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Title: Risk of tuberculosis in high-rise and high density dwellings: an exploratory spatial analysis

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Keywords: Tuberculosis (TB); sky view factor (SVF); spatial analysis; geographic information system (GIS); environmental health risk

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Abstract: Studies have shown that socioeconomic and environmental factors have direct/indirect influences on TB. This research focuses on TB prevalence of Hong Kong in relation to its compact urban development comprising of high-rise and high-density residential dwellings caused by rapid population growth and limited land resources. It has been postulated that occupants living on higher levels of a building would benefit from better ventilation and direct sunlight and thus less likely to contract infectious respiratory diseases. On the contrary, those on lower floors amid the dense clusters of high-rises are more susceptible to TB infection because of poorer air quality from street-level pollution and lesser exposure to direct sunlight. However, there have not been published studies to support these claims. As TB continues to threaten public health in Hong Kong, this study seeks to understand the effects of housing development on TB occurrences in an urban setting.

Highlights

- We examined association between TB prevalence & floor levels using sky view factor
- TB is more prevalent on lower floors & relationship manifested in taller buildings
- Floor level & building height jointly affect sky view factors at diseased locations
- GIS framework is effective in associating disease prevalence in an urban setting

Abstract

Studies have shown that socioeconomic and environmental factors have direct/indirect influences on TB. This research focuses on TB prevalence of Hong Kong in relation to its compact urban development comprising of high-rise and high-density residential dwellings caused by rapid population growth and limited land resources. It has been postulated that occupants living on higher levels of a building would benefit from better ventilation and direct sunlight and thus less likely to contract infectious respiratory diseases. On the contrary, those on lower floors amid the dense clusters of high-rises are more susceptible to TB infection because of poorer air quality from street-level pollution and lesser exposure to direct sunlight. However, there have not been published studies to support these claims. As TB continues to threaten public health in Hong Kong, this study seeks to understand the effects of housing development on TB occurrences in an urban setting.

Capsule

This research focuses on TB prevalence of Hong Kong in relation to its compact urban development that has significant public health implications for Asian cities in pursuit of high-rise and high density urban living.

Keywords

Tuberculosis (TB); sky view factor (SVF); spatial analysis; geographic information system (GIS); environmental health risk

Introduction

Tuberculosis (TB) is caused by Mycobacterium tuberculosis, a bacteria that often affects the lungs. Although TB is curable and preventable, it is highly contagious and spread from person to person through inhaling TB germs in the air. The World Health Organization (2005) considers Hong Kong as a region with good health infrastructures that bears an intermediate burden of TB. TB prevalence in Hong Kong has been declining in the past 50 years (Department of Health, 2008) but it still remains a key health concern due to steady immigration and the compact living conditions. The disease has been found to have association with smoking (Leung et al., 2004) and HIV infection (Corbett et al., 2003). Areas dominated by the socially deprived (Lönnroth et al., 2009; Pang et al., 2010) and those living in crowded (Baker et al., 2008; Beggs et al., 2003; Lienhardt, 2001) areas of poor ventilation (Canadian Tuberculosis Committee, 2007; Hang et al., 2012; Li et al., 2007) have been reported to have noticeably higher TB prevalence.

Hong Kong has a compact urban built form comprising of high-rise and high density dwellings. This high density high-rise built form gives rise to an efficient transport infrastructure with low carbon consumption to which some researchers have accredited as a model of sustainable urban development (Lau et al., 2012). However, the compact city configuration is also criticized for its poor air quality and unpleasant living conditions that pose environmental health risks to its residents. Studies have shown that high-rise blocks constructed close to each other result in severe sky obstructions and poor air ventilation especially for the lower floors (Li et al., 2012a). It is known that poor sunlight penetration, unsatisfactory air quality and impeded ventilation prevail in many urban communities of Hong Kong closely packed with mid-rise to high-rise buildings (Edussuriya et al., 2011). It is also known that ultraviolet radiation from the sun kills bacterium in dwellings but the shading effects from surrounding buildings in many communities of Hong Kong have prevented direct sunlight to reach even pockets of small open spaces at the street level. Furthermore, the daylight quality within housing units are determined by many factors, including window size, obstruction from other buildings, and distance between buildings (Lau, 2011). Because of short separation distances between buildings, windows facing neighbouring blocks are always fitted with window shades and kept closed most of the time thus defeating the purpose of bringing in light and ventilation.

High density and vertical urban development will become a way of life for the burgeoning Asian cities because of rapid urbanization and diminishing non-renewable land resources. In recent years, the quality of urban life or the well-being of people living in a specific place has gained increasing attention. Some researchers suggested that satisfaction with living may be viewed at different levels from the wider community to the neighbourhoods and down to individual housing units (Campbell et al., 1976). Others are more concerned about the physical and social dimensions of a city as reflected through social indicators in which various health measures have a prominent role along with other indicators like the level of household income, crime rates, pollution levels, and housing costs (John, 2004; McCrea et al., 2005). Indeed, the relationships between health levels and urban lifestyles and their effects on longevity have been studied (Handy et al., 2002; Lv et al., 2011). There was almost complete agreement on the inclusion of health measures and a high degree of agreement on the effects of the living environment in considering the quality of urban life among the literature.

This paper aims to examine the relationship between TB incidence and the neighbourhood environment, with specific reference to natural daylight capacity. The sky view factor (SVF) has been used to indicate the impact of urban geometry on daylight and heat island effects in cities (Chen et al., 2012). SVF is a measure of the openness of the sky relative to a specific location with values ranging from 0 (no sky visible) to 1 (no foliage/obstruction visible) (Figure 1). We made use of the geographic information systems (GIS) technology to characterize the SVF of diseased locations. The SVF in an urban environment with little vegetation, as in the case of Hong Kong, is influenced primarily by building heights and street canyon widths or spaces between buildings.

- Insert Figure 1 -

Methods

Our study is a retrospective spatial data analysis of diseased positions. The null hypothesis is that there is no relationship between TB incidents or SVF at the diseased locations and the vertical position of living quarters relative to the building height. We postulate that TB cases are associated with locations with low SVF values (i.e., SVF < 0.6) because a lower SVF indicates more blockage of the sky view. We further postulate that more TB cases are found at the lower levels of a multi-storey building for the following reasons. Firstly, TB is a disease of poverty (Lönnroth et al., 2009; Pang et al., 2010) in which the diseased individuals are expected to live on lower levels because housing costs tend to increase with higher floors (Wong et al., 2011). Secondly, studies have shown that lower levels being in the perpetual shadow of surrounding buildings suffer from poor daylight reception and ventilation (Edussuriya et al., 2011; Li et al., 2012a).

A total of 1668 cases with TB positive specimens were available from the 2007-2009 out-patient data provided by the Tuberculosis and Chest Services of hospitals in the Kowloon West Cluster. The residential addresses of these cases were geocoded for spatial analysis (Figure 2). Figure 2 shows clearly a concentration of TB cases in the Kowloon Peninsula. A total of 1227 cases with complete address entries that fell within the normal service areas of the Kowloon West Cluster (or 74% of the total data count) was the focus of this study. The vertical storey of each diseased residence was also recorded. The 50m-radius SVF at each diseased location within the

Kowloon West Cluster was computed using an ArcView (ESRI, 2011) extension developed by Gal et al. (2008). In addition, the areal average of SVF was also computed to provide a continuous SVF surface (Figure 3). The SVF calculation was field verified for selected sites using the Sigma circular fisheye 4.5mm lens.

- Insert Figures 2 and 3 -

The quintile height of each building was computed and the vertical storey of each diseased address was positioned in reference to the QUINTILE group. The quintile group of Q1 indicates the lowest floors as opposed to Q5 representing the highest floors. The buildings were also classified into 5 BUILDING groups by maximum storey (≤8; 9-16; 17-24; 25-32; ≥33). The class limits of the building groups are arbitrary as the definition of high-rise building varies in literature (McCarthy et al., 1985; Williams, 1991) and dependent on the context where it exists (Council on Tall Buildings and Urban Habitat, 2011). Two-way analysis of variance (2-way ANOVA) was conducted on SPSS using SVF as the dependent variable against QUINTILE and BUILDING as the independent variables.

Results

Table 1 shows the number of TB positive cases by QUINTILE and BUILDING groups. It is observed that a larger number of TB cases tended towards the lower quintile groups (Q1 and Q2), irrespective of the building heights (whether ≤8 or ≥33 storeys). A graphics plot of TB QUINTILE percentages by each BUILDING groups highlights the fact that more than 50 percent of TB cases were found in the two lower quintile groups of Q1 and Q2 for buildings shorter than 25 storeys (Figure 4). Even for buildings taller than 25 storeys, nearly half of the observed TB cases were found in the two lower quintile groups of Q1 and Q2. The Chi-square contingency table and maximum likelihood tests show that the difference is statistically significant (Table 1). We can thus reject the null hypothesis that TB QUINTILE groups are independent of BUILDING heights. In other words, the result suggests that TB prevalence by storey level (as classified by QUINITLE groups) is dependent on BUILDING heights which prompted further investigation of the interaction between these two variables by means of two-way ANOVA below.

- Insert Figure 4 -

- Insert Table 1 -

The normal probability plots for testing the normality of the sample groups (Figure 5) reveal that the sample distributions are not too far from the normal. The two way ANOVA to examine the impacts of natural daylight capacity (in terms of SVF_50m) on diseased neighbourhoods shows the effects of QUINTILE groups to be statistically insignificant (p=0.398, Table 2). However, BUILDING groups and the interaction between BUILDING and QUINTILE groups both show statistically significant association with SVF_50m (p=0.000 and p=0.018 respectively). This is to say that the interaction between the vertical position of a diseased residence and the height of the building is related to natural daylight capacity as reflected through SVF. The presence of such an interaction is shown by non-parallel lines in Figure 6. Indeed, Figure 6 shows that QUINTILE groups of diseased locations did not matter for shorter buildings but a decreasing trend with increasing built storeys was observed for taller structures (i.e., more diseased residence on lower floors for taller buildings). These results could be affected by a number of confounders not covered in this study (such as building orientation or presence of greenery).

- Insert Table 2 -

- Insert Figures 5 and 6 -

Discussions

We employed the GIS technology to geocode addresses of diseased individuals (confirmed Mycobacterium TB positive in their culture tests) and record the vertical position or floor level of their residential units. The point-based geographic and vertical accounts of diseased locations enable the computation of SVF and the association of floor levels with TB incidence. Among the diseased individuals, we found more TB occurrences living on lower floors as compared to those on higher levels.

Hong Kong is renowned worldwide for its large numbers of skyscrapers and high rises. Buildings of 40-70 storeys are becoming more common in Hong Kong. Our study has shown that the densely-packed high rises in Hong Kong give rise to varying degrees of SVF (in which a smaller SVF value indicates a lack of sky view and vice versa) which can be used as a surrogate measure for daylight capacity. In considering diseased cases by their QUINTILE locations, we offer empirical evidence of the positive association between SVF and QUINTILEs of diseased locations by different BUILDING groups. It appears that TB cases tend to concentrate on lower floors and the relationship is more pronounced for taller buildings. Furthermore, our statistical analysis reported that SVFs and the QUINTILE groups do not have significant association but SVFs and BUILDING groups have a positively relation. Both QUINTILE and BUILDING groups of diseased locations are found to have joint effects on SVFs.

Our findings have implications on living space and its health implications. Given that lower floors in the midst of high-rise buildings are sheltered from direct sunlight, more thoughts should be given to the layout, orientation, and separation distance between built structures. For example, an increase in the vertical height of a building should command a corresponding increase in the horizontal separation to allow for penetration of natural daylight and permit better air flow. We should also take heed of the harmful effects of ill-designed transport infrastructures (especially urban canyons of high building density) (Li et al., 2012b). With nations shifting their economic policies to exert more focus on environmental matters as driven by principles of sustainable development, our study offer empirical evidence on potential areas of disease risks in the context of rapidly emerging mega-city regions of Asia.

One limitation of our study concerns the computation of SVF at the street level. We attempted SVF computation for radii of 25m, 50m, 75m, and 100m and found that 50m seemed to yield the best results. The SVF values derived in this study were at best indicative as diseased individuals were dispersed among different floor levels which were not accounted for in the computation. Furthermore, our limited data about address, gender and age of the diseased individuals offer no information about the behaviours of individuals (whether they are smokers or homebound), their residency status (whether they have lived in the area for 3 or more years), and their socio-economic standing (occupation, educational attainment, household income, etc.). These confounders could easily have influenced our findings and their absence prevented us from conducting more detailed analysis.

Conclusions

Our study highlights important relationships between TB incidence and vertical distance of dwellings for buildings of different heights. It also reveals that building height and density as revealed by SVF could potentially inform health risks in an urban setting. These two factors are central to the “healing” features in housing design that strives to bring in sunshine and facilitate air-flow (Hobday, 2010). The land use policy in many Asian cities encourages compact development with diverse housing types where streets are kept as narrow as possible, particularly in residential areas and commercial centres. This form of development may reduce vehicle travel and provide other conveniences. However, serious health and environmental problems (including poor lighting and ventilation in individual apartments) arise when the cities grow in the vertical direction without parallel adjustments in the horizontal dimension (Lau, 2011). Because of pressures from population growth and the scarcity of land resources, our results have significant public health implications for Asian cities that are pursuing high-rise and high density urban living.

Competing Interests

None to declare.

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Table Captions

1 Summary statistics of TB cases by QUINTILE and BUILDING groups

2 Results of two-way ANOVA [Dependent Variable: SVF_50m;
Design: Intercept + QUINTILE + BUILDING + QUINTILE * BUILDING]

Figure Captions

1 Sample results of sky view factors (SVF).
SFV ranges between 0 and 1, with near zero values indicating very little visible sky and values closer to 1 indicating no obstruction of the sky.

2 TB cases and the study area.

3 SVF among building footprints and 3D buildings

4 TB QUINTILE percentage versus BUILDING groups

5 Normal Q-Q plots of SVF for BUILDING and QUINTILE groups

6 A graph showing interaction between two factors in a two-way ANOVA

Table
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Table 1

QUINTILE / BUILDING	Q1	Q2	Q3	Q4	Q5	Subtotal
≤8	25	19	17	5	9	75
9-16	139	56	49	39	35	318
17-24	94	51	31	38	33	247
25-32	47	40	43	27	26	183
≥33	90	94	81	80	59	404
Subtotal	395	260	221	189	162	1227

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	56.989[a]	16	0
Likelihood Ratio	58.229	16	0
N of Valid Cases	1227		

[a] 0 cells (.0%) have expected count less than 5. The minimum expected count is 9.90.

Table

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Tests of Between-Subjects Effects
Dependent Variable: SVF_50m

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta spread	Noncent. Parameter	Observed Power[b]
Corrected Model	3.393[a]	24	.141	4.108	.000	.076	98.584	1.000
Intercept	281.320	1	281.320	8.174E3	.000	.872	8173.944	1.000
Quintile	.140	4	.035	1.015	.398	.003	4.060	.323
Building	1.365	4	.341	9.914	.000	.032	39.655	1.000
Quintile * Building	1.038	16	.065	1.885	.018	.024	30.160	.960
Error	41.369	1202	.034					
Total	530.738	1227						
Corrected Total	44.762	1226						

[a] R Squared = .076 (Adjusted R Squared = .057)
[b] Computed using alpha = .05

Figure
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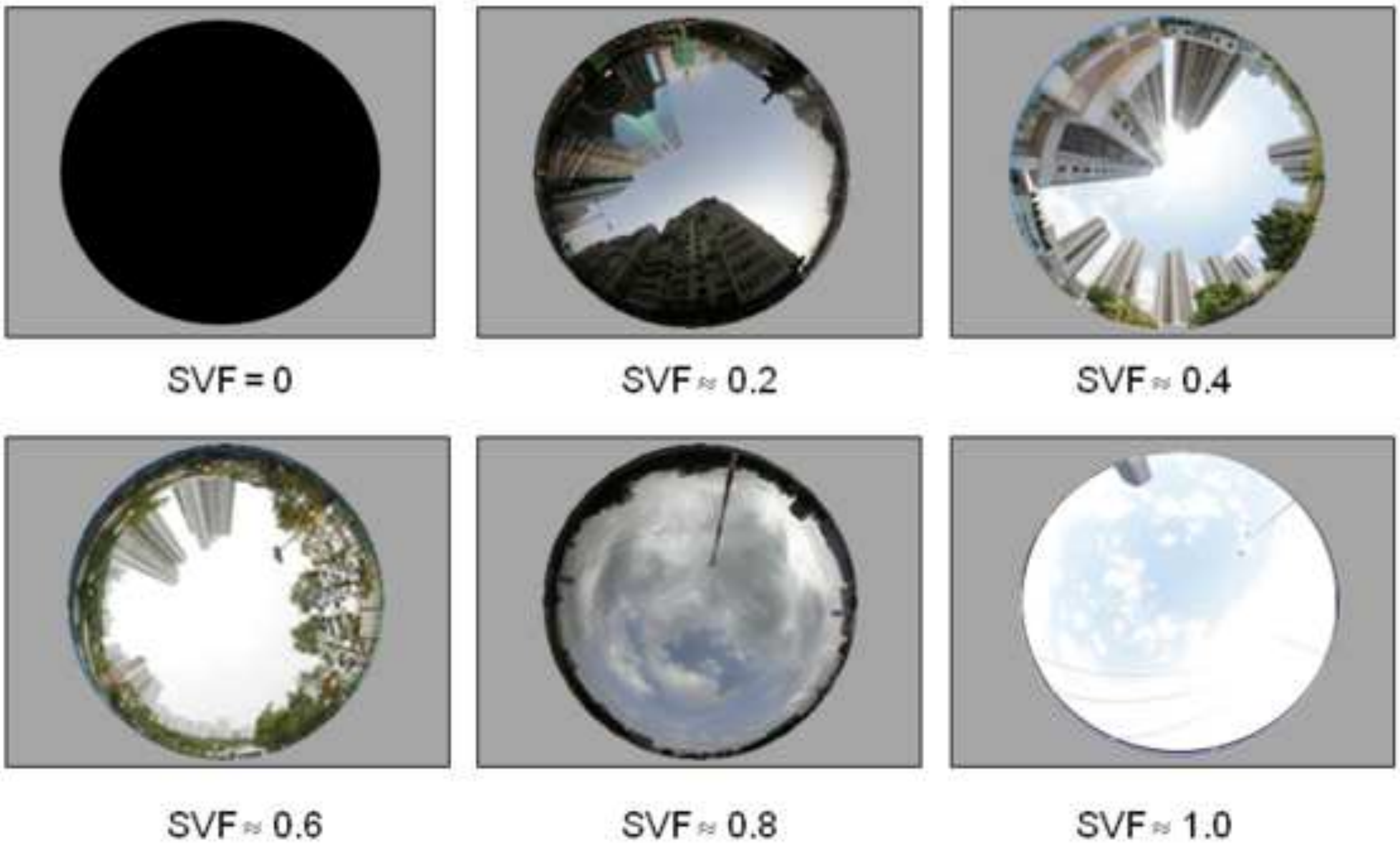

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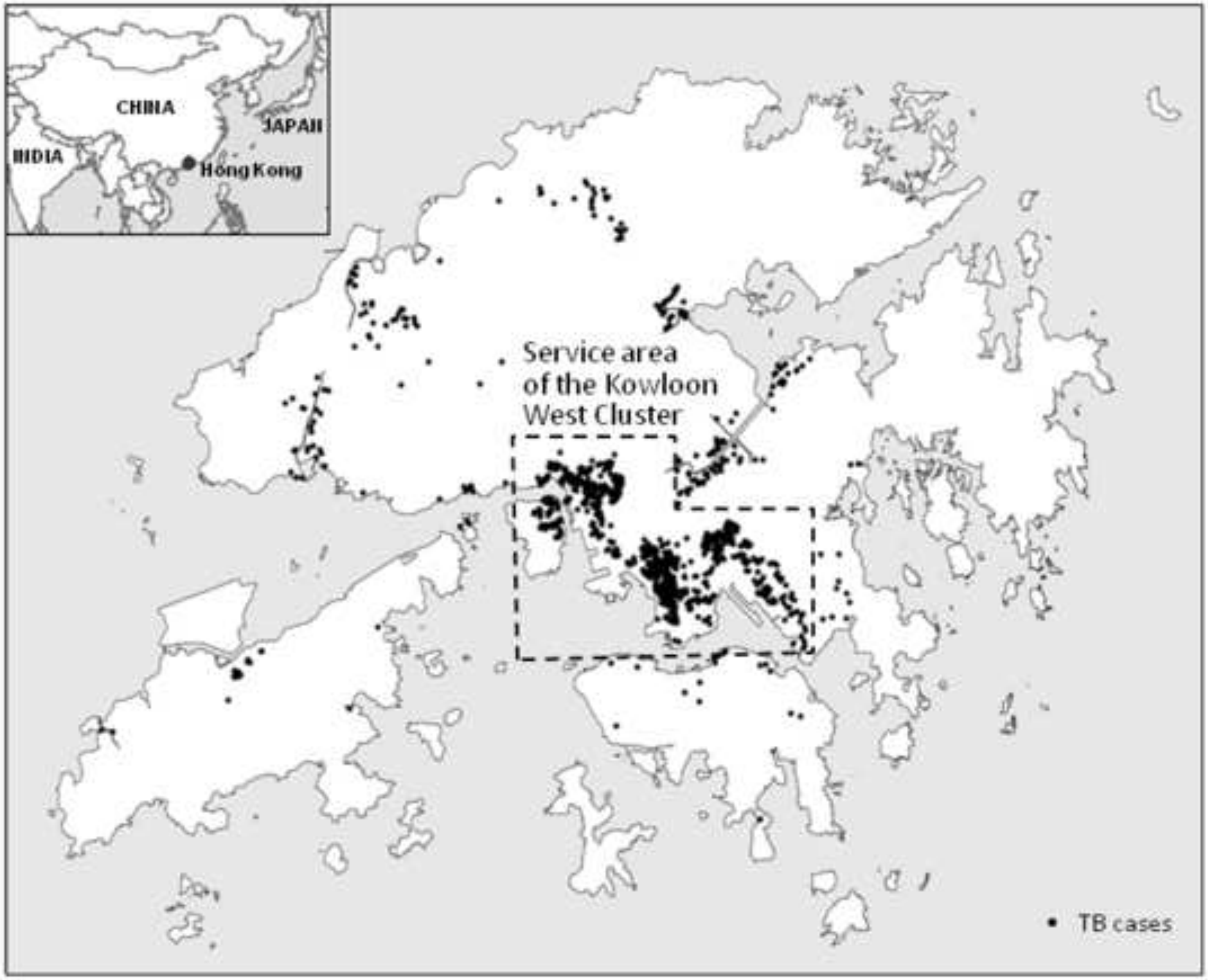

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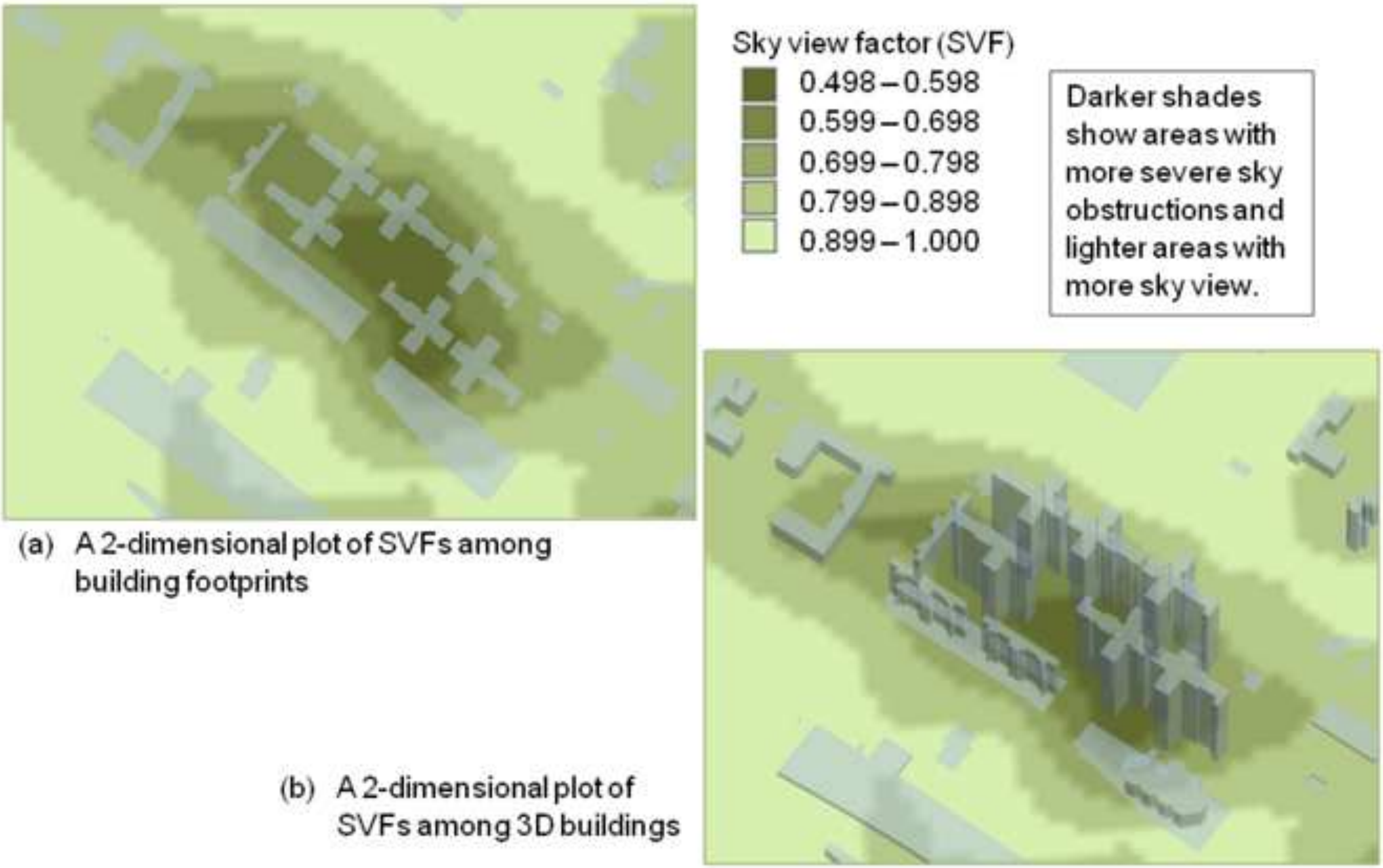

(a) A 2-dimensional plot of SVFs among building footprints

(b) A 2-dimensional plot of SVFs among 3D buildings

Figure
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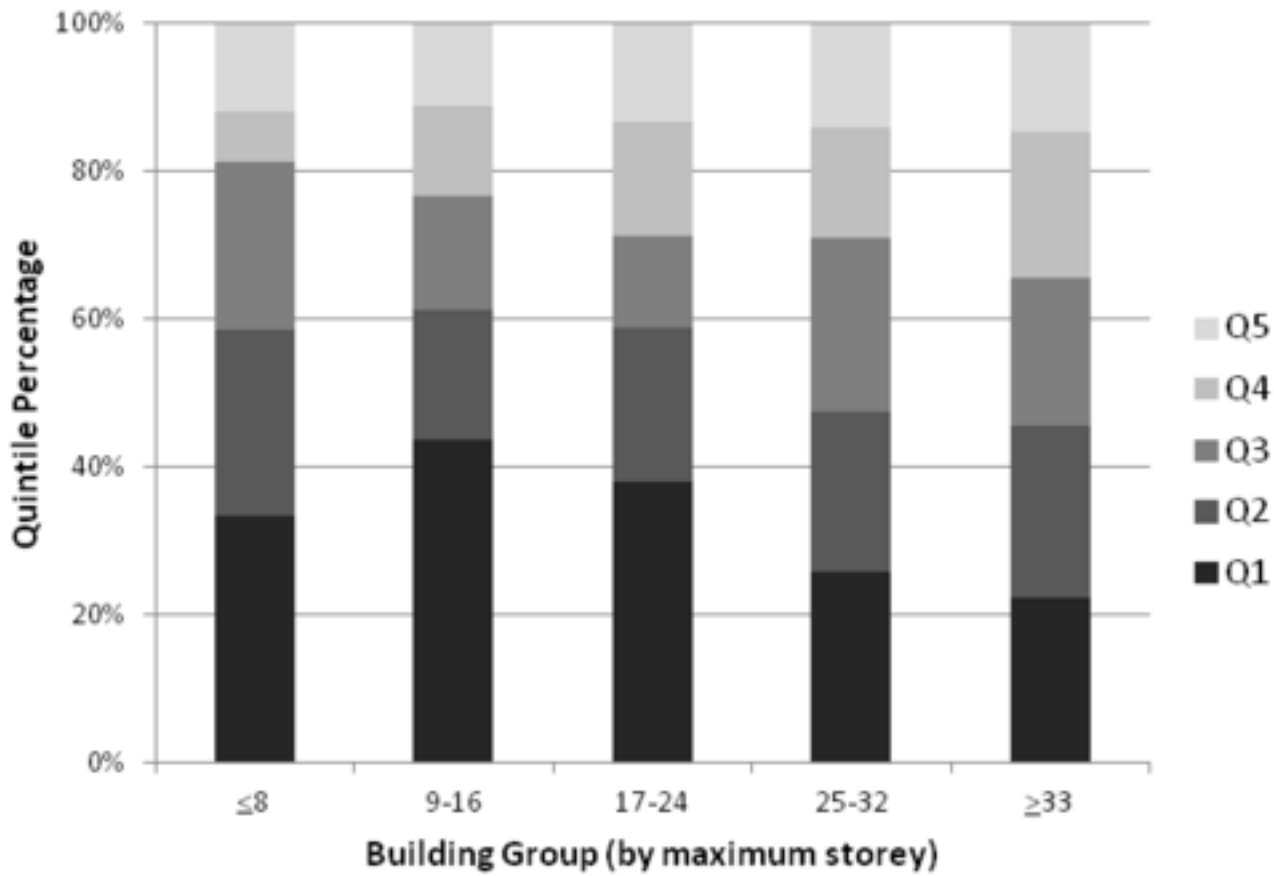

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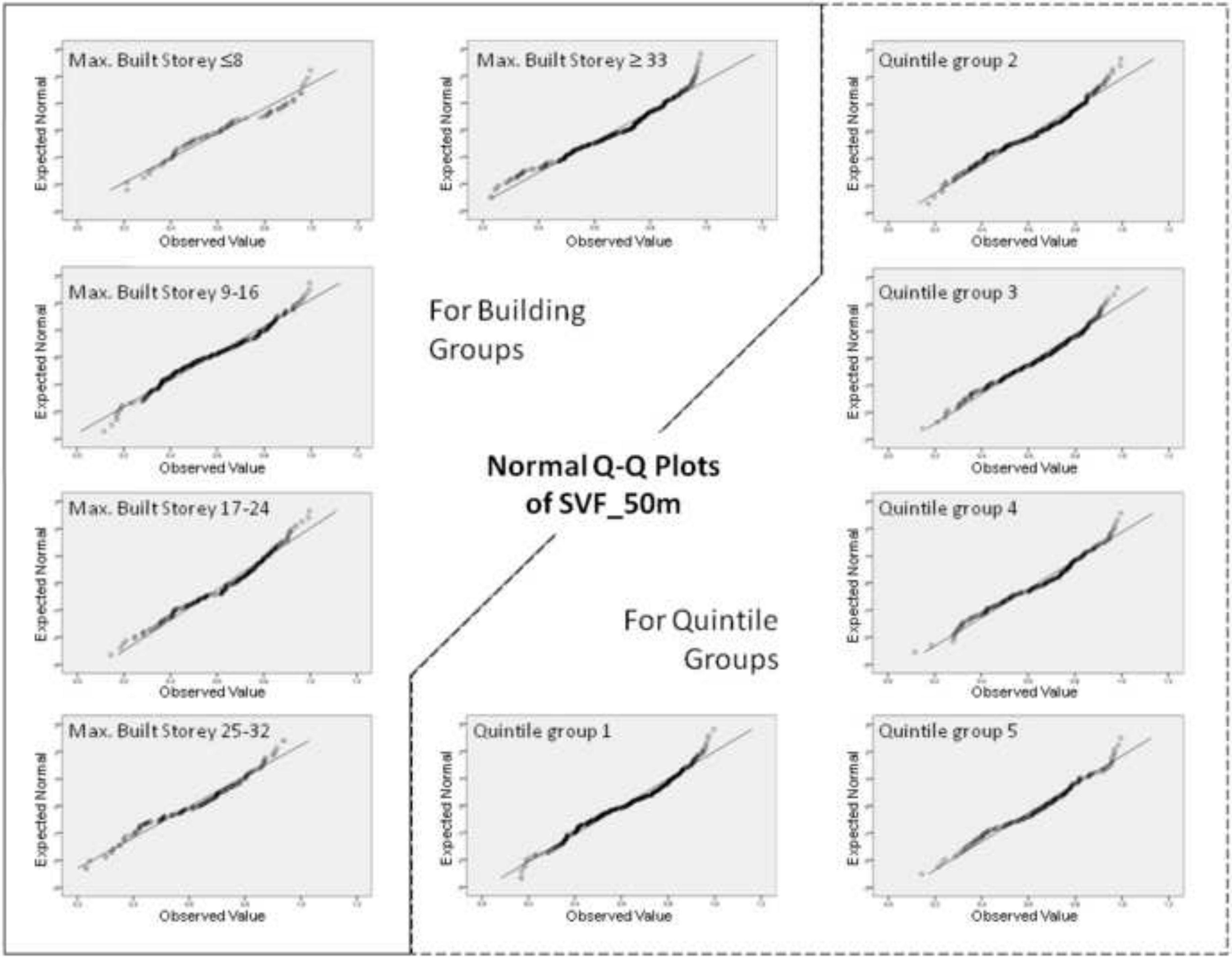

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