Dispersed Urban Spatial Structure and Increased Urban Greenness Could Reduce Intra-City Health inequalities in England

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Abstract
The persistence of socioeconomic health inequalities has garnered substantial attention, and a few researchers have explored the impact of neighborhood greenness on mitigating it. However, it remains unclear whether comprehensive planning can address this issue. In this study, we evaluated intra-city health inequality in 105 cities in England and examined the impact of urban spatial structure (measured by dispersion) on it, with adjustment for city size, population density, urban greenness, development level, income gap, and aging. Results revealed that the dispersion of urban population (β=-0.179, p=0.043) and urban greenness (β=-0.147, p=0.087) exhibited significant negative relationships with intra-city health inequalities, while the income gap showed a significantly positive relationship (β =0.5002, p<0.001). These findings underscore the critical role of city comprehensive planning in mitigating health inequalities.

Keywords: urban inequality, city comprehensive planning, urban spatial structure, health and well-being

Introduction

Health inequalities across socioeconomic groups has been increasingly acknowledged in the past decades (Kakwani, Wagstaff and van Doorslaer, 1997; Kawachi, 2002; Kröger, Pakpahan and Hoffmann, 2015). Researchers and politicians have focused on decomposing the drivers of health inequalities and identifying strategies to reduce this inequality (Erreygers and Kessels, 2013; Tan, Wang and Cheng, 2016). Apart from the individual level socioeconomic status such as income, education and employment, researchers have gradually discovered a new perspective in reducing health inequalities at the population level: urban built environment. Starting from the noteworthy Lancet article published in 2008 (Mitchell and Popham, 2008), the effect of greenness in lowering the health gap between the more well-off and less well-off groups of people has come into the view of public health researchers. Subsequent studies further investigated the effect of other neighborhood-level built environment indicators. For example, Mitchell *et al.* (2015) found that the recreational areas are also vital for delimiting the inequality in mental well-being. However, none of the existing studies have revealed the effect of the city level comprehensive planning on health inequalities.

The potential environmental and health effect of urban spatial structure – an important system in comprehensive planning –has received great attention in recent years. Urban spatial structure is defined as the spatial distribution of urban population or economic activities. Following Anas, Arnott and Small (1998), it includes two dimensions: centralisation – dispersion (whether and to what extent population and economic activities are clustered in urban centres), and monocentricity – polycentricity (whether and to what extent an urban system is organised around a single urban core or a number of proximate and functionally integrated subcentres). Several studies have shown that a more dispersed urban development might exaggerate health risks by elevating the air pollution concentration (McCarty and Kaza, 2015; Cárdenas Rodríguez, Dupont-Courtade and Oueslati, 2016; Fan *et al.*, 2018; Liu *et al.*, 2018; Gao, Yang and Liang, 2020) and greenhouse gas emission (Muñiz and Sánchez, 2018; Hong, Hui and Lin, 2022). The size and accessibility of health resources, such as green space (Han *et al.*, 2023) and urban amenities (Wang, 2021), are also shown to be influenced by urban spatial structures. Additionally, polycentricity might shorten commute distance (Hu, Sun and Wang, 2018), and has an impact on daily activity (Horton and Reynolds, 1971), thus has the potential to influence physical activity.

Although studies have shown that urban spatial structure might influence health, and compared the different urban spatial structure across different cities (Schneider and Woodcock, 2008; Liu and Wang, 2016; Li and Liu, 2018) or along a time span (Garcia-López, 2012; Y. Li, 2020), the potential of urban spatial structure to affect socioeconomic inequality in health within cities has, as far as we aware, received no attention.

In this study, we aim to explore the effect of urban spatial structure on the intra-city health inequalities across areas with varying socioeconomic statuses, so as to inform urban planning strategies and facilitate the eradication of inequality. We postulated that socioeconomic inequalities in health will be less pronounced in cities with a more dispersed and polycentric urban spatial structure. This hypothesis is based on the notion that the relationship between socioeconomic disparities and health inequalities is potentially influenced by urban spatial structure. We know that one crucial pathway of health inequalities is the limited accessibility of health-related material conditions (such as health amenities, shelters and other health resources) for individuals with low socioeconomic status. Consequently, a higher level of intra-city health inequalities indicates a greater disparity in accessing these material conditions among areas with diverse socioeconomic backgrounds. By influencing the distribution of these conditions, urban spatial structure may play a significant role in contributing to the observed inequality. For instance, a centralised city is likely to exhibit larger inequality, as the highly-centralised centre may be equipped with a wide range of high-level amenities, while the sparsely populated outliers may lack sufficient resources and a conducive walking environment. Conversely, a dispersed urban spatial structure is more likely to provide public amenities that are easily accessible. Polycentricity is expected to reduce inequality for the same reasons.

These ideas prompted us to investigate the effect of urban spatial structure on intra-city health inequalities. Here, by utilizing local-scale health and socioeconomic data, we examined this issue within the context of England. The results of this study have significant implications for health-focused urban planning and associated policies, contributing to the advancement of SDG3 (good health and well-being) and SDG10 (reduced inequalities).

Data and Methods

Study design

We compared the income-related health inequalities at the intra-city level, and investigated the effect of urban spatial structure on it, with adjustment for city size, population density, urban greenness, development level, income gap and aging.

Data and variables

We obtained the all-ages standardised mortality ratio (SMR) for deaths from all circulatory diseases from the Office for Health Improvement and Disparities (OHID) by the Office for National Statistics (ONS), which were deaths registered in the calendar years 2016 to 2020 from circulatory disease – classified by underlying cause of death recorded as ICD codes I00 to I99 – for persons of all ages. We selected this indicator because circulatory disease is a leading cause of death, while mortality is a direct measure of health care need, indicating the overall circulatory disease burden on the population and reflecting both the incidence of disease and the ability to treat it.

Data for population income was obtained from the Office for National Statistics (ONS). The total annual household income – the sum of the gross income of every member of the household plus any income from benefits such as the Working Families Tax Credit – was selected as the indicator. This indicator was produced for the financial year ending 2018.

These two indicators were captured at the Middle Layer Super Output Area (MSOA) scale and used to assess health inequalities. Middle Layer Super Output Areas (MSOAs) are a geographic unit designed to improve the reporting of small area statistics in England and Wales. They are built from groups of Lower Layer Super Output Areas, typically 4 to 6, and designed to have a population of between 5,000 and 15,000. There are 6,791 MSOAs in England.

The intra-city health inequalities in our study was calculated as the disparity in standardised mortality ratio across different income levels, with MSOA as the basic geographical unit. To derive it, we first defined the area of the city. Following *Rural and Urban Statistics in England: Guidance Notes*, settlements with populations of over 10,000 are urban. Therefore, leveraging the global urban boundaries (GUB) (Li *et al.*, 2020) and Landscan population dataset, we derived the cities to further calculate intra-city health inequalities. Moreover, to avoid any bias caused by small sample size in calculating the gradient across MSOAs within a city, we only included cities that overlapped with 10 or more MSOAs. 106 cities were identified as a result. Then, we manually excluded the Great London due to its significant disparity from other English cities, leaving 105 geographical units in our further analysis. We adopted the concentration index, which is frequently used in quantifying the health inequalities across socioeconomic gradients, to derive the intra-city income-related health inequalities. The formula is listed below.

$$\mathrm{C} = \frac{2}{\mu} cov(h_i, R_i) = \frac{1}{n} \sum_{1}^{n} \frac{h_i}{\bar{h}} (2R_i - 1) \quad (1)$$

where h_i is the health outcome of MSOA i, while R_i is the rank of income of MSOA i. $\bar{h}$ is the average health status of this city, and n is the number of MSOA included in this city. After being balanced using the average health status and number of MSOA, this indicator is comparable across different cities. Moreover, since the health outcome in our study is mortality, which is negative, we use the absolute value of the concentration index to reflect health inequalities for further analyses. The value is limited to the interval $[-1, +1]$, with -1 indicating an extreme pro-poor distribution of health and +1 an extreme pro-rich distribution of health.

In terms of the independent variables, we involved city size, population density, urban spatial structure, urban greenness, development level, income gap and aging in consideration. City size was proxied by urban land and urban population. Urban land area was directly derived from the global urban boundaries (GUB) dataset. Urban population is the total population located on the urban land, derived from the LandScan population dataset. Population density was calculated as the division of the former two indicators.

Dispersion was selected as the indicator of urban spatial structure following previous studies. Following the approach of (Lee and Gordon, 2007), we define the degree of dispersion as the share of the population in a city's non-centre areas ($POP_{total} - POP_{cnter}$) to its total population (POP_{total}).

$$DISP = \frac{POP_{total} - POP_{cnter}}{POP_{total}} \qquad (2)$$

By definition, the value of DISP ranges from 0 to 1. A higher value of DISP indicates that a city's population distribution is more dispersed.

Our measurement of dispersion draws upon the identification of centres. Following Lee (2007) and X. Liu and Wang (2016), we adopt a relative minimum cut-off approach. By setting a minimum density cut-off at the level of its 95-percentile population density with LandScan grids, we identified the top 5% most densely populated areas for each city. With equation (2), we calculated the percentage of inhabitants that reside outside of the densest urban areas.

Since most of the English cities (90 out of 105) are small cities with inhabitants less than 300,000, it is by large not necessary to involve multiple centres within a city. Therefore, we didn’t calculate the indicator polycentricity and only used dispersion as the proxy of urban spatial structure.

Furthermore, by combining the Moderate Resolution Imaging Spectroradiometer (MODIS) data product, we derived the average NDVI of each city as a proxy for greenness. Following previous studies (Kummu, Taka and Guillaume, 2018), we got the gridded GDP per capita and calculated its mean value at the city scale to represent the development level. We obtained the rate of aging over 60 years old using additional datasets from the Office for National Statistics. In addition, we involved the Gini index to measure the degree of inequality of income, with a higher value indicates more inequality. The data source is summarised in Table 1. The descriptive statistics of variables are presented in Table 2.

Table.1 Details of the original data

	Spatial resolution	Time	Source
Urban area	vector	2018	Li *et al.* (2020)
Income	MSOA	2018	The Office for National Statistics (ONS)
standardised mortality ratio for deaths from circulatory diseases	MSOA	2016-2020	the Office for Health Improvement and Disparities (OHID) by the Office for National Statistics (ONS)
Population density	~1km	2017	LandScan population dataset
NDVI	250m	2016	the Moderate Resolution Imaging Spectroradiometer (MODIS)
GDP per capita	~10km	2015	Kummu, Taka and Guillaume (2018)

the rate of aging over 60 years old	MSOA	2018	the Office for National Statistics

Table.2 Descriptive analysis of variables

	mean	sd	min	max
Absolute value of concentration index	0.09	0.03	0.02	0.14
Urban land area (km2)	65.66	111.80	8.68	639.05
Urban population (×e5)	1.95	3.45	0.13	21.95
Population density (×e3/km2)	3.40	0.63	1.90	5.36
Dispersion (%)	90.60	4.88	79.92	100
NDVI (×e-3)	0.51	0.06	0.29	0.68
GDP per capita (×e4)	2.90	0.30	2.36	3.41
Gini index of income	0.09	0.02	0.05	0.14
Proportion of aging above 60 years (%)	24.69	3.53	18.70	37.09

Methods

We pre-examined the association between urban spatial structure and other environmental variables with the intra-city health inequalities using Pearson correlation analysis. Then, we adopted a multivariable regression model to reveal their effects with socioeconomic and demographic variables under control. Urban land area was excluded from the regression due to multicollinearity.

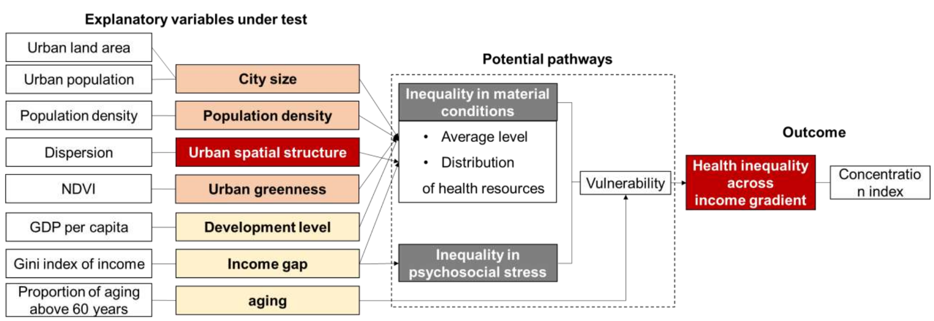

Fig.1 Analytical framework of this study

Results

Income-related health inequalities widely exists across England. We found that geographical areas with higher income presented lower mortality ratio (β=-0.621, p<0.001). Intra-city health inequalities range from 0.02 in Cannock to 0.14 in Blackburn (Fig.2), with an average value of 0.09. No significant variance was found between cities of different hierarchies (p-value = 0.388, Fig.3).

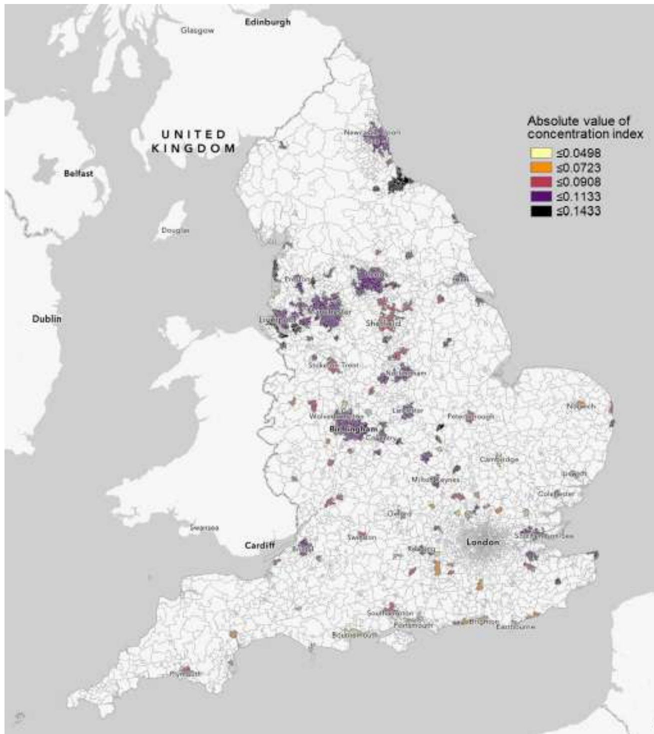

Fig.2 Distribution of intra-city health inequalities in England

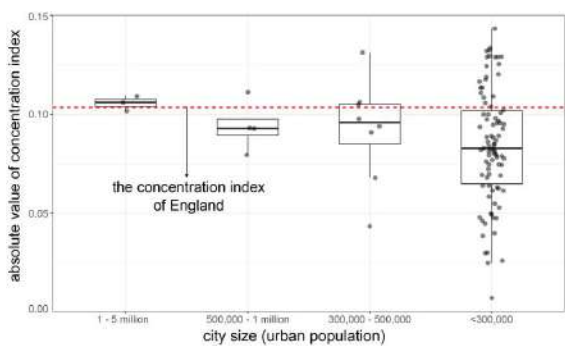

Fig.3 Distribution of intra-city health inequalities across city hierarchies
Note: The division of city size follows World Urbanization Prospects (2018)

In the binary correlation analysis, we found that cities with a more dispersed urban population (β=-0.2507, p=0.010) and a higher NDVI value (β=-0.1663, p=0.090) present lower intra-city health inequality, while cities with more inhabitants present higher levels (β=0.1842, p=0.060). This suggests that the disparity in health outcomes across areas of different socioeconomic statuses might be reduced if a city is greener and less concentrated, while it might be exaggerated when a city is larger.

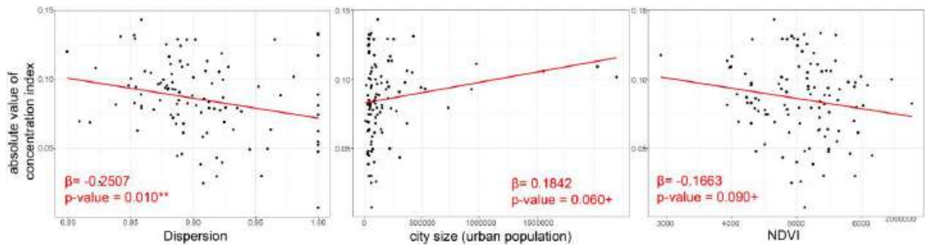

Fig.4 Relationship between environmental factors and intra-city health inequalities

Regression results revealed that the intra-city health inequalities could be explained by urban environment features (F-statistic=7.307, p<0.0001). We identified that the dispersion of urban population (β=-0.179, p=0.043) and greenness (β=-0.147, p=0.087) were in significant negative relationships with intra-city health inequalities. It indicates that cities with more dispersed population distribution and more green areas would exhibit lower levels of intra-city health inequality. Moreover, the disparity in income was also in a super significant positive relationship with income-related health inequalities (β=0.5002, p<0.001), which means that the larger the income gap, the larger the health gap.

Table. 3 Result of the multivariable regression

	Standardised coefficient	Std. Error	t value	Pr (>|t|)
intercept	-3.134e-16	0.08177	0.00	1.0000
Total urban population	0.0080	0.09044	0.088	0.9298
Population density	-0.0207	0.09023	-0.229	0.8193
Dispersion	**-0.1789**	**0.08729**	**-2.049**	**0.0431***
GDP per capita	-0.0450	0.09481	-0.475	0.6362
NDVI	**-0.1465**	**0.08462**	**-1.732**	**0.0865+**
Gini index of income	**0.5002**	**0.09394**	**5.325**	**<0.0001*****
Proportion of aging	0.1141	0.09046	1.262	0.2101
Adjusted R-squared		0.298		
F-statistic		7.307 (p-value<0.0001***)		

Discussion

Our study has demonstrated that, consistent with our hypothesis, intra-city health inequality is lower in cities with a more dispersed urban spatial structure and a greener urban environment. To our knowledge, this is the first study to identify city-scale urban planning factors that contribute to the reduction of intra-city health inequalities.

Our most significant finding is the elucidation of the impact of the urban spatial structure on reducing intra-city health inequalities. This may be attributed to the arrangement of physical conditions (urban amenities) at the city level. From an economic perspective, urban amenities are typically located in densely populated areas due to cost-effectiveness, while sparsely populated areas would have lower accessibility. Therefore, a dispersed urban spatial structure may prevent the concentration of urban amenities in densely populated urban centres, thereby reducing discrepancies in walkability – predicted based on the surrounding urban amenities

(Jones *et al.*, 2021) and significantly influences cardiovascular disease (Zhang *et al.*, 2023) – across different urban areas, leading to lower health inequality. Moreover, the more accessible healthcare resources in a dispersed city is conductive to lowering the inequality in the ability to treat cardiovascular disease. These possible mechanisms, from both the incidence and treatment perspectives, might explain the reduced health inequalities between rich and poor urban areas in dispersed cities.

It is important to note that the analysis regarding the distribution of urban amenities above is based on an assumption that the ability to pay is equally distributed spatially. However, in reality, amenities, especially those with commercial attributes, tend to cater to the rich. This means that even if a poor neighborhood is highly densified, amenities such as healthcare may not be accessible in this area. Conversely, a sparsely populated wealthy neighborhood may have access to highly qualified serves. In the context of England, we observed that the densely populated areas are mainly areas of income deprivation, especially in the Northern part of England. This implies that poor and densely populated neighborhoods might not have the advantage of amenities and may also suffer from overcrowding and poor living conditions. This possibly even exaggerates the health inequalities between rich and poor areas.

Our result also revealed that the average greenness in a city could reduce the intra-city health inequalities. It is not surprising as previous study has demonstrated its effect in mitigating health inequalities at the neighborhood level (Mitchell and Popham, 2008; Mitchell *et al.*, 2015). Here, we extend this finding to the city level, with similar mechanisms including promoting physical activity and alleviating stress (Mitchell & Popham, 2008), both of which are key risk factors for cardiovascular diseases.

Limitations of this study should also be acknowledged. First, the measurement of urban spatial structure is restricted. The population-based method used in our study is a straightforward way to derive morphological urban spatial structure, and is suitable for large scale research without efficient local data. However, during data processing, we found that although this method works well for Chinese cities and US metropolitans (Arribas-Bel and Sanz-Gracia, 2014; Liu and Wang, 2016; Li and Liu, 2018, 2018), its performance in England is not ideal. Due to the relatively small size for most England cities, we can hardly set a minimum threshold for selecting urban centres. For example, previous studies used 3 km^2 as a minimum size for urban centres. When we apply this criterion to England, most of the cities do not have a centre at all. Therefore, we simply used 1 km^2 (a grid in Landscan data) for the inclusion of city centre. But we can hardly tell whether the selected densely populated urban areas are true “centres”. Further research is needed to apply other methods to re-test the effect of urban spatial structure.

Second, our data were cross-sectional. We had no means of knowing the migration of urban residents throughout their lives. Therefore, we could not know their living environment and their access to urban amenities and greenness in their earlier life, which also have profound effect on the mortality from cardiovascular diseases (Zhang *et al.*, 2023).

Third, the geographical unit used to measure the inequality in health may also influence the results due to modifiable areal unit problem (MAUP). Therefore, the robustness of our results needs further testing by utilizing available data from other geographic units to calculate health inequalities within cities.

In conclusion, the evidence suggests that built environment interventions at the city level –

which operate upstream and are easily reversible – could be effective in reducing health inequalities across areas with different socioeconomic statuses within cities. Such levels of health inequality are lower in cities with a more decentralised urban spatial structure and higher levels of greening. The implications are clear: while the promotion of compact cities has been prevalent, our findings do not support further over-concentration of the population in existing urban centres, especially when these dense urban centres exacerbate health disparities between the poorest and least poor by worsening the living conditions of poorer urban residents. Additionally, increasing greenness is emphasised as a spatial intervention strategy to effectively mitigate health inequalities. Together, these findings highlight the role of city comprehensive planning in the fight to reduce health inequalities.

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