dimensions: transportation activity and recreational activity. Transportation activity was measured by the travel time on four-type travel modes: utilitarian walking time (TA1), cycling time (TA2), time on public transport (TA3), and driving time (TA4) on a workday level. For participants who did not commute, they could choose “not applicable” in the above measurements. Recreational activity was measured by the types, frequency (days/week) and duration (time/day) during an average week in the past six months. Household and school/work activity were not involved, since they were unlikely to be affected by neighbourhood environments (Dzhambov et al., 2018). Following Fan et al. (2014), we converted the reported types of recreational activity into three groups (vigorous one, moderate one, and walking) according to their metabolic equivalent values, and multiplied it with frequency and duration to compute total daily energy expenditure. Accordingly, three levels of recreational activity (RA level) were classified (high, moderate, and low) based on the categorical scale.[1]

3.7. Measures for demographic characteristics

Demographic characteristics in this study were nine measures for individual socio-demographic factors and individual general health as the confounders of statistical modeling, including age, gender, education attainment, *hukou* status, household type, employment status, annual income, homeownership, and self-reported health status.

3.8. Statistical analyses

A data screening was pre-applied in this study. Based on this screening, eighteen variables were of less than 5% missing values. Due to the small proportion of missing data, imputation was conducted to replace all missing values with the median for ordinal scales or the mean for continuous scales period (Pigott, 2001). A two-stage model was applied for the multivariate statistical analysis. This two-stage model was developed based on a statistical hypothesis as follow: 1) the first stage of the analysis was to follow the traditional statistical model based on clinical assumptions to evaluate the direct impacts of neighbourhood environments on persons with or without depressive symptoms (grouped by binary classification). We hypothesized that such clinical-based application can partially explain the relationship

[1] Category 1 LowThose individuals who not meet criteria for Categories 2 or 3 are considered to have a ‘low’ recreational activity level.Category 2 ModerateThe pattern of activity to be classified as ‘moderate’ is either of the following criteria:a) 3 or more days of vigorous-intensity activity of at least 20 min per dayORb) 5 or more days of moderate-intensity activity and/or walking of at least 30 min per dayORc) 5 or more days of any combination of walking, moderate-intensity or vigorous intensity activity achieving a minimum total recreational activity of at least 600 MET-minutes/week.Category 3 HighThe pattern of activity to be classified as ‘high’ is either of the following criteria:a) vigorous-intensity activity on at least 3 days achieving a minimum total recreational activity of at least 1500 MET-minutes/weekORb) 7 or more days of any combination of walking, moderate-intensity or vigorous-intensity activity achieving a minimum total recreational activity of at least 3000 MET-minutes/week.

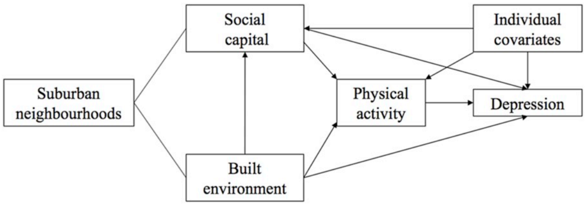


Fig. 1. A theoretically-indicated mediation model of suburban neighbourhoods and depression.

between environmental factors and depression, although this may be insufficient to report all statistical associations because environment itself is complex and dynamic. Thus, we hypothesized that an analysis to explore multiple pathways to explain all direct and indirect associations between neighbourhood environments and depression should be conducted, if insufficient results from the model of the first stage of analysis were reported. 2) Consequently, the second stage of analysis was developed based on an enhanced model. Specifically, this model can self-explain both direct and indirect relationships between neighbourhood environments and depression. Also, as the prevalence of depression should be represented in a finer-level of change, a continuous form of depression data was used instead of applying traditional binary classifier as in the case of clinical-based rapid assessment of depressive symptoms. The results of this second stage of analysis is expected to report fuller the underlying mechanism between environmental factors and depression.

The first stage of the analyses was to evaluate the direct relationship between various neighbourhood environments and depression based on a rapid assessment with clinical assumptions. With the use of four binomial regressions, we analyze the impacts of each hypothesized predictor (physical activity, social capital, perceived environment) on the prevalence of depression. Odds ratios (OR) and two-tailed 95% confidence intervals (Cis) from the beta coefficient (β) of each variable were used to evaluate the independent effect of each factor on the prevalence of depression. In details, model 1 to model 3 were the partial models, in which model 1 examined the direct influences of transportation and recreational activity indicators, model 2 examined the direct effects of social capital variables, and model 3 examined the direct influences of perceived environment vindicators. Model 4 was as a full model to comprehensively analyze the direct effects of transportation and recreational activity, social capital, and perceived environment while controlling for each other. All of these models were adjusted for age, gender, education level, *hukou*, household type, employment status, annual income, homeownership, and general health status. These regressions were performed by the software SPSS 24, and OR and CIs were reported.

The second stage of this statistical analysis was to explore the multiple (direct and indirect) pathways between neighbourhood characteristics and depression based on an enhanced framework. A path analysis was used to assess the theoretically-indicated interplay between all factors. Fig. 1 specifies the theoretically–indicated pathways of neighbourhood environments influencing depression socially and physically, incorporating the effects of individual socioeconomic and general health attributes. Five theoretical pathways were proposed: a) built environment - > depression; b) built environment - > social capital - > depression; c) built environment - > physical activity - > depression; and d) built environment - > social capital - > physical activity - > depression. With the use of structural equation model, the mechanisms of neighbourhood environments affecting depression were explained. Depression sum score of CES-D scale was

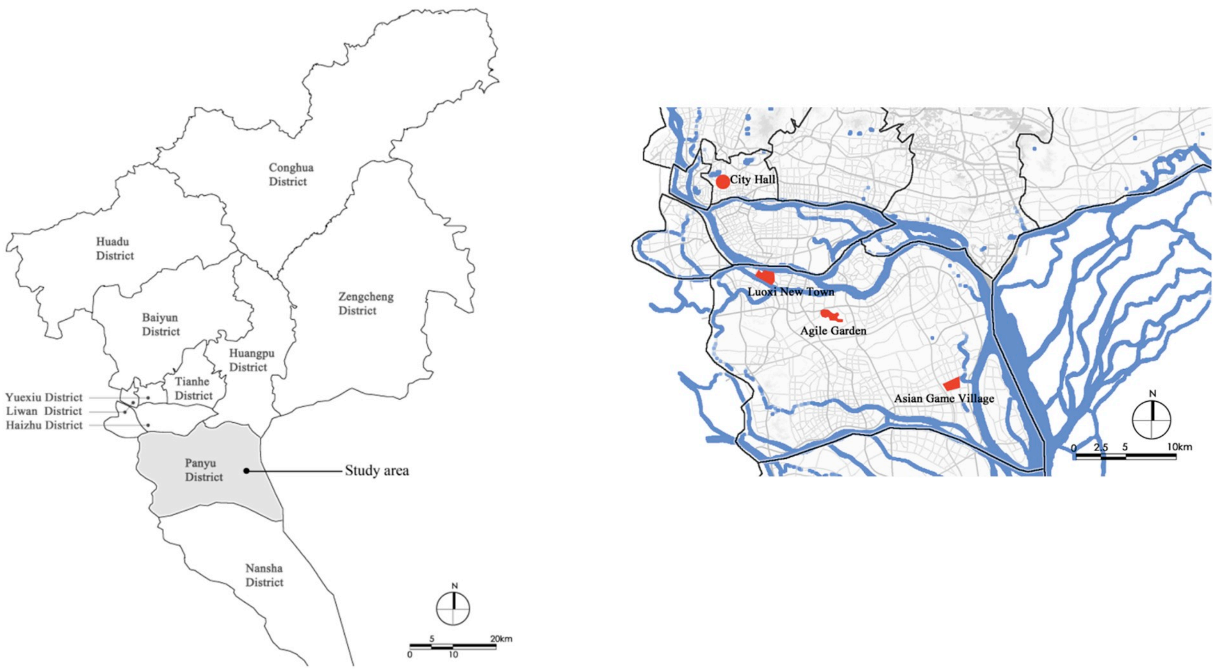


Fig. 2. Location of the cases.

Table 2
Descriptive statistics of the sample (N = 498).

	Mean	Standard deviation
Depression symptoms	13.7	5.93
Social capital (sum sore)	15.0	2.41
Trust: *I can trust my neighbors*	3.7	0.72
Help: *Residents here are willing to help each other*	3.7	0.75
Sense of belonging: *I could feel a strong sense of belonging living in this neighbourhood*	3.8	0.74
Social relationship*: We have a harmonious social relationship in this neighbourhood.*	3.8	0.74
Perceived environment		
PE1: Population density: *comfort level*	3.4	0.89
PE2: Destination accessibility: *ease of accessing to five types of destinations*	3.6	0.71
PE3: Land mix use level: *sufficiency of commercial, educational and health care facilities*	3.1	0.81
PE4: Street connectivity: *to public services, transit stops, subway station*	3.3	0.56
PE5: Public space: *sufficiency*	3.4	0.94
PE6: Green space: *sufficiency*	2.7	0.98
Transportation activity		
Utilitarian walking time		
Not available	13.1%	
< 30 min	47.4%	
30–59min	21.3%	
1h–1.5 h	7.8%	
1.5 h–2h	2.8%	
> 2 h	7.6%	
Utilitarian cycling time		
Not available	62.7%	
< 30 min	18.1%	
30–59min	12.9%	
1h–1.5 h	3.0%	
1.5 h–2h	2.2%	
> 2 h	1.2%	
Time on public transit		
Not available	29.1%	
< 30 min	28.3%	
30–59min	24.1%	
1h–1.5 h	11.2%	
1.5 h–2h	3.0%	
> 2 h	4.2%	
Driving time		
Not available	62.2%	
< 30 min	12.0%	
30–59min	9.0%	
1h–1.5 h	5.6%	
1.5 h–2h	3.2%	
> 2 h	7.8%	
Recreational activity level		
Low	66.9%	
Middle	21.3%	
High	11.8%	

used as the dependent variable, representing a variability of depressive symptoms. The six perceived environment variables (PE1-PE6) were allowed to be correlated since they were the compositional aspects of the built environment of neighbourhoods. Due to the non-normalized and categorical variables, asymptotic distribution free (ADF) method of Browne (1984) was applied to compute the covariance matrix of standardized regression coefficients (Finney and DiStefano, 2006), since ADF does not assume normality and has better performance with moderate-to-large samples (Muthen and Kaplan, 1992). This path analysis was conducted by the software Amos 24, and coefficient and standard error (SE) for all paths were reported.

4. Results

4.1. Data summary

In general, the mean sum score of CES-D was 13.7, with a standard deviation (SD) of 5.93 and range from 0 to 44. The overall prevalence of depression among all participants (N = 498) was 24.7%. This level of depression was higher than a previous finding among overall populations in Guangzhou of which the mean score of CES-D is 9.9 (Fu, 2018). The difference may be caused by the different sampling strategy, and the convenience sampling method used in this study may cause some bias. It may also be due to the nature of suburban population, who inherently have higher prevalence of depression than the general population.

Table 3
Individual covariates and the prevalence of depression (N = 498).

	%Participants (n)	%Depression (n)	Chi-square	p
Gender			3.30	0.069
Female	50.2 (250)	21.2 (53)		
Male	49.8 (248)	28.2 (70)		
Age			1.82	0.768
20–29	25.9 (129)	27.9 (36)		
30–39	32.1 (160)	23.1 (37)		
40–49	14.9 (74)	20.3 (15)		
50–59	12.2 (61)	26.2 (16)		
≥60	14.9 (74)	25.7 (19)		
Education attainment			1.89	0.596
Primary school and below	11.0 (55)	25.5 (14)		
Junior high school	16.1 (80)	18.8 (15)		
High school	22.5 (112)	25.0 (28)		
Bachelor and above	50.4 (251)	26.3 (66)		
Hokou status			0.79	0.373
Yes	17.3 (86)	20.9 (18)		
No	82.7 (412)	25.5 (105)		
Household type			6.33	0.176
Singe family	15.5 (77)	28.6 (22)		
One couple family	18.3 (91)	25.3 (23)		
Core family	29.9 (149)	24.2 (36)		
Three generation	30.3 (151)	19.9 (30)		
Others	6.0 (30)	40.0 (12)		
Employment status			0.47	0.491
Yes	74.9 (373)	25.5 (95)		
No	25.1 (125)	22.4 (28)		
Individual annual income (after tax)			1.41	0.842
<4340 US$	20.3 (101)	26.7 (27)		
4340–11,573	29.9 (149)	24.2 (36)		
11,573–2,1700	37.1 (185)	23.8 (44)		
21,700–43,400	8.4 (42)	21.4 (9)		
>43,400	4.2 (21)	33.3 (7)		
Homeownership			0.05	0.823
Yes	65.1 (324)	24.4 (79)		
no	34.9 (174)	25.3 (44)		
Self-rated health status			10.18	0.037*
Very good	7.8 (39)	17.9 (7)		
Good	30.3 (151)	18.5 (28)		
Fair	33.7 (168)	25.6 (43)		
Poor	25.1 (125)	30.4 (38)		
Very poor	3.0 (15)	46.7 (7)		

Summarizing the demographic characteristics of all participants (Table 3), the sex ratio was approximate to 1:1. The range of age of all participants were from 20 to 90 years old, with an average of 40 years with a standard deviation of about 15 years. In addition, there were 14.9% of the participants who were older adults with aged ≥ 60 years, and 25.1% of the participants were either retired or unemployed. The average individual annual income was US$11,573, and 87.4% of the participants reported an income level less than US$ 21,700. Additionally, although 50.4% of the participants received high education (obtained a bachelor degree or above), still 11.0% of them only graduated from primary school or below. There were slightly more participants from either a core family (29.9%) or a “three generations” family (30.3%) than those from one-couple family and singleton family. We also noted that a large proportion of the participants were homeowner (65.1%) or were without “citizenship” (*Hukou*) status in Guangzhou (82.7%). The health status of all participants was fairly evenly distributed, with 38.1% reported as “good” or “very good”, 33.7% reported as “fair”, and 28.1% reported as “poor” or “very poor”, respectively. Based on the Chi-square test, none of sociodemographic characteristics has significant association with prevalence of depression except the self-rated health status reported above (Table 3), indicating the need for further examination on the effects of individual sociodemographic characteristics on depression.

By summarizing the measures for perceived environment, social capital and physical activity (Table 2), PE1 to PE5 were between neutral and a positive status (3.1–3.6) in the 5-point scale while that of PE6 was between a negative status and neutral (2.7). The mean sum score of social capital was 15.0 with a standard deviation of 2.41. Specifically, the average scores of social capital indicators (trust, help, sense of belonging, and social relationship) were between neutral and agree (3.7–3.8) in the 5-point scale ranging from strongly disagree to strongly agree. For transportation activity, walking was widely used by the participants (86.9%), followed by public transit (70.9%), while few participants cycled (37.3%) or drove (37.8%) to destinations. For travelling time, around one-half of the respondents walked less than 30min with one-fifth walked 0.5–1 h on a weekday. Among respondents cycling to destinations, most of them cycled less than 1 h (83.1%). A similar percentage respondents took public transit less than 30min (28.3%) and from 0.5 to 1 h (24.1%). Among respondents driving to destinations, most of them drove less than 30min (12%), following by those drove from 0.5 to 1 h (9%). For recreational activity, around two-third respondents (66.9%) reported a low level, with one-fifth (21.3%) reported a middle level.

Table 4
Modeling the associations between depression and physical activity, social capital and perceived environment on depression.

	CES-D depression (N = 498)			
	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)	Model 4 OR (95% CI)
Individual correlates				
Female	0.66 (0.41, 1.09)	0.65 (0.41, 1.03)	0.58* (0.37, 0.93)	0.59* (0.35, 0.99)
Age (20–29)				
30-39	0.98 (0.51,1.87)	0.80 (0.43, 1.46)	0.84 (0.45, 1.57)	1.02 (0.52, 1.99)
40-49	0.71 (0.30,1.66)	0.69 (0.31, 1.52)	0.80 (0.35, 1.81)	0.82 (0.34, 2.00)
50-59	1.66 (0.64, 4.34)	1.49 (0.61, 3.67)	1.78 (0.70, 4.52)	1.90 (0.70, 5.16)
≥60	1.98 (0.63, 6.27)	1.56 (0.55, 4.39)	1.99 (0.68, 5.89)	2.47 (0.74, 8,19)
Education attainment (Primary school or below)				
Junior high school	0.58 (0.22, 1.56)	0.58 (0.23, 1.45)	0.49 (0.19, 1.28)	0.45 (0.16, 1.26)
High school	1.14 (0.45, 2.94)	1.05 (0.44, 2.54)	0.95 (0.38, 2.36)	1.01 (0.38, 2.67)
Bachelor or above	1.27 (0.48, 3.35)	1.06 (0.43, 2.62)	0.94 (0.37, 2.39)	1.11 (0.41, 3.05)
Employed	1.69 (0.75, 3.80)	1.63 (0.76, 3.52)	1.63 (0.73, 3.66)	1.64 (0.70, 3.83)
Income (<4340 US$)				
4340–11,573	0.81 (0.40, 1.66)	0.86 (0.44, 1.69)	0.81 (0.41, 1.64)	0.74 (0.35, 1.57)
11,573–2,1700	0.83 (0.43, 1.62)	0.93 (0.50, 1.72)	0.85 (0.45, 1.62)	0.74 (0.37, 1.48)
21,700–43,400	0.62 (0.23, 1.68)	0.66 (0.25, 1.72)	0.63 (0.23, 1.68)	0.58 (0.21, 1.61)
>43,400	1.55 (0.43, 5.54)	1.31 (0.42, 4.09)	1.22 (0.37, 4.00)	1.31 (0.36, 4.86)
Homeowner	1.12 (0.63, 1.96)	1.05 (0.62, 1.77)	0.88 (0.51, 1.51)	0.95 (0.53, 1.71)
Without Guangzhou Hukou	1.42 (0.74, 2.73)	1.32 (0.72, 2.41)	1.43 (0.76, 2.67)	1.55 (0.80, 3.02)
Household type (singe family)				
One couple	0.71 (0.32, 1.60)	0.90 (0.42, 1.94)	0.94 (0.43, 2.03)	0.74 (0.318, 1.708)
Core family	0.85 (0.39, 1.85)	0.99 (0.48, 2.05)	1.04 (0.49, 2.18)	0.92 (0.414, 2.037)
Three generation	0.49 (0.20, 1.21)	0.61 (0.26, 1.42)	0.63 (0.27, 1.51)	0.53 (0.209, 1.336)
Others	1.35 (0.49.3.72)	1.68 (0.65, 4.37)	1.51 (0.56, 4.10)	1.23 (0.430, 3.543)
Health status (Very poor)				
Very good	0.11* (0.03, 0.52)	0.17* (0.04, 0.67)	0.16 (0.04, 0.69)	0.10** (0.02, 0.48)
Good	0.18** (0.05, 0.65)	0.19** (0.06, 0.64)	0.20 (0.06, 0.69)	0.17** (0.04, 0.60)
Fair	0.28* (0.08, 0.98)	0.30* (0.09, 0.97)	0.31 (0.10, 1.02)	0.26* (0.07, 0.93)
Poor	0.38 (0.11, 1.34)	0.39 (0.12, 1.26)	0.41 (0.13, 1.37)	0.36 (0.10, 1.276)
Transportation activity				
Utilitarian walking time (>2 h)				
NA	0.38 (0.13, 1.06)			0.46 (0.16, 1.36)
<30 min	0.29* (0.12, 0.70)			0.34* (0.13, 0.86)
30–59min	0.31* (0.12, 0.78)			0.41 (0.16, 1.06)
1h–1.5 h	0.45 (0.15, 1.33)			0.52 (0.16, 1.65)
1.5 h–2h	0.08* (0.01, 0.79)			0.10 (0.01, 1.14)
Utilitarian cycling time (>2 h)				
NA	0.15 (0.02, 1.18)			0.18 (0.02, 1.53)
<30 min	0.19 (0.02, 1.53)			0.24 (0.03, 2.114)
30–59min	0.36 (0.04, 2.97)			0.40 (0.04, 3.60)
1h–1.5 h	0.13 (0.01, 1.53)			0.11 (0.01, 1.39)
1.5 h–2h	0.05* (0.00, 0.93)			0.04 (0.002, 1.05)
Time on public transit (>2 h)				
NA	1.72 (0.46, 6.52)			1.27 (0.34, 4.75)
<30 min	2.55 (0.66, 9.87)			1.87 (0.49, 7.19)
30–59min	3.85* (1.02, 14.51)			3.00 (0.80, 11.32)
1h–1.5 h	1.71 (0.40, 7.31)			1.30 (0.31, 5.50)
1.5 h–2h	0.87 (0.12, 6.21)			0.73 (0.10, 5.17)
Driving time (>2 h)				
NA	0.74 (0.32, 1.70)			0.84 (0.36, 2.00)
<30 min	0.57 (0.20, 1.60)			0.58 (0.20, 1.69)
30–59min	0.48 (0.16, 1.50)			0.56 (0.17, 1.78)
1h–1.5 h	0.68 (0.19, 2.38)			0.76 (0.21, 2.77)
1.5 h–2h	0.26 (0.05, 1.55)			0.29 (0.05, 1.77)
Recreational activity level (low)				
Middle	0.97 (0.52, 1.81)			0.97 (0.51, 1.85)
High	1.39 (0.67, 2.89)			1.31 (0.61, 2.78)
Social capital		1.02 (0.93, 1.12)		1.00 (0.90, 1.11)
Perceived environment				
Population density			0.64*** (0.50, 0.82)	0.65*** (0.50, 0.84)
Destination accessibility			0.77 (0.54, 1.10)	0.914 (0.62, 1.34)
Land mix use			1.26 (0.91, 1.73)	1.094 (0.77, 1.55)
Street connectivity			0.81 (0.54, 1.22)	0.75 (0.48, 1.16)
Public space			1.49** (1,14, 1.94)	1.49** (1.12, 1.96)

(*continued on next page*)

Table 4 (*continued*)

	CES-D depression (N = 498)			
	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)	Model 4 OR (95% CI)
Green space			1.04 (0.80, 1,35)	1.05 (0.80, 1.39)
Reliability				
R2 (Cox & Snell)	0.12	0.06	0.10	0.16
R2 (Nagelkerke)	0.18	0.09	0.15	0.23
-2 log likelihood	492.78	527.60	502.66	472.91

*p < 0.05, **p < 0.01, ***p < 0.001.

4.2. Rapid assessment: direct relationships between neighbourhood environments and depression

Based on the partial models controlling for demographic characteristics, model 1 found a direct association between physical activity and depression (Table 4). Specifically, transportation activity such as utilitarian walking time, utilitarian cycling time and time on public transit were significantly associated with the prevalence of depression. However, none of the variables related to recreational activity had a significant relationship with depression. Based on the model 2, none of the social capital factors had a significant association directly linked to depression of an individual. Based on the evaluation of a direct association between perceived environment and depression with model 3, only comfortable population density was negatively associated with depression and more public space was positively associated with the odds of depression. Specifically, a participant who rated one point higher for the comfort level of perceived population density is associated with 36.1% lower odds of prevalence of depression (OR = 0.64, 95%CI = 0.50–0.82), and a participant who rated a score higher for "sufficient public space" in the residential environment had a 48.7% higher odds of prevalence of depression (OR = 1.49, 95%CI = 1.14–1.94).

By additionally self-controlling for physical activity, social capital and perceived environment based on the full model (model 4), only the following variables were significantly associated with the prevalence of depression: 1) utilitarian walking time, 2) population density and 3) public space. In detail, a participant who walked for utility purposes for less than 30 min per day was 66.3% less likely to be depressed compared to those who walked longer than 2 h per day (OR = 0.34, 95%CI = 0.13–0.86). A participant who rated one point higher for the comfort level of the perceived population density is associated with 35.4% lower odds of prevalence of depression (OR = 0.64, 95%CI = 0.50–0.84), and a participant who rated a score higher for "sufficient public space" in the residential environment had a 47.8% higher odds of prevalence of depression (OR = 1.48, 95%CI = 1.13–1.96). Based on the difference and ranges in ORs as well as 95% CI in both model 3 and model 4, the influences of population density and public space on depression in the full model were consistent, indicating the relative contributions of factors associated with perceived environment on mental health risk. In addition, the change to insignificant results for utilitarian cycling time and time on public transit in model 4 implied a potential interacting effects between these transportation activity and population density and public space.

4.3. Enhanced analysis: multiple pathways between neighbourhood environments and depression

According to the insufficient results from the section above, we concluded that relationship between neighbourhood environments and depression should be a complex pathway with multiple indirect relationships.

Based on the path analysis, we found that perceived environment has partial influences on depressive symptoms through both direct and indirect pathways as follows: 1): a) perceived built environment - > depression and 2) perceived built environment - > physical activity - > depression (Fig. 3). In detail, controlling for the other pathways (Table 5), a participant who rated a higher score for comfort level of population density had a negative association with depression through a direct pathway (Coefficient: 0.94, SE: 0.30). A participant who rated a higher score for street connectivity also had a negative association with depression (Coefficient: 2.20, SE: 0.59). In contrast, those who rated a higher score for land use mix level may have a positive association with depressive symptoms through a direct pathway (Coefficient: 0.81, SE: 0.39), and those who rated a higher score for sufficiency of public space also has a positive relationship with depressive symptoms (Coefficient: 1.03, SE: 0.33). In addition, through the indirect pathways adjusting for factors, destination accessibility and land use mix had negative associations with time on public transit and street connectivity had a positive association with time on public transit, while time on public transport has a positive association with depressive symptoms. Land use mix also had a negative association with driving time while driving time has a positive association with depressive symptoms (Table 6).

5. Discussion

We examined the direct and indirect relationship between attributes of suburban neighbourhoods and depression based on a two-stage model. By the first stage model, we found that uncomfortable population density, more public space and excessive utilitarian walking time (longer than 2 h) were associated with higher prevalence of depression. Path analyses in the second stage model found various pathways of perceived environments influencing depressive symptoms comprehensively.

Specifically, comfortable population density and high street connectivity could alleviate depressive symptoms in a direct pathway, controlling for all other direct and indirect pathways. In contrast, more public space, higher land use mix level, longer time on public transit and longer driving time could exacerbate depressive symptoms. Indirect pathways can be found between perceived environment and depression through the mediations of transportation activity. In detail, better destination accessibility may decrease

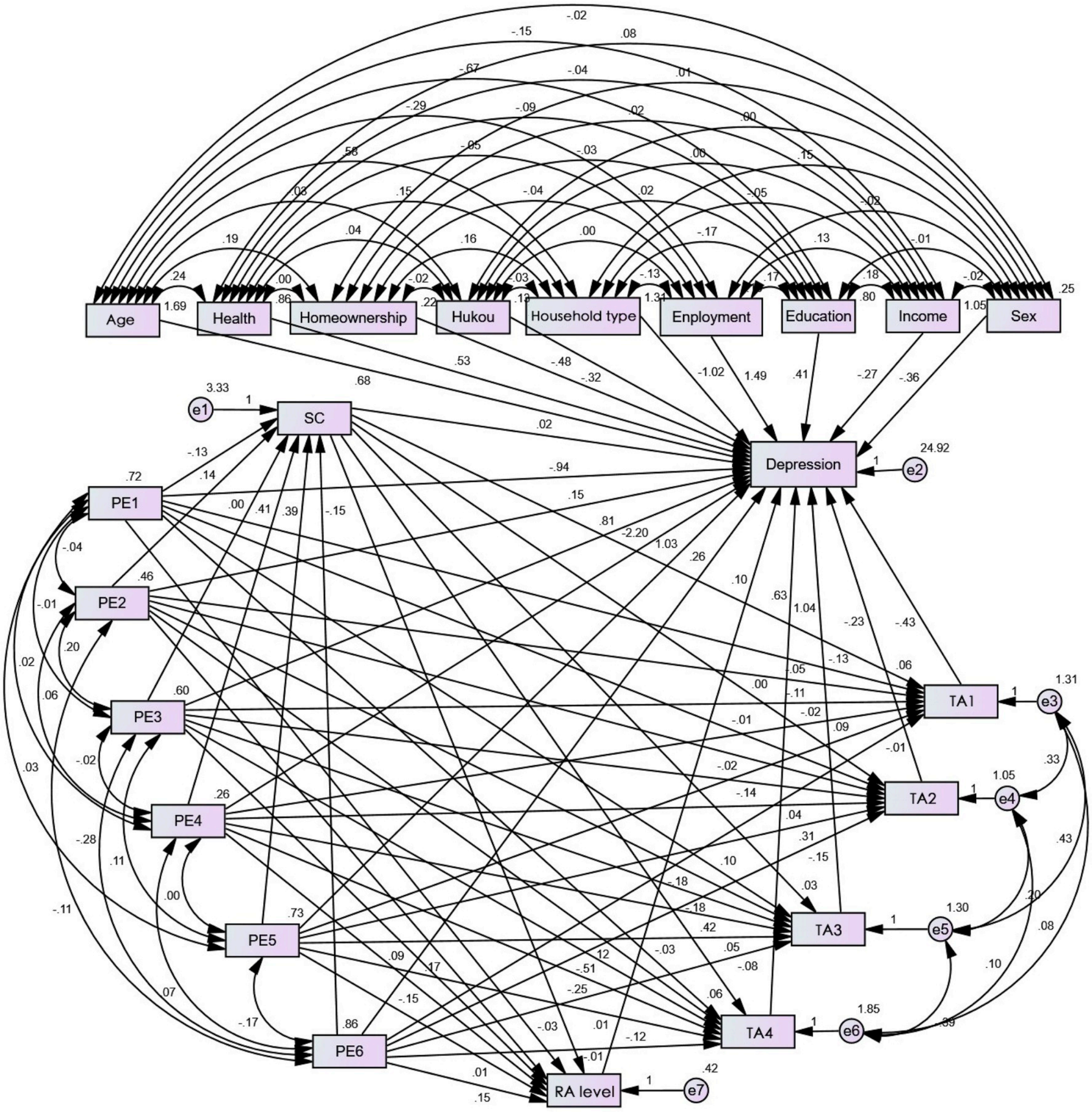


Fig. 3. Path diagram from suburban neigbourhoods to depression: standardized solution.
PE1: Population density.
PE2: Destination accessibility.
PE3: Land use mix.
PE4: Street connectivity.
PE5: Public space.
PE6: Green space.
SC: Social capital.
TA1: Utilitarian walking time.
TA2: Utilitarian cycling time.
TA3: Time on public transit.
TA4: Driving time.
RA level: Recreation activity level.

the time on public transit and further alleviate depressive symptoms. Land use mix may decrease both time on public transit and driving time and further reduce depressive symptoms. In contrast, higher street connectivity was associated with increased time on public transit, which exacerbated depressive symptoms. Through the understanding of multilevel results from this two-stage model, this study demonstrated that the urban system and its relationship with mental health is complex, and is necessary to be explained through multiple dimensions. Based on these, we deliberate the interpretations of the neighbourhood factors directly and indirectly associated with prevalence of depression in the suburban area of Guangzhou in the rest of this section.

5.1. Interpretation: transportation activity as an influential factor of depression

In the above path analysis model, we found that transportation activity acted as a significant mediator between perceived environment and depressive symptoms. Specifically, utilitarian walking time and recreational activity level did not appear to have any mediating effects; in contrast, time on public transit and driving time were positively associated with depressive symptoms, and unexpectedly the coefficients of the former (1.04) was larger than that of the latter (0.63). Although some scholars highlight negative effects of increasing automobiles on health in Chinese suburbanization (Kwan et al., 2014), this study found more negative effects of

Table 5
Results of the path analysis: unstandardized direct effects (N = 498).

	Coefficient	S.E.
PE1→ Depression	−0.94**	0.30
PE2→ Depression	0.15	0.44
PE3→ Depression	0.81**	0.39
PE4→ Depression	−2.20***	0.59
PE5→ Depression	1.03**	0.33
PE6→ Depression	0.26	0.29
SC→ Depression	0.02	0.16
TA1→ Depression	−0.43	0.33
TA2→ Depression	−0.23	0.27
TA3→ Depression	1.04**	0.33
TA4→ Depression	0.63**	0.24
RA level→ Depression	0.10	0.35
Age→ Depression	0.68**	0.26
Sex→ Depression	−0.37	0.50
Employment status→ Depression	1.49*	0.74
Household type→ Depression	−1.02***	0.23
Health→ Depression	0.53	0.32
Homeownership→ Depression	−0.48	0.54
Education→ Depression	0.41	0.37
Income→ Depression	−0.27	0.23
Hukou status→ Depression	−0.48	0.54
PE1→ SC	−0.13	0.11
PE2→ SC	0.14	0.14
PE3→ SC	0.00	0.14
PE4→ SC	0.41*	0.20
PE5→ SC	0.39***	0.12
PE6→ SC	−0.15	0.12
PE1→ TA1	−0.13*	0.05
PE2→ TA1	−0.05	0.09
PE3→ TA1	−0.11	0.08
PE4→ TA1	−0.02	0.11
PE5→ TA1	0.09	0.07
PE6→ TA1	−0.01	0.06
SC→ TA1	0.06*	0.03
PE1→ TA2	−0.02	0.05
PE2→ TA2	−0.02	0.07
PE3→ TA2	−0.15*	0.07
PE4→ TA2	0.04	0.10
PE5→ TA2	0.31***	0.06
PE6→ TA2	−0.15**	0.05
SC→ TA2	−0.00	0.03
PE1→ TA3	0.10	0.06
PE2→ TA3	−0.18*	0.09
PE3→ TA3	−0.18*	0.09
PE4→ TA3	0.43***	0.11
PE5→ TA3	0.05	0.07
PE6→ TA3	−0.08	0.07
SC→ TA3	−0.00	0.03
PE1→ TA4	−0.03	0.07
PE2→ TA4	0.12	0.10
PE3→ TA4	−0.51***	0.10
PE4→ TA4	−0.25	0.15
PE5→ TA4	0.01	0.08
PE6→ TA4	−0.12	0.08
SC→ TA4	−0.00	0.03
PE1→ RA level	−0.03	0.03
PE2→ RA level	0.17***	0.04
PE3→ RA level	0.09*	0.04
PE4→ RA level	−0.15**	0.06

(*continued on next page*)

Table 5 (*continued*)

	Coefficient	S.E.
PE5→ RA level	0.01	0.03
PE6→ RA level	0.15***	0.03
SC→ RA level	−0.01	0.02
Comparative fit index (CFI)	0.87	
χ^2 (df = 114)	422.58***	
Root mean squared error of approximation (RMSEA)	0.07	

*p < 0.05, **p < 0.01, ***p < 0.001.
PE1: Population density.
PE2: Destination accessibility.
PE3: Land use mix.
PE4: Street connectivity.
PE5: Public space.
PE6: Green space.
SC: Social capital.
TA1: Utilitarian walking time.
TA2: Utilitarian cycling time.
TA3: Time on public transit.
TA4: Driving time.
RA level: Recreation activity level.

Table 6
Direct and indirect effects of the path analysis of depression: standardized solution (N = 498).

	Direct effect	Indirect effect
PE1: Population density	−0.15**	0.02
PE2: Destination accessibility	0.02	−0.01*
PE3: Land use mix	0.11**	−0.06***
PE4: Street connectivity	−0.20***	0.03***
PE5: Public space	0.16**	−0.01
PE6: Green space	−0.04	−0.02
Social capital	0.01	0.01

public transit than private cars on depressive symptoms in suburban Guangzhou. Field work data showed that less than one quarter of suburban residents travelled by private cars, while transit-oriented mode of development and affordable housing price attracted many residents who depended on public transit. For the majority who took public transit to destinations, their opinions spoke for the negative effects of public transportation, as demonstrated by remarks such as:

> "*Metro is too crowded and uncomfortable. The long time spent on the subway affects my mood time to time (A young female); the bus and taxi are very smelly and I have to wait for a long time. Usually I travel by Uber, which is very convenient and comfortable. (A middle-age female); Convenience and comfort of the travel mode are determinative. If the bus links my destination well, I prefer to take bus; if the bus is too crowded, I prefer to drive. (A middle-age male)*"

Thus, uncomfortable travel experience, particularly the crowded and smelly indoor environment of the coaches, inconvenient transfer and excessive interval time, may provoke psychosocial stress and exacerbate depressive symptoms for passengers who were under prolonged exposure (Weich et al., 2002). At the same time, we ascertained that the long driving time associated with suburban living in Guangzhou may increase the risks of suffering from depression; such a finding is consistent with those in developed countries (e.g. US) (Moist et al., 2008). It is thus confirmed that Chinese large cities share some similar suburbanization trend and its consequential mental health outcomes with cities in developed countries (Tana et al., 2016). However, our results of the negative effect of public transit on depression diverged from the extant findings in Western countries, which argue that public transit involves walking or cycling to access bus stops or train stations, and thus benefits people's health (De Nazelle et al., 2011). To summarize, excessive travel time from suburban neighbourhoods to destinations (work or school), either on public transportation or on private car, may directly exacerbate the depressive symptoms. It is possible that long travel time on road may induce psychological burden (e.g. risk of traffic accident, time of concentration for driving, use of body energy) and increase the stress level that further increase prevalence of depression. This study thus gives no evidence for the positive effects of recreational activity and active transportation activity on depression, but it ascertains the negative effects of motor transportation activity on depressive symptoms.

5.2. Interpretation: perceived environment as an influential factor of depression

Perceived environment has significant influence on both the mediators and depression. For the direct influential factors, population density is positively correlated with the sense of crowding, which has been verified by many studies to have generated negative mental health effects such as psychological distress (Evans, 2003). This study echoes the same effect: comfortable population density reduces depressive symptoms with the absence of the sense of crowding. However, unexpectedly respondents reported higher likelihood of depression in association with perceived sufficient public space, in contrary to the generally accepted positive association between public space and mental health (Evans, 2003). This finding particularly diverges from that of Fu (2018) recent study which suggests no direct link between the use or sense of communal space and depression in Guangzhou's urban neighbourhoods. Further site investigation explained the anomaly found in this study. There were plenty of public space within the suburban neighbourhoods, such as squares, open space, and community centers, however, the majority of them was disused either on weekday or on weekend. Photos in Fig. 4 categories the use intensity of these public space in the case neighbourhoods: actively-used public space (A1-A4), public space used for a different purpose (B1–B7), disused public space (C1–C9). By comparing their attributes, it is inferred that residents do not make use of public space for the following reasons: conflicts between parking space and activity space (B1,B2,B3,B4), no provision of seats (B5), improper behaviors of users (B6,B7), dehumanized design such as putting fitness equipment in the open space without comfort consideration (C1, C2 compared with A3), seats not purpose-designed for specific activities (C2,C4, C5 compared with A1, A2, A4), and lack of attention to user behavior in designing the squares (C6,C7), poor accessibility (C8), and lack of attention to maintenance (C9). Residents were also disappointed with the public space: "*If the neighbourhood could provide appropriate places for cultural activity or sports, it would be very good for residents' health (a young male); The open space in the neighbourhood is quite fragmented, and there is no open space large enough for doing exercise (a middle-age female)*". Thus, we believe that the sufficiency and quality of public space and facilities in Guangzhou's suburban neighbourhoods did not contribute to better mental health. To the contrary, the inappropriate and poor design such as lack of attention to user behavior and the dehumanized design aggravated depressive symptoms.

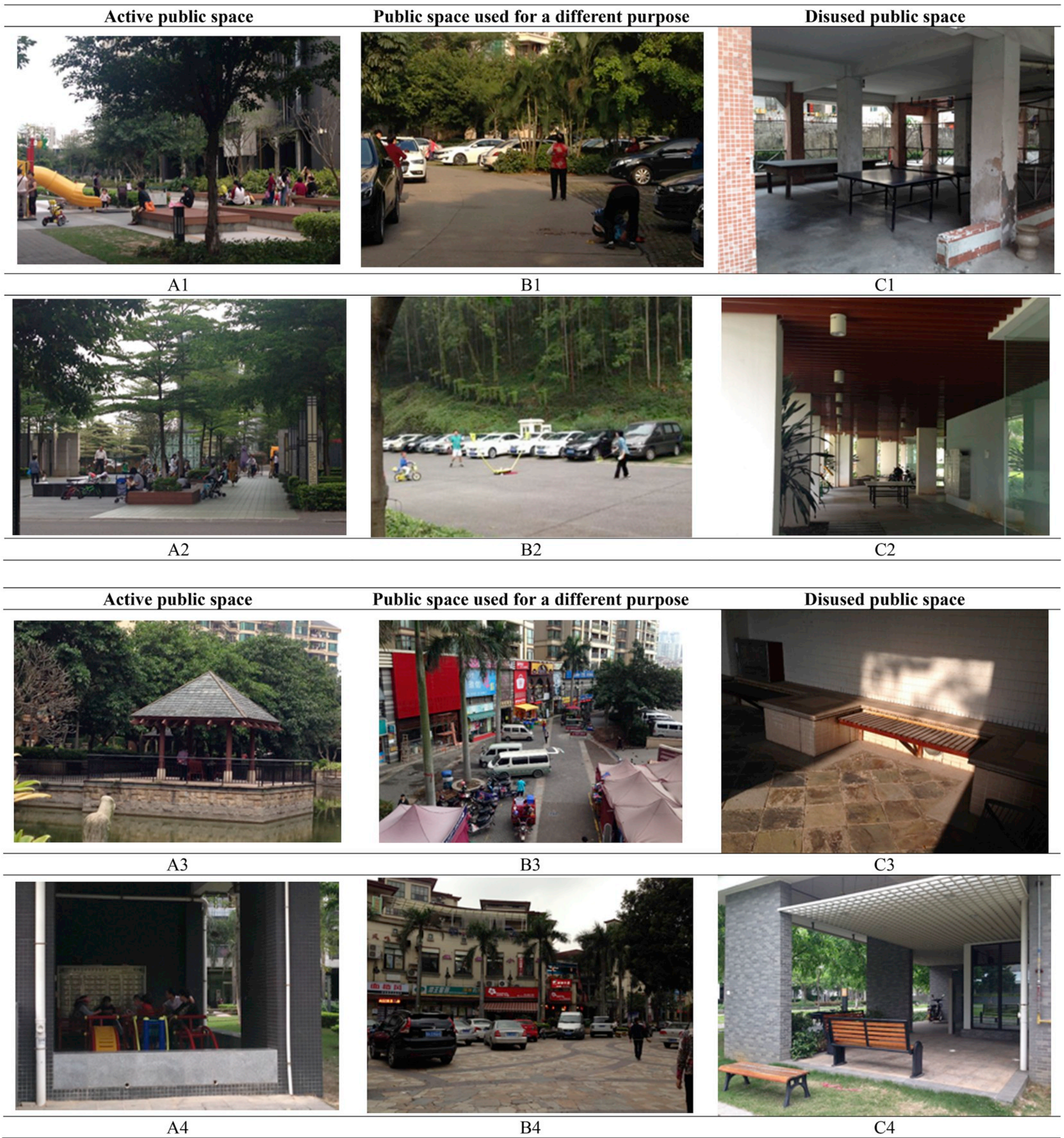
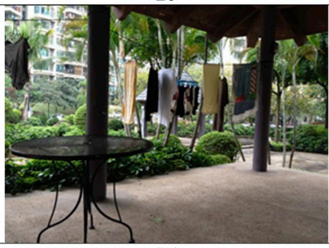


Fig. 4. Attributes of the public space within case neigbourhoods.

Active public space	Public space used for a different purpose	Disused public space
		
	B5	C5
		
	B6	C6

Active public space	Public space used for a different purpose	Disused public space
		
	B7	C7
		
		C8

Active public space	Public space used for a different purpose	Disused public space
		
		C9

Fig. 4. (*continued*)

Land use mix and street connectivity haw opposite associations with depressive symptoms in the direct and indirect pathways. In the direct pathway, land use mix always has positive associations with depressive symptoms, which is inconsistent with findings of other studies that land use mix is associated with more walking and fewer depressive symptoms (Miles et al., 2012; Frank et al., 2003). In the indirect pathway, land use mix is negatively associated with time on public transit and driving time, decreasing the depressive symptoms significantly. Thus, the indirect effects of land use mix are consistent with the extant understanding, however, the residual direct effects are unique from other studies. This anomaly finding may be partly due to the specific local context of suburban living: many suburban residents travel to urban core area for working, schooling, shopping, and receiving medical treatments, because the infrastructures and services provided in suburbs could not meet their demands or expectations. The direct negatively effects of land use mix on depression thus could verify residents' dissatisfaction on commercial, education, and health care facilities, which could increase life pressure and risks of being depressed. The interview results could also support the above point:

"*The education issue gives me great pressure, because there is no public kindergarten but a private one, and its tuition* fee *is as high as US$745 per month. Nonetheless, the quality of education is worrisome (A young male); The price of daily goods in neighbourhoods' market is 30%-50% higher than that in near village, so my mom often asks me where she can buy affordable vegetables. This bothers me a lot because it is not safe and convenient and safe for the elderly walking too long for shopping (A middle-age female).*" Thus, in the direct pathway, higher land use mix level is associated with more presence of unsatisfactory public facilities, aggravating the depressive symptoms.

For street connectivity, it can reduce depressive symptoms directly. However, as it can facilitate spatial convenience for taking public transit, street connectivity is associated with increased time on public transit, which could increase depressive symptoms indirectly. Although the overall association between street connectivity and depression is consistent with extant finding, this study does not echo the conventional argument that street connectivity benefits mental health status through the encouragement of walking (Leslie and Cerin, 2008; Sturm and Cohen, 2004). Further evidence is needed to deepen the understanding of the influence of street connectivity on depression in Chinese suburbs.

Destination accessibility is verified to have indirect influence on depressive symptoms through reducing the time on public transit. Although the relationship between destination accessibility and depression is consistent with existing studies, there is nuance in term of the influencing mechanism: the identified mediator is "time on public transit" in this study rather than "walking time" in previous studies (Sturm and Cohen, 2004). This may be due to local differences in characteristics of suburban built environment and its resultant human behaivour. Compared with Western suburbs, Chinese high-density suburbs is associated with more walking and more chances of taking public transit, making the health benefit of walking not obvious but highlighting the risk of taking public transit. This signals the importance of contextualizing investigations on health factors in local spatial and social environments. Additionally, no significant association was found between social capital and depression, disproving the hypothesis. Although some recent studies on Chinese neighbourhood environments have suggested negative association between social capital and mental health (Dong and Qin, 2017; Fu, 2018), more evidence is needed to consolidate the nil or negative impact of social capital on mental health, particularly for suburban area of Chinese metropolitan cities.

6. Conclusion

This study has enriched the discourse on geographic impacts on mental health by providing new evidence of direct and indirect associations between suburban neighbourhood environments and depression in China. We confirm direct effects of population density and public space, the dual impacts of land use mix and street connectivity, and indirect effects of destination accessibility on depressive symptoms among Guangzhou's suburban residents. In addition, this study highlights the mediations of time on public transit and driving time between suburban neighbourhoods and depressive symptoms, enriching the extant literature on the mediating effects of physical activity within the Chinese context. Therefore, to achieve better mental health performance in suburban neighbourhoods, design policies and practice should be instituted to provide comfortable, convenient, appropriate and active built environments in terms of population density, quality of public space, land use diversity, walkability and accessibility, reducing negative effects of the over-long travelling time on public transit and private cars. However, it is acknowledged that while this study is a strong pioneering effort, it is cross sectional in nature, thereby limiting the capacity in determining causality. In addition, a common but inevitable measurement error may have occurred, that is, reporting bias from respondents who were suffering from depression. It is common that people diagnosed with depression perceive the external environment negatively. While this is useful subjective data, one would have to treat them with caution when applying the data to evaluate the environmental quality.

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References

Almedom, A.M., 2005. Social capital and mental health: an interdisciplinary review of primary evidence. Soc. Sci. Med. 61 (5), 943–964. https://doi.org/10.1016/j.socscimed.2004.12.025.

Araya, R., Dunstan, F., Playle, R., Thomas, H., Palmer, S., Lewis, G., 2006. Perceptions of social capital and the built environment and mental health. Soc. Sci. Med. 62 (12), 3072–3083. https://doi.org/10.1016/j.socscimed.2005.11.037.

Breitung, W., 2012. Enclave urbanism in China: attitudes towards gated communities in Guangzhou. Urban Geogr. 33 (2), 278–294. https://doi.org/10.2747/0272-3638.33.2.278.

Browne, M.W., 1984. Asymptotically distribution-free methods for the analysis of covariance structures. Br. J. Math. Stat. Psychol. 37 (1), 62–83. https://doi.org/10.1111/j.2044-8317.1984.tb00789.x.

Butterworth, P., Leach, L.S., Olesen, S.C., 2012. Mental health in the suburbs: an investigation of differences in the prevalence of depression across canberra suburbs using data from the path through life study. J. Public Health 20 (5), 525–531. https://doi.org/10.1007/s10389-011-0482-7.

Cao, W., Li, L., Zhou, X., Zhou, C., 2015. Social capital and depression: evidence from urban elderly in China. Aging Ment. Health 19 (5), 418–429. https://doi.org/10.1007/s10389-011-0482-7.

Chen, J., Chen, S., Landry, P.F., 2013. Migration, environmental hazards, and health outcomes in China. Soc. Sci. Med. 80, 85–95. https://doi.org/10.1016/j.socscimed.2012.12.002.

Chen, J., Chen, S., Landry, P.F., Davis, D.S., 2014. How dynamics of urbanization affect physical and mental health in urban China. China Q. 220, 998–1011. https://doi.org/10.1017/s0305741014001465.

Cho, M.J., Kim, K.H., 1998. Use of the center for epidemiologic studies depression (CES-D) scale in korea. J. Nerv. Ment. Dis. 186 (5), 304–310. https://doi.org/10.1097/00005053-199805000-00007.

Clark, C., Myron, R., Stansfeld, S., Candy, B., 2006. A systematic review of the evidence on the effect of the built and physical environment on mental health. J. Public Ment. Health 6 (2), 14–27. https://doi.org/10.1108/17465729200700011.

Cohen-Cline, H., Beresford, S.A., Barrington, W., Matsueda, R., Wakefield, J., Duncan, G.E., 2018. Associations between social capital and depression: a study of adult

twins. Health Place 50, 162–167. https://doi.org/10.1016/j.healthplace.2018.02.002.
De Nazelle, A., Nieuwenhuijsen, M.J., Antó, J.M., Brauer, M., Briggs, D., Braun-Fahrlander, C., et al., 2011. Improving health through policies that promote active travel: a review of evidence to support integrated health impact assessment. Environ. Int. 37 (4), 766–777. https://doi.org/10.1016/j.envint.2011.02.003.
De Silva, M.J., McKenzie, K., Harpham, T., Huttly, S.R., 2005. Social capital and mental illness: a systematic review. J. Epidemiol. Community Health 59 (8), 619–627. https://doi.org/10.1136/jech.2004.029678.
Diez-Roux, A.V., 2001. Investigating neighbourhood and area effects on health. Am. J. Public Health 91 (11), 1783–1789. https://doi.org/10.2105/ajph.91.11.1783.
Dong, H., Qin, B., 2017. Exploring the link between neighbourhood environment and mental wellbeing: a case study in Beijing, China. Landsc. Urban Plan. 164, 71–80. https://doi.org/10.1016/j.landurbplan.2017.04.005.
Dzhambov, A., Hartig, T., Markevych, I., Tilov, B., Dimitrova, D., 2018. Urban residential greenspace and mental health in youth: different approaches to testing multiple pathways yield different conclusions. Environ. Res. 160, 47–59. https://doi.org/10.1016/j.envres.2017.09.015.
Ewing, R., Schmid, T., Killingsworth, R., Zlot, A., Raudenbush, S., 2008. Relationship between urban sprawl and physical activity, obesity, and morbidity. In: Urban Ecology. Springer US, pp. 567–582.
Evans, G.W., 2003. The built environment and mental health. J. Urban Health 80 (4), 536–555. https://doi.org/10.1016/b978-0-444-52272-6.00006-4.
Fan, M., Lyu, J., He, P., 2014. Chinese guidelines for data processing and analysis concerning the International Physical Activity Questionnaire. Zhonghua Liuxingbingxue Zazhi 35 (8), 961–964 (in Chinese).
Feng, J., Zhou, Y., Wu, F., 2008. New trends of suburbanization in Beijing since 1990: from government-led to market-oriented. Reg. Stud. 42 (1), 83–99. https://doi.org/10.1080/00343400701654160.
Finney, S.J., DiStefano, C., 2006. Non-normal and categorical data in structural equation modeling. Struct. Equ. Model.: A second course 10 (6), 269–314.
Forsman, A.K., Nyqvist, F., Schierenbeck, I., Gustafson, Y., Wahlbeck, K., 2012. Structural and cognitive social capital and depression among older adults in two nordic regions. Aging Ment. Health 16 (6), 771–779. https://doi.org/10.1080/13607863.2012.667784.
Frank, L.D., Engelke, P.O., 2001. The built environment and human activity patterns: exploring the impacts of urban form on public health. J. Plan. Lit. 16 (2), 202–218. https://doi.org/10.1177/08854120122093339.
Frank, L.D., Engelke, P.O., Schmid, T.L., 2003. Health and Community Design: the Impact of the Built Environment on Physical Activity. Island Press, Washington, DC.
Frank, L.D., Iroz-Elardo, N., MacLeod, K.E., Hong, A., 2019. Pathways from built environment to health: a conceptual framework linking behavior and exposure-based impacts. J. Transp. Health 12, 319–335. https://doi.org/10.1016/j.jth.2018.11.008.
Frumkin, H., 2002. Urban sprawl and public health. Public Health Rep. 117 (3), 201–217. https://doi.org/10.1093/phr/117.3.201.
Fu, Q., 2018. Communal space and depression: a structural-equation analysis of relational and psycho-spatial pathways. Health Place 53, 1–9. https://doi.org/10.1016/j.healthplace.2018.06.007.
Gong, P., Liang, S., Carlton, E.J., Jiang, Q., Wu, J., Wang, L., Remais, J.V., 2012. Urbanisation and health in China. The Lancet 379 (9818), 843–852. https://doi.org/10.1016/s0140-6736(10)61142-7.
Gupta, S., Goren, A., Dong, P., Liu, D., 2016. Prevalence, awareness, and burden of major depressive disorder in urban China. Expert Rev. Pharmacoecon. Outcomes Res. 16 (3), 393–407. https://doi.org/10.1016/j.jval.2015.03.686.
Guite, H., Clark, C., Ackrill, G., 2006. The impact of the physical and urban environment on mental well-being. Public health 120 (12), 1117–1126. https://doi.org/10.1016/j.puhe.2006.10.005.
He, J.J., Jia, B., 2007. Sustainable residential landscapes: a case study in Guangzhou, China. Landsc. Res. 32 (2), 241–254. https://doi.org/10.1080/01426390701231747.
Kim, D., 2008. Blues from the neighbourhood? Neighbourhood characteristics and depression. Epidemiol. Rev. 30 (1), 101–117. https://doi.org/10.1093/epirev/mxn009.
Kwan, M.P., Chai, Y., Tana, 2014. Reflections on the similarities and differences between Chinese and US cities. Asian Geogr. 31 (2), 167–174. https://doi.org/10.1080/10225706.2014.950484.
Leslie, E., Cerin, E., 2008. Are perceptions of the local environment related to neighbourhood satisfaction and mental health in adults? Prev. Med. 47 (3), 273–278. https://doi.org/10.1016/j.ypmed.2008.01.014.
Lu, Y., Hu, P., Treiman, D.J., 2012. Migration and depressive symptoms in migrant-sending areas: findings from the survey of internal migration and health in China. Int. J. Public Health 57 (4), 691–698. https://doi.org/10.1007/s00038-011-0314-0.
Miles, R., Coutts, C., Mohamadi, A., 2012. Neighbourhood urban form, social environment, and depression. J. Urban Health 89 (1), 1–18. https://doi.org/10.1007/s11524-011-9621-2.
Moist, L.M., Bragg-Gresham, J.L., Pisoni, R.L., Saran, R., Akiba, T., Jacobson, S.H., ... Saito, A., 2008. Travel time to dialysis as a predictor of health-related quality of life, adherence, and mortality: the Dialysis Outcomes and Practice Patterns Study (DOPPS). Am. J. Kidney Dis. 51 (4), 641–650. https://doi.org/10.1053/j.ajkd.2007.12.021.
Muthen, B., Kaplan, D., 1992. A comparison of some methodologies for the factor analysis of non-normal Likert variables: a note on the size of the model. Br. J. Math. Stat. Psychol. 45 (1), 19–30. https://doi.org/10.1111/j.2044-8317.1992.tb00975.x.
O'Campo, P., Salmon, C., Burke, J., 2009. Neighbourhoods and mental well-being: what are the pathways? Health Place 15 (1), 56–68. https://doi.org/10.1016/j.healthplace.2008.02.004.
Oliver, J.E., 2003. Mental life and the metropolis in suburban America the psychological covariatesof metropolitan place characteristics. Urban Aff. Rev. 39 (2), 228–253. https://doi.org/10.1177/1078087403254445.
Pan, A., Lu, L., Franco, O.H., Yu, Z., Li, H., Lin, X., 2009. Association between depressive symptoms and 25-hydroxyvitamin D in middle-aged and elderly Chinese. J. Affect. Disord. 118 (1), 240–243. https://doi.org/10.1016/j.jad.2009.02.002.
Pfeiffer, D., Cloutier, S., 2016. Planning for happy neighbourhoods. J. Am. Plan. Assoc. 82 (3), 1–13. https://doi.org/10.1080/01944363.2016.1166347.
Pigott, T.D., 2001. A review of methods for missing data. Educ. Res. Eval. 7 (4), 353–383. https://doi.org/10.1076/edre.7.4.353.8937.
Propper, C., Jones, K., Bolster, A., Burgess, S., Johnston, R., Sarker, R., 2005. Local neighbourhood and mental health: evidence from the UK. Soc. Sci. Med. 61 (10), 2065–2083. https://doi.org/10.1016/j.socscimed.2005.04.013.
Radloff, L.S., 1977. The CES-D scale a self-report depression scale for research in the general population. Appl. Psychol. Meas. 1 (3), 385–401. https://doi.org/10.1177/014662167700100306.
Sarkar, C., Webster, C., Gallacher, J., 2014. Healthy Cities: Public Health through Urban Planning. Edward Elgar Publishing, Cheltenham.
Sturm, R., Cohen, D.A., 2004. Suburban sprawl and physical and mental health. Public health 118 (7), 488–496. https://doi.org/10.1016/j.puhe.2004.02.007.
Tana, Kwan, M.P., Chai, Y., 2016. Urban form, car ownership and activity space in inner suburbs: a comparison between Beijing (China) and Chicago (United States). Urban Stud. 53 (9), 1784–1802. https://doi.org/10.1177/0042098015581123.
Vojnovic, I., Jackson-Elmoore, C., Holtrop, J., Bruch, S., 2006. The renewed interest in urban form and public health: promoting increased physical activity in Michigan. Cities 23 (1), 1–17. https://doi.org/10.1016/j.cities.2005.07.007.
Wainwright, N.W.J., Surtees, P.G., 2004. Area and individual circumstances and mood disorder prevalence. Br. J. Psychiatry 185, 227–232. https://doi.org/10.1192/bjp.185.3.227.
Weich, S., Blanchard, M., Prince, M., Burton, E., Erens, B., Sproston, K., 2002. Mental health and the built environment: cross-sectional survey of individual and contextual risk factors for depression. Br. J. Psychiatry 180 (5), 428–433. https://doi.org/10.1192/bjp.180.5.428.
Weich, S., Holt, G., Twigg, L., Jones, K., Lewis, G., 2003. Geographic variation in the prevalence of common mental disorders in Britain: a multilevel investigation. Am. J. Epidemiol. 157 (8), 730–737. https://doi.org/10.1093/aje/kwg035.
Wu, Q., Xie, B., Chou, C.P., Palmer, P.H., Gallaher, P.E., Johnson, C.A., 2010. Understanding the effect of social capital on the depression of urban Chinese adolescents: an integrative framework. Am. J. Community Psychol. 45 (1–2), 1–16. https://doi.org/10.1007/s10464-009-9284-2.
Wu, F., Xu, J., Yeh, A.G.O., 2006. Urban Development in Post-reform China: State, Market, and Space. Taylor & Francis, Abingdon.
Wu, F., 2010. Gated and packaged suburbia: packaging and branding Chinese suburban residential development. Cities 27 (5), 385–396. https://doi.org/10.1016/j.cities.2010.06.003.
Yang, J., Siri, J.G., Remais, J.V., Cheng, Q., Zhang, H., Chan, K.K., et al., 2018. The tsinghua–lancet commission on healthy cities in China: unlocking the power of cities for a healthy China. The Lancet 391 (10135), 2140–2184. https://doi.org/10.1016/s0140-6736(18)30486-0.
Zhang, J., Norvilitis, J.M., 2002. Measuring Chinese psychological well-being with Western developed instruments. J. Personal. Assess. 79 (3), 492–511. https://doi.org/10.1207/s15327752jpa7903_06.