



Development of a contextualized index of multiple deprivation for age-friendly cities: Evidence from Hong Kong

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ABSTRACT

Deprivation refers to the state of having unmet basic needs, defined by societal standards. We argue that the mono emphasis on material deprivation is insufficient, as the characteristics of physical and social environments play a crucial role in either accelerating deprivation or providing additional resources/support to compensate for lack of income or basic household demands. We extend the focal point of the multiple deprivation framework to Hong Kong, an ultra-dense metropolis experiencing rapid demographic aging. We construct a Hong Kong index of multiple deprivation with seven domains. Highly deprived neighborhoods are likely to be located in areas with ultra-high residential density, where living conditions are substandard (e.g., subdivided units). Urban areas that used to have a large proportion of resettlement and industrial lands are likely to become deprived owing to the uneven distribution of urban amenities and the fragmentation of residential areas by industrial land.

1. Introduction

Deprivation is the state of having unmet needs, such as income, nutrition, health, shelter, safety, and education (Guillaume et al., 2015), which are defined by societal standards (Walker & Pettigrew, 1984). Globally, the Sustainable Development Goals (SDGs) emphasize combating deprivation as a central mission (Islam, 2021), specifically, reducing poverty (SDG 1) and inequalities (SDG 10) and creating a sustainable urban environment (SDG 11). Deprivation can have far-reaching negative consequences for individuals and societies. Deprivation can restrict individuals' access to opportunities, which can affect their access to healthcare and support (Bernard et al., 2007). Deprivation can also cause unequal exposure to "environmental burden" (e.g., air pollution and noise), which can lead to societal inequalities across communities (Liu et al., 2024; Pearce et al., 2010).

Deprivation is more than an aggregate of individual factors. People are inherently embedded in their surroundings; hence, their interaction with the environment, as well as the quality of and support from the environment, can affect their ability to meet various needs (Lawton & Nahemow, 1973; Sun et al., 2023). The concept of areal deprivation is important, which refers to the poor surrounding environment of one's

home that cannot satisfy their essential needs and may negatively influence their health (Abascal et al., 2022). People living in deprived areas are subjected to social, environmental, economic, and ecological adversities. Studies showed the effectiveness of using multiple factors in assessing areal deprivation, such as living conditions, opportunities to interact with nature, and distribution of public facilities and services (Allik et al., 2020; Townsend, 1987).

Most multiple deprivation indices were developed for Western countries (Fairburn et al., 2016; Otavova et al., 2023; Schederecker et al., 2019), and only a few indices are tailored for non-Western contexts (Cheung et al., 2019). In Hong Kong, environmental factors have a pressing effect on deprivation owing to the city's "double aging" phenomenon. "Double aging" refers to the simultaneous aging of residential buildings and the population (Sun et al., 2020). From 2012 to 2022, the number of private buildings aged 50 years or older surged from 3900 to 8600 (Secretary for Development, 2022). Aged buildings may fail to meet contemporary standards (e.g., subdivided units, poor indoor air quality, and inadequate sound and heat insulation), which can affect residents' safety, and are associated with a number of health concerns (Urban Renewal Authority, 2022), such as respiratory ailments, allergies, sick building syndrome, sleep deprivation, depression, and

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cancer (Corburn et al., 2006; Harris, 2019; Shin & Shaban-Nejad, 2018).

Meanwhile, between 2020 and 2023, the proportion of the population aged 65 years or older increased significantly from 18.5% to 21.7%, and the proportion of the population aged 80 years or older saw a rise from 5.2% to 5.4% (Census and Statistics Department [C&SD], 2023b). Older people may demonstrate reduced competence owing to physical or cognitive decline and thus may be highly sensitive to the impact of environmental factors (Lawton, 1986). Older people who experience deprivation will likely suffer from adverse health outcomes. In Hong Kong, older people are likely to suffer from lack of income. The pension system underscores individuals' responsibility to maintain their financial stability in old age, instead of relying heavily on public expenditure (Yeh et al., 2020). Furthermore, in 2021, around 13% of individuals aged 65 years or above in Hong Kong lived alone (C&SD, 2023a) and were receiving inadequate social support (Beghi et al., 2021; Ho et al., 2022). To address deprivation, it is important to note that older people often have various area-based needs. Improvements in physical, social, and ecological environments can provide resources and support to aging in place. For example, improving accessibility to transportation and community amenities is conducive to increased autonomy (Laverty et al., 2018). Communities with a high number of elderly residents may require additional security measures and community support to ensure safety, particularly women or individuals who reside alone (Lee et al., 2021).

This study aims to develop a composite index tailored for Hong Kong, that is, the Hong Kong index of multiple deprivation (HKIMD), to consider its double aging context. HKIMD scores and spatial characteristics can help identify areas lacking "environmental stimuli" to address people's needs and propose area-specific interventions and planning recommendations. This study poses three questions. First, how can area-based deprivation be assessed by incorporating factors in multiple domains and assigning appropriate weights considering Hong Kong's contexts? Second, how is deprivation spatially distributed across different areas in Hong Kong, and what are their planning and design characteristics? Third, which deprivation domains exhibit large spatial disparities that may contribute to the emergence of different deprivation clusters in Hong Kong?

2. Literature review

2.1. Deprivation in an era of demographic aging

Deprivation refers to the state of lacking essential needs; therefore, individuals (or residents of specific neighborhoods) who experience deprivation will have a lower standard of living compared with the broad population within a specific societal context (Herbert, 1975). This concept is often discussed from the perspective of equity and social justice. The absence or lack of crucial elements in the surrounding environment can limit individuals' opportunities to take advantage of their neighborhood and adopt an ideal lifestyle (Israel & Frenkel, 2018; Mayer, 2009). Residents who experience deprivation may bear the negative consequences of their urban setting (e.g., limited access to community resources, increased traffic and noise, housing shortage, and poor air quality) more than others (Bowyer et al., 2019; Green et al., 2022; Lawrence et al., 2021). Moreover, deprivation may have detrimental effects on mental health (Aretz, 2022; Hofbauer & Rodriguez, 2021).

The impact of deprivation on an aging society has become a significant concern (Exeter et al., 2022), because older people are highly susceptible to the negative effects of their neighborhood. Many deprived neighborhoods (areas experiencing material and intangible hardships) lack the necessary investment to maintain facilities/services for the increasingly aging population (Mouratidis, 2020). The residents of such areas typically experience poor living conditions, such as air pollution, hygiene issues, and lack of green spaces, whose effects could accumulate over time (Jivraj et al., 2020; Park et al., 2019). Thus, neighborhood

deprivation can significantly influence the aging process and lead to a decline in people's intrinsic ability to maintain their independence and autonomy (Ashikali et al., 2023). Lack of autonomy can make older people highly sensitive to environmental stress, which can lead to low satisfaction and decreased sense of safety (Mouratidis, 2020; Van Der Meer et al., 2008). Senior residents living in deprived areas are at high risk of negative health outcomes (from factors such as limited access to healthcare and unhygienic living conditions; Godhwani et al., 2019; Mohan & Barlow, 2023), social exclusion (Buffel et al., 2013; Prattley et al., 2020; Salvatore & Grundy, 2021), and financial hardships (from limited skills and difficulties in keeping a stable job; Smith et al., 2004).

2.2. Measuring deprivation: From an individual-based measure to an area-based multidimensional framework

The Organization for Economic Co-operation and Development recommended the use of material deprivation measures to analyze poverty in its member countries (Boarini & d'Ercole, 2006). Material deprivation can reflect whether residents lack basic necessities or the spending power to maintain a socially acceptable minimal standard of living (Schenck-Fontaine et al., 2020). For example, Saunders et al. (2014) developed a list of 35 essential items for assessing whether individuals are experiencing material deprivation in accommodations, basic home amenities (e.g., air conditioning), food, clothing, medical care, social connections (e.g., ability to give lucky money to friends), and education. The inclusion of air-conditioners and "lucky money" considers the unique climate and cultural contexts in (sub-)tropical Asian countries.

The concept of deprivation has been progressively enriched and expanded with the identification of new domains. British sociologist Peter Townsend pioneered the multidimensional framework of deprivation by developing the Townsend deprivation index in 1988 (Dunn, 2023; Townsend et al., 1988), which consisted of four variables: unemployment, non-car ownership, non-home ownership, and household overcrowding. Housing conditions (i.e., overcrowding) were included in the index, which were assumed to affect residents' stress levels, sleep quality, and privacy (Ruiz-Tagle & Uribe, 2022).

In the 2000s, a summary index of deprivation was created in Europe, which included capacity to avail basic necessities (e.g., food, clothing, vacation, and furniture), possession of consumer durables (e.g., a car, a phone, and a television), housing conditions (e.g., leaking roof and dampness), and quality of the neighborhood environment (e.g., existence of noise, pollution, and vandalism; Nolan & Whelan, 2011). In this index, the quality of the neighborhood environment is given considerable weight in the assessment of deprivation.

Meanwhile, the social deprivation index was developed in the United States and validated in Europe in 2021 (Hofbauer & Rodriguez, 2021). The index covers five domains, namely, education (measured in years), income (sum of all reported household incomes), wealth (household net assets minus liabilities), job stability (ability to hold a job for more than five years), and health insurance status (supplementary health insurance beyond basic national insurance). In this index, health insurance coverage is considered in the assessment of deprivation, because insured residents will have better access to health services. This domain may help reflect the broad socioeconomic conditions necessary to maintain good health and reduce health disparities within the population.

Many deprivation measures are based on household surveys that consider individual factors. However, survey data can be subject to sampling bias, because they are from selected individuals (Allik et al., 2020; Brown et al., 2023; Ochsner, 2021). The opportunities and challenges of a neighborhood that can affect residents' daily lives and health can be assessed fairly by areal factors derived from aggregated data (Allik et al., 2020). Norman et al. (2019) conceptualized deprivation as attributed to "conditions (that is, physical, environmental and social states or circumstances) rather than resources and to specific and not only general circumstances" (p. 31). According to the person-environment fit theory, the co-constituted relationship between

individuals and their surrounding environment is a factor that can contribute to people's positive functioning and emotions (Lawton & Nahemow, 1973; Sun et al., 2018). Specifically, the characteristics of physical and social environments play a crucial role in either accelerating deprivation or providing additional resources/support to compensate for lack of income or household demands (Hunnicut, 2022; Pearce et al., 2010). For instance, Mohan and Barlow (2023) discovered that living in a deprived area itself does not appear to affect mental health, but the features of the area, such as area safety, service provision, and cleanliness.

Besides, the social determinants of health (SDH) theory supports the use of area-based measurement in exploring factors that may contribute to deprivation (Dover & Belon, 2019). SDH was defined by the World Health Organization, referring to nonmedical elements that can affect people's health (Chapman, 2015). The neighborhood context is a crucial component of the SDH, such as the availability of resources for daily needs, access to educational and job opportunities, healthcare services, transportation options, social support, and crime risks. According to the SDH, the area-based measurement of deprivation is important, because the neighborhood acts as an opportunity structure that can offer access to diverse resources for earning a living, gaining knowledge, participating in cultural activities, and benefiting from social relationships (Bernard et al., 2007).

Originating from the United Kingdom in 1998 and following Townsend's idea of multiple deprivation, the IMD is an area-based measurement that combines seven domains, namely, income, employment, health, education, barriers to housing and services, crime, and the living environment, into a single deprivation score (Kinsella, 2007). The seven domains encompass various needs, including physiological and safety needs, as well as opportunities for housing and a satisfactory living environment (McLennan et al., 2019; Rylands et al., 2016). The IMD has three advantages. First, the IMD relies on census and other publicly available government and geospatial data, which means that it can be updated regularly to monitor changes. Second, the continuous enrichment and updating of the data will allow the IMD to adapt to changing societal needs and provide a timely reflection of deprivation in different areas. Third, results from the IMD are widely used to develop area-based initiatives (ABIs) to provide context- and place-specific insights for decision making (Hooton, 2022). ABIs, as more targeted approaches, align with the advocates that "people belong to multiple nested and non-nested, social and geographic, past and present contexts" (Riley, 2020, p. 5); hence, disparities in health are not influenced simply by individual-level factors but the "systems" where people are exposed to (namely, the area/contextual features and activities).

For example, in the United Kingdom, the IMD score is utilized as a proxy in predicting area-level healthcare needs (Symonds et al., 2019). A strong correlation exists between IMD scores and the prevalence of certain diseases, such as cardiovascular disease and type II diabetes (Bush et al., 2022; Lang et al., 2016). Through the identification of areas with the most urgent needs, healthcare resources can be allocated efficiently, and health expenditure can be predicted for different regions (Barlow et al., 2021; Fecht et al., 2018). Government agencies use the IMD to determine the residents eligible for welfare subsidies, such as the Green Homes Grant (homeowners can apply for vouchers that will cover up to two thirds of the cost of their energy-saving home improvements; Department for Levelling Up Housing and Communities, 2022).

The IMD works well across different contexts, including in Germany (Schederecker et al., 2019), New Zealand (Exeter et al., 2017), and Belgium (Otavova et al., 2023), by incorporating localized indicators and expert scoring. However, few studies used the IMD in non-Western contexts. For instance, Yuan and Wu (2014) adapted the IMD for Guangzhou City, China, but because of data availability constraints, the index was based only on census data and consisted only of 13 indicators across five domains, namely, income, employment, education, housing, and health. In Hong Kong, a local think tank devised an IMD that consisted of four indicators, that is, the proportion of households with a

monthly income below HKD 10,000, the percentage of adults with low secondary education or low qualifications, the proportion of adult males not participating in the labor force, and the percentage of adults who are widowed, separated, or divorced (Lai, 2017). However, the indices could not capture the complexities of deprivation, because they did not reflect the quality of physical, social, and natural environments.

Despite the growing number of studies on deprivation in Hong Kong, environmental factors have yet to be considered comprehensively. Currently, the official measurement of deprivation in Hong Kong relies on the poverty line (50% of the median household income by household size). Researchers recognized that combined approaches are more effective in identifying the people experiencing deprivation than a mono approach. For instance, Chen et al. (2018) measured deprivation by calculating the percentage of deprived groups at the district council level, such as the working poor, older adults, single parents, ethnic minorities, unemployed adults, and new migrants. The results showed two districts in the downtown areas were mostly deprived. However, one district (i.e., Yau Tsim Mong) boasts a variety of high-end office buildings, retail establishments, and recreational facilities well equipped to meet people's physical activity, leisure, and employment demands. These factors can compensate for hardships faced by individuals who have certain demographic and socioeconomic disadvantages.

From such perspectives, this study identifies two interrelated gaps in the measurement of areal deprivation in Hong Kong. First, most studies in Hong Kong focused mainly on material deprivation and failed to consider deprivation comprehensively. In addition, such studies commonly used survey data to measure material deprivation, which may not be as representative as census data. Second, though the IMD is a promising approach for assessing deprivation and shedding light on areal disparities, its application in densely populated Asian cities is limited, and the number of factors considered has been inadequate. One possible reason for this limited application may be the difficulty of finding the specific data required by the IMD or constraints in data accessibility. In Hong Kong, the population census is conducted every five years. With the advent of more open data policies, a government online portal was established to integrate all available datasets (including geospatial data), which can provide easy access to multiple data types. The data framework employed in this study can serve as a template for other countries to build their data infrastructure.

3. Methodology

3.1. Development of HKIMD

3.1.1. Selection of domains and indicators

To address the first research question, we constructed the HKIMD by selecting suitable domains and indicators (Table 1) based on the IMD framework (Allik et al., 2020; Norman et al., 2019). The calculations and data processing were performed using Python and QGIS (Fig. 1). The unit for computing the index score is the Tertiary Planning Unit (TPU, See Fig. 2 for their subdivisions). TPUs are the most appropriate scale as they are linked with census data (Cerin et al., 2016; Sun et al., 2023). TPUs are street block clusters representing small spatial units for the urban planning purposes of Hong Kong. As of 2021, there are 291 TPUs in total.

The initial selection of indicators followed the original IMD developed in the UK, consisting of seven domains. In order to contextualize HKIMD, a panel of seven experts was formed from diverse disciplines, namely, urban planning, human geography, architecture, sociology, gerontology, nursing, and epidemiology. The experts considered the relevance of each indicator to the city's socioeconomic and environmental context, as well as data availability. When data on specific indicators in the IMD were unavailable, they were replaced with relevant indicators after a consensus-oriented discussion. Three localized indicators were added (two under the living environment domain and one under the barriers to housing and services domain). Justifications are

Table 1
Domains and indicators.

Name	HKIMD Indicators
Domain 1: Income (9.2%)	
Inc 1	Median monthly domestic household income (HKD)
Inc 2	Poverty rate (%)
Inc 3	Proportion of working population with low earnings (less than HKD 6000 per month; %)
Inc4	Proportion of population receiving social security benefits (%)
Domain 2: Employment (7.9%)	
Emp 1	Proportion of population involuntarily excluded from the labor market owing to caring responsibilities (%)
Emp 2	Economic inactivity rate (%)
Emp 3	Proportion of population working less than 35 h in seven days (%)
Domain 3: Education, Skills, and Training (8.4%)	
Edu 1	Proportion of people who do not have at least lower secondary education (%)
Edu 2	Proportion of people who have at least post-secondary education (%)
Edu 3	Proportion of people aged 5 years or over who are unable to speak/understand Chinese (%)
Edu 4	Proportion of people aged 5 years or over who are unable to speak/understand English (%)
Edu 5	Proportion of working population with elementary occupations (%)
Domain 4: Health (25.9%)	
Hea 1	Average years of potential life lost (years)
Hea 2	Average life span (years)
Hea 3	All-cause mortality (%)
Hea 4	Proportion of deaths from mental disorders per 100,000 people
Domain 5: Crime (4.4%)	
Cri 1	Rate of crime against a persons per 100,000 people
Cri 2	Rate of crime against property per 100,000 people
Cri 3	Financial and fraud-related crimes rate per 100,000 people
Cri 4	Rate of crime against society and public order per 100,000 people
Domain 6: Barriers to Housing and Services (24.0%)	
Fac 1	Number of supermarkets and convenience stores shared per 100,000 people
Fac 2	Number of hospitals and clinics shared per 100,000 people
Fac 3	Number of schools shared per 100,000 people
Fac 4	Number of public transport stations shared per 100,000 people
Hou 1	Median floor area of household (square meters)
Hou 2	Proportion of households without exclusively used rooms (%)
Hou 3	Ratio of median monthly household mortgage payment and loan repayment to income (%)
Domain 7: Living Environment (20.2%)	
Liv 1	Average building age (years)
Liv 2	Air quality (number of hours with low AQHI score in a year; %)
Liv 3	Road traffic accidents (density of accident black sites; number per square kilometers)
Liv 4	Proportion of green areas (%)

Elementary occupations involve the performance of simple and routine tasks which may require the use of hand-held tools and considerable physical effort.

provided in the Appendix. Finally, HKIMD includes seven domains with 31 indicators. Each indicator was normalized by the min-max method—the raw data of each indicator was transformed to a scale ranging from 0 to 100.

3.1.2. Expert scoring to assign weights for each domain

Analytic hierarchy process (AHP) was adopted to assign weights to the seven deprivation domains based on the expert scoring (Wu et al., 2022). AHP is a structured decision-making process widely used to synthesize the diverse opinions of a group of stakeholders to determine the weights of different domains for a composite index (Yang et al., 2023). Seven experts assessed the relative importance of each domain from 1 to 9 through pairwise comparison. The decision matrix derived from the expert scoring was consolidated into a set of weights based on its principal eigenvector. The decision consistency of the different experts was assessed with the consistency ratio (CR) formula, where λ is the largest eigenvalue, and n is the size of the decision matrix (Alonso & Lamata, 2006), as follows:

$$CR = \frac{\lambda - n}{2.7699 * n - 4.3513 - n}.$$

The weighted geometric mean aggregation of individual judgments method was used to merge all the expert opinions (McIntosh & Becker, 2020). All the computations were carried out in AHP-OS (Goepel, 2018). The obtained CR was 1%, which reflected consistent responses (Lin et al., 2013). The weights generated through the expert scoring and AHP were utilized to calculate the composite HKIMD scores (Table 1). Specifically, for each domain, the value of each indicator was first

normalized. The mean values of all indicators were used as a domain score. The composite HKIMD score for each TPU was calculated by multiplying the domain scores by their weights and summing up all domain scores.

3.2. Analysis methods

We ranked the HKIMD scores of all the TPUs by decile (with an equal number of TPUs in each decile), in which the top and bottom 30% were regarded as high- and low-deprivation areas. The cut-off threshold was defined based on previous research on IMD and comments from experts (McCartney & Hoggett, 2023). We also examined the planning and design characteristics of the areas through onsite visits to understand either their best practices or common features.

To address the third research question, we compared each deprivation domain across the 18 districts of Hong Kong to identify which domains demonstrated the largest spatial disparities. Then, we classified and grouped all TPUs based on their contributing factors by using Ward's hierarchical agglomerative clustering method (Ward, 1963). This approach involved treating each TPU as a separate cluster and progressively merging the clusters based on their similarities across the seven deprivation domains until only one cluster remained. The method can systematically combine the clusters to minimize the increase in the within-cluster disparities in each step (Govender & Sivakumar, 2020). A follow-up comparison of intra-cluster variance between the method and k-means clustering confirmed the former's effectiveness and adequacy.

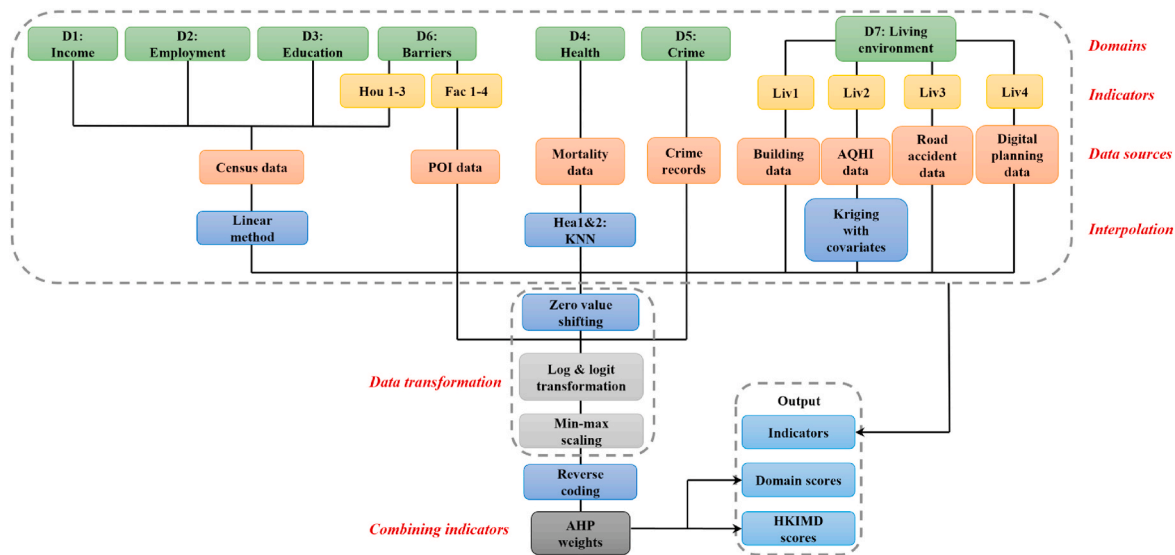


Fig. 1. HKIMD calculation workflow.

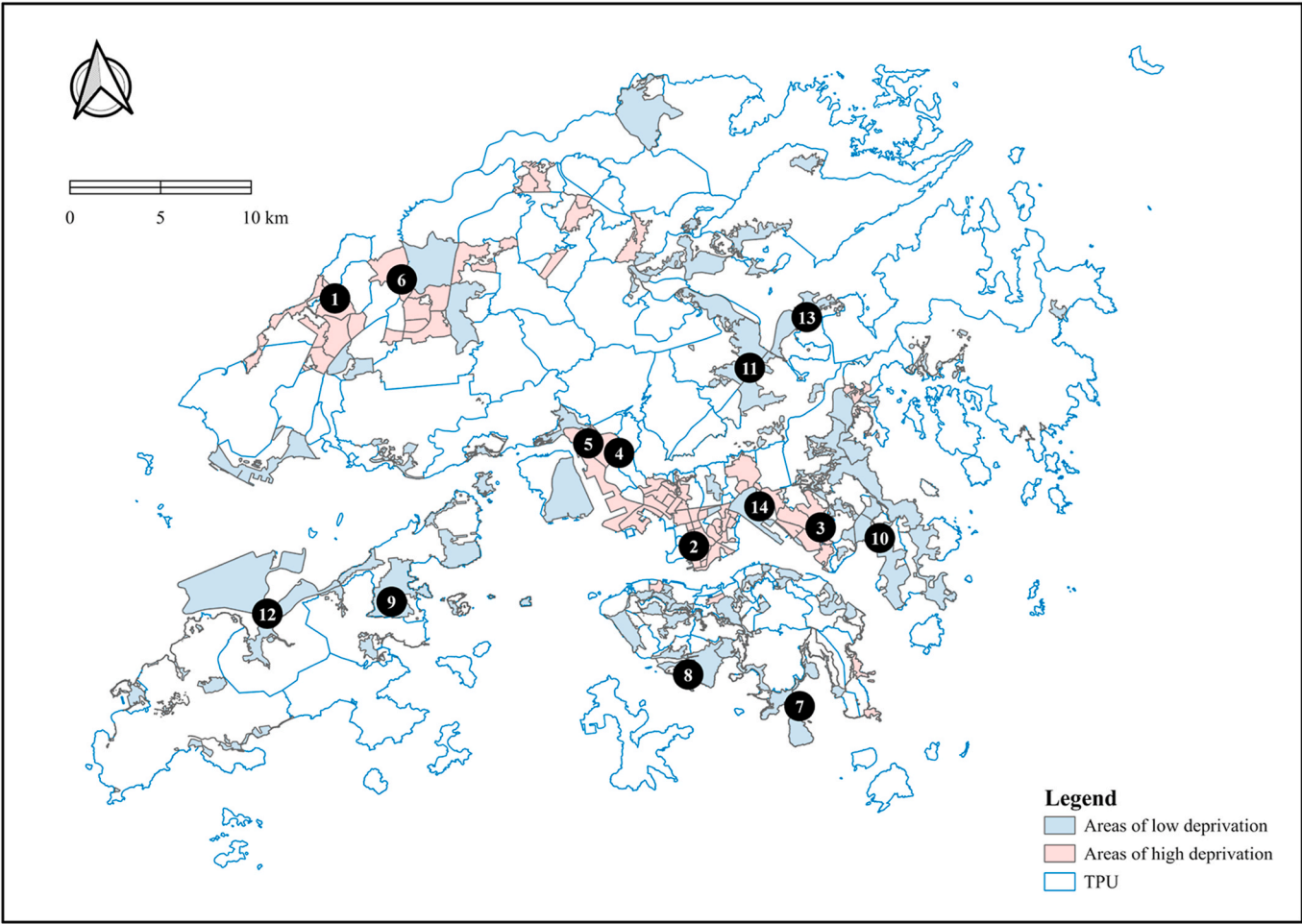
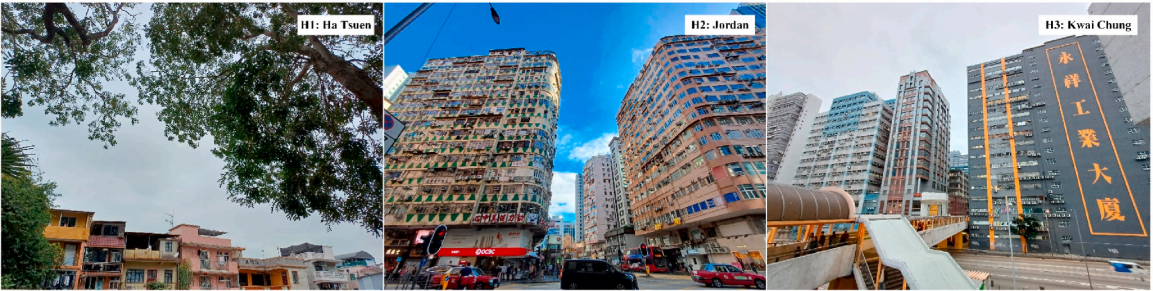


Fig. 2. Areas of high and low deprivation. “Areas of high deprivation” refers to areas with deprivation scores in the top 3 deciles; “areas of low deprivation” refers to areas with scores in the bottom 3 deciles; exclusions apply to areas that consist predominantly of green spaces.

High deprivation



This rural village lacks basic amenities such as supermarkets, convenience stores, and eateries. This area has poor air quality owing to the prevalence of warehouses and trucks.

This area has numerous subdivided flats and poorly maintained old buildings owing to its low-income populace and ultra-high residential density. Homelessness and crime-related activities are prevalent in some streets.

The mix of industrial and residential buildings in this area has resulted in less-than-ideal living conditions. The air quality and aesthetic appeal are low, and land use is fragmented.

Low deprivation



Known for its stunning sea views and abundant greenery, Stanley is a popular tourist attraction. It boasts an excellent natural environment, luxury residential areas, and high-end apartments.

This well-planned new town features a mix of public and private housing, located mostly within walking distance of the railway station. It offers easy access to recreational and shopping facilities, as well as seafront.

Located between Tolo Harbor and Ma On Shan Mountain, this new town offers an excellent natural environment. The new town follows a TOD development mode, with many residences living near the subway station.

This redeveloped area boasts excellent transport connectivity. Planned as Hong Kong's CBD2, it integrates commerce, transportation, high-end residences, green spaces, and entertainment.

Fig. 3. Examples of high- and low-deprivation neighborhoods.

Table 2
Neighborhoods of high and low deprivation by planning and design characteristics.

	Type	Planning and design characteristics	Examples
High deprivation	H1	Remote rural villages that lack public facilities	Ha Tsuen (1)
	H2	Downtown areas with ultra-high residential density Poor living conditions (e.g., subdivided flats) Lacking amenities, open spaces, and recreational facilities High crime rates	Jordan (2)
	H3	Former resettlement areas close to vacant industrial buildings; residential developments intersected by former industrial land, which can make allocating community resources and facilities evenly difficult Relatively high residential density compared with neighborhoods in other new towns Amenities and tertiary services are concentrated in the town center	Kwun Tong (3), Kwai Chung (4), Tsuen Wan (5), Yuen Long (6)
Low deprivation	L1	Affluent coastal neighborhoods with a relatively low residential density compared with downtown neighborhoods Relatively few public housing developments Spacious private housing estates with captivating natural views (mountains and sea) Home to many professional expatriates/migrants	Stanley (7), Ap Lei Chau (8), Discovery Bay (9)
	L2	Self-sufficient new towns with diverse amenities and a balanced proportion of public and private housing Satisfactory transport connectivity Relatively sufficient healthcare services	Tseung Kwan O (10), Sha Tin (11)
	L3	New towns with relatively low residential density compared with downtown and other new towns Abundant green spaces and good natural views (e.g., sea and rivers)	Tung Chung (12), Ma On Shan (13)
	L4	Redeveloped areas with a high proportion of private housing Second CBD apart from Central in Hong Kong Island State-of-the-art infrastructure and amenities	Kai Tak in Kowloon (14)

Table 3
Deprivation by domain.

District	Income	Employment	Education	Health	Crime	Barriers	Living environment	HKIMD
Central and Western	34	28	39	51	76	44	58	48
Southern	47	31	46	49	23	49	44	45
Wan Chai	25	28	40	50	84	47	55	47
Eastern	48	36	41	52	3	48	52	46
Yau Tsim Mong	52	32	41	48	100	52	72	55
Sham Shui Po	73	41	47	50	57	50	65	55
Wong Tai Sin	72	44	47	52	28	46	63	53
Kowloon City	58	36	42	45	35	50	66	50
Kwun Tong	78	40	42	52	33	45	62	52
Kwai Tsing	71	41	46	53	16	43	53	49
Tsuen Wan	53	35	37	44	51	54	43	46
Yuen Long	69	40	44	49	28	63	41	51
North	74	48	49	44	50	56	40	50
Tai Po	57	35	39	46	49	58	38	47
Tuen Mun	63	38	41	52	17	53	39	47
Sha Tin	61	40	40	53	10	44	45	46
Sai Kung	44	31	42	51	9	58	40	46
Islands	65	39	48	44	36	51	37	46
Mean	58	37	43	49	40	52	51	49

Notes: The deprivation score is between 1 and 100. For clarity, high deprivation scores are highlighted in red, whereas low deprivation scores are shown in blue.

The deprivation score ranges between 1 and 100. For clarity, high deprivation scores are highlighted in red, whereas low deprivation scores are shown in blue.

4. Results and discussion

4.1. Spatial characteristics of area deprivation

We summarize the spatial characteristics of the areas demonstrating high and low deprivation and conduct follow-up onsite investigations (Figs. 2 and 3, and Table 2).

4.2. Spatial disparities by deprivation domain

Three domains exhibit considerable spatial disparities: income, crime, and living environment (Table 3). Economic development in Hong Kong relies heavily on the finance, trade, and service sectors, which contribute less than 10% to the total employment and thus have become the root cause of income disparities. High-income jobs, such as those in the finance and service sectors, are concentrated in Hong Kong Island (Chen et al., 2018), whereas the low-income workers are concentrated elsewhere, such as in Sham Shui Po, Kwun Tong, Wong Tai Sin, and the North District (C&SD, 2021). Districts experiencing income deprivation can be classified into three types. For Kwun Tong (78) and Kwai Tsing (71), income deprivation can be attributed to the decline of former industrial areas after the relocation of the industrial sector to Mainland China in the 1980s. Most of the industrial buildings in the districts are being used as warehouses or offices or are vacant (Planning Department, 2021). A few of the industrial buildings are illegally converted into subdivided housing, which has resulted in poor and dangerous living conditions for the residents of such areas (Legislative Council, 2019). Sham Shui Po (73) is experiencing income deprivation owing to its limited community resources and poor living conditions. Historically, this area was home to many low-income and low-skilled workers from mainland China, South Asia, and Africa, as well as older people (Cheng, 2013). Meanwhile, the income deprivation of the North

District (74) can be attributed to the large proportion of village-type land, the high percentage of the unemployed population and the population with low education attainment, as well as elderly individuals who live alone (Guo et al., 2018).

We compare the HKIMD map with the income deprivation map (Appendix). The results indicate that evaluating areas based merely on income deprivation can lead to an overestimation of the deprivation level of certain areas. In some regions with income deprivation, hardships can be offset by satisfactory living environments with low crime rates and few barriers to housing and services. Such findings demonstrate the importance of developing a framework with multiple domains to understand deprivation.

Crime incidence is concentrated in Yau Tsim Mong (100), Wan Chai (84), and Central and Western (76), which are all in the downtown area. The high crime rate in Yau Tsim Mong may be attributed to the “triads,” which remain actively involved in various criminal activities, such as drug trafficking, prostitution, gambling, and extortion (Wang & Kwok, 2022). Crime in Wan Chai and in Central and Western can be attributed to land use. The zoning in the districts cuts the land into small pieces and involves a high mix of land uses to enhance land use efficiency, accompanied by the dense coverage of the public transit (e.g., buses and subways). Such land use types make the two districts highly accessible. However, such diversity can increase crime rates through concentrations of crime targets (Brantingham et al., 2020). Furthermore, the numerous bars in the area attract tourists and locals seeking recreation, which can increase crime incidence owing to intoxication. All the aforementioned factors can increase the volume of outsiders and commuters (including potential criminals) in the area, which may lead to an increase in fraud and property-related crimes (Fig. 4; He & Li, 2022).

Kowloon’s high density and complex urban forms have led to deprivation in the living environment, especially in Yau Tsim Mong. This district records the highest degree of deprivation (72) owing to the

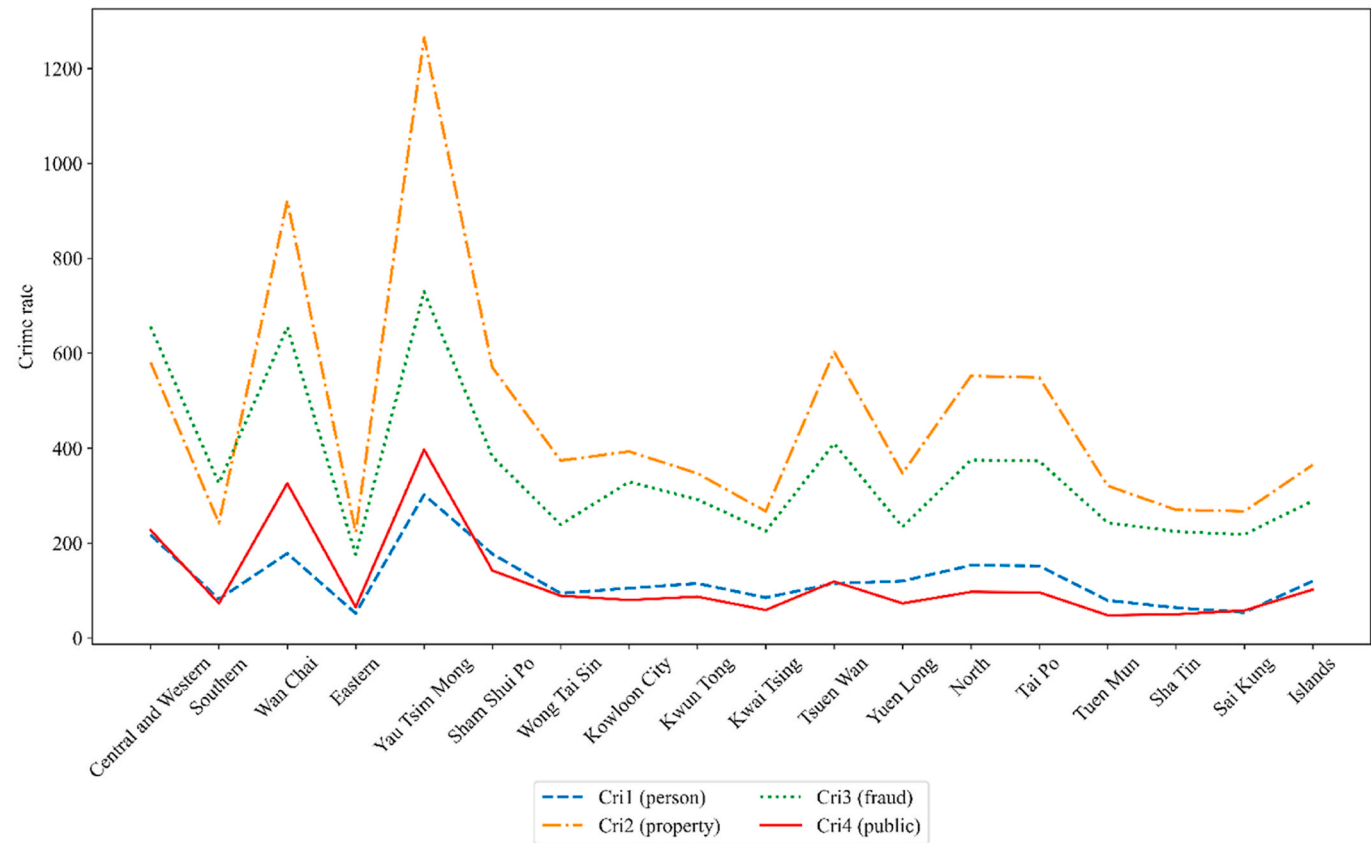


Fig. 4. Crime rate (per 10,000 people) across police districts in 2021. Types of crime include crime against a person (e.g., murder, child cruelty, and kidnapping) or property (e.g., robbery, burglary, and arson), financial and fraud-related crimes (e.g., deception, business fraud, and serious gambling offenses), and crime against society and public order (e.g., manufacturing of dangerous drugs, disorder/fighting in a public place, and possession of offensive weapon).

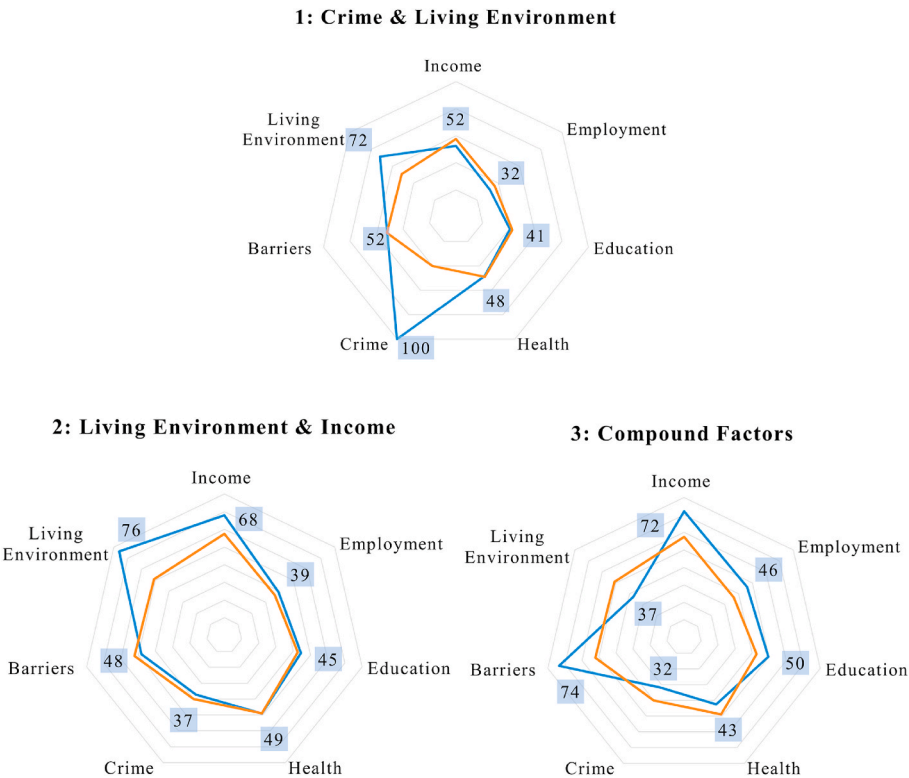


Fig. 5. Radar charts of three deprivation clusters. Blue lines represent the average deprivation score of each domain within a cluster; red lines indicate the average deprivation score across all districts.

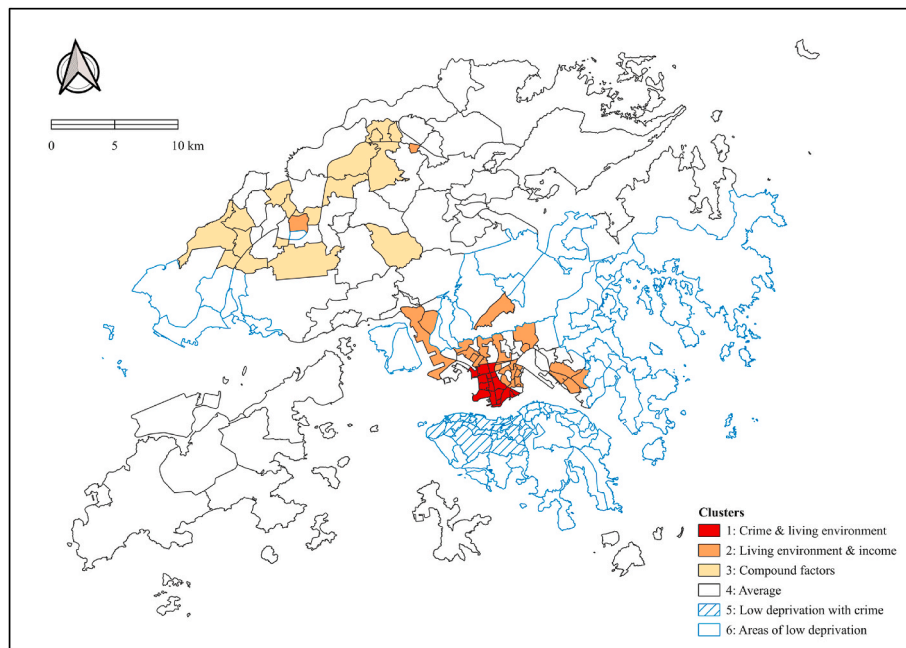


Fig. 6. Three deprivation clusters and areas of low deprivation. Three deprivation clusters are colored areas.

significantly high density of road accidents (0.199 compared with the average of 0.033) and low proportion of green spaces (11% compared with the average of 45%). Residential areas and former industrial land intersect in some districts neighboring Kowloon, such as in Kwun Tong and Kwai Tsing, which has led to poor living conditions.

The “barriers to housing and services” and “living environment” domains show contrasting spatial patterns. Remote areas such as the North District generally experience deprivation owing to barriers to housing and services. By contrast, urban areas such as Wong Tai Sin have poor living conditions. However, Yau Tsim Mong is experiencing deprivation in both domains.

4.3. Hierarchical clustering analysis

Hierarchical clustering analysis identifies deprivation areas into three clusters (Figs. 5 and 6).

Cluster 1, which is located in Yau Tsim Mong, is experiencing deprivation owing to the concurrence of **high crime prevalence** and **poor living environments**. Notably, Yau Tsim Mong has a high crime rate owing to “triad” activities and the high concentration of commercial buildings and hotels, which can attract tourists and increase passenger volume (which can make surveillance difficult; He & Li, 2022; Wang & Kwok, 2022). In terms of the living environment, the exceptionally high density of buildings and roads makes planning community facilities, such as street greenery, open public spaces, and community centers for social mingling, in this district difficult. The district also suffers from severe air pollution, which can pose a significant health threat to the population (Huang & Loo, 2023).

The former resettlement and industrial areas in or near Kowloon (e.g., Kwai Chung, Sham Shui Po, and Kowloon Tong) demonstrate deprivation owing to the hybrid factors of **low income** and **poor living conditions** (Cluster 2). Owing to their advantageous location near job opportunities and accessible mass railway transit (many of the areas are located in close proximity to Hong Kong’s first subway line opened in 1980), the areas are home to a large number of working-class individuals living in public housing estates. Besides, high-density environments may have notable drawbacks, such as air pollution, noise, and heat hazards (Hua et al., 2021), which can negatively impact the quality of life. This observation aligns with the findings of Chan et al. (2021), which

reported that residents’ anxiety and stress levels are linked with residential density.

Cluster 3 is composed predominantly of remote rural villages located in northwest New Territories (e.g., Ha Tsuen and Tai Tong Tsuen). This cluster is experiencing deprivation owing to **compound factors**. The neighborhoods are facing a number of hardships, such as unemployment, insufficient educated and professional dwellers, and barriers to housing and services.

4.4. Implications for urban planning and policymaking

This study has important implications for urban planning and policymaking, particularly in addressing the spatial disparities in deprivation and identifying the reasons behind such disparities, which are embedded in the unique neighborhood conditions. It is worth noting that these implications are not limited to Hong Kong. Many cities in Asia and Western countries are expected to face “double aging” issues in the future; thus, the findings and implications of the HKIMD can provide useful insights into potential improvements and mitigation measures that can be applied to their unique circumstances.

First, ultra-high-density urban areas are typically linked with poor living conditions (e.g., overcrowding, lack of green spaces, and road accidents), which can become a critical factor in deprivation. Yu and Kwan (2024) found that exposure to green spaces at eye level plays an important role in alleviating stress for residents (i.e., Sham Shui Po). Planners may consider using innovative greenery strategies to increase urban residents’ contact with nature, such as rooftop gardening and vertical greening. In high-density urban settings, disaggregated greenery (i.e., small green spaces rather than a single large green space) can provide residents with more mental health benefits (Ha et al., 2022). Pedestrian safety is another issue that requires attention. Many cities worldwide are promoting walkability to boost citizens’ physical activity and health. Ensuring sufficient signages to guide the pedestrian flow and providing barrier-free crossings are essential to enhance walkability, especially at identified accident black sites.

The specific spatial features of the downtown area, such as dense commercial activities, heavy pedestrian flow, and a high concentration of bars, may lead to a high concentration of crime. Crime can be prevented through the redesign of spaces, such as enhancing visibility and

allowing people to observe their surroundings easily through well-placed windows, lighting, security cameras, and open layouts.

Second, former industrial areas in Hong Kong are typically near residential areas, which is a counterexample of a land use mix that can reduce quality of life because of pollution, traffic congestion, and lack of community facilities. Besides, the presence of industrial lands poses limits to allocating community facilities and amenities to enhance livability. Most industrial buildings are now used for storage and offices instead of factories. Rezoning and designating specific land for industrial use may be possible solutions to this issue. For example, the transfer of plot ratio was piloted in Yau Tsim Mong's redevelopment plan, which will allow strategic sites to be upzoned to increase the development intensity and other sites to be downzoned to create open spaces or pedestrian paths.

Third, for villages in northwest New Territories, deprivation is due to lack of employment and educational opportunities, lower income, and limited access to facilities. A possible solution could be to transfer some urban functions from downtown to rural areas while preserving the natural environment. Currently, the government is exploring the development potential of some remote lands, through planning science and innovation parks and implementing transport-oriented development (TOD). These strategies can also be beneficial to large cities in western countries where residential areas are far from commercial zones.

Last, this study develops an HKIMD against the backdrop of Hong Kong's double aging context. The suggested improvements for the deprived neighborhoods of Hong Kong, such as the promotion of a moderate residential density and mixed land use with sufficient open spaces and diverse community facilities, will also contribute to the creation of age-friendly communities. It is important to consider the varying levels of competence among older people who live in the same neighborhoods, especially those with hearing, visual, mobility, and memory impairments. Urban planning and policies should create an inclusive and accessible environment that caters to their needs. Technology can play a significant role in improving their quality of life, such as AI-powered mobile applications to assist visually/physically impaired residents remain independent in navigation, object detection, and obstacle avoidance (Khan et al., 2020).

4.5. Limitations

This study conducts a robust analysis of deprivation; however, it is not without limitations. Further research, particularly a longitudinal study, is necessary to monitor the changes in deprivation levels and identify the underlying mechanisms leading to such changes (Anacker, 2019). In addition, Hong Kong's double aging context was only considered through expert scoring. Future studies may consider conducting interviews and surveys to identify older people's needs and include subjective data in the index, such as perceived ease of walking in neighborhoods, residential satisfaction, and so on. Besides, including data from GIS analysis will be beneficial to reflect the lived experience of older people, such as network analysis of people to specific services. Considering the fast development of digitalization, future research should explore new aspects for measuring deprivation in the digital age, such as digital awareness, online banking, remote medical consultation, and the adoption of smart services (Yang et al., 2022).

5. Conclusion

This study makes important contributions to applied geography by offering a content-specific measure of deprivation. The HKIMD is the first index in Hong Kong to assess areal deprivation in seven domains with 31 indicators. The HKIMD is a useful tool for identifying high- and low-deprivation areas (and their geographic characteristics) and generalizing best practices to improve urban planning. With the improvement of data availability, the HKIMD can be updated and

enriched continually to monitor changes and improvements. The results can evaluate the efficiency and efficacy of public policies that address deprivation in selected domains and provide additional scientific evidence for deprivation alleviation. In order to aid government agencies and other organizations in creating relevant policies and strategies, HKIMD domain scores will be accessible online in the future. Most important, the insights gained from this study demonstrate the successful application of the IMD framework in a non-Western context. The protocol can provide a useful reference to other cities to calibrate their IMD, considering their unique contexts and societal challenges.

Our findings reveal that affluent coastal neighborhoods, self-sufficient new towns, and redeveloped areas with state-of-the-art facilities are likely to become low-deprivation regions. By contrast, overcrowded downtown areas with a huge volume of traffic/commuters, former industrial sites and resettlement areas, as well as the rural areas in northwest New Territories, are marked by high deprivation. A moderate residential density, a balanced proportion of public and private housing, sufficient amenities and healthcare services, adequate transport connectivity, satisfactory housing quality, and sufficient contact with nature should be emphasized in urban planning to address deprivation from more than one aspect. Integrated efforts can help create livable, age-friendly, and inclusive urban environments for citizens to stay healthy, prosperous, and fulfilled.

CRediT authorship contribution statement

Shi Chen: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Siqiang Wang:** Writing – review & editing, Validation, Methodology, Conceptualization. **Yi Sun:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Conceptualization. **Justina Yat Wa Liu:** Writing – review & editing, Validation, Supervision, Conceptualization.

Declaration of competing interest

All authors of the paper have reviewed and approved the final version of the manuscript. The authors declare no conflicts of interest. This work has not been published elsewhere. Ethical considerations and guidelines were followed throughout the research process.

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Appendix A. Supplementary data

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