Approaches to calculating urban project boundaries (Agglomeration) in Shymkent city, Kazakhstan.

Estrategias para calcular límites de proyectos urbanos (aglomeración): Caso Shymkent, Kazajistán.

Arslan Barakbayev[1*], Meruert Baidrakhmanova[2], Leonid Bulyga[2], Yelena Feoktistova[3], Yulia Manzina[2], Seimur Mamedov[4]

Highlights

- The Shymkent agglomeration's boundaries were defined using a novel methodology that combines various factors and GIS technologies.
- The study identified counter-magnet cities that can alleviate population pressures on the core city and promote regional balance.
- The results showed that the Shymkent agglomeration meets the criteria for first-level agglomerations and has a high development coefficient.

Innovaciencia
ISSN: 2346-075X

E- ISSN: 2346-075X
Innovaciencia 2024; 12(1); e4416
http://dx.doi.org/10.15649/2346075X.4416

SHORT COMMUNICATION

How to cite this article:
Barakbayev A., Baidrakhmanova M., Bulyga L., Feoktistova Y., Mazina Y., Mamedov S. Proposals For Calculating the Urban Project Boundaries (*Agglomeration*) on the Example of Shymkent City (Kazakhstan), Innovaciencia 2024; 12 (1): e4416
http://dx.doi.org/10.15649/2346075X.4416

Received: 5 September 2024
Accepted: 25 November 2024
Published: 19 December 2024

Keywords:

Urban space; urban planning; agglomeration.

Palabras clave:

Espacio urbano; urbanismo; aglomeración.

ABSTRACT

Introduction. A thorough evaluation of the calculations used to determine the boundaries of urban planning projects enables a comprehensive understanding of the socio-economic, cultural, and labor connections between cities and settlements. The significance of developing agglomerations in resource-limited environments lies in their potential to achieve a synergistic effect, where the whole exceeds the sum of its parts. **Objectives**. The research aims to identify the functional boundaries of the Shymkent agglomeration. **Materials and Methods**. The boundaries of the Shymkent agglomeration were determined using a methodological approach that integrates the agglomeration development coefficient, Reilly's gravitational theory, and geographic information system (GIS) technologies. **Results and Discussion**. Potential countermagnet cities were identified by employing GIS technologies to calculate the force of demographic gravity from proximate settlements to the city of Shymkent. These cities serve as centers of attraction that intercept migration flows towards Shymkent, thus assisting in mitigating excess population growth in the city. **Conclusions**. The strategic development of suburban settlements and key nodes within the Shymkent agglomeration can effectively manage urban growth challenges, promoting a balanced and sustainable development pattern. it is necessary to prevent the spontaneous growth of settlements caused by population growth, which leads to the formation of imbalances in comprehensive service systems and provides workplaces that can provoke social tensions.

RESUMEN

Introducción. Una evaluación exhaustiva de los cálculos utilizados para determinar los límites de los proyectos de planificación urbana permite una comprensión integral de las conexiones socioeconómicas, culturales y laborales entre ciudades y asentamientos. La importancia de desarrollar aglomeraciones en entornos con recursos limitados radica en su potencial para lograr un efecto sinérgico, donde el conjunto supera la suma de sus partes. **Objetivo**. La investigación tiene como objetivo identificar los límites funcionales de la aglomeración de Shymkent. **Materiales y Métodos**. Los límites de la aglomeración de Shymkent se determinaron utilizando un enfoque metodológico que integra el coeficiente de desarrollo de la aglomeración, la teoría gravitacional de Reilly y las tecnologías de sistemas de información geográfica (GIS). **Resultados y Discusión.** Se identificaron ciudades potenciales con efecto contra imán. Estas ciudades sirven como centros de atracción que interceptan los flujos migratorios hacia Shymkent, ayudando así a mitigar el exceso de crecimiento poblacional en la ciudad. **Conclusiones**. El desarrollo estratégico de asentamientos suburbanos y nodos clave dentro de la aglomeración de Shymkent es crucial para gestionar los desafíos del crecimiento urbano y fomentar un patrón de desarrollo equilibrado y sostenible. Es necesario prevenir el crecimiento espontáneo de asentamientos causado por el crecimiento de la población, que conduce a la formación de desequilibrios en los sistemas integrales de servicios y proporciona lugares de trabajo que pueden provocar tensiones sociales.

1 S. Seifullin Kazakh Agrotechnical Research University, Faculty of Land Management, Architecture and Design, Astana, Kazakhstan.
* Corresponding author: arslaninter@gmail.com
2 Toraighyrov University, Faculty of Architecture and Construction, Pavlodar, Kazakhstan.
3 NJSC «D. Serikbayev East Kazakhstan technical university», school of architecture, civil engineering and energy, Ust-Kamenogorsk, Kazakhstan.
4. Eurasian National University, Faculty of Architecture and Construction, Astana, Kazakhstan.

INTRODUCTION

The rapid urbanization and demographic growth in many regions of the world pose significant challenges for urban planning and territorial management [1, 2, 3]. The formation of agglomerations, defined as spatial concentrations of interconnected cities and settlements, offers an opportunity to leverage synergies and optimize the use of resources in constrained environments. In the context of Kazakhstan, territorial development issues are particularly relevant, with cities requiring modernization to meet the country's environmental, social, and economic demands. The national plan aims to form hubs and control agglomeration development, but currently, only Astana, Almaty, and Shymkent meet the criteria defining an agglomeration in Kazakhstan. The city of Shymkent and its surrounding areas exhibit all the main fundamental factors driving agglomeration processes, a substantial population in the city center approaching one million, a strategic location on international transport corridors, and a relatively high population density in the surrounding areas [1].

The precise delimitation of agglomeration boundaries is essential to understand the complex socioeconomic, cultural, and labor interactions between urban and rural settlements [4,5,6,7]. A robust methodological approach that integrates multiple dimensions of urban development is crucial to achieve an effective and meaningful delimitation [8,9,10]. The need for regional urban planning approaches to agglomeration formation and sustainable development in Kazakhstan's conditions further emphasizes the importance of this research.

In this study, we focus on the Shymkent agglomeration, one of the fastest-growing urban centers in Kazakhstan, experiencing a significant influx of migrants from surrounding regions [11]. Our objective is to delineate the boundaries of this agglomeration by applying a methodological approach that combines the agglomeration development coefficient [12], Reilly's gravitational theory [13], and GIS technologies. This approach is particularly relevant in Kazakhstan, where existing foreign methodologies for defining agglomeration boundaries may not fully capture the unique characteristics of the region's developing agglomerations. In this context, two main strategies are employed in the delineation of agglomeration boundaries: morphological and functional. The morphological strategy and its methods consider elementary physical structures, such as buildings, plots, or types of land use. In recent years, morphological strategies have relied increasingly on clustered data, where the elements under consideration (e.g., pixels, buildings) are grouped into basic spatial units (BSUs) [14]. These BSUs are generally administrative entities, such as neighborhoods or municipalities, or cells of a regular grid. Due to this grouping process, boundaries obtained through morphological methods depend significantly on the clustering level, as well as the shape and positioning of the BSUs.

For example, Zhou and Guo [15] compared the delimitations for cities in New Zealand obtained from different spatial resolutions of input data (varying pixel sizes) and settings of the smoothing function. They found that the threshold values for the most appropriate parameters were mostly identical or close across cities. Nonetheless, in the case of Shymkent, the lack of substantial dense development and absence of dense peripheral zones make morphological approaches challenging to apply effectively.

The functional approach, by contrast, focuses on analyzing the socioeconomic characteristics of a settlement through its functional relationships within a specific management system [16]. Unlike the morphological approach, the functional method is more widely used because socioeconomic data—such as GDP indicators, employment rates, income levels, and tax information—are critical for a comprehensive analysis. Numerous studies employ active indicators and set specific thresholds to evaluate these characteristics, which can vary depending on each country's unique developmental factors [16].

One prominent model in functional approaches is the Klaassen agglomeration model [17], which is based on population dynamics between a core and its periphery, assuming four stages of agglomeration defined solely by changes in population density. However, this model does not account for the intensity of economic, social, and transport links between the center and periphery. Given the substantial number of rural settlements within the Shymkent agglomeration, migration and population distribution are heavily influenced by agricultural conditions and seasonal factors. Thus, the Klaassen model, with its rigid stages based solely on population size, is overly limited in addressing these factors for the Shymkent region.

In this work, by analyzing migration patterns, economic activity distribution, and spatial connectivity between settlements, we aim to define the functional boundaries of the Shymkent agglomeration and evaluate its development potential [18]. Additionally, we explore the role of counter-magnet cities in shaping the demographic and economic dynamics of the region. Our research contributes to the existing literature by providing a robust methodological framework for agglomeration delimitation in contexts characterized by rapid urban growth and resource constraints, which is particularly relevant to the conditions in Kazakhstan. The findings have significant implications for urban planning, territorial management, and sustainable development in the Shymkent region and its surrounding areas [19, 20].

MATERIALS AND METHODS

To evaluate the development of the urbanization process, the agglomeration development coefficient proposed by Polyan (Kr) was exploited [12], which depends on the size of the urban population of the agglomeration, the number of cities and urban-type settlements, and their share in the total population of the agglomeration. Agglomeration effects have been shown to appear in cities with more than 500,000 inhabitants. An indicator characterizing the economic, labor, and sociocultural relationship between the core city and the surrounding network of settlements can be the force of demographic gravity, calculated based on Reilly's gravitational theory [13]. A territory's potential coefficient is used to estimate the force of demographic gravity based on socio-economic indicators (number of economically active populations, regional budget, transport infrastructure, population migration, etc.) using GIS technologies [14].

To assess the level of development of agglomerations, the development coefficient (Kr), which must be at least 1.0, was used. The formula determines the calculation of the agglomeration development coefficient: $Kr = P (M \times m + N \times n)$, where P is the size of the urban population of the agglomeration; M and N – are the number of cities and towns respectively; m and n are shares in the total population of the agglomeration.

To identify the socio-economic state of the centers of attraction, potential coefficients Kj are determined for each center of attraction, including the agglomeration core, based on the following indicators: (i) Population, (ii) the remoteness of the settlement from the center of gravity the area of the land, (iii) Length of paved roads; Migration (amount of arrivals/number of departures), (iv)Number of unemployed, (v) Number of employees in a given locality, (vi) Number of economically active populations, (vii) Volume of local budget revenue, (viii) Volume of local budget expenditure.

To calculate Kj, a confidence interval is determined for the agglomeration center and separately for potential centers of attraction according to the 3 Sigma rule:

$$x_{ij} \varepsilon [m_i - 3\sigma_{i;} m_i + 3\sigma_i] \qquad (1)$$

where x_{ij} is the i-th value of the indicator for the j-th center of gravity.

The formula calculates the standard deviation of the x_{ij} value:

$$\sigma_{i\,=} \sqrt{1/r} \sum_{i=1} (x_{ij}) - [m]_i) \qquad (2)$$

where m_i is the arithmetic mean value of the i-th indicator.

If x_{ij} lies outside the confidence interval, then y_{ij} = (0 or 1), if x_{ij} is inside the confidence interval, then $y_{ij} = (x_{ij} - m_i + 3 \times \sigma_i) / (6 \times \sigma_i)$ - for a positive indicator or $y_{ij} = 1 - (x_{ij} - m_i + 3 \times \sigma_i) / (6 \times \sigma_i)$ - for a negative indicator, where y_{ij} is the i-th value of the reduced derivative indicator for the j-th center of gravity.

The weighting coefficients of the significance of the given derived indicators of the j-th locality are determined by the formula:

$$\alpha_{ij} = \frac{y_{ij}}{\sum_{i=1}^{r} y_{ij}} \qquad (3)$$

where y_{ij} is the reduced derived indicator of the i-th value for the j-th territory.

The weighting coefficient determines the comparative importance of the given derived indicator.

After determining the given derived indicators and weighting coefficients, the values of the territory potential coefficient Kj are calculated using the following formula:

$$K_j = \alpha_{1j} * y_{1j} + \alpha_{2j} * y_{2j} + \ldots + \alpha_{rj} * y_{rj} \qquad (4)$$

where r is the number of centers of attraction; Kj is the potential coefficient of the j-th center of attraction.

Calculation of the forces of demographic gravity Glj determines the closeness of economic, labor, and socio-cultural ties between populated areas and centers of gravity and is calculated using the following formula:

$$G_{ij} = K_j \frac{P_l P_j}{d^a{}_{il}} \qquad (5)$$

Where, l, j – the considered settlements; P_l – population size of the l-th center of gravity;

P_j – population of the j-th settlement; d_{jl} – the distance of the j-th settlement from the center of gravity; K_j – potential coefficient of the l-th center of attraction; a is the degree of remoteness of a settlement to the center of gravity.

RESULTS

The development coefficient of the Shymkent agglomeration is 6.9. The calculation shows that Shymkent is in an advanced stage of agglomeration development. Settlements will be determined based on their location within a 1.5-hour isochrone for first-level agglomerations and a 1.0-hour isochrone for second-level agglomerations from the core of the agglomeration. The city of Shymkent belongs to the first level. Studies of cities and large towns are being conducted to identify potential centers of gravity. Probable counter-magnets are selected from cities or large settlements with at least 5,000 people for a 2nd level agglomeration and 10,000 for a 1st level agglomeration. The Shymkent agglomeration has chosen cities and towns with more than 10,000 people as centers of gravity. According to initial data, the cities and towns are recognized as centers of gravity. The initial analysis focused on identifying settlements falling within Shymkent's zone of influence. Centers of gravity function as counter-magnets, intercepting migration flows and "unloading" excess population from agglomeration centers. Each center of gravity could influence nearby settlements, with the strength of influence being dependent on the socio-economic status of the center **(Table 1)**.

The greater the value of the potential coefficient Kj, the greater the level of the socio-economic state of the center of gravity, which directly proportionally affects the strength of demographic attraction G_{lj} **(Table 1)**. Thus, 327 settlements were identified within the agglomeration, with a population of 2,235,104 people. Saryagash [43] has the most significant number of settlements attracted to the centers of gravity (except the core of the agglomeration) because of the following: high indicators of transport provision in the city of Saryagash and a relatively high population [61,485], remote distance from the core of the agglomeration city of Shymkent [102 Km]. The lowest number of settlements attracted to the centers of the gravity city of Aksukent [19], is as follows: Low share of transport provision in Aksukent City [1.4], close vicinity to the core of the agglomeration city of Shymkent [28.8 Km], the negative balance between Aksukent migration and a relatively low population [35,929]. The results of the calculations include a demographic gravity of centers of gravity shown in **(Figure 1)**.

Table 1. Shymkent Agglomeration analysis: satellite, gravity centers, population, influence, and potential for 2022 [21].

Center type	Name of the center of gravity	Population	Distance to agglomeration core (Km)	Potential assessment factor	# of settlements attracted to the center of gravity	Population of settlements attracted to the center of gravity (2022)
Core	Shymkent	1 192 120	-	698	148	504 209
Satellite	Arys	51 996	68	565	41	54 380
Satellite	T. Ryskulov	20 306	64	0.47	38	62 114
Satellite	Saryagash	61 485	102	0.46	43	154 497
Satellite	Aksukent	35 929	28.8	0.38	19	28 320
Satellite	Lenger	33 856	33.7	0.39	32	35 892

Satellite = cities and centers of local settlement systems of the Shymkent agglomeration

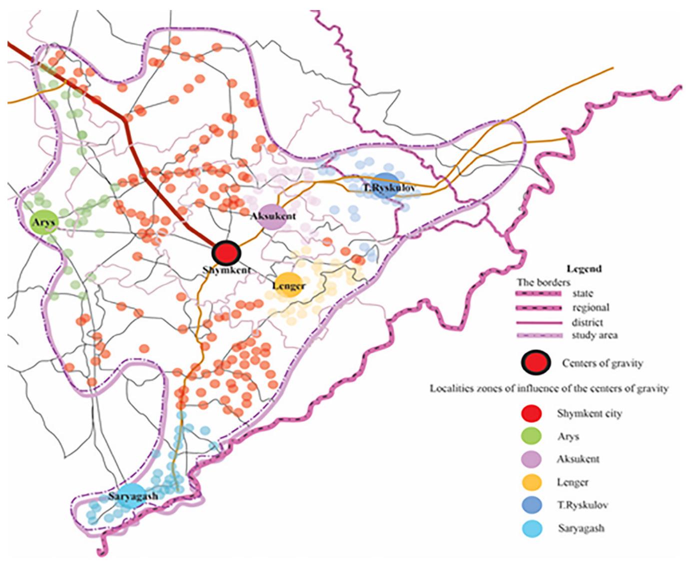

Figure 1. The project borders the Shymkent agglomeration with centers of gravity. The red color indicates settlements attracted to the core of the agglomeration - the city of Shymkent and centers of gravity (green - to Arys, blue - to the village named after T. Ryskulov, and blue - to the city of Saryagash), which will function as counter-magnets cities, pulling migration flows from the core of the agglomeration.

DISCUSSION

The present research has demonstrated the effectiveness of a combined methodological approach for the delimitation of the Shymkent agglomeration [18]. By integrating the agglomeration development coefficient, Reilly's gravitational theory, and GIS technologies, we have achieved a deeper understanding of the socioeconomic and spatial dynamics that shape this rapidly growing urban region.

Our results reveal that Shymkent, as the core of the agglomeration, exerts a considerable demographic pull on the surrounding settlements [22]. However, the identification of counter-magnet cities such as Arys, T.

Ryskulov, and Saryagash underscores the importance of considering the spatial distribution of economic activity and migration flows in urban planning [4]. These emerging cities have the potential to alleviate pressure on Shymkent, fostering a more balanced and sustainable development throughout the region.

The methodology employed in this study incorporates the unique geographical, historical, and social characteristics of the Shymkent agglomeration, representing a novel approach that has not been previously applied in studies to delineate agglomeration boundaries. It is important to highlight that our methodology, although effective, has certain limitations. The availability of up-to-date and accurate data on socioeconomic and demographic indicators is crucial for the accuracy of the results. Furthermore, the delimitation of agglomerations is a dynamic process that must be periodically reviewed and adjusted to reflect changes in the urban landscape and interactions between settlements [19, 20].

Despite these limitations, our study offers a significant contribution to the field of urban planning and agglomeration management [4,5,6,7]. The proposed methodology can be adapted and applied to other urban contexts, especially in regions with limited resources where synergy between cities and settlements is essential for sustainable development [1]. On the other hand, it also allows for a more precise definition of agglomeration boundaries, thereby facilitating a more nuanced understanding of the territorial distribution of economic activity, migration flows, and social infrastructure.

Future studies could explore the incorporation of additional data, such as mobility patterns and transportation networks, to further refine the delimitation of agglomerations [8, 9]. Additionally, it would be valuable to investigate the impact of urban planning policies on the evolution of agglomerations and their capacity to foster balanced and sustainable development.

CONCLUSIONS

The Shymkent agglomeration, characterized by its monocentric nature, necessitates a strategic approach to population settlement planning. Prioritizing the development of suburban settlements and key nodes along planning axes can effectively manage population growth, mitigate unregulated migration, and ensure the provision of essential services and employment opportunities. This approach fosters a balanced and sustainable urban development pattern, reducing pressure on the core city while promoting the growth of satellite centers and countermagnets. The findings of this study underscore the importance of proactive planning in managing the complexities of urban agglomeration and highlight the potential of GIS technologies in supporting evidence-based decision-making for sustainable urban development.

REFERENCES

1. **Abilov A, Mametov A. Shymkent**. In: Urban development and territorial planning in Kazakhstan: origins and development trends. Almaty; 2022. p. 67-80.
2. **Tiwari AK, Antoniuk VS, Lapo AS, Vansovich ER**. Managing urban agglomeration processes in Russia in the context of agglomerative and socio-economic development. Heliyon. 2024;10(7). https://doi.org/10.1016/j.heliyon.2024.e28654
3. **You S, Feng Z, You Z, Shi H, Zhao G**. Identification and structural characteristics of urban agglomerations in China based on Baidu migration data. Appl Geogr. 2023; 156:102999. https://doi.org/10.1016/j.apgeog.2023.102999
4. **Li L, Tang A, Porter N.** Defining and effectively delineating the peri-urban area: a synthesis and analysis from a literature review. J Urban Plan Dev. 2023;149. https://doi.org/10.1061/JUPDDM.UPENG-4456
5. **Zhang X, Wang H, Ning X, Zhang X, Liu R, Wang H**. Identification of Metropolitan Area Boundaries Based on Comprehensive Spatial Linkages of Cities: A Case Study of the Beijing-Tianjin-Hebei Region. ISPRS Int J Geo-Inf. 2022;11:396. https://doi.org/10.3390/ijgi11070396
6. **Zhang B, Zhong C, Gao Q, Shabrina Z, Tu W**. Delineating urban functional zones using mobile phone data: A case study of cross-boundary integration in Shenzhen-Dongguan-Huizhou area. Comput Environ Urban Syst. 2022;98:101872. https://doi.org/10.1016/j.compenvurbsys.2022.101872
7. **You S, Feng Z, You Z, Shi H, Zhao G**. Identification and structural characteristics of urban agglomerations in China based on Baidu migration data. Appl Geogr. 2023;156:102999. https://doi.org/10.1016/j.apgeog.2023.102999
8. **Moreno-Monroy A, Schiavina M, Veneri P**. Metropolitan areas in the world. Delineation and population trends. J Urban Econ. 2020;125:103242. https://doi.org/10.1016/j.jue.2020.103242
9. **He X, Yuan X, Zhang D, Zhang R, Li M, Zhou C.** Delineation of Urban Agglomeration Boundary Based on Multisource Big Data Fusion-A Case Study of Guangdong-Hong Kong-Macao Greater Bay Area (GBA). Remote Sens. 2021;13(9):1801. https://doi.org/10.3390/rs13091801
10. **Caudillo-Cos CA, Montejano-Escamilla JA, Tapia-McClung R, Ávila-Jiménez FG, Barrera-Alarcón IG.** Defining urban boundaries through DBSCAN and Shannon's entropy: The case of the Mexican National Urban System. Cities. 2024; 149:104969. https://doi.org/10.1016/j.cities.2024.104969
11. **Bosker M, Park J, Roberts M.** Definition matters. Metropolitan areas and agglomeration economies in a large-developing country. J Urban Econ. 2021; 125:103275. https://doi.org/10.1016/j.jue.2020.103275
12. **Polyan PM, Treyvish AI**. The Centrographic Method of Studying Spatial Structure. Mapping Sci Remote Sens. 1990;27:262-279. https://doi.org/10.1080/07493878.1990.10641813
13. **Paolilli AL**. Reilly's Law and Logistic Type Equation in a Model for Studying Group Selection and Intercity Relations. Global J Arts Humanit Soc Sci. 2023;11(10):69-79. https://doi.org/10.37745/gjahss.2013/vol11n106979
14. **Tannier C, Montero G, Tannier C, Thomas I.** Morphological delineation of urban agglomerations. In: Tannier C, editor. Fractal Geometry in Human Geography and Planning. 2024. https://doi.org/10.1002/9781394306565.ch5
15. **Zhou Q, Guo L.** Empirical approach to threshold determination for the delineation of built-up areas with road network data. PLOS ONE. 2018;13(3):e0194806. https://doi.org/10.1371/journal.pone.0194806
16. **Kravchenko K, Niemets K, Sehida K, Niemets L, Suptelo O.** Methods and approaches of determining the boundaries of agglomerations (basic case Kharkiv region). Human Geography Journal. 2020;28:5-16. https://doi.org/10.26565/2076-1333-2020-28-01

17. **Klaassen LH, Scimemi G.** Theoretical issues in urban dynamics. In: Klaassen LH, Molle WTM, Paelinck JHP, editors. Dynamics of Urban Development. New York: St. Martin's Press; 1981. p. 8-28.
18. **Girres JF**. Land-Use Dynamics Analysis Based on Spatial Interactions Models and Satellite Images Time-Series. Remote Sens Spat Inf Sci. 2020; 43:97-101. https://doi.org/10.5194/isprs-archives-XLIII-B4-2020-97-2020
19. **Habrel M, Denis M, Majewska A, Habrel M, Izdebski M, Fenchuk O.** Delimitation of the metropolitan areas of Warsaw and Lviv over the last 100 years. The Polish-Ukrainian experience. Cities. 2024; 144:104664. https://doi.org/10.1016/j.cities.2023.104664
20. **Mikhaylova A, Gorochnaya V**. Spatial scale of urban agglomeration externalities on the Rostov region in Russia. Regions Cohesion. 2022;12(1):78-101. https://doi.org/10.3167/reco.2022.120105
21. **Ministry of Justice of the Republic of Kazakhstan.** On approval of the State Program for the Development of the Aul - El Besigi for 2019-2027. Adilet [Internet]. 2018 Dec 27 [cited 2024 Aug 02]. Available from: https://adilet.zan.kz/rus/docs/P1800000074
22. **Strumsky D, Bettencourt L, Lobo J.** Agglomeration effects as spatially embedded social interactions: identifying urban scaling beyond metropolitan areas. Environ Plan B Urban Anal City Sci. 2023;50(7):1964-1980. https://doi.org/10.1177/23998083221148198