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# Multi-scalar drivers of urban well-being inequality: diagnosing deprivation–environment mismatch in Tokyo

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**Multi-scalar drivers of urban well-being inequality: diagnosing deprivation–environment mismatch in Tokyo**

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**Abstract**

Urban well-being is increasingly regarded as a central theme in urban studies, yet its uneven spatial distribution within cities remains poorly understood. Existing research typically treats social deprivation and environmental quality as parallel determinants, often assuming their spatially uniform effects. This paper argues that inequalities in urban well-being are structurally linked to spatially uneven resource transformation processes—where social and environmental resources operate at differing spatial scales, potentially leading to their misalignment. Using Tokyo as a case study, we constructed a 0.5 km grid dataset linking a Multidimensional Social Deprivation Index (MSDI), a street-view-based Built Environment Quality Index (BEQI), and a Spatial Well-being Indicator (SWBI) derived from geotagged social media data. MGWR analysis reveals a clear scale separation: social deprivation displays a highly localised relationship (bandwidth = 487), whereas built environment quality operates at a broader regional scale (bandwidth = 1227). Translating these estimates into a 3D mismatch typology, we identified unique combinations of social advantage, environmental quality, and well-being outcomes. The results indicate that high environmental quality is not automatically associated with higher well-being among disadvantaged groups, while socially advantaged areas may face constraints under environmental stressors. By highlighting these mismatch issues, this study provides a framework for aligning governance instruments with the specific spatial scales of underlying well-being mechanisms.

## 1. Introduction

Over the past two decades, urban and regional studies have increasingly adopted subjective well-being (SWB) as a key metric for assessing liveability and governance effectiveness. SWB is typically composed of constituent indicators such as life satisfaction and positive/negative emotions, influenced both by individual endowments and significantly shaped by community and urban environments (Diener, 1984). This tradition emerged from psychology and behavioural science before permeating public policy and urban planning, where it serves as a complementary indicator for evaluating societal prosperity and residents' quality of life. Concurrently, multidisciplinary evidence on the environment-health-well-being nexus has accumulated: exposure to natural environments (green space accessibility, landscape visibility, etc.) correlates with physiological recovery, psychological restoration, stress reduction, and narrowing health inequalities (Ulrich, 1984; Kaplan & Kaplan, 1989; Mitchell & Popham, 2008). These studies have established a theoretical continuum from environmental aesthetics and attention restoration (ART) to health-promoting urban design, suggesting that urban green infrastructure serves not merely as an aesthetic resource but potentially as a public good for equitable well-being. Conversely, measuring socioeconomic relative deprivation and spatial deprivation holds a longstanding tradition in urban policy—from Townsend's (1979) concept of relative poverty to the development of the UK's Index of Multiple Deprivation (IMD) for small areas (Noble et al., 2006), to Japan's integration of census tract data into the Area Deprivation Index (ADI) to explain disparities in mortality and self-rated health (Nakaya et al., 2014; Nakaya Lab data note).

These indices provide stable, reproducible tools for identifying vulnerable neighbourhoods and allocating public resources with precision. Methodologically, Multi-Scale Geographically Weighted Regression (MGWR) offers a means to test the hypothesis that ‘different mechanisms operate at different spatial scales’. Unlike traditional GWR, which assumes a single bandwidth, MGWR estimates the optimal spatial scale for each explanatory variable, thereby better approximating the multi-scale nature of real urban processes (Fotheringham, Yang & Kang, 2017; MGWR documentation/tools). MGWR's advantages are particularly evident when examining spatially heterogeneous phenomena such as the relationship between subjective well-being (SWB), deprivation, and the built environment. The policy context of Japan and Tokyo lends particular relevance to this research topic. Japan has entered a ‘super-aged society,’ with those aged 65 and above accounting for approximately 29% of the population in 2024 (Statistics Bureau 2024). The overlapping trends of ageing and solitary living have heightened demand for neighbourhood accessibility, green spaces, and pedestrian-friendly environments. Concurrently, prolonged commuting times in metropolitan areas (Tokyo's average daily commute is approximately 100 minutes, with one-way journeys around 50 minutes, NHK Time Use Survey) intensifies the interdependence between daily environmental quality, commuting stress, and well-being (Matsushita et al., 2025). At national and Tokyo Metropolis levels, the 2002 Urban Regeneration Special Measures Act, 2006 Basic Act on Housing and Living, 2014 Tokyo Metropolis Long-Term Vision, and Walkable/Machinaka Walkable policies collectively form an institutional framework integrating redevelopment, housing, well-

being, and walkability. Although the aforementioned literature provides a solid foundation through approaches to social deprivation, green exposure, and spatial methods, research integrating social deprivation (e.g., MSDI), built environment quality (e.g., BEQI), and SWB while explicitly depicting their spatial heterogeneity and relative importance within Tokyo remains relatively scarce. This paper therefore poses three research questions: (1) How are MSDI and BEQI respectively related to the spatial variation of SWB? (2) Do these factors exhibit spatially differentiated scales and intensities of influence? (3) Can a governance typology be developed based on the three-dimensional mismatch of 'subjective well-being – social deprivation – built environment' to support differentiated spatial policies? To address these questions, this study focuses on . focuses on the Tokyo Metropolis, integrating census and multi-source spatial data. It employs MGWR to identify the optimal scales of variable effects, thereby proposing an urban governance typology and targeted policy recommendations.

## 2. Literature Review

Existing research predominantly addresses theory, institutions, and urban processes in isolation. Yet in global cities such as Tokyo, social deprivation, the built environment, and subjective well-being are not explained separately by sociology, environmental psychology, or urban planning. Rather, they emerge from a complex, interwoven process shaped by long-term policy-driven theoretical frameworks, institutional evolution, and spatial outcomes. Consequently, this study refrains from segmenting theory, policy and spatial outcomes into three distinct components. Instead, it constructs a holistic logical framework encompassing Tokyo's urban evolution from 1990 to 2020. These three elements constitute a dynamic interactive system that collectively shapes Tokyo's spatial patterns of

well-being.

### 2.1. Literature Integration and Conceptual Framework: From Relative Deprivation and Restoration to Well-being Justice

Concerning the uneven distribution of urban well-being and its spatial expression, existing research has advanced primarily along two pathways: one originating from sociology and social policy, emphasising multidimensional measurements of relative deprivation and comparative mechanisms at the neighbourhood scale (Townsend, 1979; Noble et al., 2006); the other from environmental psychology and urban health, highlighting how factors such as green space exposure, green views, and walkability influence psychological well-being through attention restoration and stress reduction, yielding greater marginal effects for vulnerable groups under certain conditions (Kaplan & Kaplan, 1989; Ulrich, 1984; Mitchell & Popham, 2008). Within the Japanese context, census-based neighbourhood deprivation indices demonstrate significant correlations with mortality rates and self-rated health outcomes, underscoring the foundational role of the neighbourhood scale in explaining well-being disparities (Nakaya et al., 2014). Concurrently, research on social capital and cultural capital indicates that networks, trust, and norms can amplify the efficiency with which resources translate into life outcomes (Bourdieu, 1986; Putnam, 2000). However, these two pathways have long operated in conceptual and spatial isolation, often treating deprivation as solely a social condition and the environment as merely a physical backdrop. This approach struggles to explain paradoxes such as high social advantage coexisting with low environmental quality yet elevated well-being, or high deprivation alongside high environmental quality yet diminished well-being. Furthermore, reliance on city-wide averages or single-scale empirical practices tends to obscure how different mechanisms operate across varying spatial scales (Ballas, 2013; Diener,

1984). In recent years, an increasing body of empirical research has begun to challenge traditional linear assumptions and the efficacy of universal interventions. For instance, Khazbak (2025) demonstrated that the ‘mixed-community renewal’ strategy, designed to alleviate poverty clustering, often fails to improve the lives of low-income adolescents in practice. Instead, it may exacerbate social injustice through mechanisms of stigmatisation and exclusion, indicating that physical environmental renewal does not necessarily translate into enhanced wellbeing for vulnerable groups. Concurrently, Du's (2025) research in Shenzhen further reveals profound social heterogeneity within this relationship: even within the same city, registered and non-registered migrants exhibit significant disparities in their sense of local belonging and home, with their spatial perceptions profoundly shaped by differing legal and economic factors. Moreover, Heu and Brennecke (2023) challenge the traditional paradigm of forcibly promoting social interaction through public space design, noting that such interventions overlook certain groups' legitimate need for “solitude spaces” and may even exacerbate experiences of loneliness through design mismatches. These findings underscore the necessity of shifting from a “one-size-fits-all” average effect approach towards refined spatial diagnostics.

To bridge this disconnect, this study adopts the capability approach as its normative and analytical foundation, emphasising that well-being is not the sum of resources but rather the space of capabilities through which people transform resources into valued life conditions (Sen, 1999). Accordingly, multidimensional social deprivation (MSDI) and built environment quality (BEQI) are treated as distinct resource inputs. What truly Shapes subjective well-being (SWB) are the conditions of transformation, including time budgets and commuting burdens, accessibility and barrier-free design, social capital and institutional thresholds, residential stability, and security.

Environmental justice supplements distributive and procedural dimensions by addressing inequalities in environmental benefits and risks across groups alongside participatory rights (Schlosberg, 2007). Spatial mismatch further illustrates how marketisation and redevelopment may create structural disconnections between people, places, and opportunities; the initial focus on work-residence separation can be extrapolated into broader opportunity mismatches (Kain, 1968). Integrating these perspectives forms a welfare justice framework centred on resources and transformation, diagnosed through justice and injustice, and spatially characterised by mismatches: MSDI and BEQI describe resource endowment, transformation conditions determine whether resources become functional and experiential, while SWB represents the subjective assessment of capability realisation. The framework's central proposition concerns scale differences and their coupling or mismatch: relative deprivation is more likely to operate at the neighbourhood scale through proximity comparisons and status cues; environmental restorativeness aligns more closely with cumulative exposure within cross-neighbourhood regional atmospheres and activity spaces. Both coexist within the same city yet operate on distinct scales; when social and environmental resources spatially coordinate, well-being is amplified. When mismatched, scenarios emerge where social advantages coexist with environmental pressures, or where disadvantaged groups reside in high-quality environments yet struggle to enhance well-being due to insufficient transformative conditions. This proposition provides a conceptual anchor for subsequent mechanism identification and typological diagnosis.

### 2.2. Identification Strategy and Institutional Embedding

Within this integrated framework, Multi-Scale Geographically Weighted Regression (MGWR)

estimates optimal bandwidths for each explanatory variable, distinguishing localised processes at neighbourhood scales from regional diffusion processes at broader scales within the same model (Fotheringham, Yang & Kang, 2017). This transforms the local nature of MSDI and the regional scope of BEQI into testable empirical propositions, thereby avoiding average effects and coefficient biases arising from scale mismatch. Compared to single-bandwidth GWR, MGWR better aligns with the requirement for theory-driven identification. Complementarily, this study translates estimation outcomes into spatial typologies: synergistic zones, environmentally enabling zones, socially resilient zones, and physically constrained zones are identified based on combinations of SWB, MSDI, and BEQI levels. This facilitates translating statistical relationships into governance targets and policy priorities. It should be noted that spatial variable unit issues, weighting settings for variable construction, residential self-selection, and commuting-housing linkages may all affect extrapolation and causal interpretability (Sen, 1999; Bourdieu, 1986; Putnam, 2000).

Tokyo's institutional trajectory provides a contextualised explanation for these identifications. From the 1990s to the early 2000s, growth-oriented policies and core concentration enhanced functional density and economic efficiency in central districts through redevelopment and regulatory relaxation. Concurrently, this raised land prices, rents, and entry barriers, path-dependently cementing the spatial concentration of social advantages. This shaped the present MSDI pattern of low central values and high peripheral values. From the mid-2000s to the early 2010s, a quality-of-life orientation incorporated street environments, greening, and accessibility into policy priorities. However, investment exhibited pronounced site selectivity, with high-quality environments tending to cluster in already advantaged areas. Environmental improvements in disadvantaged zones progressed slowly, resulting in the juxtaposition of high BEQI-low MSDI and low BEQI-high MSDI

patterns. From the mid-to-late 2010s to 2020, capability and resilience-oriented approaches emphasised community building, age-friendliness, and inclusive public spaces. Yet institutional and spatial adjustments lagged, leaving numerous intermediate zones in a state of tolerable social conditions, mediocre environmental quality, and low subjective evaluations. Integrating institutional processes with statistical identification yields a set of testable propositions for the Urban Studies community: Firstly, the neighbourhood-scale relative deprivation proposition—controlling for other conditions, MSDI shows a significant negative correlation with SWB, with its optimal bandwidth narrower than environmental variables, reflecting the localised nature of neighbourhood comparisons (Townsend, 1979; Noble et al., 2006; Nakaya et al., 2014); second, the regional-scale environmental restorative proposition—BEQI influences SWB through regional ambience spillover that gradually diminishes, exhibiting higher marginal effects for vulnerable populations (Kaplan & Kaplan, 1989; Ulrich, 1983; Mitchell & Popham, 2008); thirdly, the mismatch proposition—core areas are more prone to coexisting social advantages and environmental pressures, while some disadvantaged areas may experience capability expansion and well-being enhancement driven by high-quality environments. However, environmental advantages remain unrealised without accessibility, temporal well-being, and community support (Kain, 1968; Schlosberg, 2007); fourthly, the mediating factors proposition—social capital, residential stability, and civic engagement can mitigate deprivation's negative impact on SWB while amplifying BEQI's positive effects (Bourdieu, 1986; Putnam, 2000; Diener, 1984; Oshio & Kan, 2014). These propositions correspond directly to the bandwidth and coefficient planes of the MGWR framework, enabling direct testing of mechanism differences across Tokyo's distinct zones. This provides a basis for designing policies at both neighbourhood and regional scales.

As illustrated in the theoretical framework (Figure 1), this study integrates policy evolution, spatial outcomes, and the capability approach to analyze the mismatch mechanisms governing urban well-being.

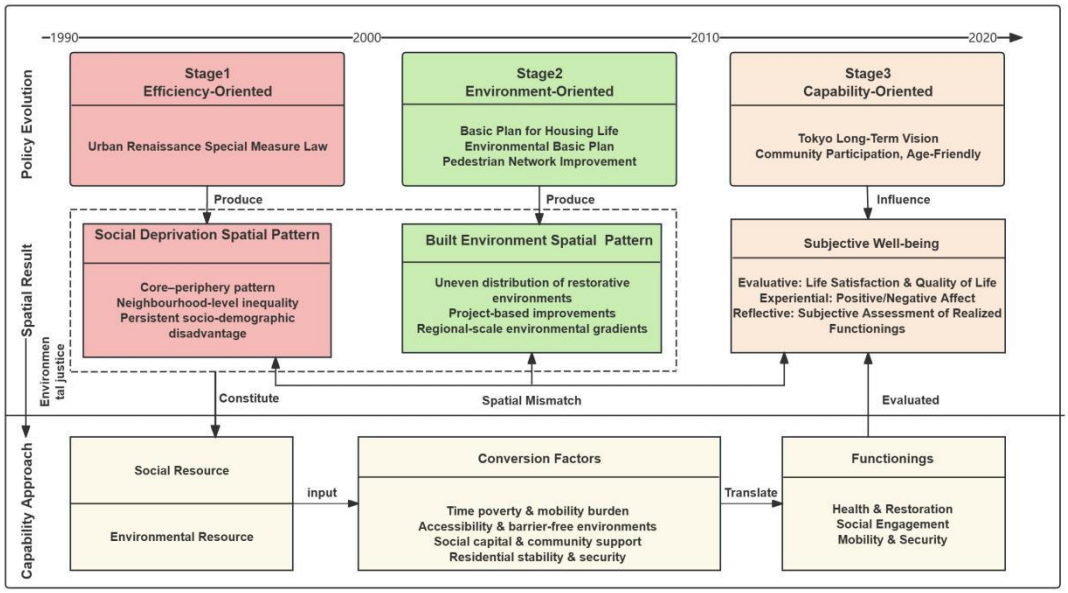



**Figure 1.** The Theoretical Framework of Spatial Mismatch: Coupling Policy Evolution (1990–2020), Spatial Outcomes, and Capability Conversion.

## 3. **Method**

### **3.1. Study Area and Spatial Unit**

Tokyo serves as an exemplary case study due to its status as a high-density global metropolis characterised by marked internal heterogeneity and a highly informatised data environment. These features make it an ideal setting for examining the complex spatial mechanisms underlying urban well-being. To ensure analytical precision and mitigate the Modifiable Areal Unit Problem (MAUP) inherent in irregular administrative boundaries, this study employs the Standard Grid Square System (Third-order Grid Square) established by the Statistics Bureau(1973) of Japan. By dividing the research area into uniform 0.5 km × 0.5 km spatial units, we constructed a standardized framework

that effectively integrates multi-source data across subjective perceptions, social structures, and physical environments.

### 3.2. Variable Construction and Data Sources

A three-dimensional data framework was constructed to integrate subjective perception, social structure, and physical environment (Figure 2).

**3.2.1** Subjective Well-being Index (SWBI)

Based on measurements from social media and large language models, this study employs geotagged social media data to capture residents' instantaneous well-being in specific contexts, distinguishing itself from traditional questionnaire surveys characterised by low frequency and low spatial precision. While acknowledging that social media users are not perfectly representative of the general population (leaning younger and more tech-savvy), previous studies have validated the utility of such data in capturing fine-grained spatiotemporal patterns of urban perception and collective mood effectively (Longley et al., 2015;). Data originates from Twitter geotagged data spanning the entirety of 2020. (1) Semantic Classification and Scoring: Utilising large language models (LLMs) to conduct semantic analysis of tweet content. Building upon existing indicator frameworks (Carpi, 2022), an evaluation system encompassing eight dimensions — positive/negative emotion, life satisfaction, work quality, interpersonal relationships, vitality, resilience, etc.—was constructed to calculate emotional scores for each grid cell. (2) Bayesian Smoothing: To address estimation instability potentially arising from sparse grid data, empirical Bayesian smoothing (also termed shrinkage estimation) is applied to correct raw scores (Marshall, R. J. 1991). By incorporating global prior information, the smoothed SWBI more robustly reflects the region's true well-being level, serving as the model's dependent variable.

**3.2.2** Multi-dimensional Social Deprivation Index (MSDI)

To characterise relative deprivation at the neighbourhood level, the MSDI was constructed using data from the 2020 Japanese Census. Drawing upon Townsend's (1979) theory and the framework of the UK's Index of Multidimensional Deprivation (IMD), the index was adapted to the Japanese context of super-ageing and social disparities. Twelve indicators across six dimensions were selected to comprehensively capture social vulnerability, encompassing demographic burdens, socioeconomic status, and mobility constraints (Appendix Table A1). Weights were determined through Principal Component Analysis (PCA) to synthesise the index, with higher values indicating a more disadvantaged position within the socio-economic structure.

3.2.3 Built Environment Quality Index (BEQI)

Distinct from traditional bird's-eye functional metrics, this study employs computer vision techniques to process Google Street View (GSV) imagery. Following the semantic segmentation framework established by Ma et al. (2024) , the BEQI is constructed from eye-level visual features that proxy restorative potential and behavioral support, specifically encompassing greenness and openness, visual enclosure and traffic disturbance, and pedestrian-interface qualities. These indicators were standardised and aggregated into a composite index to quantify environmental experiences (Appendix Table A2).

**3.3 Analytical Strategy**

**3.3.1** 3D Mismatch Diagnosis and Spatial Typology

Using the Jenks Natural Breaks method, standardized SWBI, MSDI, and BEQI scores were classified into High, Medium, and Low tiers. Spatial superposition identified distinct “Resource–Conversion–Result” patterns, specifically Synergistic Zones (e.g., Well-being Advantage Zones)

and Discordant Zones (e.g., Experiential Discordance Zones).

**3.3.2** Multi-scale Geographically Weighted Regression (MGWR)

This study uses the MGWR model to reveal the scale differences in the spatial relationships between social deprivation, the built environment, and happiness. Compared to traditional GWR, MGWR allows different variables to have their own optimal bandwidth, thereby distinguishing local processes from regional trends (Fotheringham, Yang & Kang, 2017). The model formula is as follows:

$$SWBI_i = \beta_0(u_i, v_i)\&\beta_{msdi}(u_i, v_i)MSDI_i\&\beta_{beqi}(u_i, v_i)BEQI_i\&\varepsilon_i$$

Where (ui,vi) denotes the grid coordinates, β0 represents the intercept, and βmsdi and βbeqi denote the local regression coefficients for MSDI and BEQI respectively. Unlike GWR, the MGWR model calculates optimal bandwidths for β0(ui,vi), βmsdi(ui,vi), βbeqi(ui,vi) BEQIi respectively, automatically determining optimal bandwidths for MSDI and BEQI. A smaller bandwidth for a variable indicates. its explanatory power operates at the neighbourhood micro-scale, whereas a bandwidth approaching global scale suggests its effect operates at the macro-regional scale. This provides statistical support for verifying the comparative effects of deprivation in immediate neighbourhoods and the regional ambience effects of the environment.

Based on the aforementioned methodology, this study first describes the spatial patterns across three major dimensions in Section 4 and employs spatial typology to diagnose “dysfunction” phenomena. Subsequently, the MGWR model is utilised to quantitatively analyse the underlying driving mechanisms.

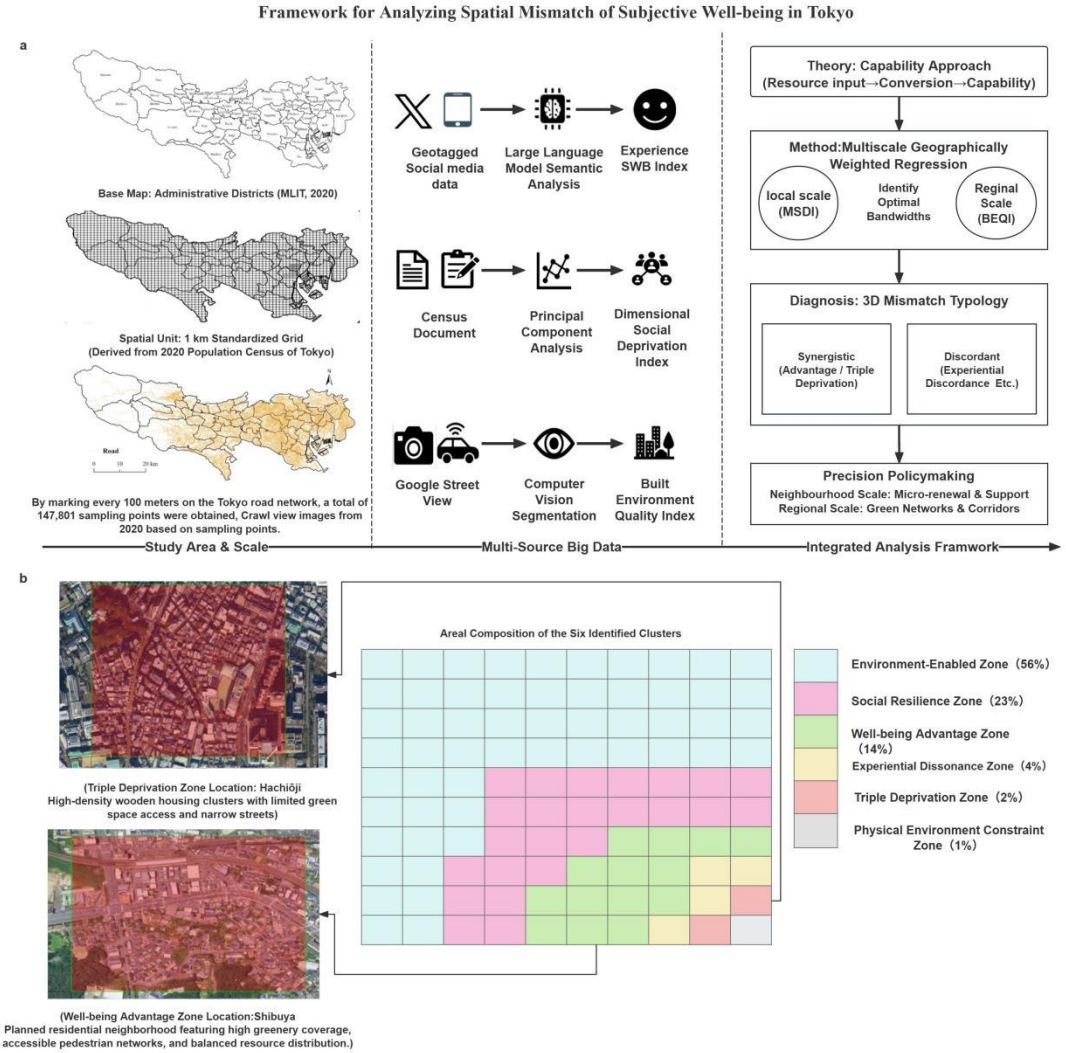



**Figure 2**. The Integrated Analytical Framework: Multi-source Data Processing, MGWR Modeling, and Spatial Mismatch Diagnosis.

## 4. Results

### 4.1 Descriptive Spatial Patterns: Association, Contradiction, and Mismatch

Prior to delving into multi-scale identification, three small-area maps provide preliminary evidence of the spatial relationships between multidimensional social deprivation (MSDI), built environment quality index (BEQI), and subjective well-being index (SWBI)(Figure 3).

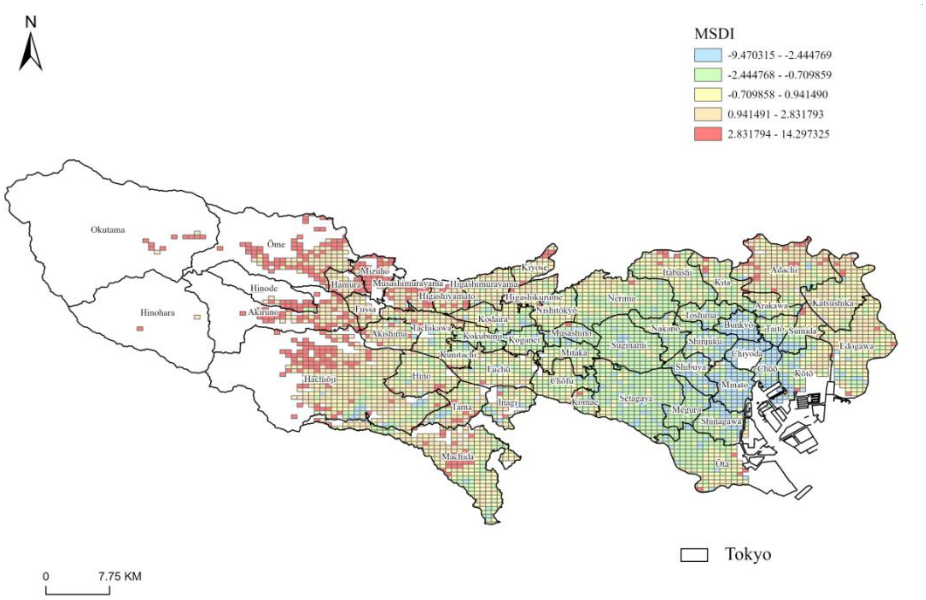
Firstly, MSDI exhibits a typical centre-periphery structure (Knox & Pinch, 2014): socio-economically advantaged areas with low deprivation are highly concentrated around the three

central wards, while relatively high deprivation forms a continuous belt in the Tama suburbs and traditional downtown areas of the northeast. This pattern is not coincidental but stems from institutional resource allocation driven by long-term policy biases. Growth- and agglomeration-oriented redevelopment, coupled with path dependencies in infrastructure and public services within core areas, renders peripheral regions more susceptible to accumulating multidimensional disadvantages through relative comparison. Spatial comparison between MSDI and SWBI reveals near-mirrored macro-level distributions: high SWBI scores typically occur in socio-advantaged zones with low MSDI. This pronounced spatial negative correlation indicates that welfare disparities primarily manifest as the spatialisation of social differences, aligning with relative deprivation theory's proposition on the coupling of neighbourhood comparison and subjective evaluation (Townsend, 1979; Noble et al., 2006; Nakaya et al., 2014).

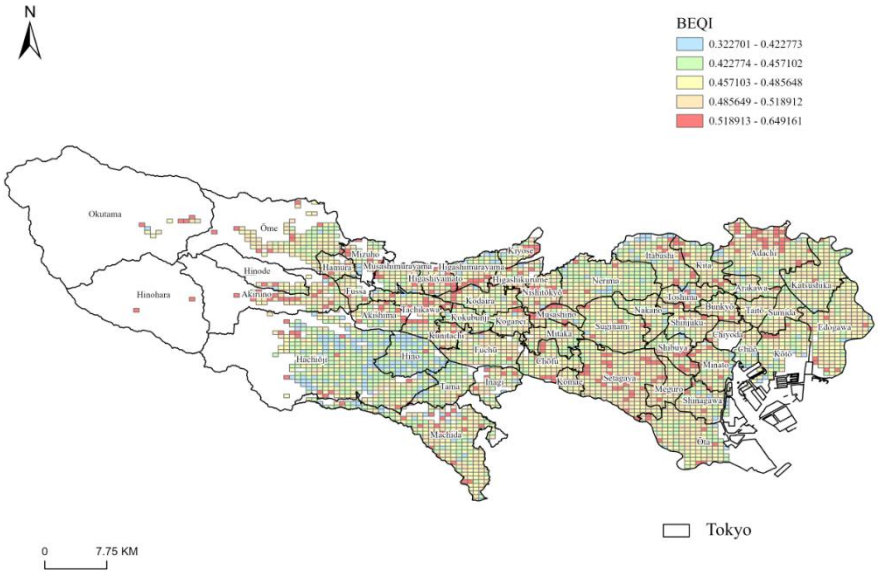
When BEQI is overlaid, the linear socio-economic determinism is challenged. BEQI exhibits a spatial gradient nearly opposite to MSDI: generally lower in central areas, while higher in peripheral and some marginal inner-city zones. Interpreting BEQI as a composite measure of restorative environments and everyday walkability, this distribution — lower centrally and higher peripherally—aligns with attention restoration and stress reduction theories (Kaplan & Kaplan, 1989; Ulrich, 1984), and aligns with Japan's mid-to-late 2000s policy agenda integrating street quality, greening, and neighbourhood accessibility, alongside its discernible investment rhythms driven by locational preferences. This raises a critical question: why does SWBI remain elevated in urban centres with lower BEQI and greater environmental stress, while it is comparatively low in peripheral areas with higher BEQI and stronger ecological restorativeness? This counterintuitive pairing constitutes a welfare mismatch, interpretable as a misalignment between perceived

experiences and available resources. It suggests that the relationship between resources and outcomes is non-linear, likely reshaped by mediating or moderating mechanisms (Mitchell & Popham, 2008; Ballas, 2013).

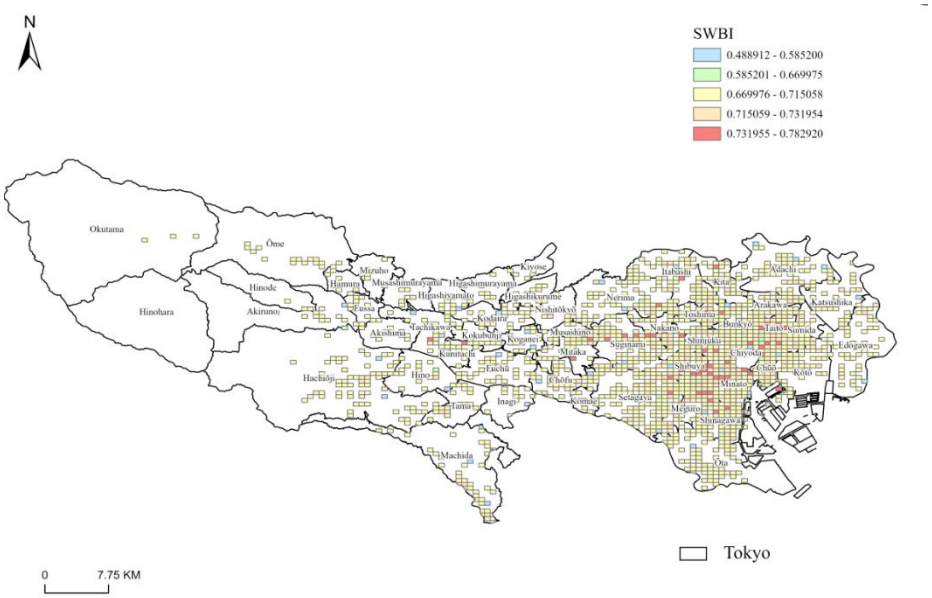
Regarding this disparity, two opposing explanatory mechanisms emerge. The first is the social resilience mechanism: in core areas, socially advantaged groups with low MSDI possess strong resource conversion capabilities. They can mitigate the adverse effects of low BEQI through richer employment, education, healthcare, and transport opportunities, coupled with tighter social networks, thereby sustaining high SWBI. The second is the environmental disempowerment mechanism: in peripheral areas, vulnerable groups with high MSDI may struggle to translate environmental advantages into everyday experiences and subjective evaluations, despite being situated in superior physical environments. This is due to constraints imposed by conversion factors such as time poverty, accessibility barriers, commuting burdens, social exclusion, or insufficient public participation (Sen, 1999; Bourdieu, 1986; Putnam, 2000). Moving from mapping to proposition, two empirical expectations emerge: first, deprivation effects exhibit pronounced localisation primarily at the neighbourhood scale; second, environmental effects align more closely with cross-neighbourhood regional ambience and yield higher marginal returns for disadvantaged groups. Elevating this dual intra-city mechanism from intuitive mapping to testable empirical identification requires methods capable of simultaneously handling spatial heterogeneity and variable-specific scales of action, with clear distinctions between agents, spaces, and scales. The MGWR method was selected precisely for this purpose (Fotheringham, Yang & Kang, 2017).




(a) Multidimensional Social Deprivation Index(MSDI)




(b) Built Environment Quality Index (BEQI)




(c) Subjective Well-being Index (SWBI)

**Figure 3.** Spatial Patterns of the Three Key Dimensions in Tokyo (2020): (a) Multi-dimensional Social Deprivation Index (MSDI), (b) Built Environment Quality Index (BEQI), and (c) Subjective Well-being Index (SWBI).

### 4.2 MGWR Model Results: Spatial Heterogeneity

The MGWR estimation captures diffusion processes reflecting regional ambience by determining optimal bandwidths for each variable. Spatially, local $R^2$ values indicate a distinct contrast: explanatory power is robust in parts of Tama and Setagaya but diminishes significantly in the three central wards and northeastern inner city ($R^2 \approx 0.042$ vs. $R^2 \approx 0.010$)(Figure 4). This pattern signifies a critical theoretical demarcation. In zones of high explanatory power, well-being (SWBI) is tightly coupled with local social conditions (MSDI) and environmental quality (BEQI), reflecting a dependence on immediate surroundings. In contrast, the low explanatory power within the metropolitan core suggests that well-being there is decoupled from local factors, driven instead by non-local resources and networks—such as cross-district employment, metropolitan-scale amenities, and high mobility.

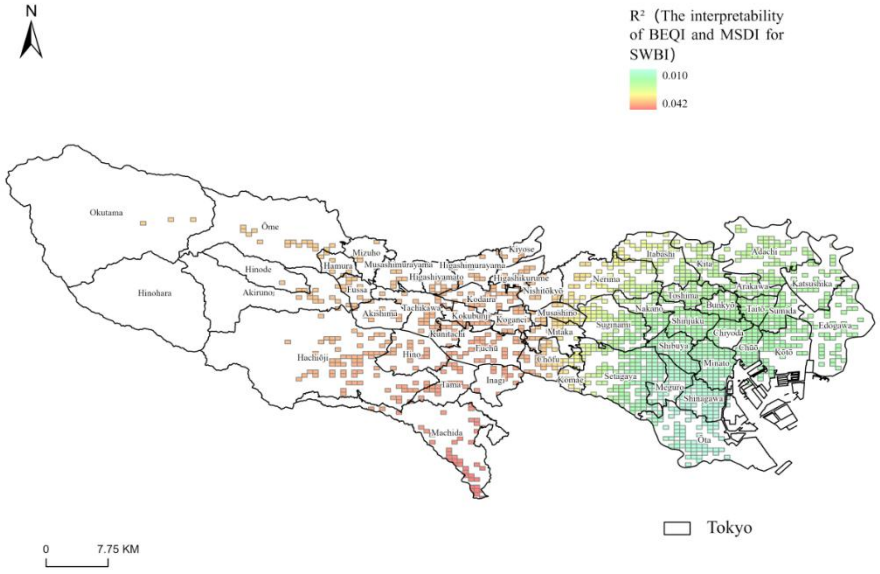
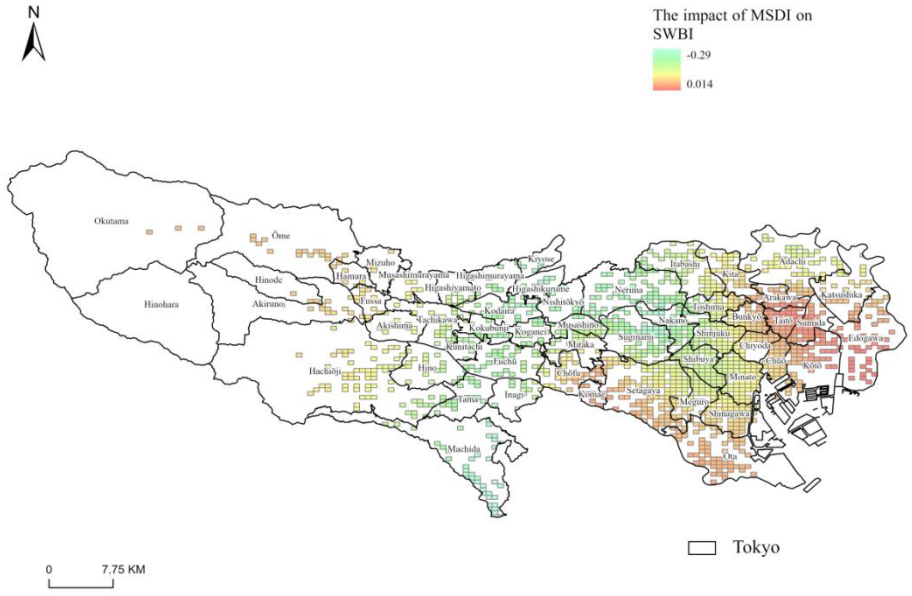


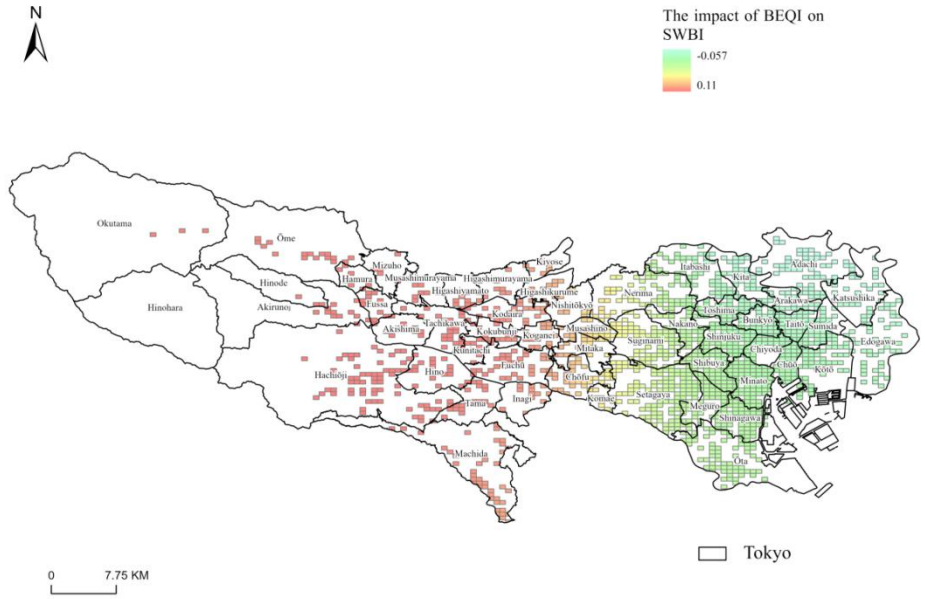

**Figure 4.** Spatial Heterogeneity of Model Performance: Local R2 Distribution from the MGWR Model.

Further examination of the local coefficient map reveals systematic spatial and scale-dependent variations(Figure 5) in social deprivation and environmental quality. The negative coefficient of MSDI on SWBI is most pronounced in the northeastern inner city and certain peripheral corridors, while significantly diminishing in the central urban core. This does not imply the absence of deprivation in central areas, but rather indicates that its adverse effects are more readily mitigated by high-density accessibility and opportunity structures. The effects of BEQI exhibit marked duality: in peripheral and certain marginal inner-city areas, it demonstrates a positive influence consistent with restorative qualities; conversely, within several high-density, low-green-view corridors in the city centre, BEQI's coefficient diminishes and may even become negative. This reflects the erosion of daily experience by extreme density and environmental pressures, challenging the linear assumption that high density necessarily accompanies high well-being (Kaplan & Kaplan, 1989; Ulrich, 1984; Mitchell & Popham, 2008). This spatial variation resonates with the normative framework of resources-transformation-capacity: in opportunity-dense city centres, compensatory

effects from functional resource bundles are stronger; in peripheries with larger living radii, the restorative quality of the everyday environment becomes more critical for subjective evaluations.




(a) Local Coefficients of MSDI




(b) Local Coefficients of BEQI.

**Figure 5**. Spatial Variation of Determinants: (a) Local Coefficients of MSDI and (b) Local Coefficients of BEQI.

The model confirms a distinct scale separation between social and environmental mechanisms. As shown in Table 1, the optimal bandwidth for MSDI is approximately 487 neighbours, significantly smaller than that of BEQI (1227 neighbours). This statistical disparity indicates that social

deprivation operates primarily as a localised process at the neighbourhood scale, whereas built environment quality patterns are consistent with regional diffusion processes across neighbourhoods. Furthermore, integrating the effective number of parameters (ENP) and adjusted critical t-values reveals distinct spatial morphologies of significance: MSDI's significant coefficients cluster densely, forming localised hotspots, whereas BEQI's significance exhibits greater sparsity, manifesting as continuous bands across broader areas.

**Table 1** : Summary Statistics of MGWR Model Estimation: Optimal Bandwidths and Model Diagnostics.

| Explanatory Variable | Optimal Bandwidth | Effective Number of Parameters | Corrected Alpha | Corrected Critical t-value |
|---|---|---|---|---|
| Intercept (Adjusted) | 1368 | 2.19 | 0.0228 | 2.2784 |
| MSDI (Adjusted) | 487 | 8.72 | 0.0057 | 2.7665 |
| BEQI (Adjusted) | 1227 | 2.86 | 0.0175 | 2.3794 |

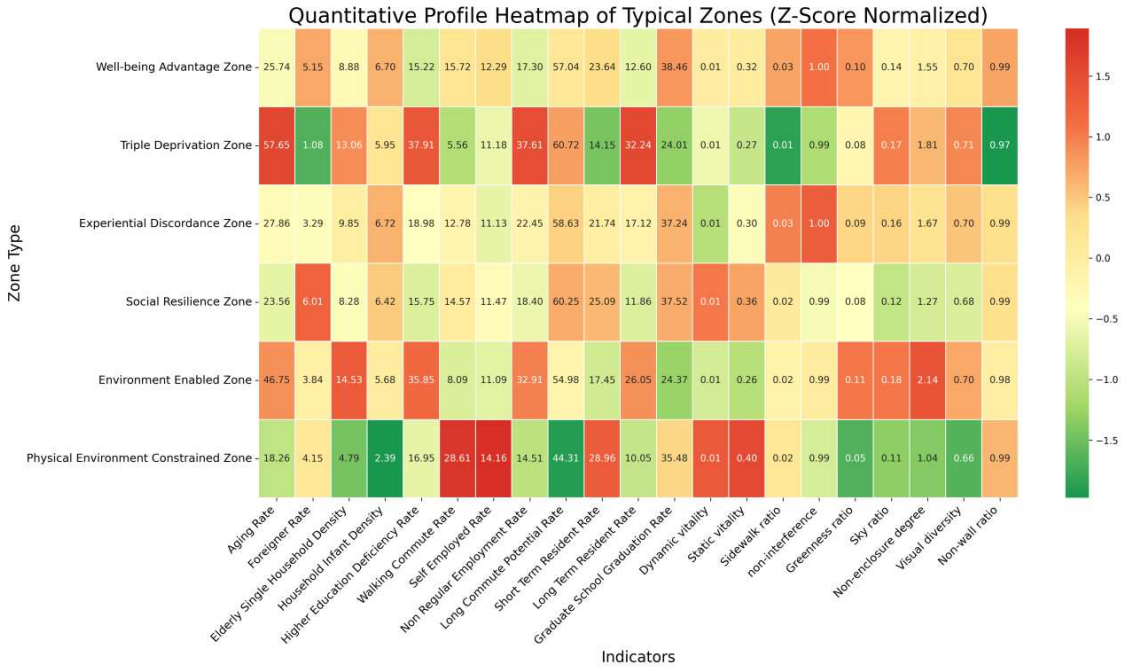
### 4.3 Three-Dimensional Mismatch Analysis

The MGWR model reveals a high degree of spatial heterogeneity among social, environmental, and well-being dimensions in terms of both correlation and explanatory power. However, to diagnose urban issues from a well-being justice perspective, we must shift from relational analysis to state analysis—specifically, how the spatial combinations of 'high/low' levels across these three variables manifest. The definition of the 3D mismatch typology is presented in Table 2.

**Table 2 :** Definition of the 3D Mismatch Typology Based on SWB-MSDI-BEQI Combinations

| Mismatch Type | SWBI | MSDI | BEQI |
|---|---|---|---|
| Synergistic Zones | | | |
| Well-being Advantage Zone | High | Low | High |

| | | | |
|---|---|---|---|
| Triple Deprivation Zone | Low | High | Low |
| Discordant Zones | | | |
| Experiential Discordance Zone | Low | Low / Mid | High |
| Physical Environment Constrained Zone | Low | Low | Low |
| Environment Enabled Zone | High | High | High |
| Social Resilience Zone | High | Low | Low / Mid |
| Other Transition Types | | | |




406

407 **Figure 6** . Quantitative Profiling of the Six Clusters: A Heatmap of Normalized Indicator Values

408 (Z-scores)

409 Based on the spatial combination of three-dimensional states (SWBI–MSDI–BEQI), this study

410 further conducted a heatmap analysis of standardised indicators for representative regions,

411 presenting quantitative profiles of six regional categories(Figure 6). The heatmap is not merely a

412 descriptive outcome but provides crucial empirical evidence for examining whether the resource–

413 conversion efficiency–capability space aligns.

(1) Well-being Advantage Zone This zone exemplifies 'resource consistency', where high social capital and superior environmental quality (High BEQI) synergistically translate into elevated well-being. Governance here should prioritize preservation strategies, utilising strict zoning and landscape regulations to safeguard this optimal resource-conversion efficiency from degradation.

(2) Triple Deprivation Zone This typology represents 'cumulative injustice', defined by the simultaneous overlap of high social deprivation (High MSDI), poor restorative environments, and consequently low well-being. The critical governance lever is integrated regeneration, prioritising welfare provision alongside the physical renewal of ageing housing stock to break the cycle of disadvantage.

(3) Experiential Discordance Zone This zone exhibits a 'conversion failure' paradox, where high socioeconomic resources fail to translate into well-being due to mediocre or disconnected environmental quality. Policy interventions should focus on 'experiential upgrades'—such as streetscape enhancement and family support—to activate the latent well-being potential of these socially advantaged groups.

(5) Environment Enabled Zone This typology illustrates 'environmental empowerment', where high-quality public spaces significantly expand the capability space for otherwise disadvantaged groups, breaking the deprivation-wellbeing link. Policy must prioritize 'anti-displacement' measures to ensure vulnerable populations retain access to these restorative benefits amidst potential gentrification pressures.

(6) Physical Environment Constrained Zone This zone reflects an 'elite-environment mismatch', where the environmental stress of high-density core areas diminishes the efficiency of converting high social resources into subjective well-being. Governance requires 'micro-environmental repair',

such as ventilation corridors and vertical greening, to mitigate stressors without compromising the area's functional density.

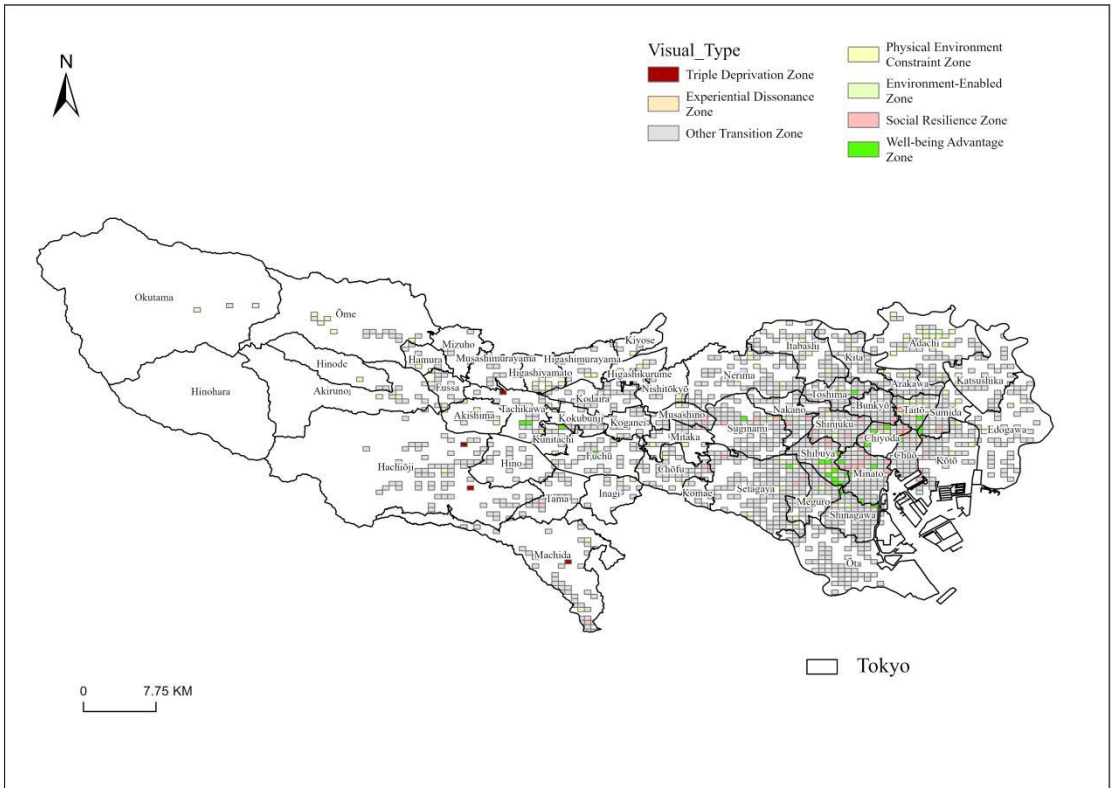



**Figure 7.** The Geography of Well-being Mismatch: Spatial Distribution of the Six Typologies in Tokyo.

This analysis of Tokyo reveals six distinct urban district types(Figure 7), spatially differentiated and corresponding to markedly divergent policy requirements. Firstly, the city exhibits pronounced polarisation: the “Well-being Advantage” districts, exemplified by Setagaya and Meguro, prioritise maintaining their high-quality environments through stringent zoning and landscape regulations; while the ‘Triple Deprivation Zones’, exemplified by older new towns in Tama, urgently require social regeneration policies prioritising welfare provision and the renewal of ageing housing stock. However, the most critical finding concerns the ‘Physical Environment Constrained Zones’ in the eastern Shitamachi districts, which exhibit pronounced spatial mismatch: despite possessing vibrant traditional streetscapes, residents face significant social challenges such as high ageing rates. This creates a complex policy dilemma, necessitating a difficult balance between disaster prevention

renewal (addressing risks from ageing timber structures) and cultural preservation, while simultaneously committing substantial social welfare resources. Meanwhile, other areas exhibit distinct development trajectories: Environment Enabled zones, concentrated in CBDs and waterfront areas, are products of large-scale redevelopment and policies attracting international investment; Social Resilience Zones (such as Kichijoji) rely on meticulous community governance to maintain high stability and equilibrium; whilst areas exemplified by Experiential Discordance Zones prioritise policies to attract and retain families through enhancing urban appeal and childcare support.

## 5. Discussion

This study challenges the conventional linear paradigm that treats social deprivation and built environment quality as parallel, additive determinants of urban wellbeing. Instead, we propose a spatial capability framework that redefines wellbeing disparities as a function of mismatched resource conversion. Our findings demonstrate that mere possession of social or environmental resources does not guarantee wellbeing; outcomes instead depend on whether these resources spatially align with specific scales of human capability conversion. By disentangling the localised effects of deprivation from the regional impacts of the built environment, this study resolves the "Tokyo Paradox", explaining why resource-rich elites may experience low wellbeing due to environmental constraints, while socially resilient communities thrive despite physical deficiencies.

### 5.1. Explaining the Tokyo Welfare Paradox

**5.1.1.** Micro-spatial evidence from synergistic zones: resource segregation versus resource synergy

The macro-level MGWR model reveals spatial heterogeneity in social and environmental impacts. By contrasting micro-textures across representative areas (Figure 8), this study further deconstructs

the physical mechanisms underpinning this heterogeneity. Figure 8 illustrates the stark spatial contrast between Tokyo's Triple Deprivation Zone and Well-being Advantage Zone, revealing two fundamentally distinct ‘human-land’ interaction logics.

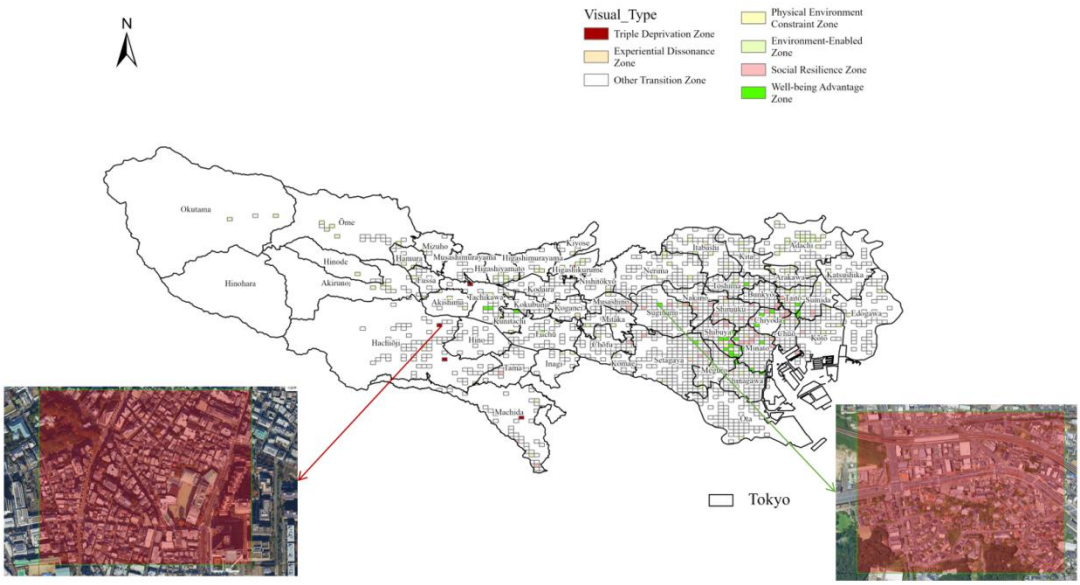



**Figure 8.** Micro-scale Morphology Comparison: (Left) Resource Segregation in the Triple Deprivation Zonevs. (Right) Resource Synergy in the Well-being Advantage Zone

For the triple-deprivation zone in the lower left corner, the wall effect and conversion failure vividly illustrate the micro-level predicament of such areas. Firstly, this zone exhibits an extremely dense impervious fabric. Fragmented residential plots and a hardened street network devoid of green buffers obstruct natural ventilation and visual respite, rendering the physical environment itself a persistent source of environmental stress. Secondly, and more critically, residents endure resource segregation. Although imagery reveals the area's proximity to large green spaces or school open areas, these resources are largely enclosed by walls, topography, or institutional boundaries. For vulnerable groups residing in narrow alleyways, these green assets are visible yet inaccessible. This results in a severe failure of capacity conversion: the physical presence of resources fails to translate into residents' actual restorative experiences. This powerfully explains why such areas, despite statistically possessing green spaces, remain trapped in low well-being. In contrast, the well-being

advantage zone on the right exhibits a spatially structured resource synergy. Its spatial texture features moderate density and high permeability. Private courtyard greening organically interweaves with surrounding public open spaces (such as park edges and woodlands), ensuring green resources are no longer isolated but deeply embedded within residents' daily life pathways. This spatial form fosters positive advantage accumulation. Residents of high social standing (low MSDI) not only possess superior social resources but also occupy physically restorative environments (high BEQI). This spatial overlay of social and environmental capital significantly enhances the efficiency of converting resources into subjective well-being, forming a virtuous well-being cycle. Micro-level visual evidence indicates that Tokyo's well-being inequalities stem not only from macro-level resource disparities but also from micro-scale accessibility differences. The shift from isolated resources to their integration into daily life directly determines residents' spatial capacity to convert environmental resources into well-being, offering concrete spatial annotation to Sen's capability approach.

**5.1.2.** Explanation of Mismatch Mechanisms

The following four mismatch mechanisms, framed within the capability approach (Sen, 1999), explain why distinct Tokyo districts exhibit markedly divergent welfare outcomes despite superficially comparable resource endowments. Collectively, they emphasise the coupling of resource endowments, transformative conditions, and spatial contexts rather than the linear influence of singular social or environmental factors.

To explain the observed spatial paradoxes, we identify four distinct interactive mechanisms rooted in the capability approach. First, the Experiential Disruption Mechanism characterizes areas with

favourable socioeconomic conditions (low MSDI) but insufficient restorative qualities. In these zones, persistent congestion and low green exposure disrupt the resource-outcome chain, causing social advantages to fail to translate into positive subjective experiences, a finding consistent with Attention Restoration Theory. Conversely, the Social Resilience Mechanism explains how residents in areas with lower environmental quality (low BEQI) sustain high well-being through strong social capital and residential stability. Here, social networks and reciprocal norms function as critical conversion factors, buffering against physical environmental deficits. Third, the Environmental Empowerment Mechanism highlights how high-quality environments benefit vulnerable groups (high MSDI). Accessible public open spaces and safe pedestrian networks act as external supports that compensate for insufficient private resources, thereby expanding capability spaces and narrowing well-being gaps. Finally, the Elite-Environment Mismatch Mechanism is observed in high-density central corridors, where environmental stressors — such as noise and visual enclosure — diminish the efficiency of converting abundant social resources into experiential benefits. This challenges the linear assumption equating density with well-being, suggesting that without restorative qualities, even the highest functional resources cannot fully sustain subjective well-being.

Collectively, these mechanisms demonstrate that well-being inequality is not determined by social or environmental conditions in isolation, but by the complex interaction between resource bundles (potential ceiling), transformation factors (degree of realisation), and spatial context (scale of operation). This understanding necessitates differentiated policy pathways: priority should be given to enhancing restorative qualities and walkability in experience-disconnected zones; consolidating community networks and stability in socially resilient zones; safeguarding long-term benefits

through anti-displacement measures in environmentally empowered zones; and reducing environmental pressures through micro-interventions—such as ventilation corridors and vertical greening—in elite-mismatch zones to ensure functional and restorative resources mutually reinforce one another.

### 5.2 The Politics of Scale

The bandwidth identification of MGWR provides quantitative evidence for scale politics: the optimal bandwidth for MSDI is significantly narrower than that for BEQI, indicating that relative deprivation primarily operates at the local scale through neighbourhood comparisons. The effects of BEQI align more closely with cross-neighbourhood regional ambience, gradually diminishing along block boundaries while accumulating within activity spaces (Townsend, 1979; Fotheringham, Yang & Kang, 2017; Kaplan & Kaplan, 1989). Accordingly, governance requires dual-scale design: neighbourhood-level precision interventions must run parallel to regional-scale networked governance. The former may be precisely located based on deprivation maps, enhancing pocket parks, tree clusters and shade, continuous pedestrian spaces and quiet walking routes within a 300–500-metre service radius, while institutionalising temporal well-being and care support (night-time and weekend public services, community care and childcare). The latter should establish interconnected green networks and waterways across districts, create continuous walking and cycling corridors, and implement green noise barriers and thermal environment management along transport corridors. Scale politics also manifests in evaluation metrics: relying solely on citywide averages or single-scale regression risks treating neighbourhood mechanisms as noise and compressing regional mechanisms into local coefficients, leading to tool and resource misallocation. Hence, a dual-scale performance system is recommended: neighbourhood level focuses on

deprivation convergence and disparity reduction rates, while regional level prioritises improvements in accessibility, connectivity, and restorative indices.

### 5.3. Institutional Path Dependence and Spatial Production

The spatial findings of this study do not exist in isolation but represent the direct spatial projection of Tokyo's urban policy evolution over the past three decades. By contrasting the spatial heterogeneity identified through the MGWR model with institutional changes documented in the literature review (1990 – 2020), this research reveals profound connections between policy objectives and spatial outcomes.

Phase One Legacy: Core Priorities and Elite Physical Constraints The dominant policy theme from the 1990s to the early 2000s was economic regeneration. Centred on the 1992 Urban Regeneration Special Measures Act as its primary instrument, this approach aimed to revitalise Tokyo's competitiveness through agglomeration effects by relaxing floor area ratios. Empirical correspondence identified: This policy legacy precisely corresponds to the ‘Physical Environment Constrained Zone’. Concentrated in the three central wards, this zone exhibits extremely high MSDI (elite concentration) and extremely low BEQI (environmental pressure). This confirms that while early policies successfully achieved the re-concentration of capital and functions (high social resources), this came at the cost of sacrificing the ecological resilience and open spaces of the core areas. This spatial condition of functional excess and environmental deficit was precisely the result of institutional entrenchment driven by an efficiency-first orientation during that period.

Legacy of Phase Two: Uneven Quality Differentiation and Environmental Empowerment Around 2006, policy focus shifted towards Quality of Life with the introduction of the Basic Plan for

Housing and Living and the Basic Environment Plan. However, scholarly critiques note that environmental improvements during this period often exhibited project-oriented characteristics, concentrated in specific redevelopment zones. Empirical findings from this study correspond: this trait explains the coexistence of Environmental Empowerment Zones and Triple-Deprivation Zones. Environmentally empowered zones frequently overlapped with large-scale redevelopment projects (e.g., Roppongi, Tokyo Bay Area), demonstrating leaps in environmental quality under policy intervention. Conversely, triple-deprived zones (e.g., certain ageing neighbourhoods in Adachi and Arakawa wards) suffered dual decline in physical environment and social vitality due to exclusion from this round of capital-intensive environmental renewal. This spatial differentiation validates scholarly arguments that market-driven environmental improvements can lead to distributional inequity.

Third Phase Shift: The 2014 Tokyo Long-Term Vision signalled a policy pivot towards community building and soft capabilities. However, the widespread presence of experiential mismatch zones identified in this study indicates that despite the policy discourse shift, physical spatial renewal lags behind. Numerous middle-class residential areas (such as the periphery of Setagaya) remain trapped in mediocre environments inherited from previous planning generations, struggling to meet residents' growing demands for welfare transformation. This highlights the paramount challenge confronting current policy: how to mend the intermediate zones that are neither core commercial districts nor areas of extreme deprivation.

In summary, MSDI's configuration was primarily shaped by Phase One's functional and capital zoning, BEQI's heterogeneity was largely determined by Phase Two's differentiated environmental

investments, while Phase Three's capability orientation has yet to align sufficiently with the preceding two in many districts. This chain—from three policy phases to dual spatial textures, culminating in welfare mismatch—provides an institutional lens for explaining Tokyo's welfare paradox. It suggests future reforms should align resource supply with conversion capacity, rather than focusing solely on visible expansion of existing stock (Kain, 1968; Schlosberg, 2007).

### 5.4 Policy Implications

To address the identified spatial mismatches, we propose a dual-scale governance strategy rooted in precision and equity. At the neighbourhood scale, 'Precision Micro-Regeneration' should replace generic beautification with climate-adaptive interventions—such as continuous shading, quiet commuting routes, and micro-scale sponge infrastructure—to mitigate local heat and noise stressors. In high-density centres facing functional oversupply, this necessitates overlaying corrective form controls, including ventilation corridor regulations and public interest reviews, to enforce vertical greening and rectify the imbalance between density and ecological restoration. Concurrently, at the regional scale, policy must advance 'Networked Environmental Justice' by prioritising cross-district green networks and pedestrian corridors that systematically link disadvantaged neighbourhoods to broader ecological assets. Crucially, these interventions must adhere to strict equity standards regarding quality, public ownership, and safety rather than mere quantity. Furthermore, when advancing neighbourhood living circles such as the “15-minute Community-life Circle”, vigilance is required against the misalignment between facility proximity and actual well-being experiences. Wu et al. (2023), drawing on empirical research in Shanghai, indicate that while accessibility to community facilities generally enhances subjective well-being, this uplift is uneven across income groups and community types. Overemphasising physical proximity while neglecting social

environmental quality (such as safety and social inclusivity) may yield limited benefits. Consequently, Tokyo's policy formulation should not merely satisfy physical coverage of facilities but prioritise vulnerable groups' actual capacity to access resources and their perceived experiences within “living circles”. Concurrently, anti-displacement clauses should be incorporated into redevelopment approvals (covering tenancy protection, land value and rent buffers, reinvestment of development profits into public space operations) to prevent green premiums from translating into population displacement (Mitchell & Popham, 2008; Schlosberg, 2007). Thirdly, regarding social resilience, funding allocation should moderately shift from hardware upgrades towards soft infrastructure: community organisation empowerment, neighbourhood mutual aid platforms, participatory budgeting and co-governance mechanisms, housing stability and long-term tenancy protection. This will solidify the chain converting resources into experiential benefits (Putnam, 2000; Sampson, 2012). The evaluation framework proposes a dual-tiered indicator system and testable propositions anchored in capability approaches. At the neighbourhood level, performance centres on the MSDI gap reduction rate, temporal well-being (commuting duration, night-time service availability, care support accessibility), and the Proximal Recovery Index (pathway green visibility, shade continuity, environmental quietness), targeting enhanced conversion efficiency. At the regional level, performance centres on green network connectivity, walkability corridor integrity, integrated exposure to landscape-heat-noise, and public accessibility (reachability time and access thresholds), aiming to broaden restorative coverage. Research frontiers encompass three areas: verifying whether environmental investments yield systematically higher marginal returns in disadvantaged areas; testing whether the optimal bandwidth of deprivation variables remains consistently lower than that of environmental variables; and conducting causal assessments through

quasi-experimental designs centred on metro line openings, green space completions, and street rapid improvements. Within the Japanese context, super-aged society and long commutes must be integrated as transformative factors. For instance, linking pedestrian and public space safety, accessibility, and continuity standards to age-friendliness, while promoting live-work proximity and family support along rail corridors to ensure residents can practically utilise environmental advantages from a temporal perspective

## 6. Conclusions

This research establishes a unified analytical framework integrating SWB, MSDI and BEQI across the Tokyo Metropolitan Area. Employing MGWR, it reveals the spatial heterogeneity and multi-scalar nature of their interrelationships: MSDI exerts a stronger negative impact on SWB in several older districts, while BEQI's positive influence predominantly manifests as an "accessible–visible–walkable" effect at the neighbourhood scale. The resulting three-dimensional mismatch governance typology offers pathways for Tokyo's metropolitan and ward governments to advance welfare-friendly, environmentally equitable and resilient cities amidst coexisting challenges of ageing populations, long commutes and redevelopment. At the policy level, deprivation indicators such as ADI should be incorporated into routine assessments, with performance metrics centred on walking-network connectivity and green-space service radii, complemented by green-affordability clauses in redevelopment profit distribution and a chain mechanism of rapid assessment–micro-renewal–rolling upgrades to enhance micro-environmental quality. These contributions, however, should be interpreted in light of several limitations: the Twitter-based SWBI captures "observational SWB" and may be demographically biased relative to survey-based measures; the visual BEQI omits non-visual and temporal dimensions such as noise, air quality and time-of-day variation; the 0.5 km grid

may obscure finer-grained street- or block-level phenomena; and the MGWR results remain correlational, calling for longitudinal or quasi-experimental designs to more firmly establish causal pathways. Even with these caveats, the study theoretically introduces capability approaches and environmental/ecological justice into urban well-being research in the Japanese context, methodologically demonstrates MGWR's value for identifying policy-relevant scales, and practically provides an evidence base for the implementation, prioritisation and evaluation of Japan's "compact & networked & walkable" urban policy.

## Author Contributions

S.J.S. conceived of the idea of the research made the structure. S.J.S. and X.P.Q. supervised this research work and provided guidance. J.S.Z., S.J.S. and Y.J.H. conducted the modeling work, data analysis and wrote the original manuscript. S.J.S., Y.J.H., X.P.Q., L.D. and J.S.Z. finished the data collection and data verification. S.J.S., Y.J.H., J.S.Z., L. L., Z.H.Z., L.D., X.P.Q., and J.W. verified the research findings and revised the manuscript. All author engaged the discussion. Also, all authors contributed significantly to this work by reading and editing.

## Reporting summary

Further information on research design could be found in the Nature Research Reporting Summary.

## Data availability

All data are clearly described in methods and the Appendix.

## Code availability

The codes are available from the first author or corresponding author upon reasonable request.

## Ethics declarations

### Competing interests

The authors declare no competing interests.

### Funding Declaration

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## Appendix A

Table A1 Description of indicator system construction for MSDI

| Dimension | Indicator | Sign | Calculation Formula / Definition | Social Significance & Theoretical Basis |
|---|---|---|---|---|
| Population structure | Old-age Dependency Ratio(Aging Index) | (+) | Pop. aged ≥65 / Pop. aged 15-64 | Ageing Index Beard & Bloom (2015) proposed in a WHO report that an old-age dependency ratio exceeding 30% would challenge community care systems. |
| | Foreign Resident Density | (+) | Foreign population / Total population | Nee (2005) theory of social integration emphasises that immigrant density exceeding a critical threshold may lead to social segregation, directly corresponding to the 'challenges of social integration'. |
| Family structure | Elderly Single-Person Households | (+) | Elderly living alone / Total households | Density of Elderly Single-Person Households Klinenberg (2013) reveals in Going Solo that areas with high concentrations of elderly single-person households face risks of 'social death |
| | Households with Young Children | (+) | Households with children <6 / Total households | Parenting Stress Model (Lareau, 2003): Lareau (2003) revealed that densely populated parenting neighbourhoods are prone to resource shortages (such as insufficient childcare facilities), creating "parenting deserts" that exacerbate families' time poverty and financial pressures. |
| Education | Insufficient Higher Education | (+) | Pop. without university degree / Pop. aged ≥15 | Theory of Cultural Capital (Bourdieu, 1986): Checchi (2006) demonstrates that the intergenerational transmission of education constitutes the core mechanism of spatial deprivation, with areas of low educational attainment forming 'educational deserts'. |
| | Postgraduate graduation rate | (-) | Graduate school graduates / Graduates aged 15 and over | Florida's (2002) theory of the creative class posits that the density of highly educated individuals serves as a key indicator of a community's developmental potential. |
| Quality of employment | Informal employment rate | (-) | (Part-time & Casual & Temporary Staff) / Total Number of Employees | Theory of Labour Market Segmentation: Standing (2011) argues in The Precariat that informal employment constitutes the central marker of a new form of social deprivation, directly linked to income instability and the absence of social security. |
| | Self-employed rate | (-) | Self-employed persons / Population aged 15 years and over | Harrison's (1982) theory of deindustrialisation posits that a decline in the proportion of self-employed individuals reflects economic structural fragility. |
| Commuting conditions | Walking commuting rate | (-) | Walkers / Total commuters | Job-Housing Balance: Low walkability correlates with poor health and low community interaction (Frank et al., 2006). |
| | Long Commute Potential Rate | (+) | (Train & Bus commuters) / Total commuters | Roberts et al. (2011) found that commutes exceeding 45 minutes caused psychological stress to surge by 2.3 times. |
| Residential stability | Proportion of short-term residents | (+) | (Residing for less than 1 year & 1 to less than 5 years) / Total population | Sampson (2012) demonstrated that residential stability below 25% undermines community collective efficacy. |
| | Percentage of long-term residents | (-) | Resident for 20 years or more / Total population | Putnam's (2000) longitudinal study indicates that a residency tenure exceeding 20 years constitutes the threshold for the accumulation of community social capital. |

The ‘Ageing Index’ and ‘Proportion of Households with Young Children’ are used to reflect the dependency burden and care pressures within a community; The “proportion of elderly single-person households” is specifically included to capture the risk of social isolation characteristic of a super-aged society, which directly relates to the hidden dangers of solitary deaths and declining psychological wellbeing. “Foreign resident density” is incorporated as a proxy indicator for barriers to social integration, reflecting potential social isolation or cultural barriers. Regarding socioeconomic status, the “underachievement rate in higher education” measures deficiencies in human capital stock; the “informal employment rate” reflects labour market instability, corresponding to the “precariat” class defined by Standing (2011), a group frequently facing heightened economic anxiety and psychological stress. The ‘residential instability rate (short-term residence proportion)’ was chosen because high mobility tends to weaken community social capital and collective efficacy (Sampson, 2012). The inclusion of the ‘long-distance commuting potential rate’ stems from a time geography perspective, where lengthy commutes are regarded as a form of ‘time poverty’ that directly encroaches upon residents' leisure resources, which could otherwise be converted into well-being.

Table A2 Description of indicator system construction for BEQI

| Dimension | Indicator | Formula | Element |
|---|---|---|---|
| Space vitality | Dynamic vitality | $P_n\&D_n\&C_n$ | Person, rider, car, truck, bus, train, motorcycle, bicycle |
| | Static vitality | $B_n$ | Building |
| | Sidewalk ratio | $S_n/(R_n\&S_n)$ | sidewalk, road |
| Space security | Vehicle non-interference | $1-C_n$ | Car, truck, bus, train, motorcycle, bicycle |
| Spatial landscape | Greenness ratio | $G_n$ | Vegetation |
| | Sky ratio | Kn | Sky |
| | Non-enclosure degree | (Sn&Rn)/Bn | Building, Sidewalk,road |
| Spatial perception | Visual diversity | $1-\sum O_j^2$ | Road, sidewalk, building, wall, fence, pole, traffic light, traffic sign, vegetation, terrain, sky, person, rider, car, truck, bus, train, motorcycle, bicycle, license plate, polegroup |
| | Non-wall ratio | $1-(W_n\&F_n)$, | Wall |

The Green View Index and Sky View Factor were selected. According to Kaplan & Kaplan's (1989) Attention Restoration Theory (ART), visual exposure to natural elements and a sense of spatial openness effectively alleviate directed attention fatigue, serving as key transformative factors for enhancing psychological wellbeing. Vehicle Disturbance and Visual Enclosure are selected. According to Ulrich's (1983) Stress Relief Theory (SRT), excessive visual intrusion from motor vehicles and enclosed, oppressive spatial forms constitute significant environmental stressors, directly inducing negative emotions and hindering stress release. Pavement Coverage and Interface Softness (Wall-Free Rate) are selected. These metrics correspond to Gehl's (2013) human-scale urban theory, measuring the affordance of physical space for active travel and social interaction – that is, whether the environment permits and invites walking and lingering. The BEQI is generated through standardisation and weighted aggregation, focusing on assessing an environment's psychological recovery potential and behavioural support rather than mere development intensity

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